1984 INTERNATIONAL CONFERENCE ON COCOA AND COCONUTS PROGRESS AND OUTLOOK

KUALA LUMPUR HILTON 15 – 17 OCTOBER

VOLUME II

SPONSORED BY
INCORPORATED SOCIETY OF
PLANTERS – KUALA LUMPUR

Population Dynamics of Cocoa Pod Borer *Acrocercops Cramerella*: Importance of Host Plant Cropping Cycle

R.K. DAY

Silwood Centre for Pest Management, Imperial College at Silwood Park, Great Britain

The cocoa pod borer is the major insect pest of cocoa in Sabah, East Malaysia. The level of pest attack and the size of the pest population for this species is documented over several cropping seasons in Sabah. The pest population cycles in phase with the crop cycle. One possible reason for this is that since larval survival in the pod is dependent on pod age, the changing age structure of the pod population causes fluctuations in overall larval survival. This is demonstrated using a simple numerical model. The model is then used to investigate the effect of the amplitude of the cropping cycle on the pest population. Overall larval survival is lowest when the amplitude of the model crop cycle is greatest. Natural events or management practices that alter the pod population age structure may therefore increase or decrease larval survival. Sleeving young pods and the removal of pods from the trees (rampassen) are two control methods that affect the pod population age structure. Correct application of such control methods may reduce the pest population, but incorrect application could aggravate the problem.

The cocoa pod borer *Acrocercops cramerella* Snellen (Lepidoptera: Gracillariidae) has been considered the major limiting factor to the development of the cocoa industry in Indonesia (Wardojo, 1980) and the Philippines (Vanialingam, *et al.*, 1981). In late 1980 the pest was found in Sabah at the heart of a rapidly expanding cocoa industry, causing considerable alarm because no satisfactory control measure was known. This was due in part to the paucity of "fundamental information" (Norton & Mumford, 1982) on the pest, and it is to this gap that the present paper is addressed.

The generation time of the pod borer is approximately one month, and breeding is continuous. Eggs are laid singly on developing pods, and the larvae emerge through the floor of the eggshell and tunnel directly into the pod. There they feed on the placenta, the pith surrounding the beans and sometimes the developing beans themselves. Damage is caused due to hardening of the pith, which makes bean extraction difficult or impossible, and to a reduction in bean size. The mature larvae tunnel out of the pod again to pupate on leaves in the tree or on the ground, or on any suitable surface encountered. Further details of the life cycle are given by Lim *et al.*, (1982), Wardojo (1980), Vanialingam *et al.*, (1981) and Entwistle (1972).

The proportion of ripe pods showing internal borings fluctuates during the cocoa cropping cycle. It has long been known (*e.g.* Roepke, 1912), that pods harvested during the later part of the peak crop period show more damage than those harvested during the earlier part of the season. However, no previous published work has given a detailed quantitative description of this observation, nor has there been any work aimed at describing the underlying dynamics of the pest population itself.

This paper documents the fluctuations in infestation levels observed in a field of Amelonado cocoa over several cropping seasons and shows that the pest population is

cycling in phase with the number of ripe pods. A numerical model is used to show that one reason for this may be that larval survival fluctuates through the cropping cycle due to the changing age structure of the pod population. The model is then used to assess the potential effects of the amplitude of the crop cycle on the pest population.

METHODS

The study was carried out in a square 4 ha field of Amelonado cocoa planted in 1960 and surrounded by mature cocoa. Amelonado cocoa was chosen for the study as it is a relatively homogeneous variety, with little phenotypic variation between trees.

Harvesting and Infestation Monitoring

The study field was harvested weekly. Harvested pods were counted and the numbers summed over two weeks to give a fortnightly total. Records were kept beginning in August 1981.

The infestation rate in the field was assessed once a fortnight. The ripe pods from 81 sample trees were harvested, split open and pods showing any internal borings, whether current or old, were scored as "infested". Pods in which less than half the beans were extractable by hand were scored as "badly infested". This gave a further indication of the extent of damage suffered as the percentage of badly infested pods is roughly equal to the percentage loss of yield.

Pest Population Monitoring

The population of pod borer eggs was sampled at four weekly intervals. From the central 1 ha of the study field, trees were randomly selected and all pods greater than 60mm long were removed to the laboratory to be examined microscopically for fresh eggs. Trees were sampled until 100–150 pods had been collected, the number of trees sampled ranging from 4 to 16. The population was then expressed as eggs per tree.

Modelling

A numerical model was constructed to assess the effect of the cropping cycle on overall larval survival. The model has three components: a pod cycle, a function for distributing eggs between the different age classes of pods and a set of values for larval survival in the different age classes of pods. The model operates on a time interval of a fortnight. At each interval the model calculates the proportion of the total number of pods in each two-week age class. Then the proportion of eggs laid on each age class is calculated according to the egg distribution function, and finally the overall larval survival is calculated on the basis of the age class specific survival values.

Pod Cycle

The cocoa cropping cycle is modelled using the expression:

$$ln\,P(t) = M + A\,\cos\,(2\pi\,t/T)$$

where $P(t)$ is the number of pods harvested in fortnight t, M is the meam $ln\,P(t)$ value, A is half the amplitude of the $ln\,P(t)$ cycle and T is the period of the cycle (which is 13 fortnights, there being two cropping seasons a year).

The number of pods in each of the fortnightly age classes prior to ripening can be calculated from the number of pods due to ripen in subsequent intervals, and thus the proportion of pods in each age class can be determined.

The crop cycle is varied by changing the value of A. Increasing it increases the peak to trough crop ratio, or the maximum value of P over the minimum value of P (P/T ratio). Making A time-dependent would allow the amplitude of the cycle to vary irregularly.

Distribution of Eggs among Age Classes.

The female moths rarely oviposit on fully matured ripe pods or on pods younger than six fortnights prior to ripening; so only the intervening pod ages are considered. Older pods are generally preferred for oviposition and the simplest mechanism causing the observed preference would result in the ratio of the mean number of eggs per pod in the six age classes remaining constant for all pod population age structures. These values have been estimated from field data and are shown in *Table 1*. At each time interval the model allocates the eggs between the age classes according to this ratio.

TABLE 1. RATIO OF MEAN EGGS PER POD, AND LARVAL SURVIVAL IN THE SIX POD AGE CLASSES USED IN THE MODEL (from unpublished data).

Age Class (Fortnights prior to ripening)	Ratio of Mean Eggs per Pod	Larval Survival (%)
1	0.18	0.5
2	0.37	3.2
3	0.21	7.9
4	0.14	6.2
5	0.06	0
6	0.02	0

Larval Survival.

Larval survival in Amelonado pods of known age has been measured in the field, and the values are given in *Table 1*. Total larval survival for eggs laid in a given time interval is then the sum over all six pod age classes of the product of larval survival and the proportion of eggs in each class.

RESULTS

Study Field

Figure 1 shows the number of ripe pods harvested per fortnight and the infestation rate in the study field from August 1981 to December 1983. The low points of the infestation curves correspond well with the peaks of the cropping cycle and *vice versa*.

Figure 2 shows the results of the egg sampling carried out from October 1982 to December 1983 together eith the harvest records for that period. In this case the peaks of the two curves are roughly coincident. Thus the actual pest population is highest at the time in the cropping cycle when the observed level of attack is lowest.
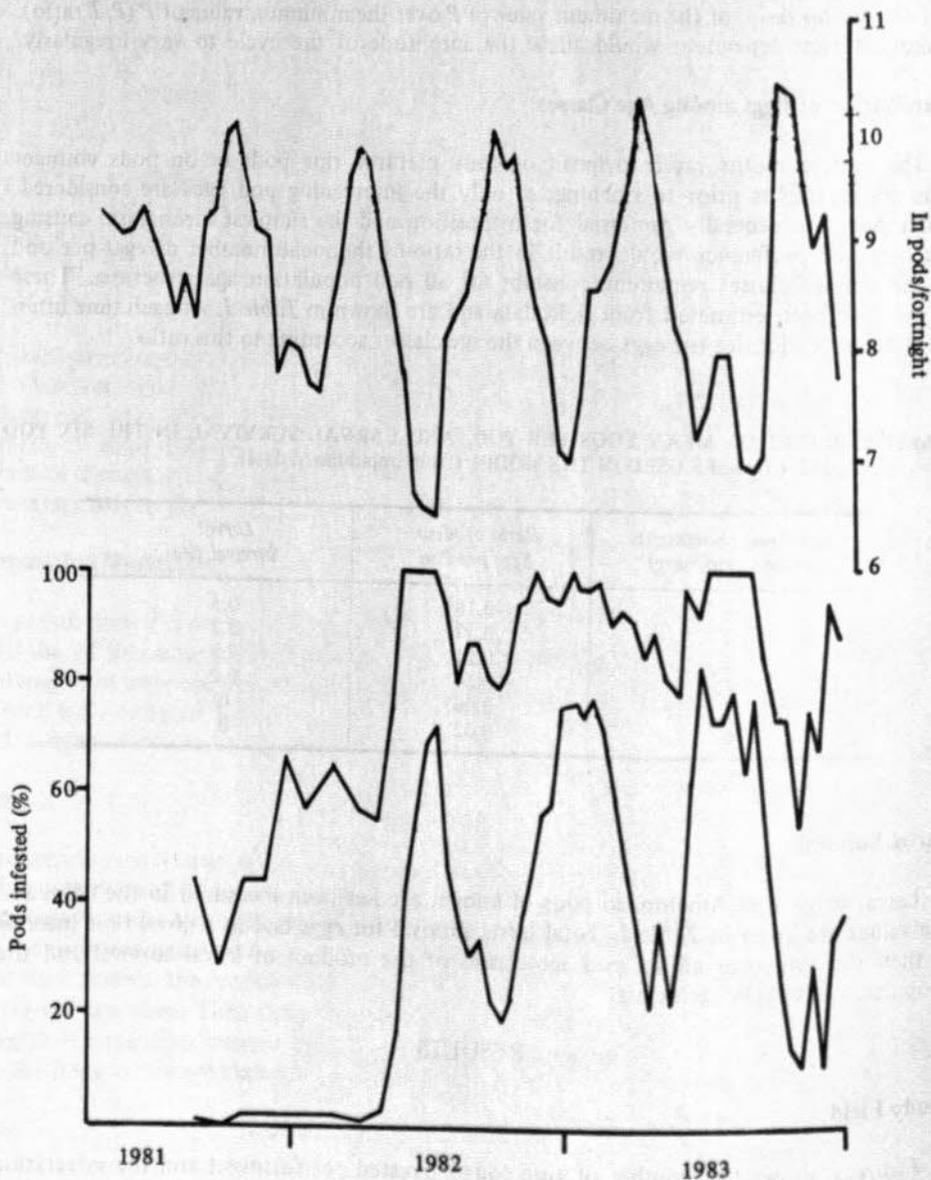
3

Figure 1. Infestation levels in the study field over five consecutive cropping seasons. The upper line shows the number of pods harvested per fortnight; the middle and lower lines show respectively the percentage of infested and badly infested ripe pods from the sample trees.
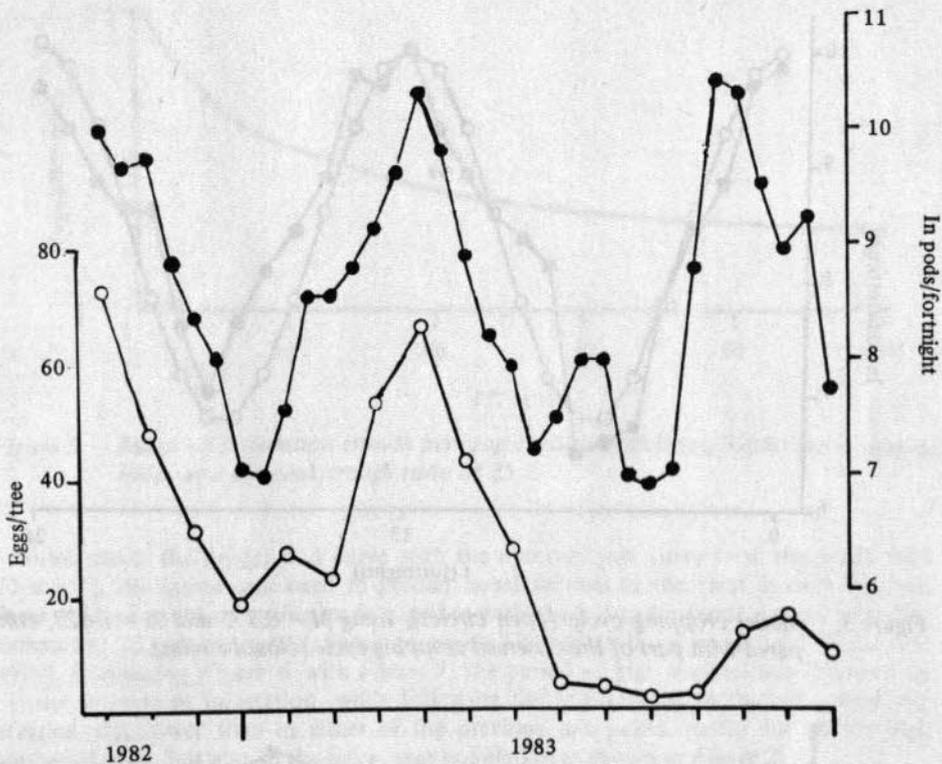
Figure 2. Pod borer egg population (open circles) in the study field. The upper line shows the number of pods harvested per fortnight over the same period.

Modelling

By choosing values for M and A in the pod cycle model of 8.375 and 1.623 respectively, a realistic crop production cycle is generated. In *Figure 3* this curve is compared with the central cycles from the study field, during which time the cycles were relatively regular. The ratio of harvested pods per fortnight at the peak of production to pods per fortnight at the trough of production (p/T ratio) for the model curve with $A = 1.623$ is 25.7.

Figure 4 shows the predicted larval survival of eggs laid at each interval through one crop cycle using this model pod curve. If, for this pod cycle, the pest population is assumed to be constant from one cycle to the next, a "zero growth" value for larval survival can be calculated, assuming other mortalities and fecundity remain constant. Within the course of a single cycle, larval survival above this value would lead to population growth, and survival values below it to population decline. The "zero growth" line is drawn on *Figure 4*. One interval after the points at which the "zero growth" line intersects the survival curve gives the predicted times for the high and low points of the pest population within one cropping season. These times correspond with the peak and trough of the crop cycle, as was the case for the observed population in the study field (*Figure 2*).

Altering the P/T ratio changes the predicted larval survival through the crop cycle, although the general shape of the sruvival curve remains the same. But overall larval

5

DISUCSSION

The model described is an exponential growth curve modulated by the rate of increase varying through time as a function of the crop cycle. Population change is independent of density and only larval survival is included; so predictions arising must be considered within this context.

The model indicates that the change in larval survival caused by the seasonal cropping pattern of the host plant could be an important factor contributing to the fluctuations in the pest population within a season. Although changing the P/T ratio has some effect on the season-to-season population change, in this model the effect is not marked until more extreme P/T ratios are involved. Nevertheless, the cocoa pod borer would thus be a specific example of the general prediction from theoretical models (May, 1976) that organisms with high fecundity and short generation time will tend to track long time scale environmental fluctuations, and that the greater these fluctuations are, the lower the average pest population will be.

These predictions suggest reasons why some control methods are not as effective as might otherwise be expected, and also suggest ways in which improvements might be made. There are two control methods that affect the pod population age structure: pod sleeving and rampassen.

Sleeving involves the covering of young pods with a plastic sleeve which prevents oviposition by the pod borer, and the pod is therefore protected from attack. This practice is generally done during the low crop period when the pods due to ripen in the approaching peak crop are still small and not yet attractive to oviposition. But sleeving these pods effectively lowers the size of the susceptible peak crop (by making all of the sleeved pods unavailable to the moths) and therefore lowers the peak/trough ratio. As the model has shown, in the absence of any density effects, this increases overall larval survival; so although the sleeved pods remain unattacked, the pest population could be increased by the practice. An alternative strategy would be to sleeve (when young) the pods that will be harvested in the trough crop period, which would increase the effective peak/trough ratio. As this would mean sleeving during the peak crop period when labour is largely committed to harvesting, it would be more practical to remove the relatively small number of cherelles present at that time rather than sleeve them. Timing of the operation in that case would be more critical in order to minimise the number of pods lost.

Rampassen is the removal from the trees of all cocoa pods on which pod borers lay eggs (greater than 6 cm), and then maintaining the "pod-free" situation for at least one generation of the pest, so that the life cycle is broken. If, however, the rampassen is not done properly, so that in an attempt to minimise crop loss only the oldest pods are removed, survival of the remaining pest population could be higher than if there had been no rampassen. So, despite the removal of a part of the pest population in the rampassed pods, the remaining population could rapidly build up again. Even if the rampassen is done properly, there will inevitably be a subsequent period in which larval survival would be very high (due to there being no older pods in which survival is low), so any immigrant moths would again lead to a rapid build up of the pest population. This, therefore, is a possible explanation of why it has been found that rampassen often fails to produce the degree of control that other considerations indicate should be possible. Van der Knaap (1955) noted that even a well conducted rampassen was only effective over the first part of the following cropping season, by the end of the season the infesta-

tion having built up to high levels again. The rampassen in the initial outbreak area in Sabah in 1981 also did not result in any long-term pest reduction.

Natural phenomena also affects the cocoa cropping cycle. The low predicted larval survival during mid 1983, for example, was partially due to a long trough crop arising from a drought earlier in the year. If cropping patterns could be predicted in advance, the effect on pod borer populations could be predicted and appropriate action taken.

In conclusion, although the model described is in many ways unrealistic, it is useful in the following ways. First, an explanation is suggested for the fluctuation of the pest population through the season. Second, it indicates that extreme variation in the amplitude of the cropping cycle may affect the pest population, and thus presents a warning on the use of control methods that alter the age structure of the pod population. And finally, it provides a basis to which other factors such as density effects may be added so that a more realistic model is produced which can then be used to make more accurate predictions concerning the use of each of the control methods available and under development.

ACKNOWLEDGEMENT

REFERENCES

ENTWISTLE P.F. (1972) *Pests of Cocoa*, pp. 370–375. London: Longman.

LIM, G.T., TAY, E.B., PANG, T.C., & PAN, K.Y. (1982) The biology of cocoa pod borer *Acrocercops cramerella* Snellen and its control in Sabah, Malaysia. *Proc. Int. Conf. Plant Protection in the Tropics, Kuala Lumpur, 1982*, 275.

MAY, R.M. (1976) Models for single populations. In *Theoretical Ecology Principles and Applications* (ed. R.M. May), pp. 4–25. Oxford: Blackwell Scientific Publications.

NORTON, G.A. & MUMFORD, J.D. (1982) Information gaps in pest management. *Proc. Int. Conf. Plant Protection in the Tropics, Kuala Lumpur, 1982*, 589.

ROEPKE, W. (1912) Over den huidigen stand van het vraagstuk van het rampassen als bestrijdings middel tegen de cacaomot op Java. *Meded. Proefst. Midden-Java, No. 8.*

VAN DER KNAAP, W.P. (1955) Invloed van het rampassen op de productie van cacao-bomen (1). *Bergcultures*, 24, 219–223.

VANIALINGAM, THOMAS, E., IRSHAD, M., MANALO, J., & CRUZ, P. (1981) Early work in the control of the cocoa pod borer (*Acrocercops cramerella*) in the Philippines. *Proc. 8th Int. Cocoa Research Conference, Cartegena, Colombia 1981*, 345.

WARDOJO, S. (1980) The cocoa pod borer – A major hindrance to cocoa development. *Indonesian Agriculture Research & Development Journal*, 2, 1–9.

WOOD, G.A.R. (1975) *Cocoa*. London: Longman.

Occurrence and Status of
Acrocercops cramerella Snellen in
Peninsular Malaysia

W.H. LOKE

Malaysian Agricultural Research and Development Institute, Serdang, Selangor

MOHD SHAMSUDIN OSMAN

Department of Agriculture, Kuala Lumpur

AND

ZAIN KARIM

Malaysian Agricultural Reserach and Development Institute, Serdang, Selangor

Acrocercops cramerella *Snellen occurs in Peninsular Malaysia. It is found to be a minor but endemic pests of* Nephelium lappaceum. *Besides* A. cramerella, *10 other lepidopterous species have been recovered from rambutan. The pest never attacks young, developing fruits, preferring mature and ripening fruits. At least two generations are possible in one fruiting season. The pestiferous insect is found all over Malaysia in rambutan-growing areas. Clonal susceptibility varies widely with eight clones apparently resistant to the pest, and three clones highly susceptible.*

A. cramerella *is not found in cocoa in Peninsular Malaysia. This was determined through a series of surveys of small-holdings and research plots. Only an external husk-boring lepidopteran,* Dichocrocis punctiferalis, *was detected in the surveys.*

The developmental stages of A. cramerella *from rambutan are similar to those obtained from cocoa except for slight variations in colour and size. The feeding behaviour and damage inflicted in rambutans are quite different and less dramatic than those in cocoa.*

Besides N. lappaceum *and cocoa, four other plant species are confirmed to be hosts of* A. cramerella. *A species of* Acrocercops *(tentatively named* A. litchiella*) recovered from longan leaves resembles* A. cramerella *very much. From* A. cramerella, *two endoparasitic larval parasitoids have been recovered, viz.* Phanerotoma *sp. (Braconidae) and* Ooencyrtus *sp.* erionatae *(Encyrtidae).*

Acrocercops cramerella Snellen is a microlepidopteran belonging to the family Gracilariidae (Lithocolletidae). It used to be known as *Zaratha cramerella* and *Gracilaria cramerella* (Wessel-Riemens, 1981). Though often commonly called 'cocoa moth', a much more accurate common name would be 'cocoa pod borer' or 'cocoa pod borer moth' (Wardojo, 1980; Wood, 1980). This insect is considered native to S.E. Asia, living on wild and cultivated rambutan and related fruits (Conway, et al., 1983).

A. *cramerella* became an important pest of cocoa in Indonesia about 100 years ago. It was reported as a cocoa pest in Sulawesi since the 19th century, Java since 1895, Mindanao

since the 1930s, New Guinea since 1961, Sumatra since the 1970s and Sabah (Malaysia) since 1980 (Day, 1983; Entwistle, ·1972). Adaptation to cocoa is believed to have originated in Manado in the mid-19th century, some 10–20 years after an intensification of cocoa planting in that area (Day, 1983).

Mumford (1980) reported that the earliest possible sighting of the cocoa pod borer in Sabah was from Apas Claremonth Estate in September, 1979 (although there was a previous record of the insect in Sabah intercepted in cocoa pods illegally imported from the Philippines in 1963). Since then the cocoa pod borer has spread rapidly and widely within Sabah to many other areas of cocoa cultivation. It was detected in Rumidi in 1981, Semporna, Lahad Datu and Kunak in 1982 and Tenom, Tuaran, Kudat and Keningau in 1983 (Kang *et al.*, 1983). Lately, Sarawak is also recording the presence of the cocoa pod borer (Mumford, 1983). Not only has the problem of the pod borer increased in terms of spatial distribution, its severity, especially around the Tawau area has also increased tremendously. Losses in the off-peak period can be well over 50% in the worst affected areas, and in some areas in the peak period, losses can be in the order of 20–30% (Mumford, 1983). This could translate to a monetary loss of M$1760 per hectare if yield is one tonne per hectare with the price of cocoa at M$3500 per tonne and losses in the order of 50%.

The current situation in Sabah certainly does not augur well for the cocoa-planting industry in Peninsular Malaysia. The constant threat that the cocoa pod borer will eventually find its way here is very real and of grave concern. It is therefore imperative that concerted attention is given to the study of this species in Peninsular Malaysia, at least starting with studies on the *A. cramerella* attacking rambutan.

ACROCERCOPS CRAMERELLA ON RAMBUTAN

Pest Status

Rambutan, *Nephelium lappaceum*, has been grown in Malaysia for a long time, much longer than cocoa, which is an introduced crop. It is considered indigenous to South-East Asia (Chan, 1984). The first confirmed record of *A. cramerella* as a pest of rambutan was in January, 1949 (Ahmad Yunus & Ho, 1980).

The status of *A. cramerella* as a pest of rambutan can be stated as minor but endemic (Mohd. Shamsudin Osman & Vijayasegaran, 1982). In normal fruiting seasons, infestation levels are generally low and yield and quality are not significantly affected. Ripe fruits (including aborted/dropped fruits) collected and kept in holding cages yielded 10 other lapidopterous species besides *A. cramerella* (*Table 1*). Two of the species collected are also microlepidopterans, and it is possible to misidentify their larvae as those of *A. cramerella*. However, in most instances, the majority of lepidopterans obtained are indeed *A. cramerella*. In the study conducted, 69% of the adults collected were *A. cramerella*, 14% *Dichocrocis punctiferalis* and (17% others).

Field Infestation and Seasonal Dynamics

Rambutan is seasonal, with fruiting occurring in two periods, *viz.* June–August and November–January. The fruit takes about three months to mature. Although there appears to be two distinct seasons, it has been observed that sporadic fruiting can occur during supposedly off-season months.

TABLE 1. LEPIDOPTEROUS SPECIES RECOVERED FROM RAMBUTAN IN
SERDANG IN 1982 AND 1983.

Family	Species
Gracilariidae	*Acrocercops cramerella*
Pyralidae	*Cryptoblaszes plagioleuca*
Geometridae	*Indiochlora* sp. in *andromes* Pront gp.
Gelechiidae	*Anarsia erotias*
Stathmopodidae	*Eretmocera impactella*
Stathmopodidae	*Stathmopoda coneoma*
Pyraustidae	*Dichocrocis punctiferalis*
Lycaenidae	*Deudorix epijarbas cinnabarus*
Tortricidae	*Gatesclarkeana erotias*
Eucosmidae	*Lobesia aelopa*

The phenology of fruit infestation by *A. cramerella* was studied by sampling and examining fruits of various stages of growth and this showed that young fruits (less than eight weeks) were never attacked. Early instar of *A. cramerella* was only detected in fruits that were beginning to ripen. *Table 2* shows infestation levels in two categories of fruits. In general, ripe fruits harboured higher levels of *A. cramerella* infestation compared to mature but still green fruits. The percentage of ripe fruits infested also increased as the ripening period advanced.

TABLE 2. COMPARISON OF *A. CRAMERELLA* INFESTATION IN FRUITS OF DIFFERENT
STAGES OF MATURITY (1980/81).

State	Infestation (%)	
	Ripe fruits	Mature but green fruit
Johore	3.7	0.0
Negeri Sembilan	3.6	5.8
Selangor	3.0	0.0
Perak	50.7	9.3
Penang	16.7	0.0
Kelantan	14.0	17.1
Terengganu	1.5	0.0
Pahang	1.4	0.6
Average	11.8	4.7

From *Figure 1*, it appears that during the fruiting season, there are at least two generations of the pest. The curves for R_{162} R_{134} show this very clearly.
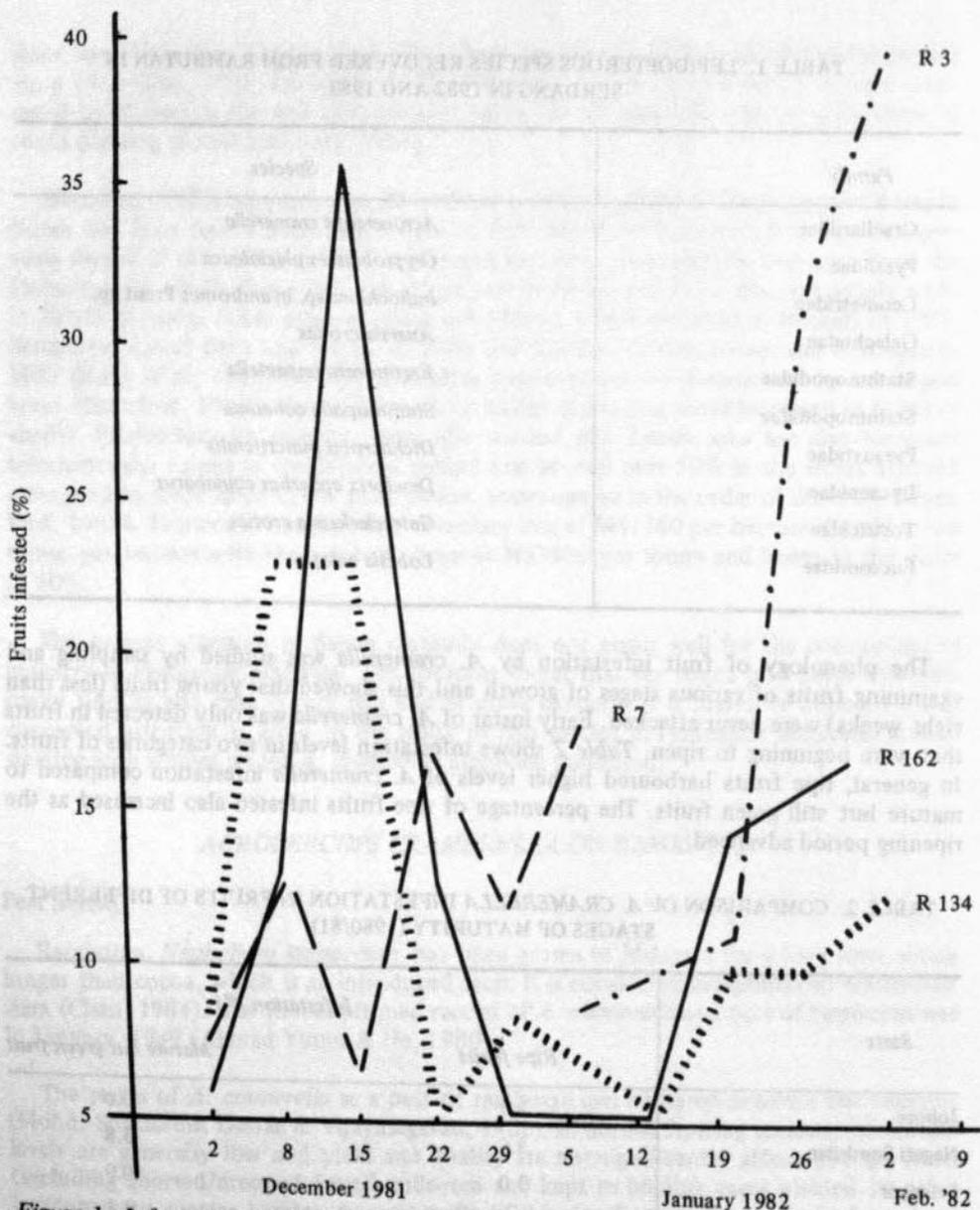
Figure 1. Infestation trend of A. cramerella *in rambutans during the December – February 1983 season in MARDI, Serdang.*

Observations on seasonal dynamics also show this to be variable. Infestation could be high in one season but low in the next. Infestation is low in seasons of low productivity and high when yield is abundant. Also the seasonal dynamics of field infestation is often confounded by the variable fruiting trends of mixed clonal plantings.

Spatial Distribution

Rambutan is grown all over the country but more abundant in certain states. The occurrence of *A. cramerella* in major rambutan-growing states was checked out by a field survey of plantings in Agricultural Centres in June–Ocotber, 1981. In every centre

4

visited, 200–300 fruits were randomly collected from the field for examination. Fruits sampled included both mature green and ripe fruits. Results obtained showed that *A. cramerella* was widely distributed and present in the major rambutan-growing areas (*Table 3*). Infestation levels were variable but generally low (< 5%) in most states. In Perak, Penang and Kelantan, infestation levels of 40.1%, 16.7% and 13.6% were recorded (*Table 3*). These were much higher than the national mean of 7.3%. The high infestation situation in Perak warrants attention as Perak also happens to be a major cocoa-growing state.

TABLE 3. DISTRIBUTION AND INFESTATION LEVELS OF *A. CRAMERELLA* IN RAMBUTANS IN PENINSULAR MALAYSIA (1980/81).

State	Total number of fruit examined	Total number of fruits infested	Infestation (%)
Johore	4574	134	2.9
Negeri Sembilan	1248	48	3.9
Selangor	1113	39	3.5
Perak	720	289	40.1
Penang	227	38	16.7
Kelantan	1753	238	13.6
Terengganu	750	10	1.3
Pahang	667	8	1.2

Clonal Susceptibility

Concurrent with the survey on spatial distribution of *A. cramerella*, a study on clonal susceptibility was also conducted. A total of 25 clones was investigated (*Table 4*), and results obtained showed that clonal susceptibility was highly variable. Perak Tok Ali, Serdang and R_{134}, with percentage infestation of fruit of 27.1, 19.3 and 15.6 respectively, appeared to be the highly susceptible clones compared to R_{18}, R_{19} and R_{20}. Altogether, eight clones seemed to be resistant to *A. cramerella* infestation. It is also interesting to note that out of the six DOA-recommended clones, two suffered infestation greater than 12%.

SURVEILLANCE OF *A. CRAMERELLA* IN COCOA IN PENINSULAR MALAYSIA

Survey of Small-holdings

As a result of the discovery of the cocoa pod borer problem in Sabah, surveys were carried out in smallholdings in Peninsular Malaysia to monitor the situation. The first survey in 1981 involved questioning farmers whether they had observed any internal damage by insects to their cocoa pods. In addition, ripe cocoa pods were also examined. This involved randomly selecting 10 trees per survey site and visually inspecting all ripe pods on the trees for external signs of *A. cramerella* damage. Ten fruits were then picked and dissected for internal inspection. No *A. cramerella* was detected (*Table 5*).

In 1982, only smallholders in Perak were surveyed and all 23 sites inspected did not have any *Acrocercops* damage. No survey was conducted in 1983. A new survey pro-

TABLE 4. CLONAL SUSCEPTIBILITY OF RAMBUTAN TO *A. CRAMERELLA* IN PENINSULAR MALAYSIA (1980/81).

Clone	Infestation of fruits (%)
R 18	0.0
R 19	0.0
R 20	0.0
R 21	0.0
R 29	0.0
R 99	0.0
R 161	0.0
Cik Mat	0.0
R 169 (Lychee)	1.4
R 170[a] (Delicheng)	2.4
R 7	3.0
R 162[a]	4.6
R 3[a] (Gula Batu)	4.8
R 156[a] (Muar Gading)	5.9
R 4	6.7
R 10	6.7
R 9	9.0
R.C.E.	9.8
Sola Merah	10.8
R 168 (Cik Embong)	11.1
R 160[a]	12.2
R 154	13.3
R 134[a]	15.6
Serdang	19.3
Perak Tok Ali	27.1

[a] DOA — recommended clone.

TABLE 5. SURVEY OF COCOA SMALL-HOLDINGS FOR *A. CRAMERELLA* INFESTATION.

Year	State	No. of sampling sites	No. of fruits examined		Status
			On tree	Dissected	
1981	Perak	93	–	930	No borer
	Selangor	18	–	180	No borer
	Johore	29	–	290	No borer
	Penang	27	–	20	No borer
1983	Pahang	21	1980	965	No borer
	Terengganu	3	116	100	No borer

In Penang it was not possible to dissect more pods due to a firm commitment of the crop by small-holders to buyers. However, 1758 pods were thoroughly inspected externally.

gramme was developed in early 1984. This programme was the outcome of the setting up of the National Working Committee on Monitoring and Control of the Cocoa Pod Borer. The new survey procedure advocates bimonthly sampling of one sampling point per 200 ha of smallholder cocoa. One hundred trees will be inspected and all mature pods

(three and a half months and older) will be thoroughly inspected. Ripe pods will be split open for internal examination. So far only one round of survey has been conducted and results obtained from Pahang and Terengganu (*Table 5*) showed no *A. cramerella* infestation.

Surveys in Research Plots

In addition to the survey of small-holder plots, surveys were also conducted in Serdang and Jerangau (MARDI plots). The survey in Serdang was done in 1983. A small plot (ca. ¼ ha) of fruiting cocoa trees planted near to rambutans was inspected and sampled. Fifty ripe pods dissected for internal scrutiny showed no pod-borer infestation.

The Jerangau survey consisted of two parts. First ripe pods that had been harvested for 10 field plots for splitting were examined. For each plot, 30 pods were scrutinised. Results obtained were negative for pod-borer infestation (*Table 6*). Only a few pods were externally attacked with no damage to the internal parts. Larvae collected were keyed out to be pyraustids, and later confirmed as *D. punctiferalis*. The second part of the survey involved inspection of a cocoa plot near the rambutan trees. Three hundred trees were inspected and the ripe cocoa pods were scrutinised. Only pods (25) with suspicious damage signs were dissected for internal examination. Results obtained showed that no *A. cramerella* infestation was detected but again several (8) *D. punctiferalis* larvae were collected.

TABLE 6. SURVEY FOR COCOA POD BORER IN JERANGAU (1982/83).

Field	No. of pods examined	Boring damage (%)	Type of boring	No. of larvae collected
TR 42	30	3.3	external	1
C 41	30	0.0	–	–
TR 38	30	0.0	–	–
SG D. D	30	0.0	–	–
C 37	30	0.0	–	–
C 39	30	3.3	external	0
C 35	30	3.3	external	0
C 65	30	3.3	external	0
KS 19	30	3.3	external	1
KS 18	30	16.7	external	3

BIOLOGY AND ECOLOGY

A. cramerella is such a minor pest of rambutan that there is very little documented information about its biology and ecology in the rambutan agroecosystem. Because of its status as a serious pest of cocoa in Sabah it is only recently that more attention was focussed on it in Peninsular Malaysia.

Developmental Stages and Comparative Morphology

All the known developmental stages of the insect from rambutan were collected and examined.

7

Egg. The egg measures 0.45 ± 0.01 mm long and is similar to that of the cocoa pod-borer in terms of size, gross morphology, colour (orangish) and chorion pattern. Most of the eggs observed were laid singly at the basal portion or in grooves around the basal portion of the rambutan trichome. It is not common to find more than three to four eggs per fruit. Like its cocoa counterpart, the newly hatched larvae penetrates directly into the rambutan fruit without emerging outside. This is confirmed to be so because eggs that have hatched (greyish colour) have intact chorions on the upper side.

Larval stages. Newly hatched larvae are 0.82 ± 0.05 mm long with head capsules measuring 0.1 ± 0.004 mm. There appear to be four larval instars based on observation and measurement of the head capsule and body length of the larvae collected. The larvae are creamish white in colour and appear to be smaller in comparison with counterparts in cocoa. This could be attributed to differences in the dietary medium. Morphologically they look similar to the cocoa ones except for a slight difference in colour. There is no difference in chaetotaxy, crochet arrangement and other morphological characters of taxonomic importance.

Pupa. The pupa is 6.11 ± 0.09 mm long and 1.08 ± 0.07 mm wide. The pupa also does not differ in any distinct morphological manner from its cocoa counterpart, except, again, it is much smaller in dimensions. The cocoon membrane is also smaller than that of the cocoa pod-borer (8.75 ± 0.50 mm long by 4.49 ± 0.044 mm wide).

Adult. The male moths have body lengths and wing spans of 5.11 ± 0.26 mm and 11.85 ± 0.72 mm, while females measure 5.52 ± 0.29 mm by 12.79 ± 0.61 mm. Morphologically, there appears to be no difference between the specimens obtained from rambutan and cocoa. This was throughly checked out and also confirmed by Dr. J. Bradley of the Commonwealth Institute of Entomology. Again, the only slight difference appears to be in size, which is subjective.

Feeding Behaviour and Damage

The newly hatched larva bores directly into the skin of the fruit and tunnels within the rind, sometimes going into the fleshy aril. Most of the time it will make its way up to the area of the aril around the base of the fruit peduncle. Sometimes it penetrates into the seed coat in this region. *Table 7* shows that in most cases, larvae prefer feeding in the basal part below the attachment of peduncle. Emergency of the mature larvae also often occurs in this region, evident by traces of reddish brown dust. The peculiar preference for feeding and emerging in the described region may lead to premature fruit drop as a result of weakening of tissues or induced abscission.

Observation on number of larvae within the fruit shows that usually there is only one larva although sometimes two to three larvae have been encountered. Comparing the severity of damage, that inflicted by the rambutan pest is not so dramatic as the damage observed in cocoa pods.

Field Observations

Observations in the field show that mature larvae pupate on dry leaves around the base of the trees. Pupation also occurs on the foliage in the canopy and on the outside of the fruit itself. Pupation on the bark was not common.

Adults are rarely seen during the day. In rare encounters, the adults will flutter from one hiding spot to another when disturbed. They prefer the underside of branches. Light

TABLE 7. COMPARATIVE STUDY OF PART OF RAMBUTAN FRUIT DAMAGED BY
A. CRAMERELLA (1980/81).

State	Fruits showing damage (%)		
	Base of peduncle	Skin	Peduncle base & skin
Johore	76.4	20.8	2.8
Negeri Sembilan	79.2	20.8	0.0
Selangor	59.1	40.9	0.0
Perak	80.6	13.2	6.2
Penang	65.8	34.2	0.0
Kelantan	19.5	80.5	0.0
Terengganu	100.0	0.0	0.0
Pahang	25.0	75.0	0.0

traps (H.P. and M.V. types) do not attract adults and pheromone trials in Penang also did not catch any adults (although in the laboratory, adults of the rambutan borer have been demonstrated to respond positively to the synthetic A. cramerella pheromone in electro-antennogram tests).

Alternate Host and Other Acrocercops spp.

Besides N. lappaceum and Theobroma cacao, several other plant species have also been named as hosts of A. cramerella (Table 8). The specimens collected as leaf-miner of Lansium domesticum (langsat) and N. malaiense (mata kucing) and identified as A. cramerella were rechecked and believed to be erroneously identified. It seems unlikely that the pod-boring or fruit-boring A. cramerella could switch to a leaf-mining habit. The rare reports of the borer found within imported longans (M. longana) and lychees (Litchi sinensis) have not been confirmed as A. cramerella. The search for alternate hosts of A. cramerella is important in understanding its survival and existence during periods when rambutans are not in season. Information on this will be useful in managing the pest by manipulating or interfering with its alternate hosts.

Apart from A. cramerella, there are 12 other Acrocercops species (Table 9) collected in Peninsular Malaysia. Of interest is one leaf-mining species collected from longan leaves. The specimens of adults look very similar to A. cramerella except that they are smaller and slightly paler in colour. Three hymenopterous parasitoids were recovered from this species. This species has been provisionally named A. litchiella.

Natural Enemies

Very little is known of the natural enemies of the rambutan A. cramerella. This aspect of the pest is very important. The generally low population levels of the pest in ram-butans could indicate the possibility of efficient natural control of which natural enemies could be a significant component. These natural enemies could be potentially useful in controlling the cocoa A. cramerella in Sabah. Related to this is the possibility, too, of using natural enemies of other Acrocercops spp. particularly egg and pupal parasitoids and predators.

TABLE 8. LIST OF PLANT SPECIES NAMED AS HOSTS OF *A. CRAMERELLA*

Species	Family	Plant part attacked/habit	Actual State
Nephelium lappaceum	Sapindaceae	Fruit/borer	Confirmed
Theobroma cacao	Sterculiaceae	Fruit/Podborer	Confirmed
Nephelium mutabile	Sapindaceae	Fruit/borer	Confirmed
Cynometra cauliflora	Leguminosae	Fruit/borer	Confirmed
Cola nitida	Sterculiaceae	Fruit/borer	Confirmed
Lansium domesticum	Meliaceae	Leaf/miner	Fallacious
Nephelium malaiense	Sapindaceae	Leaf/miner	Fallacious
Nephelium longana	Sapindaceae	Fruit/borer	Unconfirmed
Litchi sinensis	Sapindaceae	Fruit/borer	Unconfirmed

To-date only two species of hymenopterous parasitoids have been recovered from the rambutan *A. cramerella*. The first one is a solitary, endoparasitic larval parasitoid belonging to the family Braconidae. It has been identified as a *Phanerotoma* sp. (This species was also recovered from *A. litchiella*.) It is not known at this stage when it attacks the rambutan borer, except that it appears to force the borer larva to cocoon and die prematurely in the penultimate instar. The second species is a gregarious endoparasitic encyrtid, tentatively identified as *Ooencyrtus* sp. *erionatae* Ferr. Very little is known about this species except that it may be an egg-laval parasitoid. The suspicion is based on the fact the several *Ooencyrtus* spp. have been recorded locally and most are egg parasitoids (Ahmad Yunus & Ho, 1980).

DISCUSSION

The fact that *A. cramerella* is only a minor pest of rambutans with infestation levels of a generally low status is encouraging. This could indicate a well-balanced ecological relationship between the pest and its natural controlling factors. Probing more deeply into this relationship could yield valuable information beneficial to the management of the cocoa pod borer problem in Sabah.

The widespread occurrence and proximity of the rambutan *A. cramerella* to cocoa plantings is of some concern. There is possibility that the biotype attacking rambutan may eventually evolve to attacking cocoa too. This possibility can only be minimised through vigilance and avoidance of close planting of rambutans and cocoa. The latter may be hard to achieve or enforce as presently many smallholders have rambutan trees within their cocoa smallholders. Also, rambutan is so widespread as a *dusun* tree in Peninsular Malaysia.

So far, monitoring work has shown that the cocoa pod borer is not found in Peninsular Malaysia cocoa fields. This is a desirable situation and the *status quo* should be maintained. Continual vigilance and monitoring should go on systematically and regularly in both estates and smallholdings, and an emergency action programme needs to be formulated to remedy the situation should monitoring indicate present of the pod borer in cocoa here. All effort to prevent entry of the pest from outside Peninsular Malaysia has to be seriously undertaken at all times.

TABLE 9. OTHER SPECIES OF *ACROCERCOPS* COLLECTED IN
PENINSULAR MALAYSIA*.

Species	Host plants	Local name
A. austeropa	Bauhinia purpurea	Pokok tapak kuda
A. caerulea	Vigna catjang (Leaf)	Kacang panjang
	Glycine hispida	Kacang soya
	Caesalpinia pulcherrima (Flower)	Pokok jambul merak
	Dolichos lablab (Leaf)	Pokok kacang kara
	Glycine mar (Leaf)	Kacang soya
	Vigna sinensis (Leaf)	Kacang panjang
A. eugeniella	Eugenia aquea (Leaf)	Jambu air
A. euthycolona	Mimusops elengi (Leaf)	Pokok Tanjung
	Anarcardium occidentale (Leaf)	Gajus
A. globulifera	Bauhinia purpurea (Leaf)	Pokok tapak kuda
A. isonoma	Mangifera indica (Shoot)	Mangga
A. macroclina	Derris elliptica (Leaf)	Tuba
A. regulifera	Terminalia catappa	Ketapang
A. syngramma	Anarcardium occidentale (Leaf)	Gajus
A. syrista	Mallotus sp.	Mahang
Acrocercops sp.	Persea gratissima	Avocado
	Vigna catjang (Leaf)	Kacang panjang
	Durio zibethinus (Leaf)	Durian
	Glycine max (Leaf)	Kacang soya
	Vigna sinensis (Leaf)	Kacang panjang
	Eugenia aquae (Leaf)	Jambu air
	Acalypha siamensis	Tumput
	Mangifera indica (Bark)	Mangga
Acrocercops sp. n.	Nephelium longana (Leaf)	Longan

*Source: Ahmad Yunus and Ho (1980) and MARDI records.

The biological and ecological information obtained about the rambutan *A. cramerella* so far is just the tip of the iceberg; nevertheless, it forms an initial database on which more relevant and potentially useful data could be accumulated. Of particular relevance would be information and data on the pest's ecology, alternate hosts and natural enemies. It is, therefore, hoped that this paper will trigger off more work on *A. cramerella* in Malaysia for the benefit of all concerned with suppressing the cocoa pod borer problem.

ACKNOWLEDGEMENT

AHMAD YUNUS & HO, T.H. (1980). List of Economic Pests, Host Plants, Parasites and Predators in West Malaysia (1920–1978). Min. of Agric., Kuala Lumpur, Malaysia. 538 pp.

CHAN, Y.K. (1984). Private communication. MARDI, Serdang, Selangor, Malaysia.

CONWAY, G.R., MUMFORD, J.D. & DAY, R.K. (1983). EMPA Cocoa Pod Borer Research – Report of a visit to Sabah. 14 pp. (mimeo).

DAY, R.K. (1983). Progress towards an Integrated Control Programme for the Cocoa Pod Borer, *Acrocercops cramerella* Snellen in Sabah. Paper presented in MAPPS Seminar on Advances in Cocoa Plant Protection in Malaysia, 10 January.

ENTWISTLE, P.F. (1972). *Pests of Cocoa*. Longman Group Ltd., London, 779 pp.

KANG, S.M., AZHAR ISMAIL, LOKE, W.H., & MUSA MOHD. JAMIL (1983). The Cocoa Pod Borer *Acrocercops cramerella* Snellen in Sabah – A threat to the cocoa industry in Peninsular Malaysia. Crop Protection Branch, Department of Agriculture. KualaLumpur, Malaysia. 18 pp.

MOHD. SHAMSUDDIN OSMAN & VIJAYASEGARAN, S. (1982). A short report on cocoa pod borer, *Acrocercops cramerella* Snellen in Peninsular Malaysia. MARDI, Serdang, Selangor. 8 pp. (mimeo).

MUMFORD, (1980). Summary of visit to Quoin Cocoa Estate, Tawau, Sabah to assess the cocoa moth situation in that vicinity. Imperial College, London, 13 pp. (mimeo).

MUMFORD, J.D. (1983). Private communication. Imperial College, London, U.K.

WARDOJO, S. (1980). The Cocoa Pod borer – A major hindrance to cocoa development. *Indon. agric. Res. Devt. J.*, 2 (1), 2–4.

WESSEL – RIEMENS, P.C. (1981). The Cocoa Moth Pod borer-Review and Translation of Research in Indonesia 1990–1918. A special report prepared for Internat. Office of Cocoa and Chocolate. 43 pp.

WOOD, B.J. (1980). The cocoa pod borer moth in Malaysia. *Ann. J. Sel. Planters' Assoc.*, 28–36.

Control of the Cocoa Pod Borer
(Acrocercops Cramerella):
A Critical Review

J.D. MUMFORD

Imperial College at Silwood Park, Great Britain

Acrocercops cramerella, *the cocoa pod borer, is the major insect pest of cocoa in East Malaysia, the Philippines and the eastern islands of Indonesia. It has adapted to cocoa from local hosts and has spread on cocoa through the region over the past 150 years. Major research efforts prior to 1920 and since 1980 have resulted in several control measures and recent work offers the prospect of additional control options for the future. Currently available controls include selective branch spraying with insecticides to kill adult moths, and cultural practices to reduce pupation and egg laying. These practices include frequent harvesting of ripe fruit and removal or enclosing of pods and husks after harvest, and sleeving pods from the time they are about 7cm in length with small open ended plastic bags. Methods still under development include mass rearing of naturally occurring egg parasites, introduction of exotic natural enemies, trapping or confusion of male moths using sex pheromones, and breeding and planting resistant cocoa varieties.*

Acrocercops cramerella, the cocoa pod borer (also known as the cocoa moth), has been a pest of cocoa in parts of South East Asia for over a century. During this time it has been an important limiting factor in cocoa production in the areas infested. There was a flurry of research activity prior to the First World War in the then Dutch East Indies (Wessel, 1983), but this declined after the war along with the local cocoa industry. Interest in the cocoa pod borer increased again recently due to a general revival of commercial interest in cocoa in the region, and the moth's appearance in the vigorous East Malaysian cocoa industry, which has made pod borer control of greater importance.

Over the years considerable research has been done on the biology and control of this pest, and quite a few control methods have been suggested and tried. In the last few years several new control techniques have been developed, or are in the process of being developed. These are reviewed below in their historical context, following a discussion of the rise of the pest itself.

HISTORIC BACKGROUND

A. cramerella only occurs in S.E. Asia and the Western Pacific, and its origin within this area has been the subject of speculation since the turn of the century. It is a pest of cocoa and rambutan (*Nephelium lappaceum*), and also occurs on other *Nephelium* species, kola (*Cola* spp.), and nam-nam (*Cynometra cauliflora*). Other reported hosts appear to be erroneous.

Zehntner (1901a) believed it originated in Java, since at that time he thought it was not found on cocoa elsewhere. However, Zehntner (1901b) soon found other host species

and could no longer be certain that the moth was originally from Java, since these other host species, rambutan and kola, were present in other parts of S.E. Asia. Wardojo (1980) suggests the insect may have originated in Sulawesi, or even from the Philippines, based on an early outbreak in North Sulawesi and traffic between the islands.

Cocoa was introduced to the Philippines in the late 16th century by Spaniards directly from Central America (van Hall, 1949). van Hall assumed that small commercial plantings of cocoa began in the district of Minahassa in North Sulawesi about 1780, with planting material probably from the southern Philippines. These cocoa plantings were said to be scattered sparsely among other trees, presumably including fruit trees such as rambutan. In 1822, large and intensive plantations were set up near Manado in Minahassa (N. Sulawesi) to supply cocoa traders at Manila (Jansen, 1860). These plantations were apparently developed using planting material that was already available locally and these plantations began producing in 1825. van Hall quotes Graafland (1898) that there was cocoa everywhere, "from the beaches to the mountains, from Likupang to Belang" (a distance of almost 100 kilometers). By 1853, there were over 1 million cocoa trees in the area, covering approximately 1,600 ha.

In 1841, about 15 years after the great intensification of cocoa around Manado, an infestation appeared with symptoms typical of cocoa pod borer: dry and blackened pith, small cream coloured "worms", and small black "speckles" (exit holes) on the pod surface (Jansen, 1860). It is possible that an infestation may have been present earlier than 1841, but no record can be found of conditions during the years before 1822. In any event, a serious pod borer infestation arose soon after this major intensification of cocoa growing at Manado, and we can speculate that this may have occurred when the change in cultivation put large numbers of cocoa trees into proximity with a relatively small number of alternate hosts, such as rambutan, which may already have been harbouring a population of *A. cramerella*. The selective advantage for a part of the moth population that could adapt to cocoa would have been very great in what was apparently the first example of near monoculture cocoa in S.E. Asia.

It has been suggested that the cocoa pod borer may not have adapted to cocoa in S.E. Asia from local fruits, such as rambutan, but may have been introduced from elsewhere. This could have happened with the introduction of cocoa, kola, or possibly some other unknown host plant. However, this type of insect has not been recorded from cocoa, kola, or any other plant in Africa or the Americas. Therefore, local adaptation is much more likely than importation as an explanation for the cocoa pod borer's presence on cocoa in the region.

While I believe that the moth itself may have originated in Malaya along with rambutan (Corner, 1952), it seems that the cocoa form or race first appeared in, and spread from, North Sulawesi, as Wardojo (1980) suggested. In Sulawesi, a portion, and possibly a very small portion, of the population of moths (maybe at some distance from their centre of origin, and so likely to be more adaptable) could have had the capacity to develop on cocoa. With the advent of large plantings of cocoa, this genetic group could have quickly become the predominant type in that part of Sulawesi. Support for this theory comes from the distribution of rambutan and cocoa moths that has subsequently been discovered, with only the rambutan borers in Malaya, while cocoa moths have spread in the wake of cocoa moved for planting.

After the appearance of cocoa pod borer at Manado in the 1840's the cocoa industry declined rapidly. By 1860 only 223,000 cocoa trees remained in the district, with very

poor yields (van Hall, 1949). Toxopeus and Giesberger (1983) reviewed the similar rise and fall of the industry in the islands and districts near Minahassa. The industry began to move elsewhere, to the Philippines and to Java. There had long been movements of cocoa between Minahassa and Manila, which could have introduced whole infested pods into the Philippines. About 1880 cocoa was introduced into Central Java on a plantation scale to replace coffee (van Hall, 1949), although there had been some trade in cocoa between Java, Sulawesi, and the Philippines even before that date (Wardojo, 1980).

At that time this planting material was probably transported as seedlings in pots or as pods, the latter being capable of transferring infestations. It was often the practice in the new area to plant a small acreage as a test, and if it produced well after a few years to introduce more planting material then to establish a full scale plantation. As a result, already infested pods could be brought to an area of bearing cocoa where emerging moths could begin a new infestation. Wardojo (1980) suggests that the infestation in East and West Java, and in North Sumatra, developed in this way from Central Java material. He goes on to suggest that the cocoa "race" of *A. cramerella* throughout the Philippines and Indonesia may ultimately have arisen from the same population that initially adapted in Minahassa. It is not possible to determine yet whether the appearance of a cocoa form of *A. cramerella* in Sabah in 1980 followed a local adaptation accompanying the intensification of cocoa in the post 1977 "cocoa boom", or an introduction from Indonesia or the Philippines.

In addition to the infestations in cocoa and rambutan in Java, *A. cramerella* was also found for the first time in kola fruit (Zehntner, 1903) and nam-nam fruit (van Hall, 1913). Kola was imported from Africa (Purseglove, 1968) and nam-nam is believed to have come originally from India (Roepke, 1917). *A. cramerella* has also been found on hosts other than coca in the Northern Territory of Australia (J.D. Bradley, 1981, pers, com.), Western Samoa (Meyrick, 1927), New Britain (PNG) (Froggatt, 1940), and Peninsular Malaysia (Ahmad and Balasubramaniam, 1975).

CONTROL MEASURES

There appear to be seven main control methods potentially available, each of which is discussed in turn.

Insecticide Spraying

The earliest observations on spraying cocoa pod borers were by Zehntner (1904), who felt that spraying cocoa would be too expensive to do regularly. With the poisons and application equipment available at the time it would probably have been very ineffective as well, and little more was done about chemical control until the early 1950's.

Laoh (1953; 1954) reported results of tests spraying DDT, dieldrin, gamma-HCH, endrin, and aldrin in Indonesia. Spraying overall with mistblowers at 0.5 l/ha/week for five months brought infestations down to 43% in the treated area (with 98% in the untreated). Only endrin was considered to give economical results.

van Willigen (1954), also in Java, described estate practised spraying with endrin at .32 l/ha in four batches of four ten-day interval rounds in a year, at about 100 l/ha. As an estate manager he seemed quite happy with the initial results ("with chemical treatment

we are on the right road"), and he also advocated mixing in a copper fungicide for black pod control, and a squirrel poison. The results he gives however, are not very conclusive.

While the initial response in 1953/54 may have appeared promising, Giesberger (1983) suggested that five years of spraying pod borers in this way on one estate in Java (from 1958) 1,200 ha of cocoa had to be uprooted as a result of stem and branch borer (*Glenea novemguttata*) attack. Wardojo (1980) also associated these spraying practices with devastating attacks from another stem borer (*Zeuzera coffeae*). Conway (1973) showed that widespread overall spraying of cocoa with endrin and similar chemicals (not for pod borer) contributed to the serious bagworm (*Clania* spp.) outbreaks in Sabah in the early 1960's.

Considerable insecticide testing was also done in the Philippines in the late 1950's and early 1960's (Matthysse, 1957; Viado *et al.*, 1956; Eloja and Gandia, 1961; 1962). These generally found that spraying frequently with organochlorines reduced infestations, in some cases reducing losses by about half. No mention was made of the development of secondary pests there, but it may be significant that there were no further reports on pod borer control for 20 years.

By the early 1970's there seemed to be little enthusiasm for spraying pod borers. Situmorang (1971) said that chemical control had so far given poor results, and by the mid 1970's much of the pod borer infested cocoa in Java had been abandoned, in many cases due to the appearance of secondary pests as mentioned above.

Two problems seem to have been responsible for the lack of success with these early spraying programmes: relatively persistent chemicals, and poor, nonspecific targetting. The advent of less persistent chemicals with greater toxicity to pod borers, such as carbamates and pyrethroids, and the development by Day (1983) of a selective application technique aimed at adult resting sites has made the prospect of effective, safe, and relatively inexpensive insecticidal control of cocoa pod borers much more likely.

Several trials (R.K. Day, unpublished reports) in Sabah have shown very good results from spraying deltamethrin or propoxur onto the underside of lower canopy branches four to five times at 10–14 day intervals during the low crop period. Vanialingam *et al.* (1981), in the Philippines, have reported good results from repeated overall sprays of deltamethrin mixed with gamma-HCH. In both cases, the reduction in infestations only lasted for up to a few months.

The method of spraying developed by Day in 1982 is to specifically spray only the daytime resting sites of the moths, the underside of roughly horizontal, lower canopy branches. This should not disrupt the beneficial insects in the cocoa, which, as mentioned above, is a very real danger. In younger plantings with low branches spraying is best done with a hydraulic knapsack sprayer. In older trees, a motor blower may be needed, or hydraulic sprayers with extended lances. The effectiveness of sprays is likely to be greater in younger plantings where better coverage can be obtained. Deltamethrin at 25ppm in 70 l/ha in five ten-day rounds has shown good effectiveness and high economic returns in serious infestations (R.K. Day, unpublished reports).

Branch spraying with the chemicals suggested above, carried out only for limited periods, should avoid the problems that occurred in the past with organochlorine chemicals sprayed throughout the year (which were much longer in persistence). The timing of sprays in the low crop period has three advantages: it reduces moth numbers during

the early part of the following peak crop, thus protecting the most vulnerable stage o
the main revenue producing crop; it is less likely to reduce the effectiveness of natur
enemies and pollinators, which are likely to be most efficient just after the peak cro
and it is a time when labour is least limiting. A further advantage of chemicals suc
as the modern pyrethroids is their relatively low mammalian toxicity, making them suc
safer for sprayer operators.

Sleeving

Sleeving was first suggested by Zehntner (1903), using cotton bags to cover youn
pods in seed gardens. The bags prevent oviposition on the pods, and so eliminate infesta
tion, if placed on pods before they attract egg laying female moths. Nowadays, plasti
sleeves (small polythene bags, generally) are used by some growers in Sabah, in smal
holdings in the Philippines (Vanialingam et al., 1981), and on some estates in Indonesi
(Youdeowei, 1980). Pods are harvested in the normal way when they are ripe (the colou
is easily seen through modern plastic sleeves, but it was a problem to determine whe
using cloth or paper sleeves, as were commonly used in the past).

While sleeving protects the pods covered, it does not reduce the population of moths
since they will continue to infest and breed in the unsleeved pods in the trees. Mos
sleeving is aimed at protecting the peak crop. However, this is the period when infestatio
levels are lowest, and unless significant losses are expected during the peak, sleeving ma
not be cost effective. It is important to recognise that during the peak crop period, whil
the percentage of pods infested declines, the actual number of pods infested increases
As a result, actual monetary losses can be greatest during the peak crop period, despit
the lower percentage infestation.

Sleeving to protect the peak crop may also effectively reduce the size of the peak cro
available to the moths, and so lower the ratio of peak: trough crop. This could mak
life easier for the moth (Day, 1984), and would be inadvisable (unless there is consider
able short term gain from protecting a peak crop that you expect will be severely in
fested).

There has been some suggestion from planters using sleeves that sleeved pods have
greater tendency to wilt and that those maturing produce small beans. Increased wiltin
or rotting is likely, especially in very wet weather, and if cherelles or very young pod
(less than about 7cm) are sleeved. The effect on bean size has not been shown definitely
to my knowledge, but is possible.

Frequent Harvesting/Bagging

Mumford (unpublished) observed that many caterpillars emerge from ripe pods botl
before and after harvest, while relatively few emerge from unripe pods. Mumford and Day
(1982) suggested frequent harvesting, rapid breaking, and subsequent destruction ol
husks by bagging, burying, drying, etc. to reduce the successful emergence of caterpillar
in the field.

The effectiveness of this control can depend on the season, since it appears that the
proportion of larvae emerging from old pods is greatest during peak crops, while during
the low crop period the proportion emerging from unripe and newly ripe pods increases
In addition the variety of cocoa may greatly influence the survival of larvae at different
pod ages (R.K. Day, unpublished reports), and this in turn may determine the proportion

emerging after the pods appear ripe. Clearly, frequent harvesting and bagging (or other destruction) of pods and husks can only be useful when a large proportion of larvae emerge from pods after they appear ripe.

Parasites/Other Natural Enemies

Naturally occurring natural enemies contribute greatly to mortality of pod borers, and a number of attempts have been made over the years to rear or encourage parasites. In Indonesia Roepke (1912b; 1914; 1917) studied several Ichneumonid pupal parasites, some spider and ant predators, and Trichogrammatid egg parasites. None developed into practical control agents.

In the Philippines Vanialingam *et al.* (1981) found an Ichneumonid pupal parasite and a number general predators attacking the cocoa pod borer. Again, these were not amenable to rearing and release.

The most intensive effort to develop pod borer control with natural enemies has taken place in Sabah, in particular by rearing and releasing a naturally occurring egg parasite, *Trichogrammatoidea bactrae fumata* (Lim & Sim, 1982). Natural parasitism by this wasp sometimes reaches 60% in Sabah, and it is hoped that by mass rearing and release high levels of parasitism may be ensured and maintained. Considerable development work on field release of this wasp has already been done by the Sabah Department of Agriculture, and trial releases are underway from pilot rearing facilities (E.B. Tay, pers. com.).

Considering the importance of naturally occurring parasites and the fact that mass release of specially reared parasites may eventually be undertaken, every effort should be made to protect natural enemies, and if spraying is done it should be as noted above to avoid disturbing either natural enemies or pollinators.

Further benefits may arise with introductions of exotic natural enemies, if suitable ones are found and approved by quarantine authorities. The naturally occurring parasites that have been found in various pod borer infested areas have not reduced the pest population to economically tolerable levels on their own. This may be due to the presence of hyperparasites or the availability of a wide range of suitable hosts other than pod borers. Introduced parasites may, therefore have the advantage of being free of these hyperparasites and would be chosen, where possible, for their specificity on pod borer like moths.

Rampassen

Zehntner (1903) advised planters that pod borer populations could be reduced by complete stripping of immature and mature pods for a short period during the cropping cycle. In theory, this would break the life cycle of the pod borer by removing all of the egg laying sites. Many estates in Java began to practise rampassen during the low crop period, and while control was not complete (since some pods were inevitably left on the trees) most planters seemed to feel that the improvement in crops was worthwhile (Wurth, 1909; Foepke, 1912b, 1913).

There was some debate about the duration and frequency of rampassen, whether it should provide a pod free period of as little as three weeks or as long as two months, and whether it should be done once or twice a year. Strictly in terms of the control effect, the longer the pod free period and the more frequently it is carried out the better. Eco-

6

nomic constraints, such as the cost and availability of labour, and the nature of the cocoa cropping cycle largely determined the practice on estates.

Rampassen remained the principal pod borer control method in Java into the 1950's (van der Knapp, 1955a & b), when it was superceded by the use of organachlorine insecticides (which precipitated some notable failures, as mentioned above). Even then, van Willigen (1954) observed that some planters would stick to "the good old way of stripping". The era of rampassen was one of continual decline for the cocoa industry in Indonesia, and it must have become more and more difficult to achieve good pod stripping as the trees got older.

Rampassen (along with insecticide spraying) was used in an attempt to contain the initial infestation of pod borer in Sabah, soon after it was discovered in 1980. At that time a single area of cocoa covering about 5,000 ha was affected, generally with a low level of infestation. Because of the great threat this initial infestation posed to the whole cocoa industry in Sabah, it was widely felt that a major attempt should be made to crush the pest while it was still in this early stage.

Unfortunately, in many cases only a partial rampassen was achieved, since the cost and difficulty of the operation in several thousand hectares of often very tall cocoa was enormous. Despite the difficulties, as many as 30 million pods may have been stripped near Tawau early in 1981. When harvesting officially resumed several months later the infestation remained, and was, in fact, at a higher level than prior to the rampassen attempt.

Rampassen is probably only a suitable control measure in estates with a very high level of management, numerous skilled labour, and with young cocoa in which stripping can be very efficient (i.e. complete). In estates with mature trees the degree of management required and the technical accomplishment of finding all the pods in the trees would be difficult to achieve.

Resistant Varieties

Soon after the cocoa pod borer was identified in Java entomologists began observing the susceptibility of different cocoa varieties (Roepke, 1912a). Djati Roenggo, and other Forastero hybrids, were found to be less susceptible than Criollo cocoas, and it was assumed that the resistance arose from the smoother, less furrowed surface characteristics of the DR hybrids (which was thought to make them less favourable for egg laying). Roepke also noted that the DR pods had harder husks, but felt that smoothness was a more important factor. Wellensiek and De Haan (1932) also identified certain hybrids that were less susceptible to pod borers in Java; they also noted that smooth surfaces in pods appeared to be associated with resistance.

Several hard shelled cocoa varieties have recently been observed in Sabah that show considerable, but not complete, resistance to pod borer. Pod borer larval mortality is much greater in varieties with a hard sclerotic layer than in softer varieties, and this character should be of prime importance in varietal selections for future planting in pod borer infested areas (Day and Mumford, 1983).

Further screening is necessary, but planters should begin thinking of increasing the proportion of partly resistant varieties in future plantings.

Pheromones

In 1981 Day (unpublished) showed that female pod borers produce a pheromone to attract male moths. This pheromone has subsequently been identified and a synthetic pheromone is being developed by the Tropical Development and Research Institute in London (Beevor, *et al.*, 1984). So far the synthetic pheromone is being used on a trial basis for monitoring, and trials for control using mass trapping or mating disruption/confusion are also underway. It is hoped that these might substantially reduce infestations in the long run.

CONCLUSION

At present there are three available control measures worth considering on estates to control the cocoa pod borer. These include frequent harvesting and destruction of ripe pods and husks to prevent pupation in the field, selective spraying of the moth resting sites with carbamate or pyrethroid insecticides to kill adult moths, and sleeving young pods with small polythene bags to prevent moths laying eggs. The relative cost effectiveness of these methods depends on the state of the crop, labour cost and supply, management skill, and the extent of infestation suffered.

Several other promising methods are under development. These include mass rearing of parasitic wasps for release against pod borer eggs, and a synthetic pheromone for trapping or mating disruption. There is also a considerable level of resistance to pod borers in some varieties of cocoa which can be exploited in future planting programmes. The cost and technical feasability of these methods remained to be determined.

The outlook for cocoa growing in the infested regions of S.E. Asia is, therefore, considerably brighter now than in the days when the cocoa industry in Indonesia and the Philippines succumbed to pod borers. However, the cocoa industry must recognise that this is a pest that requires management, and will not go away of its own accord.

ACKNOWLEDGEMENT

REFERENCES

AHMAD, Y. & BALASUBRAMANIAM, A. (1975). Major crop pests in Peninsular Malaysia. *Min. Agric. Malaysia. Bull.*, 138.

BEEVOR, P.S., DAY, R.K. & MUMFORD, J.D. (1984). Female sex pheromone of the cocoa pod borer, *Acrocercops cramerella:* Identification and field evaluation *Proc. 1984 Int. Conf. Cocoa and Coconuts, Kuala Lumpur, Malaysia.*

CONWAY, G.R. (1973). Ecological aspects of pest control in Malaysia. In: *The Careless Technology.* (ed. M.T. Farvar and J.P. Milton). Tom Stacey Ltd, London. pp 467–488.

CORNER, E.J.H. (1952). *The Wayside Trees of Malaya.* 2 Vols. 2nd Ed., Government Printer, Singapore.

DAY, R.K. (1983). Progress towards an integrated control programme for the cocoa pod borer, *Acrocercops cramerella* (Snellen), in Sabah. *Proc. Seminar on Crop Protection in Cocoa, Kuala Lumpur, Malaysia.*

8

DAY, R.K. (1984). Population dynamics of the cocoa pod borer: the importance of the host plant cropping cycle. *Proc. 1984 Int. Conf. Cocoa and Coconuts, Kuala Lumpur, Malaysia.*

DAY, R.K. & MUMFORD, J.D. (1983). Control of the cocoa pod borer *(Acrocercops cramerella)* in Sabah. *Proc. 10th Int. Cong. Plant Protection, Brighton, UK.,* 1025.

ELOJA, A.L. AND GANDIA, I.M. (1961). The control of cacao pod borer with insecticides. *Coffee Cacao J.* (Nov. 1961), 204–205, 209.

ELOJA, A.L. And GANDIA, I.M. (1962). Progress report on the control of the cacao pod borer *Acrocercops cramerella* Sn. with insecticides. *Phillip. J. Agric.,* 27, 97–103.

FROGATT, J.L. (1940). Entomologist's report. *New Guinea Agric. Gaz.,* 6, 9–13.

GIESBERGER, G. (1983). Biological control of the *Helopeltis* pest of cocoa in Jaya. *Archs. Cocoa Res.,* 2, 91–180.

GRAFFLAND, N. (1898). *De Minahassa.*

JANSEN, A.J.F. (1860). Aanteekeningen betreffende de kakao kultuur, in de Residentie Manado. *Natuurk. Tijdschr. Ned. Indie,* 20, 289–307.

LAOH, J.P. (1953). De bestrijding van *Helopeltis* met DDT en andere chloorhoudende insecticiden. *Bergcultures,* 22, 84–88.

LAOH, J.P. (1954). De bestrijding van *Acrocercops cramerella* in cacao. *Bergcultures,* 23, 671–676.

LIM, G.T. & SIM C.H. (1982). Major insect pests of cocoa in Sabah. *Proc. Seminar Penyelidikan Koko Untuk Pembangunan Pertanian Negara.* Cocoa Research Station, Tawau, Sabah, Malaysia. pp. 1–9.

MATTHYSSE, J.G. (1957). Research on insecticidal control of Philippines crop pests. *J. Econ. Entomol.,* 50, 517–518.

MEYRICK, E. (1927). *Insects of Samoa. Part III. Lepidoptera.* British Museum (Natural History), London.

MUMFORD, J.D. & DAY, R.K. (1982). Control of the cocoa pod borer. *Planter, Kuala Lumpur,* 58, 97–98.

PURSEGLOVE, J.W. (1968). *Tropical Crops: Dicotyledons.* Longman, London.

ROEPKE, W. (1912a). Voorloopige mededeeling omtrent het optreden van mot in verschillende typen van den Djati-Roenggo-cacao. *Meded. Proefst. Midden-Java, No. 3,* 1–3.

ROEPKE, W. (1912b). Over den huidigen stand van het vraagstuk van het rampassen als bestrijding-smiddel tegen de cacaomot op Java. *Meded. Proefst. Midden-Java. No. 8.*

ROEPKE, W. (1913). Verslag van het rampascongres gehouden door het Proefstation Midden-Java te Salatiga den 17den en 18den Januari 1913. *Meded. Proefst. Midden-Java. No. 11.*

ROEPKE, W. (1914). Verslag 1913–1914, Werkplan 1914–1915. *Meded. Proefst. Midden-Java. No. 18.*

ROEPKE, W. (1917). Verslag over het jaar 1916–1917. *Meded. Proefst. Midden-Java. No. 28,* 10–33.

SITUMORANG, S. (1971). Usaha-usaha pemberantasan cacao mot pada tjoklat. In: *Budidaja Kopi – Tjoklat. Vol. III.* Tretes Indonesia, Komisi Tehnis Perkebunan, Balai Penelitian Perkebunan Tjabang Djember, Java, Indonesia.

TOXOPEUS, H. & GIESBERGER, G., (1983). History of cocoa and cocoa research in Indonesia. *Archs. Cocoa Res.,* 2, 7–34.

VAN DER KNAPP, W.P. (1955a). Invloed van het rampassen op de productie van cacao-bomen (1). *Bergcultures*, 24, 219–223.

VAN DER KNAPP, W.P. (1955b). Invloed van het rampassen op de productie van cacaobomen (slot). *Bergcultures*, 24, 255.

VAN HALL, C.J.J. (1913). Verslag over het jaar 1912–1913 betreffende de technisches werkzaamheden. *Meded. Proefst. Midden-Java. No. 13*, 14–15.

VAN HALL, C.J.J. (1949). Cacao. In: *De Landbouw in de Indische Archupel IIB*. (ed. C.J.J. van Hall and C. van de Koppel). N.V. Uicgeverij W. van Hoev, 'S-Gravenhage. pp 272–346.

VANIALINGAM, THOMAS, E., IRSHAD. M., MANALO, J., & CRUZ, P. (1981). Early work in the control of the cocoa pod borer *(Acrocercops cramerella)* in the Philippines. *Proc. 8th Int. Cocoa Research Conf., Cartegena, Colombia*. pp 345–351.

VAN WILLIGEN, B. (1954). Report on the control of the cocoa pod borer of the Ngobo Plantation–Ungaran. Translation from *De Bergcultures*, Vol. 23, No. 24. Shell Agricultural Bulletin.

VIADO, G.B., ORILLO, F.T., BASIO, D.G., & VALDEZ, R.B. (1956). Six combination sprays in the control of insect pests and diseases of cacao. *Phillip. Agric.*, 40, 129–134.

WARDOJO, S. (1980). The cocoa pod borer – A major hindrance to cocoa development. *Indones. Agric. Res. Dev. J.*, 2, 1–9.

WELLENSIEK, S.J. & DE HAAN, J.T. (1932). Onderzoekingen over cacao-selectie in 1930 en 1931. *Archf Koffiecult*, 6, 103–145.

WESSEL, P.C. (1983). The cocoa pod borer moth 1900–1918. *Archs Cocoa, Res.*, 2, 37–62.

WURTH, T. (1909). De mottenplaag bij de cacao en het rampassen. *Cultuurgids*, 11, 164.

YOUDEOWEI, A. (1980). Review of cocoa pests in Indonesia and the Philippines and the development of research strategies for cocoa pest management. *Developing Bulk Cocoa in Indonesia*, Sect. 4. Report of a visit, 7 Feb.–14 Mar., 1980.

ZEHNTNER, L. (1901a). Over eenige insectenplagen bij cacaocultuur op Java. *De Nieuwe Gids*, 3, 567–572.

ZEHNTNER, L. (1901b). Een nieuwe voedsterplant van de cacaomot (voorloopige mededeeling). *De Nieuwe Gids*, 3, 1014–1017.

ZEHNTNER, L. (1903). Rapport over de mottenbestrijding op de onderneming banaran 1901–1902. *Proefst. v. Cacao, Salatiga. Bull.*, 5, 1–53.

ZEHNTNER, L. (1904). Rapport over de werkzaamheden – Mei en Jun 1904. *Korte Meded. Proefst. Cacao, Salatiga*. No. 12.

Female Sex Pheromone of Cocoa Pod Borer Moth, *Acrocercops cramerella:* Identification and Field Evaluation

P.S. BEEVOR
Tropical Development and Research Institute, London, U.K.

AND

R.K. DAY AND J.D. MUMFORD
Silwood Centre for Pest Management, Imperial College at Silwood Park, U.K.

The cocoa pod borer, Acrocercops cramerella *Snellen (Lepidoptera: Gracillariidae), is a serious pest of cocoa in S.E. Asia. The sex pheromone produced by the female moth has been shown to consist of at least five components using gas chromatography and electro-antennography. These were identified and synthesised, and a synthetic blend of five components in 100:10:10:1:10 ratio was used to optimise the design, positioning and colour of pheromone traps for this species in Sabah, E. Malaysia. Subsequent experiments showed that a mixture of the five components in 40:60:4:6:10 ratio was the most attractive to male moths. Brown, "sandwich"-pattern, sticky traps (30 cm x 30 cm with 5 cm separation between top and bottom) positioned just above the cocoa canopy and baited with polythene vials impregnated with 1 mg of the optimum synthetic pheromone blend caught more than twelve times as many moths as similar traps baited with a virgin female moth.*

This paper discusses the prospects of the synthetic pheromone in monitoring and control of cocoa pod borer.

The cocoa pod borer, *Acrocercops cramerella* Snellen (Lepidoptera: Gracillariidae), is a serious pest of cocoa in S.E. Asia. During the 1930's it contributed to the collapse of the cocoa-growing industry in the Philippines and Indonesia. In 1980 it was discovered in Sabah where some areas are now suffering considerable crop loss.

The female moth lays eggs singly on cocoa pods and the larva bores into the soft pod centre. This may cause production of smaller beans, difficulties in extraction of beans from the pod and yellowing of the immature pod leading to premature harvesting.

Several control methods for cocoa pod borer are being investigated, including selective application of insecticides, improved cultural practices and biological control with introduced predators and parasites. The female moth was shown to produce a volatile chemical attractant for the male moths, since sticky traps baited with virgin female moths caught significantly more male moths than unbaited traps. Identification and synthesis of the chemical structure of this sex attractant or "pheromone" was undertaken in anticipation that it would provide a powerful tool for interfering with the mating of cocoa pod borer moths and reducing the number of larvae produced.

RESULTS

Pheromone Identification

The pheromone was obtained by extraction of the pheromone glands of virgin female moths or by collection of the volatile materials given off by a female moth, and the resulting mixtures were analysed by gas chromatography. Simultaneous electroantennographic recording of changes in electrical potential difference across the antenna of a male moth positioned at the outlet of the gas chromatograph was used to determine which components of the mixtures were biologically active. At least five active components were detected, and these were identified and synthesised. Less than 1 nanogram (10^{-9} g) of each component was obtained per female moth, and the relative proportions of the five components could only be estimated as 100:10:10:1:10. Polythene vials impregnated with 1 mg of the synthetic mixture were shown to attract male cocoa pod borer moths to sticky traps, and experiments were carried out in Sabah to optimise the design of the trap, the height at which it should be positioned and its colour. Further tests were then conducted to find the most attractive blend and dosage of the pheromone components.

Full details of the chemical identification and field evaluation of the pheromone complex will be published elsewhere.

Trap Design

Early experiments showed that the types of pheromone trap used for other moth species were ineffective for cocoa pod borer moth. These included sticky boards, sticky delta traps, water pan traps and dry funnel traps. However, these experiments led to the design of a "sandwich" trap consisting of two sheets of galvanised metal held apart by wire spacers and suspended horizontally with the upper surface of the lower sheet coated with a polybutene sticker.

The sandwich traps caught more male cocoa pod borer moths than other traps e.g. sticky delta traps (*Table 1*).

TABLE 1. CATCHES OF MALE COCOA POD BORER MOTHS IN DELTA AND SANDWICH TRAPS (30 cm x 30 cm)

Trap type	Total moth catch	Moth catch/trap/night
Sticky delta	13	0.31
Sandwich (5 cm separation)	40	0.95
Sandwich (7.5 cm separation)	34	0.81

Varying the distance between the two sheets of the sandwich trap showed that 5.0 cm separation was optimal (*Tables 1* and *2*).

A range of sizes of sandwich trap was tested, but there were no significant differences in the numbers of male moths captured, and 30 cm x 30 cm was selected as the most convenient size (*Table 3*).

2

TABLE 2. CATCHES OF MALE COCOA POD BORER MOTHS IN SANDWICH
TRAPS (30 cm x 30 cm)

Trap type	Total moth catch	Moth catch/trap/night
Sandwich (2.5 cm separation)	9	0.38
Sandwich (5.0 cm separation)	17	0.71

TABLE 3. CATCHES OF MALE COCOA POD BORER MOTHS IN SANDWICH TRAPS OF
VARIOUS SIZES (5 cm SEPARATION BETWEEN TRAP TOP AND BOTTOM)

Sandwich trap size (cm)	Total moth catch	Moth catch/trap/night
22.5 x 22.5	18	0.56
30.0 x 30.0	25	0.78
37.5 x 37.5	17	0.53
45.0 x 45.0	18	0.56

Trap Height

The position of the pheromone trap was found to be a very important factor in
maximising the number of male moths caught. Traps at a height of about 8 m, *i.e.* above
the cocoa but below the tops of the *Gliricidia* shade trees, caught many more male moths
than those positioned within the cocoa canopy or above the *Gliricidia* trees (*Table 4*).

TABLE 4. CATCHES OF MALE COCOA POD BORER MOTHS IN SANDWICH TRAPS
(30 cm x 30 cm WITH 5 cm SEPARATION) SUSPENDED AT VARIOUS HEIGHTS

Position of trap	Approx. trap height (m)	Total moth catch	Moth catch/ trap/night
Below cocoa canopy	2	3	0.02 a
Top of cocoa canopy	5	57	0.46 b
Middle of *Gliricidia* canopy	8	49	0.39 b
Top of *Gliricidia* canopy	12	·1	0.01 a
Above *Gliricidia*	14	0	0 a

Numbers followed by the same letter are not significantly different at the 5% confidence level as
determined by the *t* test.

In subsequent experiments, traps were positioned 0.3 — 1.0 m above the top of the
cocoa canopy.

Trap Colour

The effect of trap colour was examined by comparing catches of male moths in the
original, unpainted, galvanised metal traps (30 cm x 30 cm with 5 cm separation) with

those in traps painted yellow, green, brown, black and white. Mean moth catches per trap per night ranged from 0.42 in the unpainted traps to 1.27 in the yellow traps, but the differences were not statistically significant. However, yellow or brown traps were used in subsequent studies.

Pheromone Blend and Dosage

Having optimised the design, positioning and colour of the traps, an extensive series of experiments was carried out to find the most attractive blend of the pheromone components. A mixture of the five components in 40:60:4:6:10 ratio was found to be the most attractive of those tested, and polythene vials impregnated with 1 mg of this mixture attracted more male moths than those impregnated with 0.1 mg or 0.01 mg (*Table 5*).

TABLE 5. CATCHES OF MALE COCOA POD BORER MOTHS IN SANDWICH TRAPS BAITED WITH POLYTHENE VIALS IMPREGNATED WITH DIFFERENT LOADINGS OF SYNTHETIC PHEROMONE (40:60:4:6:10 MIXTURE)

	Pheromone loading (mg)	Total moth catch	Moth catch/ trap/night
Expt. 1	1.0	161	2.68 a
	0.1	127	2.12 b
Expt. 2	0.1	149	2.48 a
	0.01	101	1.68 b

Numbers followed by the same letter are not significantly different and at the 5% confidence level as determined by the t test.

The success of all these studies was demonstrated using brown-coloured sandwich traps (30 cm x 30 cm with 5 cm separation) positioned just above the cocoa canopy and baited with polythene vials impregnated with 1 mg of the optimum synthetic pheromone blend (40:60:4:6:10). Catches of male cocoa pod borer moths in these were over twelve times higher than catches in similar traps baited with a virgin female moth (*Table 6*) with maximum catches on any one day of 95 and 3 moths respectively.

TABLE 6. CATCHES OF MALE COCOA POD BORER MOTHS IN BROWN SANDWICH TRAPS (30 cm x 30 cm WITH 5 cm SEPARATION) POSITIONED 0.3 – 1.0 m ABOVE THE COCOA CANOPY

Attractive source	Total moth catch	Moth catch/tray/night
Synthetic pheromone (1 mg)	373	12.93 a
Virgin female moth	29	0.97 b
Unbaited	1	0.37 c

Numbers followed by the same letter are not significantly different at the 5% confidence level as determined by the t test.

4

CONCLUSION

Laboratory and field studies have produced a powerful synthetic attractant source and an effective trapping system for male cocoa pod borer moths. These have great potential for both monitoring and control of cocoa pod borer infestations.

Monitoring

The pheromone traps provide a very sensitive means of detecting the presence of and measuring the abundance of cocoa pod borer moths. Many factors control the relationships between trap catches of adult male moths, the numbers of larvae and the levels of damage caused, but preliminary results in Sabah suggest that high trap catches are associated with high larval infestation. This could form the basis of a method for determining whether it is necessary to introduce control measures as well as for detecting the spread of cocoa pod borer to previously unaffected areas. The pheromone traps are cheap and easy to construct and maintain, and the synthetic pheromone attracts only male cocoa pod borer moths so that highly-trained personnel are not needed to identify the moths caught.

Control

Large numbers of pheromone traps could trap sufficient male cocoa pod borer moths to cause a reduction in mating and in subsequent numbers of larvae. The moths generally occur at low population densities — 200 pairs per hectare is considered to be high — and the synthetic pheromone source has been shown to be much more attractive to male moths than a virgin female moth. In addition, as the moths are weak fliers there will be little immigration of females already mated into an area where mass trapping is used. Evidence for the validity of these hypotheses has been obtained in the course of the trapping experiments described here. When pheromone traps are set up at a new site, catches on the first night are invariably much higher than those on subsequent nights. This is interpreted as being due to moths of varying ages being present initially; the traps take out a high proportion (estimated to 75—80%) of these on the first night so that on subsequent nights essentially only moths that have newly emerged in that area are available for trapping.

A second method of using the synthetic pheromone for control of cocoa pod borer involves permeating the atmosphere with synthetic pheromone. Male moths are "confused" so that they cannot detect and follow the pheromone plumes produced by female moths, and the probability of mating taking place is reduced.

These control methods based on the sex pheromone have the great advantage of specificity mentioned here. Only cocoa pod borer is affected. Other insects, including natural and introduced predators and parasites as well as insects responsible for pollination, are unharmed, and the pheromone has no toxic effects on other forms of animal and plant life.

All these monitoring and control techniques are being actively studied. Experiments are being carried out to examine the correlation between catches of male moths in pheromone traps and the routing cocoa pod borer infestation surveys. A mass-trapping trials is to be set up in 200 ha of cocoa to test whether pheromone traps can reduce cocoa pod borer infestation and damage levels below economic thresholds. Various formulations of the synthetic pheromone are being tested for use in the "confusion" technique.

Problems of *Phytophthora* Bark Canker on Cocoa in Papua New Guinea

C. PRIOR

Cocoa Industry Company Limited, Rabaul, Papua New Guinea

Canker, black pod and chupon infections caused by Phytophthora palmivora *were present on 13% of trees in a block of three and half year-old hybrid cocoa at Keravat, Papua New Guinea, an unusually high level of infection at this age. In these trees, cankers arose most frequently from infected pods and chupons and in the jorquette. Cankers on both hybrid and Trinitario trees spread intermittently. Actively growing cankers produced sporangia in cracks in the bark, providing a perennial on-tree source of inoculum. Many naturally occurring cankers stopped growing and were sloughed off but some remained, enlarged and eventually killed the cambium. Canker infections are cumulative and eventually lethal and treatment should begin when the trees are young. Scraping the surface of the cankers does not eliminate the fungus from the lesions and it is recommended that scraped cankers should be painted with 0.25% a.i. metalaxyl/1.25% a.i. cuprous oxide as Ridomil Plus 72 w.p.*

Bark canker caused by *Phytophthora palmivora* (Butl.) Butl. s.st. (Brasier & Griffin, 1979) is found on cocoa of all ages throughout Papua New Guinea. Prior (1981) described the occurrence in Papua New Guinea of "sudden death" of cocoa trees. This condition was most common in trees more than 10 years old and was a major cause of death in trees 15 − 20 years old. Bark canker and attack by scolytid beetles were associated with "sudden death" and canker was suggested as the primary cause. The severity of bark canker in Papua New Guinea's Trinitario cocoa is partly explicable by the known susceptibility of some of this material (Firman & Vernon, 1970; Prior & Sitapai, 1980) compared to Amelonado and some Amazonian types (Vernon, 1971; Okaisabor, 1972). Although good resistance to bark canker occurs in Papua New Guinea's cocoa (Prior & Sitapai, 1980), regular attention to canker control is considered necessary in the Amazonian x Trinitario hybrid cocoa now being planted (Moxon, 1983): this hybrid material varies in susceptibility (Tan, 1982). An effective treatment for canker is available (Prior & Smith, 1982).

Cankers may provide a source of inoculum for initiating black pod infections and provide a permanent source of infection on the tree, allowing the fungus to survive during dry conditions when pod infections rarely occur (Henry, 1977; Jackson & Newhook, 1978). The ability of both cankers around cushions and of deep-seated cushion infections to grow out and infect pods is well known (Firman, 1974).

However, evidence for sporulation on cankers under natural conditions is scanty (Jackson & Newhook, 1978; Maddison & Griffin, 1981) although Henry's findings strongly suggested that it occurred (Henry, 1977).

This paper describes the initiation and spread of canker infections in young and mature trees. Some additional information on canker treatment is also presented.

METHODS

Observations on Naturally Infected Bark

Observations on the initiation of cankers were made in a block of three and half year-old hybrid seedlings at Keravat, growing under mixed *Leucaena* and *Gliricidia* shade, to determine the extent of canker infection and the relative frequency of entry of the fungus through various infection courts. Some observations were also made on naturally occurring infections in older Trinitario seedling trees.

To check for the production of sporangia on cankers, pieces of naturally and artificially infected bark were examined in the laboratory both directly after collection and after 24 h incubation in a damp chamber. Collections were made during wet weather and immediately after rain following an extended period of dry weather.

Artificial Inoculation of Cocoa Bark

Cankers were produced in the trunks of 12-year-old seedling trees using the disc inoculation technique of Prior & Smith (1982). Lesions produced by this method were used for observations on the growth of cankers and also for an experiment on the effect of bark scraping on the survival of *P. palmivora* in cankers; bark scraping is recommended for canker control in Malaysia (Chan, *et al.*, 1977). In this experiment three inoculations were made into each of 30 trees. After eight weeks, one of the three following treatments was applied to each of the three lesions on every tree: (1) control (no treatment), (2) scraped to remove the surface bark and (3) scraped and painted with 0.25% metalaxyl (as Ridomil 25 wp). Ten trees were sampled two, eight and twenty-five weeks after treatment to determine the presence of *P. palmivora* in the lesions. Three samples of canker from each lesion were baited into fresh cocoa pods as described by Prior & Smith (1982).

RESULTS

Observations on Naturally Infected Bark

Observations on the origin and frequency of cankers in the three and half year-old hybrid trees are summarised in *Table 1*. Only 45% of the block was bearing, due to the unevenness of the stand caused mainly by pruning for vascular-streak dieback (vsd). Some trees were in their second year of bearing whereas some had been recently stumped or replanted as a result of vsd infection. Already, 10.8% of the total trees (24.2% of the bearing trees) had canker infections. Some had black pod infections or infected chupons but no detectable canker and the proportion of the total stand with *Phytophthora* infections of all kinds was 13.0%. Cankers originating from infected pods and cankers originating in the jorquette region but not associated with an obvious entry point were most common. Chupons were also a frequent entry point but entry via wounds and insect damage was less frequent than previously reported (Prior & Smith, 1981), doubtless because such wounds were less common on these young trees. Longicorns were present but *Pantorhytes* was not.

TABLE 1. ORIGIN AND FREQUENCY OF *PHYTOPHTHORA* INFECTIONS IN A BLOCK OF THREE AND A HALF YEAR OLD COCOA HYBRID SEEDLINGS AT KERAVAT'

Item	Number of trees	Total trees (%)	Bearing trees (%)
Total positions	1073		
Total bearing trees	479	45	
Trees with black pod[a]	59	5.5	12.3
Fresh black pod			
Distal	9		
Proximal	3		
Not determined	4		
Total	16	1.5	3.3
Canker			
Associated pod	43	4.0	0.0
Associated chupon	24	2.2	5.0
Associated jorquette	48	4.5	10.0
Associated insect damage	8	0.7	1.7
Associated other damage	8	0.7	1.7
Not determined	10	0.9	2.1
Total cankered trees[b]	116	10.8	24.2
Total with infected chupons (not forming cankers)	16	1.5	3.3
Total cankers on non-bearing trees	3	0.3	
Total trees with *Phytophthora* infections[c]	140	13.0	29.2

a Undoubtedly an underestimate because of very dry weather at the time of assessment (Jan 1984). Trees were scored positive for black pod only if old black pods were associated with stem canker (43) or not so but fresh black pod was present (16).
b Some trees had cankers associated with more than one source.
c Comprises all trees with black pod, canker or infected chupons or any combination of these (114 with canker, 16 with fresh black pod but no canker, 10 with infected chupons but not canker or black pod).

In two separate samplings of actively growing cankers taken from naturally infected mature trees in wet weather, sporangia were found on two out of ten and three out of nine samples. Clusters of sporangia were seen, with sometimes <5 but sometimes 20 to 50 individual sporangia present. In one case, a dense mass of sporangia (170/mm) was seen in a crack in the bark over an actively growing canker. In a single sample of cankers taken immediately after rain following a period of dry weather (six days without rain), only two out of 53 had sporangia, although in a further two cases sporangia were present on the shrivelled chupon from which the canker had originated. All the sporangia appeared old and shrivelled and may have been the remnants of those produced during the last period of wet weather.

Artificial Inoculation of Cocoa Bark

Cankers produced by artificial inoculation ceased to spread after about two weeks. Growth was slightly more extensive in the outer bark directly beneath the epidermis than in the inner bark. However, vertical spread in the cambium was twice as great as in the bark, as described by Firman & Vernon (1970) in very susceptible trees in Fiji, although subsidiary lesions did not develop from this cambial spread as described by these authors. Young cankers had diffuse and ill-defined margins. Cankers older than two to four weeks had 0.5 mm wide, dark and sharply defined margins. On the outside of these margins, narrow and regularly spaced cells were present, suggesting active cell division. Older cankers shrank away from the bark along the margin after scraping allowed them to dry out, indicating a tissue weakness in this region.

Some cankers exhibited an irregular series of dark lines, resembling growth rings. These appeared to be successive margins which had developed and then been overwhelmed, indicating that the fungus was growing intermittently. During the period of regular observations on cankers developing from inoculations (Nov 1983 – Jan 1984) no further spread occurred after two weeks although some cankers developed one or two "growth rings" during this period. Weather during this period was drier than average (rainfall for Dec 1983 was 119 mm compared to a fifteen year average of 277 mm). In naturally infected trees much larger cankers were seen with multiple "growth rings" indicating intermittent growth over a longer period.

The results from sampling *P. palmivora* in scraped and metalaxyl-treated lesions after two, eight and 25 weeks are shown in *Table 2*. Scraping did not eliminate the fungus from the lesions during the course of the trial. Metalaxyl completely eliminated the fungus for two weeks but it was reisolated from metalaxyl-treated lesions after eight and 25 weeks. All the lesions, including the untreated controls, had started to callus over by 25 weeks.

DISCUSSION

In the young hybrid trees examined in this study cankers were most often found associated with infected pods, infected chupons and the thick, wrinkled bark of the jorquette region. Jackson & Newhook (1978) also found that *P. palmivora* infections were frequent in the jorquette. This is particularly interesting because it suggests that the fungus can infect the bark in the absence of any wound or pre-infected organ. The jorquette region of cocoa trees fills with leaves and organic rubbish which retains moisture and therefore forms an environment more favourable environment for *Phytophthora* infection than occurs on other parts of the tree. It is also an exceptionally dangerous place for canker to develop because the infection is hard to see beneath the thickened bark and may girdle the stem or main branches before it is detected.

TABLE 2. PRESENCE OF *P. PALMIVORA* IN SCRAPED AND METALAXYL–PAINTED LESIONS[a]

Frequency (week)	Control	Scraped	Scraped and metalaxyl-painted
2	9 (19)	9 (17)	0 (0)[b]
8	9 (17)	7 (15)	4 (6)
25	5 (9)	8 (11)	6 (7)

[a]The figures are the number of inoculations. out of 10 with *P. palmivora*; the figures in parenthesis are the total number of successful isolations out of 30.
[b]Total number of successful isolations was significantly different ($p < 0.001$) at two weeks after the application of this treatment but not at eight or 25 weeks (Chi–squared test).

By contrast to the situation in these young trees, Prior & Smith (1981) found that in old Trinitario trees that were badly attacked by insects, insect damage was the most important entry point for canker. It is assumed that most of this was re-infection via the wounds from other inoculum sources on the trees.

It is evident from the observations in *Table 1* that canker infections can begin to build up from the first year of bearing; three trees were actually attacked by canker before they bore their first pods. Such a rapid build up of *Phytophthora* infections does not always occur; in another block of hybrids of similar age at Keravat, less than 1% of the trees were infected (Anon., 1983). These trees were in the first year of bearing (McGregor, 1984). Keravat). The data in *Table 1* came from a block that had mixed shade, including *Leucaena* which may be a source of *Phytophthora* inoculum (Jackson & Newhook, 1978), and was also damp, with a creek flowing through one part. The susceptibility of these Amazonian x Trinitario hybrids is already established (Tan, 1982) and the data in *Table 1* indicate that under some conditions the two diseases canker and black pod may build up very rapidly. The observations of canker formation from infected pods and sporangial production by cankers indicate how closely the two diseases are linked and how failure to control either one will inevitably lead to an increase in both.

Cankers appeared to show intermittent growth, being confined behind sharply-defined margins, between periods of activity. Tippett, *et al.*, (1983) also observed this in cankers in *Eucalyptus marginata* caused by *P. cinnamomi*, where periderm activity eventually eliminated the canker but where the fungus sometimes "broke out" and renewed growth under favourable climatic conditions. Tippett & Hill (1983) correlated canker growth with bark moisture content and suggested that renewed growth was associated with periods of high moisture content. Most cocoa cankers including those produced by artificial inoculation stopped growing after two to four weeks and were enclosed behind a reaction zone by the action of the bark. Such cankers will inevitably be sloughed off unless they can break through the reaction zone and renew growth. Some naturally occurring cankers do this and eventually reach and kill the cambium. Once this happens bark healing can only occur from the edge of the damaged area and the damage may not be repaired within the remaining life of the tree, especially since the infection spreads more rapidly in the cambium than in the bark.

The factors which determine the rate of spread of *P. palmivora* in cocoa bark are those that contribute to the balance between host and pathogen. Prior & Sitapai (1980) and

Tan (1982) have shown that a range of resistance occurs in Papua New Guinea's cocoa. Tippett & Hill (1983) have shown that environmental conditions may favour renewed growth of *P. cinnamomi* in *Eucalyptus*. A similar demonstration has not been made for cocoa. Okaisabor (1972) and Henry (1977) showed that the number of active cankers increased in the wet season but this might have been due to increased inoculum from infected pods. The intermittent spread of cankers observed at Keravat is probably associated with periods of wet weather but firm evidence for this is not yet available, Other factors that may help the fungus to overwhelm the inherent resistance of cocoa include insect attack which wounds the bark and allows the fungus to circumvent initial bark responses to infection, progressive decline in soil nutrients with age and the gradual build up of canker infection which debilitates the trees. As the trees age the canker problem becomes progressively worse until large, spreading cankers exist on the trunks and main branches.

The results presented here indicate that canker infections begin early in the life of the crop and act as a source of black pod infection. If untreated, canker progressively destroys the trees. Treatment at the later stages of attack is costly and the cumulative effect of neglect cannot be reversed; it is probably better to replant. Since canker is cumulative, the best approach to control is early and regular treatment. In Malaysia, scraping the cankers gave effective control without chemical treatment (Chan *et al.*, 1977) although Turner & Shepherd (1980) recommended painting with captafol after scraping. In Papua New Guinea, painting with 0.25% metalaxyl is recommended (Prior & Smith, 1982).

The results of the scraping trial indicated that scraping did not eliminate the fungus from the lesions and thus a source of inoculum remained on the tree. In this experiment the untreated lesions were healing by the end of the experiment so treatment with metalaxyl might appear superfluous, especially as *P. palmivora* was reisolated from metalaxyl-treated lesions after eight weeks. However, since renewed growth of naturally occurring cankers can occur and since scraping does not eliminate the fungus, the metalaxyl treatment seems worthwhile. The reappearance of the fungus in the treated lesions eight weeks after application could have been due either to recontamination of the lesion with inoculum from other parts of the tree or to regrowth of the fungus after the effect of the fungicide had worn off; at concentrations below those that are fungitoxic, metalaxyl is fungistatic (Kerkenaar & Kaars Sijpesteijin, 1981). Since Jan 1984 metalaxyl has been available in Papua New Guinea only as Ridomil Plus 72, a metalaxyl/cuprous oxide mixture. When this product is applied to cankers the copper component will certainly reduce the possibility of renewed growth.

ACKNOWLEDGEMENT

REFERENCES

ANON. (1983). LAES Annual Report for 1982. Department of Primary Industry, *Konedobu*, Port Moresby, Papua New Guinea.

BRASIER, C.M. & GRIFFIN, M. J. (1979). Taxonomy of 'Phytophthora palmivora' on cocoa. Trans. Br. mycol. Soc., 72, 111–143.

CHAN, C.L., TEOH, C.H. & ANG, B.B. (1977). Control of cocoa stem canker caused by Phytophthora palmivora (Butler) Butler. MARDI Res. Bull. 5, 21–29.

FIRMAN, I.D. (1974). Cocoa Canker. In Phytophthora Disease of Cocoa, (ed. P.H. Gregory). Longman Group Limited, 348 pp.

FIRMAN, I.D. & VERNON, A.J. (1970). Cocoa canker caused by Phytophtora palmivora. Ann. appl. Biol., 65, 65–73.

HENRY, C.E. (1977). Primary sources of Phytophthora palmivora (Butl.) Butl. inoculum in Jamaica and methods of control. Proceedings of the Fifth International Cocoa Research Conference, Ibadan, 1975.

JACKSON, G.V.H. & NEWHOOK, F.J. (1978). Sources of Phytophthora palmivora inoculum in Solomon Island cocoa plantations. Trans. Br. mycol. Soc., 71, 239–249.

KERKENAAR, A. & KAARS SIJPESTEIJN, A. (1981). antifungal activity of metalaxyl and furalaxyl. Pesticide Biochemistry and Physiology, 15, 71 – 78.

McGREGOR, A. (1984). Personal communication, LAES, Keravat.

MADDISON, A.C. & GRIFFIN, M.J. (1981). Detection and movement of inoculum. In Epidemiology of Phytophthora on Cocoa in Nigeria, (ed. P.H. Gregory and A.C. Maddison) ch. 3. Commonwealth Agricultural Bureaux.

MOXON, J.E. (ed.) (1983). Review of the research requirements for cocoa in Papua New Guinea. Technical Report 83/7, Department of Primary Industry, P.O. Box 417, Konedobu, Papua New Guinea.

OKAISABOR, E.K. (1972). Ambient on-tree reservoirs of Phytophthora palmivora (Butl.) Butl. in Nigeria. Proceedings of the Fourth International Cocoa Research Conference, Trinidad, 1972.

PRIOR, C. (1981). Phytophthora bark canker of cocoa in Papua New Guinea. Proceedings of the Seventh International Cocoa Research Conference, Douala 1979.

PRIOR, C. & SITAPAI, E. (1980). Resistance of clonal cocoa in Papua New Guinea to bark canker caused by Phytophthora palmivora (Butl.) Butl. Trop. Agric. Trin., 57, 167–169.

PRIOR, C. & SMITH, E.S.C. (1981). Association of Phytophthora palmivora bark canker and insect damage in Papua New Guinea. Ann. appl. Biol., 97, 27–30.

PRIOR, C. & SMITH, E.S.C. (1982). Control of bark canker of cocoa with metalaxyl. Trop. Pest Mgmt, 28, 45 – 48.

TAN, G–Y. (1982). Breeding for disease resistance to vascular-streak dieback, canker and black pod in hybrid cocoa. Proceedings of the Eighth International Cocoa Research Conference, Cartagena 1981.

TIPPETT, J.T., SHEA, S.R., HILL, T.C. & SHEARER, B.L. (1983). Development of lesions caused by Phytophthora cinnamomi in the secondary phloem of Eucalyptus marginata. Aust. J. Bot., 31, 197 – 210.

TIPPETT, J.T. & HILL, T.C. (1983). The relationship between bark moisture content and invasion of Eucalyptus marginata by Phytophthora cinnamomi. Australas. Pl. Path., 12, 40 – 41.

TURNER, P.D. & SHEPHERD, R. (1980). Cocoa diseases in Malaysia and Indonesia: their present and potential importance. *Proceedings of the International Conference on Cocoa and Coconuts, Kuala Lumpur 1978.*

VERNON, A.J. (1971). Canker, the forgotten disease of cocoa. *Cocoa Growers' Bull.*, 16, 9 – 14.

Potential for Biological Control of Root Disease of Cocoa in Papua New Guinea

P. JOLLANDS

Cocoa Industry Co., Ltd., c/o Lowlands Agricultural Experiment Station, Keravat, East New Britain, Papua New Guinea

Root disease of cocoa caused by Rigidoporus lignosus *and* Phellinus noxius *could become a problem now that large areas of cocoa are being replanted for the first time and large numbers of stumps are exposed. Artificial inoculation of stumps with spores and mycelial suspension of the two pathogens was unsuccessful though field observations have shown large numbers of stumps to be infected by the pathogens. Stump protection is required and use of a biological agent has the advantage over chemical stump treatment as it can degrade the stump and replace the pathogen in already colonised tissue. Saprophytic fungi isolated from cocoa and* Leuceana *stumps, and fallen logs were tested for their ability to decay wood and to compete with* P.noxius *in blocks of wood. Two of those tested showed potential and will be further tested in field experiments.*

The two major pathogens causing root disease in cocoa in Papua New Guinea, are *Phellinus noxius* (Corner) G.H. Cunn. and *Rigidoporus lignosus* (Klotzsch) Imazeki. The problem was identified by Thrower (1955) and was considered to be of little economic importance. Recent large-scale redevelopment of cocoa in PNG has meant the exposure of a large number of stumps of both cocoa and shade trees both of which are ideal habitats for the pathogens.

If these stumps could become infected by spores of the pathogens as reported elsewhere (John, 1964; Rao, 1967; Lim 1976) in Malaysia on fresh rubber stumps and Bolland on hoop pine in Australia (pers.comm.), then the disease could spread to newly planted cocoa from the infected stumps. From there, how fast it might spread within a cocoa block is unknown but very damaging disease outbreaks might occur.

Chemical treatments can prevent establishment of the root disease pathogens. However, biological agent, which also prevents establishment of pathogen on the cut stump surface and quickly degrades the stump tissue, removing it as a food base, would give more long-lasting control. This method has been successful in controlling butt rot of pine caused by *Heterobasidion annosum* (Fr.) Bref. using the basidiomycete, *Peniophora gigantea* (Fr.) Massee (Rishbeth 1963).

This paper describes the preliminary work to establish whether spore infection occurs and to investigate possible antagonistic fungi.

METHODS

Production of Spores

Spores of *R. lignosus* were readily discharged when pieces of fresh sporophore collected from the field were placed on microscope slides in a damp chamber overnight.

Spores of *P.noxius* were collected in the field by suspending microscope slides below fresh sporophores which were still attached to stumps. The following day the slides were collected and a spore suspension was prepared.

Spore discharge of *P.noxius* was determined over 24h using a modified thermohydrograph. The paper on the drum was replaced by two pieces of sellotape with the sticky side up and the drum was marked so the hours could be recorded. One of the 'windows' of the casing was replaced with a piece of thick cellophane with a narrow slit (2mm wide) in the centre. This was placed directly beneath the hymenial surface of a fresh sporophore of *P.noxius*. After 24h the sellotape was removed, placed on microscope slides and examined to assess the periodicity of spore discharge.

Spore viability was tested. Three pieces of cocoa twig 3mm long were placed on microscope slides and covered with a drop of the spore suspension; this gave good germination of the spores compared with germination of spores in water.

Inoculation of Cut stumps with Spores and Mycelial Suspension of *P. noxius* and *R. lignosus*

Cocoa trees of approximately 10 m diameter were felled at 1 m and then the trunk cut again at 30 cm above the ground. This was to prevent splitting or tearing of the bark. Depending on the size of the stump a 1 or 2 ml of spore suspension of either *P.noxius* or *R. lignosus* was applied to the cut stump surface. The number of spores per millilitre was counted and approximately 1×10^5 per millilitre was applied. After one to four months, the stumps were sampled by cutting off the remaining stump at ground level and splitting it. Samples from the discolored wood were removed aseptically and placed on basidiomycete agar (containing 5% malt extract, 5 ppm benomyl and 100 units crystamycin) in Petri dishes. A total of 50 stumps were inoculated with *P.noxius* and 50 with *R.lignosus* on three different occasions.

Trees were felled as before. Inoculum was prepared by homogenising mycelium from a culture of *P.noxius* in a blender with 10 ml distilled water. This was applied with a paint brush to the cut stump surface. A total of 30 stumps were used on two different occasions.

Saprophytic Fungi

Isolation. Sporophores were collected from cocoa stumps, shade tree stumps and coconut stumps and cultures prepared. The sporophores were photographed, labelled, and spore size and colour noted for subsequent identification. A letter code was used for unidentified fungi. The growth rate of the fungus was assessed on agar and the size of the hyphae was measured. Basidiomycete fungi were also isolated from decayed cocoa and shade tree wood.

Weight loss of wood colonised by different fungi. The ability of selected saprophytes to rot fresh cocoa wood was tested, as a measure of how quickly a cocoa stump could be degraded by fungi. Fresh cocoa stem of 6 cm diameter was cut into lengths of 15 cm. A hole 3 cm long and 1 cm in diameter was drilled in the centre of the wood at one end. Each piece was then weighed and labelled. Mycelial inoculum of test fungi, which had been grown on malt extract agar, was inserted into each hole, the end plugged with a small piece of carpenter's dowelling and the ends of the wood painted with 0.5% malachite green solution to prevent fungal growth on the outside of the piece. Forty pieces were used for each of the eight test fungi, and one set of 40 logs was left un-

inoculated as control. The pieces, except the control set which was left in a shade house, were stored in a pit covered with corrugated iron to keep them damp. After eight weeks, 20 pieces for each fungus were collected. These were weighed, dried for one day and reweighed. After 16 weeks, the rest were sampled and dried for two days and the percentage loss of wood was calculated. Samples were taken from the pieces before drying and plated onto basidiomycete agar to check the fungus was still present in the wood pieces.

Interactions between Root Rot Pathogens and Saprophytic Fungi

Five saprophytic fungi were selected on the basis of their frequent field occurrence and their ability to degrade wood. Interactions were studied *in vivo* in wood blocks in the laboratory. The selected fungi and the root rot pathogens were grown on malt agar in Petri dishes. Pieces of *Leuceana* stick approximately 1 cm in diameter were cut into 3 cm lengths, soaked in 3% malt extract and autoclaved. These were then placed on the cultures of the fungi and left for about three weeks until the fungus had permeated the wood. Interactions on agar in Petri dishes bear little resemblance to results from interactions in wood and therefore an experiment was set up to test interactions in living and dead cocoa wood. Lengths of cocoa and approximately 5 cm in diameter and 15 cm long were prepared and a 1 cm-hole drilled 3 cm into each end. Half the blocks were autoclaved to simulate poisoned wood. The saprophytic and pathogenic fungi growing on *Leuceana* sticks were used as inoculum and the interaction between them was tested by inoculating one end of the length with a pathogen and the other with a saprophyte. After inserting the dowels the non-autoclaved wood blocks were painted with a 1% a.i. benomyl (Benlate) and thiophanate methyl (Topsin M) to prevent growth of contaminants. The blocks were individually wrapped in aluminium foil, placed in polythene bags and left for six to 12 weeks. They were then split and the interaction between the two fungi determined by observation and by isolation onto basidiomycete agar.

RESULTS

Production of Spores

Spore discharge of *P.noxius* occurred throughout the day when the sky was cloudy but on hot sunny days spore discharge ceased in the morning when the relative humidity was low. Between 0700 and 0900 h, discharge declined sharply but built up again through the day until about 1600 h when it stayed constant throughout the night. The relationship between spore discharge and relative humidity and temperature is shown in *Figure 1*.

Inoculation of Cut Stumps with Spores and Mycelial Suspension

None of the stumps sampled had been colonised by either *P.noxius* or *R.lignosus*, although other basidiomycetes had colonised and in some cases decayed the wood.

Weight Loss of Wood Colonised by Different Fungi

Five of the eight fungi decayed the wood more than the uninoculated control after 16 weeks. Only one caused a significant decrease in weight after eight weeks. The results were analysed using a t-test and are shown in *Table 1*.

Interactions between Root Rot Pathogens and Saprophytic Fungi

Field observations have shown that three fungi commonly occur on the Gazelle Peninsula on newly felled cocoa and shade trees, *Flavodon flavus* (Kl.) Ŕyv. *Trametes*
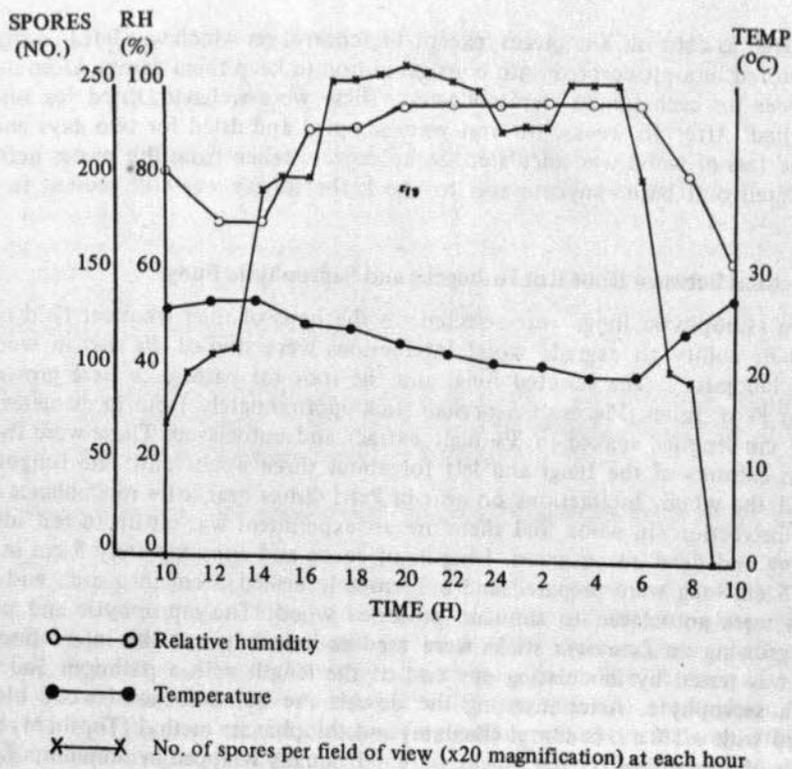
SPORES RH
(NO.) (%)
TEMP
(°C)

O——O Relative humidity
●——● Temperature
X——X No. of spores per field of view (x20 magnification) at each hour

Figure 1. Spore discharge of P.noxius in relation to temperature and relative humidity.

TABLE 1. WEIGHT LOSS OF WOOD INOCULATED WITH TEST FUNGI

Fungus	Week Sampled	Mean Weight Loss (%)
T.scabrosa	8	50
	16	70*
S.commune	8	58
	16	71*
A	8	46
	16	55
B	8	53
	16	71*
D	8	48
	16	66*
E	8	29
	16	61
F	8	49
	16	56
Control	8	63*
	16	69*
		59

* significantly more weight loss (p<0.01) than the control.

scabrosa (Pers.) Cunn. and *Schizophyllum commune* Fr.. *F.flavus* occurred on 90% of *Leuceana* stumps which had been felled and treated two months previously with 2,4,5-T in diesoline. *T. scabrosa* has been observed mainly on cocoa, either on stumps, or old branches and logs. *S. commune* colonises fresh branches, cut wood etc. of a variety of trees. The ability of these fungi to colonise and grow through stumps must be determined. Preliminary observations indicate that *F.flavus*, although a frequent coloniser of *Leuceana* stumps, does not grow into the stump.

The results of interactions are shown in *Table 2*. The situation changed between six and 12 week sample. After six weeks, in most cases where a single fungus had been inoculated, the fungus had colonised the whole block. In addition, there was a varying amount of external colonisation by the inoculated fungi. *P.noxius* caused a crust on the outside of the wood similar to that formed on living trees. *S.commune* formed a profusion of rudimentary fruit bodies on both autoclaved and non-autoclaved wood.

TABLE 2. INTERACTION *IN VITRO* BETWEEN *P.NOXIUS* AND FIVE SAPROPHYTIC FUNGI

Interaction		Time of Sampling (weeks)	Number out of five colonised by				
			P. noxius (P.n. end)	P. noxius (Saprophyte end)	Saprophyte (Saprophyte)	Saprophyte (P.n. end)	Other
Pn v A	(A)	6	4		5		
	(A)	12	5		5		
	(NA)	6	3		3		2
	(NA)	12	2	1	3	2	
Pn v Ts	(A)	6	3	2		3	
	(A)	12	2	1			5
	(NA)	6	4	3	1		
	(NA)	12	1	1			5
Pn v Sc	(A)	6	2		5	3	
	(A)	12	0			1	5
	(NA)	6	2		5	2	1
	(NA)	12	3	1	2		4
Pn v B	(A)	6	4	1	4		1
	(A)	12	4		3		3
	(NA)	6	2	3	2		
	(NA)	12	3		3		4
Pn v Ef	(A)	6	4	1	4		
	(A)	12	1	1			5
	(NA)	6	3	2			
	(NA)	12	1	2			5

A	Autoclaved
NA	Non autoclaved
Pn	*P.noxius*
Ef	*E. flavus*
Ts	*T.scabrosa*
Sc	*S.commune*
A	Basidiomycete A
B	Basidiomycete B

The fungicide application on the outside prevented growth of contaminants but did not prevent growth of the basidiomycetes outside the block. When the pathogen and saprophyte were inoculated together, after six weeks *S.commune* was the only fungus

that was isolated from the pathogen-end of the block. With Basidiomycete A, there was deadlock between the pathogen and the antagonist and an interaction zone was formed between the two. In all the others (*F.flavus*, *T.scrabrosa* and Basidiomycete B) the pathogen was re-isolated, sometimes from the antagonist-end of the block. After 12 weeks the situation had changed and isolations of both pathogen and antagonist were much less successful. *S.commune* was isolated in one case from the pathogen-end of the block but *P.noxius* was isolated from the antagonist-end of the same interaction. Basidiomycete A had further colonised the block and overcome the interaction zone in two cases with *P.noxius* to be isolated from the pathogen-end.

The average position of interaction zones is shown in *Table 3*. This changed over six to 12 weeks generally in favour of the pathogen except with B. Here in the non-autoclaved wood another basidiomycete was commonly isolated which may have interfered with the interaction. With autoclaved wood there was a definite increase in colonisation by *P.noxius:* in three out of five cases there were two zone lines formed and in all three *P.noxius* was isolated from the in-between zone. Interactions between the fungi also occurred on the outside of the block: *P.noxius* generally colonised externally in advance of its internal colonisation which is typical of the ectotrophic infection habit (Garrett, 1970).

TABLE 3. EXTENT OF COLONISATION OF *P.NOXIUS* AND SAPROPHYTIC FUNGI IN AUTOCLAVED AND NON-AUTOCLAVED BLOCKS OF WOOD

Interaction		Mean Growth of Fungi (cm)			
		6 Weeks		12 Weeks	
		NA	A	NA	A
P.noxius vs A	Pn	10.6	7.6	11.5	7.8
	A	4.6	8.6	4.0	7.8
P.noxius vs Ts	Pn	13.7	15.0	13.5	12.6
	Ts	1.3	0.0	1.8	3.1
P.noxius vs Sc	Pn	2.3.	1.5	10.5	5.0
	Sc	12.7	13.8	5.0	10.0
P.noxius vs B	Pn	14	11.4	9.8	10.8
	B	2.5	5.0	6.0	4.8
P.noxius vs Ff	Pn	9.5	10.0	12.8	9.9
	Ff	6.0	5.5	3.3	5.6

A   Autoclaved
NA   Non-Autoclaved
Pn   *P.noxius*
Ff   *F.flavus*
Ts   *T.scabrosa*

DISCUSSION

P.noxius and *R.lignosus* spread from tree to tree by root contact from an uninfected to a healthy root (John, 1958; Thrower 1955). However, the role of spores in dissemination of these diseases is not well understood. Conidia and basidiospores of *H.annosum* commonly initiate infection in pine plantations (Rishbeth, 1951) and though

infections initiated by spores of *Armillaria mellea* (Fr.) Kummer were rare (Rishbeth, 1970) they could give rise to new infection foci. With *R. lignosus* and *P. noxius* in tropical tree crops the evidence is conflicting. In Malaysia Rao (1967) reported 17% infection 15 months after spore inoculation of fresh stumps of rubber with *P. noxius*. Bakshi (1976), however, indicated that *P. noxius* in plantations of rubber in India spread only by root contact. Some success with infection by spores of *R. lignosus* was obtained on rubber stumps in Malaysia when the stumps were covered with soil (John, 1965). Later Lim (1976) showed that basidiospores could cause new infection foci. However in Sri Lanka, Liyanage *et al.*, (1980) found no natural colonisation of stumps and concluded spread was by root contact only.

No success was obtained in Papua New Guinea using spore and mycelial inoculation of freshly cut cocoa stumps although there is a readily available spore inoculum from fresh sporophores. However, observation of areas with a high incidence of infection showed that large numbers of stumps in second rotation cocoa were colonised by the pathogens, especially *P. noxius*. The fungus could either have been present when the tree was felled, or the stump infected by spores, or by root contact from an infected stump or tree to an uninfected stump. Whichever is the case, these stumps are a potential disease hazard to replanted cocoa and increase the need for a biological control agent which can degrade the stump quickly. Although artificial inoculations have failed, field observations suggest that spore infection of a stump can occur.

A saprophytic fungus which would prevent establishment of the pathogens in stumps whether by root or spore infection is one way of preventing the spread of the disease. Ideally, it would be able to establish rapidly and replace the pathogen in previously colonised wood. It must not be replaced by other fungi which are less antagonistic towards the pathogen, and must degrade the stump tissue, thus removing it as a food base for the pathogen. Of the fungi tested, five were able to colonise and cause a weight-loss in wood. A notable exception is Basidiomycete A which did not degrade the tissues significantly more than the control. However in interactions in blocks of wood with *P. noxius* this fungus was isolated from the pathogen-end of the blocks of non-auto-claved wood in two cases out of the five after 12 weeks. The zone line formed in the original interactions at six weeks was overcome by Basidiomycete A and it had started to replace *P. noxius*. *S. commune* was also successful at competing with *P. noxius*, in this case possibly because of a more rapid growth rate. It is a primary coloniser of cut stumps and felled wood, and as a primary coloniser may be replaced by other Basidiomycetes. If either Basidiomycete A or *S. commune*, can replace the pathogens in stump tissue their use in root disease prevention should be investigated.

. Further tests to discover how these fungi perform under field conditions are necessary. It may be possible that by manipulating the stump environment using chemicals such as ammonium suphamate or urea, the stump can be made a more favourable environment for colonisation by antagonistic fungi. However, application of such a treatment to stumps must remain simple. In the U.K. *Peniophora gigantea*, used to control *H. annosum*, is applied to cut stumps from a sachet containing conidia of the fungus plus a marker dye. Any procedure adopted here must be equally quick and cheap if it is to be accepted.

REFERENCES

BAKSHI, B.K. (1976). *Forest Pathology. Principles and Practices in Forestry*. Delhi: Controller of Publications, 400 pp.

GARRETT, S.D. (1970). *Pathogenic root-infecting fungi.* Cambridge University Press.

JOHN, K.P. (1958). Inoculation experiments with *Fomes lignosus* Klotzsch. *J. Rubb. Res. Inst. Malaya,* 15, 223–230.

JOHN, K.P. (1965). Some observations on spore infection of Hevea stump by *Fomes lignosus* (Klotzsch) Bres. *J. Rub. Res. Inst. Malaya,* 19, 17–21.

LIM, T.M. (1976). Spore production, germination and infection in *Rigidoporus lignosus* on *Hevea. Jurnal Sains Pusat Penyelidikan Getah Malaysia,* Jilid 1, Bilangan 1, 15.

LIYANAGE, N.I.S., PERIES, O.S., & LIYANAGE, A DE S. (1981). The role of the basidiospore of *Rigidoporus lignosus* in the spread of white root disease of Hevea. *J. Rubb. Res. Inst. Sri Lanka,* 57, 37–40.

RAO, B.S. (1967). *Rep. Rubb. Res. Inst. Malaysia 1966,* 61–65.

RISHBETH, J. (1951). Observations on the biology of *Fomes annosus,* with particular reference to East Anglian pine plantations. 111. Spore production, stump infection and saprophytic activity in stumps. *Ann. Bot.,* 15, 1–21.

RISHBETH, J. (1963). Stump protection against *Fomes annosus.* III. Inoculation with *Peniophora gigantea. Ann. appl. Biol.,* 52, 63–77.

RISHBETH, J. (1970). The role of basidiospores in stump infection by *Armillaria mellea.* In *Root Diseases and Soil-borne Pathogens,* (Ed., T.A. Toussoun, R.V. Bega and P.E. Nelson). University of California Press, Berkeley, California.

THROWER, L.B. (1955). The root diseases of cacao in Papua and New Guinea. *Papua and New Guinea Agric. J.,* 10(1), 1–13.

Screening of Some Systemic Fungicides Against *Oncobasidium theobromae* and Translocation Studies of Benomyl in Cocoa

M.J. MUSA AND C.C. TEY

Malaysian Agricultural Research and Development Institute, Hilir Perak.

Oncobasidium theobromae *Talbot and Keane, the pathogen of vascular streak dieback of cocoa, grows in the xylem vessels of the host. Hence, conventional contact fungicides are unable to protect the cocoa trees from the disease. Systematic fungicides, which are apoplastically translocated, are much more suitable for this purpose.*

Several systemic fungicides from the benzimidazoles, the carboxamides, the morpholines, the piperidines and the imidazoles groups were selected for their activities against Basidiomycetes and in the case of benzimidazole, for its broad-spectrum action. These selected chemicals were screened in vitro *and on seedlings against* O. theobromae. *Except for triademefon and oxycarboxin, most of the chemicals tested were able to totally inhibit mycelial growth at 10 ug/ml, whilst benomyl and pyracarbolid at 5 µg/ml, Screening of these chemicals on seedlings, by drenching and spraying, showed that benomyl was able to protect the seedlings, perhaps due to the plant's ability to translocate the chemical.*

Further experiments were carried out to study the translocation of benomyl on seedlings and mature trees. Seedlings, growing in pots in loamy soil, were able to accumulate appreciable amounts of the fungicide in the shoots only 8 h after the application of the chemical by drenching. Mature cocoa trees growing in alluvial clay of Hilir Perak were also applied with benomyl by drenching and burying the chemical around the root region. This was carried out during the wet period. The young flushes were then sampled and the amounts of fungicide in the young flushes were determined. Three days after the application, it was found that the amounts of benomyl in the flushes were more than the amount required to totally inhibit mycelial growth of O. theobromae. *The fungitoxicity of the flushes persisted for more than 30 days.*

Oncobasidium theobromae Talbot and Keane, the causal agent of Vascular Streak Dieback (VSD), is a xylem inhabiting fungus (*Figure 1*). The spores colonise young flushes, then penetrate and enter the xylem vessels of the leaves (Prior, 1980). From here, the fungus grows down in the xylem vessels of the branches and the trunk. From the initial infection, it usually takes three to five months for any visible symptom to be seen.

Once the fungus has colonised the young flushes and xylem vessels, the use of contact fungicides is inappropriate. Systemic fungicides which are translocated apoplastically are more capable of dealing with fungus inhabiting the xylem vessels. Some of the systemic fungicides accumulate in young leaves, thus giving protection against infections.
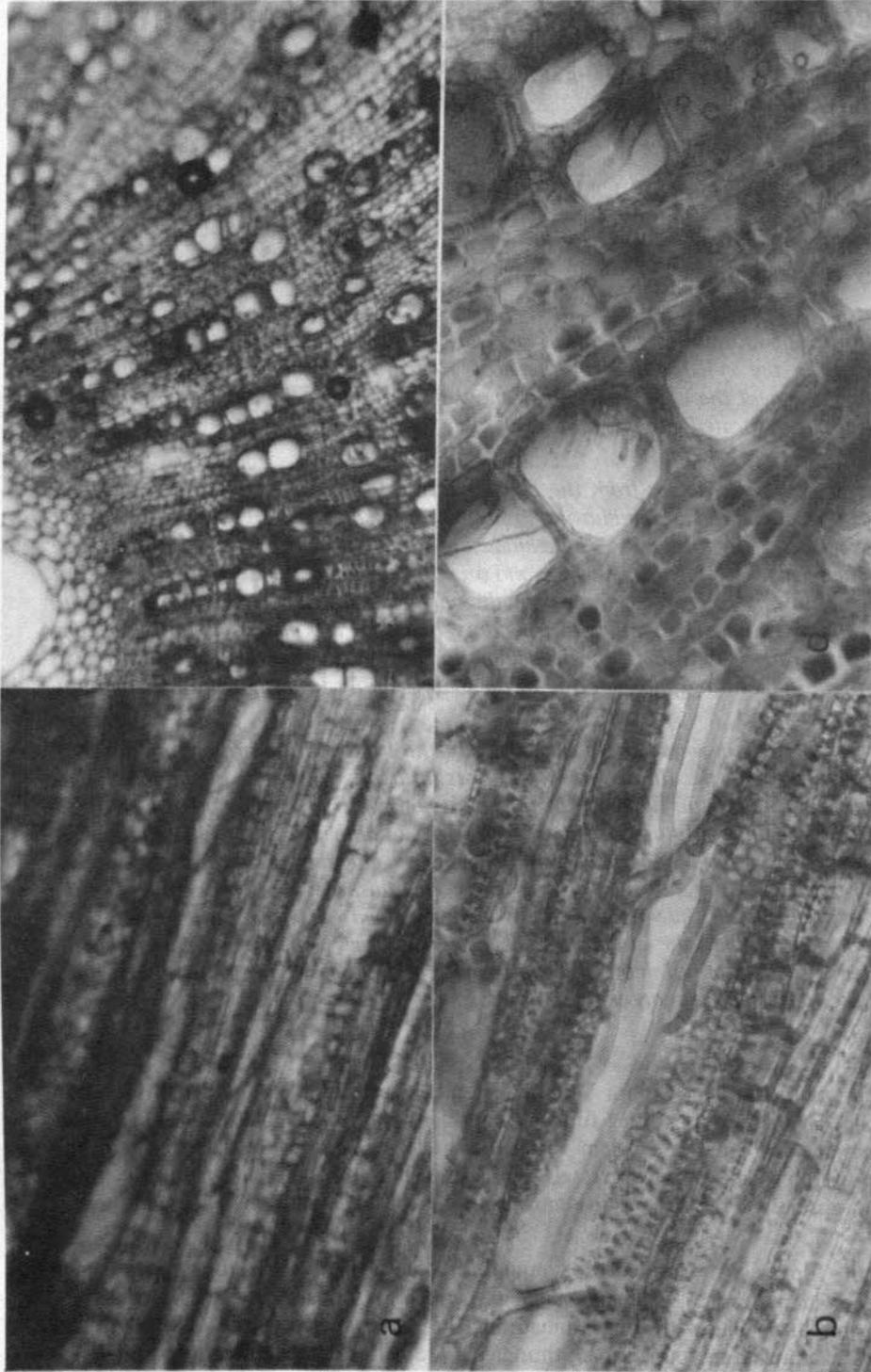
Figure 1. Photomicrographs of thin sections of VSD tissue (a and b longitudinal section; c and d tranverse section) Sections stained with trypan blue (a and c low power 10 x 20; b and d high power 10 x 40). Fungal hyphae seen in the xylem vessels stained blue.

This paper reports *in vitro* screening of selected systemic fungicides against *O. theobromae*. Translocation and accumulation of benomyl in young flushes are also evaluated.

MATERIALS AND METHODS

Inoculum

Cocoa branches of 2 cm long, infected with *O. theobromae*, were collected from MARDI Hilir Perak Station and cut using sterilised secateurs. The bark of the stem pieces were removed aseptically, plated onto 1.5% (w/v) water agar and then incubated in an incubator (25°C, 12h light/day). Mycelial plugs from the fungal colonies were used as inoculum. Prior to this, the identity of the fungus was checked under the microscope. The presence of the fungus in the diseased tissue was determined by making thin longitudinal sections (*Figure 1a, b*).

Fungicides Screened

Systemic fungicides screened against the fungus are listed in *Table 1*. They were selected according to their activities against Basidiomycetes, and in the case of benzimidazole, its broad spectrum activity.

In vitro Screening of Fungicides

The fungicides were screened against *O. theobromae* by culturing the fungus in 50% coconut water (Musa, 1983) amended with various concentrations of the fungicide. Percentage inhibition of mycelial growth was determined by comparing the decrease in mycelial growth caused by the fungicide over the amount of mycelium in the control petri dishes (*i.e.* without fungicide). For each concentrations, at least 16 plates readings were taken.

Translocation of Benomyl in Cocoa Trees

It was found from pot experiments, that all the systemic fungicides tested were translocated in cocoa seedlings. Since benomyl was found to be the most fungitoxic *in vitro*, its translocation in mature cocoa tree was further illucidated. Two experimental plots (Plot A and Plot B) were selected on marine alluvium soil (Udult, Ultisol) of MARDI Hilir Perak Station. Plot A consisted of six-year old clonal planting while Plot B consisted of six-year-old hybrids planting. Identical experiments were carried out on these two plots.

Five methods of benomyl applications (treatments) were tested.

1. 4 g benomyl drenched around the collar of the tree (D).
2. 4 g benomyl planted (5 cm deep) at four points (1 g/point) around the tree, at 30 cm radius (T_4).
3. 2 g benomyl planted (5 cm deep) at two points (1 g/point) around the tree, at 30 cm radius (T_2).
4. As in (2) except the benomyl was wrapped in filter paper, whatman 24 (TB_4).
5. As in (3) except the benomyl was wrapped in filter paper, whatman 24 (TB_2).

Trees which were not treated with benomyl served as controls (C). Each treatment was replicated six times in a randomised block. Filter paper was used in the hope that it would act as a slow-release barrier for benomyl. The experiments were carried out in December 1982, as it was a wet period and the trees were flushing. After the application

This paper reports on in vivo screening of selected systemic fungicides against O. tuberosum. Translocation and accumulation of fungicidal in sampling fluids are also evaluated

TABLE 1. SYSTEMIC FUNGICIDES SCREENED

Fungicides	Commercial Name	Chemical Groups	a.i. (%)	Formulation	Description[a]
Pyracarbolid	Sicarol	Carboxamide	50	WP	Specific for basidiomycetes, interference with fungal respiration.
Oxycarboxin	Vitavax	Carboxamide	75	WP	Active on basidiomycetes, interference with fungal respiration.
Benomyl	Benlate	Benzimidazole	50	WP	Broad spectrum, antimitotic.
Triforine	Saprol	Piperazines	20	EC	Active on basidiomycetes, ergosterol synthesis inhibitor.
Tridemorph	Calixin	Morpholines	75	EC	Active on basidiomycetes, ergosterol synthesis inhibitor.
Triademefon	Bayleton	Imidazole	25	WP	Active on basidiomycetes, ergosterol synthesis inhibitor.

[a] from Kaars Sijpesteijn (1977)

4

of benomyl the young flushes were sampled to determine the amount of benomyl in the leaves. From each tree, two flushes from opposite side of the canopy were sampled. These samples were brought to the laboratory, extracted, and the amount of benomyl was determined by bioassay, using the cup-plate method. Samplings were carried out three days after treatment and then every 10 days consecutively until no more benomyl was detected in the flushes. The identity of benomyl (or its product, carbendazim) in the leaves was confirmed by thin layer chromatography (*Figure 2*).
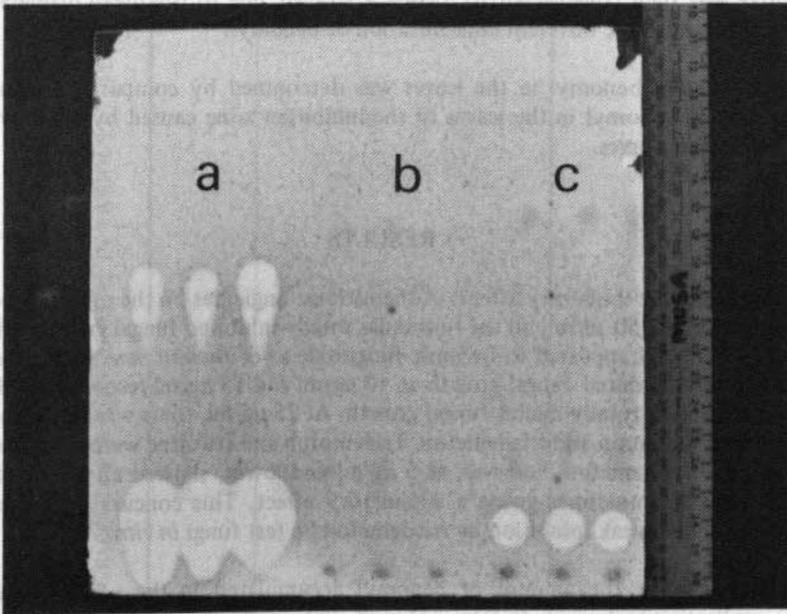

Figure 2. *Thin layer chromatography of benomyl and leaf-extracts. (Extraction with chloroform, TLC solvent chloroform/acetone 6 : 1)*
a = benomyl solution.
b = extract of control leaf.
c = extract of leaf from benomyl treated plant.
Spots, benomyl at Rf 0.70 and carbendazim at Rf 0.14 (Plate sprayed with P. expansum)

Extraction and Bioassay of Benomyl in Cocoa Leaves

A calibration curve of benomyl concentration was constructed using bioassay technique with *Penicillium expansum* as the test fungus (see *Appendix*). Autoclaved PDA (potato dextrose agar, Oxoid) was cooled in water bath 45°C and was seeded with concentrated conidial suspension of *P. expansum*. The seeded medium was then poured into petri plated at 25 ml per plate. The medium was allowed to solidify and a well of diameter of 7 mm was punched in the middle of each plate using a cork borer.

Benlate suspension (in chloroform) containing 1, 5, 10, 25, 100, 250, 500 and 1,000 μl benomyl/ml was then prepared, and 100 μl of the benomyl suspension was put into the well using a micropipette. Six plates were used for each concentration of benomyl. This methodology was also used for the leaf-extracts.

The sampled flushes were immediately taken to the laboratory and the leaves were detached and cut into small pieces. Three 1.5 g sub-samples of the leaf pieces were homogenised with 15 ml of chloroform per sub-sample. The macerate was then squeezed using muslin clothe and 100 μl of leaf extract was put into the well of the *P. expansum* seeded plate. Three plates were used for each sub-sample.

All the plates were incubated on laboratory bench (25 ± 2°C) for five days. Two diameters of the inhibition zones, at right angle to each other were measured. The calibration curve was then constructed by fitting a straight line to the mean diameter of the inhibition zones for the different concentration of benomyl.

The amount of benomyl in the leaves was determined by comparing the inhibition zone caused by benomyl in the leaves to the inhibition zone caused by benomyl shown in the calibration curves.

RESULTS

Table 2 presents the inhibitory effects of the various fungicides on the mycelial growth of *O. theobromae*. At 50 μl/ml, all the fungicides totally inhibited fungal growth. Of the six fungicides, benomyl appeared to be most fungitoxic to *O. theobromae*. Pyracarbolid and triforine totally inhibited fungal growth at 10 μg/ml and 15 μg/ml respectively. Benomyl required 5 μg/ml to totally inhibit fungal growth. At 25 μg/ml, there was still slight fungal growth for oxycarboxin and triademefon. Tridemorph and triforine were of rather similar fungitoxicity. Triademefon, however, at 5 μg/ml and lower, showed an erratic effect on mycelial growth, sometimes giving a stimulatory effect. This concurs with Frohberger (1975) who found weak inhibition by triademefon on test fungi *in vitro*.

Table 3 presents the amount of benomyl accumulated in the young flushes after various application techniques (treatment) used. The result suggests that carbendazim, the fungitoxic breakdown product of benomyl could not be detected in the flush 43 days after application. The use of filter paper did not prolong the availability of benomyl, hence prolonging the protective period for the flushes. Treatment, T_4, appeared better than the others, for the fact that the initial accumulation of carbendazim in the leaves was relatively high three days after treatment. Except for drenching, D, all the treatment were able to protect the leaves from infection since the amount of carbendazim was higher than 5 μg/ml. This protection persisted at least for 30 days. Drenching had shorter protective period, perhaps due to benomyl run-off from the soil surface due to rain. Since the young flushes are the entry point of the pathogen, and flushing appears to occur during wet period, this will enhance the uptake of benomyl because of their availability of water. Pattern of benomyl accumulation of benomyl in leaf-flushes of cocoa tree in plot A and B appeared to be slightly different.

DISCUSSION

The efficacy of a systemic fungicide for the control of a particular disease cannot be evaluated by *in vitro* screening only. However, such screening can give preliminary indication on the possibility of using the fungicide. The use of systemic fungicides for chemotherapeutic purposes is well known. From this preliminary evaluation, benomyl, pyracarbolid and triforine can be further evaluated in the field.

TABLE 2. PERCENTAGE INHIBITION OF MYCELIAL GROWTH OF *O. THEOBROMAE* IN VARIOUS SYSTEMIC FUNGICIDES

Fungicides	Fungicide Dosage (µg/ml)							
	0.1	0.5	1.0	5.0	10.0	15.0	25.0	50.0
Pyracarbolid	– 6.0	11.8	41.9	68.6	100.0	100.0	100.0	100.0
Oxycarboxin	–	–	9.6	4.3	11.6	–	48.6	100.0
Benomyl	–	35.6	60.2	100.0	100.0	100.0	100.0	100.0
Triforine	–	10.6	31.2	40.8	75.9	100.0	100.0	100.0
Tridemorph	–	8.7	1.3	56.9	67.9	100.0	100.0	100.0
Triademefon	–	–49.5	4.3	–1.7	38.4	–	81.1	100.0

– not tested

Negative figure signifies stimulatory effect

TABLE 3. AMOUNT OF BENOMYL ACCUMULATED IN THE LEAF-FLUSHES
AFTER DIFFERENT DAYS OF TREATMENT

| Treatments | Benomyl accumulation ($\mu g/ml$) | | | | | | | | | |
| | 3rd day | | 13th day | | 23rd day | | 33rd day | | 43rd day | |
	Plot A	Plot B	Plot A	Plot B	Plot A	Plot B	Plot A	Plot B	Plot A	Plot B
TB 4	9	7	9	10	9	10	8	7	Trace	0
T 4	9	9	9	12	10	12	7	7	0	0
TB 2	7	6	8	7	9	7	7	6	0	0
T 2	8	8	7	9	9	9	6	6	0	0
D	7	8	8	9	8	7	6	4	0	0
C	0	0	0	0	0	0	0	0	0	0

Bearing in mind that soil application of fungicide on large scale is difficult, other means of application, particularly spraying, should be looked at in the context of protecting the young flushes from infection. To this end, triforine appears to be interesting. There is indication that triforine is able to penetrate the leaf tissues and have good *in vivo* efficacy due to accumulation of the fungicide in the leaves (Albert, undated). Other investigation should concentrate on modification of the sprayed chemical so that it persists on the leaf surfaces of young flushes for a longer time, thus providing protection.

The application of benomyl through soil application can at least protect the young flushes for 30 days (after single application). This will at least give time for a flush to harden, and from observation, after the experimental period in Plot A and Plot B, there is a reduction in disease severity after the next flushing period. This evaluation study was carried out in clay soil, there is possibility of different length of protection period in loamy inland soil. For trees that have already been infected, the chemotherapeutic activity of the systemic fungicide applied will depend on whether the chemical is translocated to the infected area. In this case, in the xylem, the transpiration stream should not be impeded too much by the fungus.

The possibility of using systemic fungicides for VSD control is evident. However, its use should be strategically instituted aiming at protecting the young flushes and reducing inoculum potential. For young seedlings, fungicides can be applied to the soil in polybags. Ideally, chemical should be used in combination with cultural control, *viz.* pruning, so that the better protection against VSD can be achieved.

ACKNOWLEDGEMENT

REFERENCES

ALBERT, G. (Undated) Biological properties of Triforine. Mimeo., 22 pp.

FROHBERGER, P. — E. (1974) New approach to control of cereal disease with triademefon (MEB 6447) *Proc. 8th Int. Plant Prot. Cong. Moscow* (Cited in Marsh, 1977).

KAARS SIJPESTEIJN (1977) *Effects on Fungal Pathogens,* (Cited by Marsh, 1977) pp. 131—159.

MARSH, R.W. (1977) *Systemic Fungicides,* 2nd. Edition. Longman, London and New York.

MUSA, M.J. (1983) Coconut water as culture medium for *Oncobasidium theobromae. MARDI Res. Bull.* **11, 1** : 107—110.

APPENDIX

Calibration curve for benomyl

Benomyl concentration (µg/ml)	Mean diameter of inhibition zone (cm)
1	1.25 ± 0.08
5	2.55 ± 0.08
10	3.73 ± 0.16
25	4.52 ± 0.13
50	5.20 ± 0.06
100	6.08 ± 0.09
250	6.50 ± 0.00
500	6.62 ± 0.04
1000	6.82 ± 0.03

Regression line $y = 1.55 + 1.96x$

Diameter of inhibition zone (cm) of leaf-extract

Plot A

	3	13	23	33	43
TB 4	1.42 ± 0.08	1.43 ± 0.10	1.50 ± 0.10	1.35 ± 0.10	Trace
T 4	1.46 ± 0.10	1.43 ± 0.08	1.52 ± 0.12	1.26 ± 0.15	0
TB 2	1.25 ± 0.08	1.33 ± 0.08	1.45 ± 0.05	1.20 ± 0.06	0
T 2	1.33 ± 0.14	1.30 ± 0.13	1.47 ± 0.08	1.17 ± 0.08	0
D	1.26 ± 0.10	1.32 ± 0.08	1.33 ± 0.10	1.10 ± 0.06	0
C	0	0	0	0	0

Plot B

	3	13	23	33	43
TB 4	1.25 ± 0.06	1.55 ± 0.10	1.52 ± 0.10	1.28 ± 0.08	0
T 4	1.47 ± 0.08	1.72 ± 0.08	1.67 ± 0.05	1.23 ± 0.05	0
TB 2	1.10 ± 0.06	1.27 ± 0.05	1.25 ± 0.06	1.15 ± 0.05	0
T 2	1.40 ± 0.13	1.47 ± 0.14	1.42 ± 0.08	1.17 ± 0.05	0
D	1.37 ± 0.08	1.46 ± 0.11	1.30 ± 0.09	0.68 ± 0.05	0
C	0	0	0	0	0

i) reading mean of 12 diameters

Possible Methods to Minimise Losses due to Vascular Streak Dieback

M.P.G.S. JAYAWARDENA
Kuril Plantations Sdn Bhd Sungai Sumun, Perak

ELANJARAN MOHAN
Kuril Research Unit Sungai Sumun, Perak

AND

M.J. MUSA
Malaysian Agricultural Research and Development Institute
Hilir Perak

Currently, the most widely adopted method to control vascular streak dieback (VSD) in mature cocoa is to remove infected branches 30 cm beyond the point of visible streaking, but efficient removal of these infected branches is most often not possible or practical. Thus, two other possible methods were studied to minimise the yield loss due to VSD, viz – (1) Multiple-stemmed trees and (2) Bud grafting with bud patches from trees apparently tolerant to VSD.

The first method comprised four treatments each with different number and age of chupons and a control. The yield pattern remained same in all the five treatments, but the mean cumulative number of pods per tree per year was higher than the control for three of the treatments by between 20 and 46%.

Planting clones which are proven to be tolerant to VSD would be ideal, but these were not available. Therefore, in the second method infected mature trees in three blocks were grafted with bud patches obtained from trees free of VSD symptoms in fields with high VSD incidence. Yields in these rehabilitated blocks have increased by 25.30 to 63.44% and the percentage VSD infected branches/trees have reduced.

The economics of these two approaches are also discussed.

The term 'dieback' is applied in cocoa to symptoms with a number of different causes (Turner 1967, 1968). These include various sub-optimal environmental factors and insect attack, sometimes associated with invasion of saprophytic or weakly parasitic fungi especially *Botryodiplodia theobromae* and *Calonectria rigidiuscula.*

The most severe form of dieback is caused by a fungus which was named *Oncobasidium theobromae* Talbot & Keane (Talbot & Keane 1971; Keane *et al.*, 1972). This particular form of dieback was termed as *Vascular Streak Dieback* (VSD) (Keane *et al.*, 1972). Occurrence of VSD in Malaysia was reported by Keane & Turner (1972) both

on cocoa planted under coconut (at Bagan Datoh, Teluk Intan area of Perak) and under thinned jungle (Jerangau area of Trengganu). In a survey carried out by Chan & Lee (1972), VSD appeared to be the single most widely spread disease of cocoa.

On Blenheim Estate, the disease was first identified in 1971 (Keane & Turner 1972). In 1976, it was noticed that the disease level was high, due largely to the high density planting of 1,300–2,000 plants per hectare (Blencowe & Hubbard 1972), which was conducive for the rapid spread of the disease. To contain and control the disease, selective thinning of cocoa trees with minimum economic losses was initiated in 1976 and regular pruning of diseased branches based on the age and performance of the plants was carried out. The practical experience of this exercise was reported earlier by Jayawardena *et al.* (1979). Following this, two methods were investigated in greater detail. This paper presents the findings and the practicality of these methods to minimise losses due to VSD.

MATERIALS AND METHODS

Two methods were investigated to determine the practicality and economics of controlling VSD. These are discussed below.

Multiple Stemmed Trees

The experiment was established in June 1982 on Blenheim Estate in the Hilir Perak area. The plants were of Sabah Seed Garden Mixed Hybrids parentage, planted in 1970 at 1,430 plants per hectare. At the time of initiating the experiment the number of plants per hectare was 1,075. Chupons were induced readily by scarifying the bases of trees (*Figure 1*). Selection of recording trees was based on the uniformity of the immediate environment, girth of trees and age of chupons for each treatment to reduce within treatment variations. The trees selected were grouped into the following categories:

Treatment 1 — Only Main Stem (Control)
Treatment 2 — Main Stem + 1 Immature Chupon
Treatment 3 — Main Stem + 1 Mature Chupon
Treatment 4 — Main Stem + 1 Mature Chupon + 1 Immature Chupon
Treatment 5 — Main Stem + 2 Immature Chupons

Fifteen trees were sampled for each category at random. Girth of the stem and chupons were measured at three-month intervals at 30 cm above the ground level. Yield performance was recorded by counting the number of three-month old pods monthly. All data are presented as a mean of the 15 individual trees.

Bud Grafting with Material from Trees Apparently Tolerant to VSD

Rehabilitation trial was carried out on trees planted in 1970 which showed high level of VSD infections. Three blocks were selected with an area of 6.07, 4.05 and 6.07 ha. The infected trees in these three blocks were grafted (*Figure 2*) in 1976 with bud patches

Figure 1. Inducing chupons to grow from mature cocoa trees at the same height consistently

Figure 2. Mature scion from root stock of mature cocoa tree approximately six years from field plantings, at time of budding.

obtained from trees not exhibiting VSD symptoms in blocks with widespread VSD symptoms. Bud patches from these trees had to be used, as budwood from VSD-resistant clones were not available. As control, three more blocks were selected in the same vicinity with an area of 4.05, 4.44 and 5.07 ha, thus, replicating the trial three times.

The bark of the mature tree at the site selected for budding was shaved, then peeled to insert the scion so that it was in direct contact with the cambium. This technique gave a success rate of 35–50%, thus rebudding had to be done on other sites of the trunk. Rebudding caused delay in bringing the scion to maturity and increased cost of budding. To increase percentage success during the initial budding itself, trees were budded with three bud patches each and the most vigorous scion was retained. The root stock was pruned off systematically to ensure that yield was not reduced during the rehabilitation period. The branches of the original tree were completely removed only after the scions had started to produce considerable number of pods.

Yield figures, obtained from the regular harvests, are presented as number of pods per hectare. VSD incidence was recorded at three-month intervals during the regular pruning rounds.

RESULTS AND DISCUSSION

Multiple Stemmed Trees

From the graphs presented in *Figures 3* and *4*, it is evident that the yield trend in the main stem and mature chupons in all the treatments were similar. Data collected also indicate that the immature chupons in Treatments 2, 4 and 5 had started to produce pods towards the later part of the trial period.

Table 1 shows that, though there is a large variation within treatments, the difference between treatments and the control vs treatments was significantly different at 0.05% level. This signifies that retaining chupon(s) will contribute towards yield.

Over the 12-month period, Treatments 2, 3, 4 and 5 produced 20.52, 46.51, 28.14 and 1.34% more pods respectively compared to the control (*Table 2*). The yield difference in Treatments 2 and 4 against the control is similar. This indicates that there may not be any yield advantage by retaining more than one chupon. This is possibly due to the higher partitioning of nutrients for the growth of the chupons, and once the chupons attain self-sufficiency the partitioning of metabolites towards pod production increases. This phenomenon is further substantiated by the very low yield increase in Treatment 5 where both the chupons were immature, in which case most of the nutrients produced would have been utilized for vegetative growth.

However, earlier workers, Are (1969) in Nigeria and Lee (1976) in Malaysia have reported increase in yield with increased number of chupons. It is possible that the optimum productive leaf area was not attained in the double-stemmed trees and was obtained only in the three-stemmed or four-stemmed trees in their trials. Whilst in our trial, the optimum productive leaf area had been achieved with double-stemmed trees and the additional chupon i.e. the three-stemmed trees only utilized the nutrient manufactured by the productive leaves for vegetative growth, thereby having little or no increase in pod production.

4
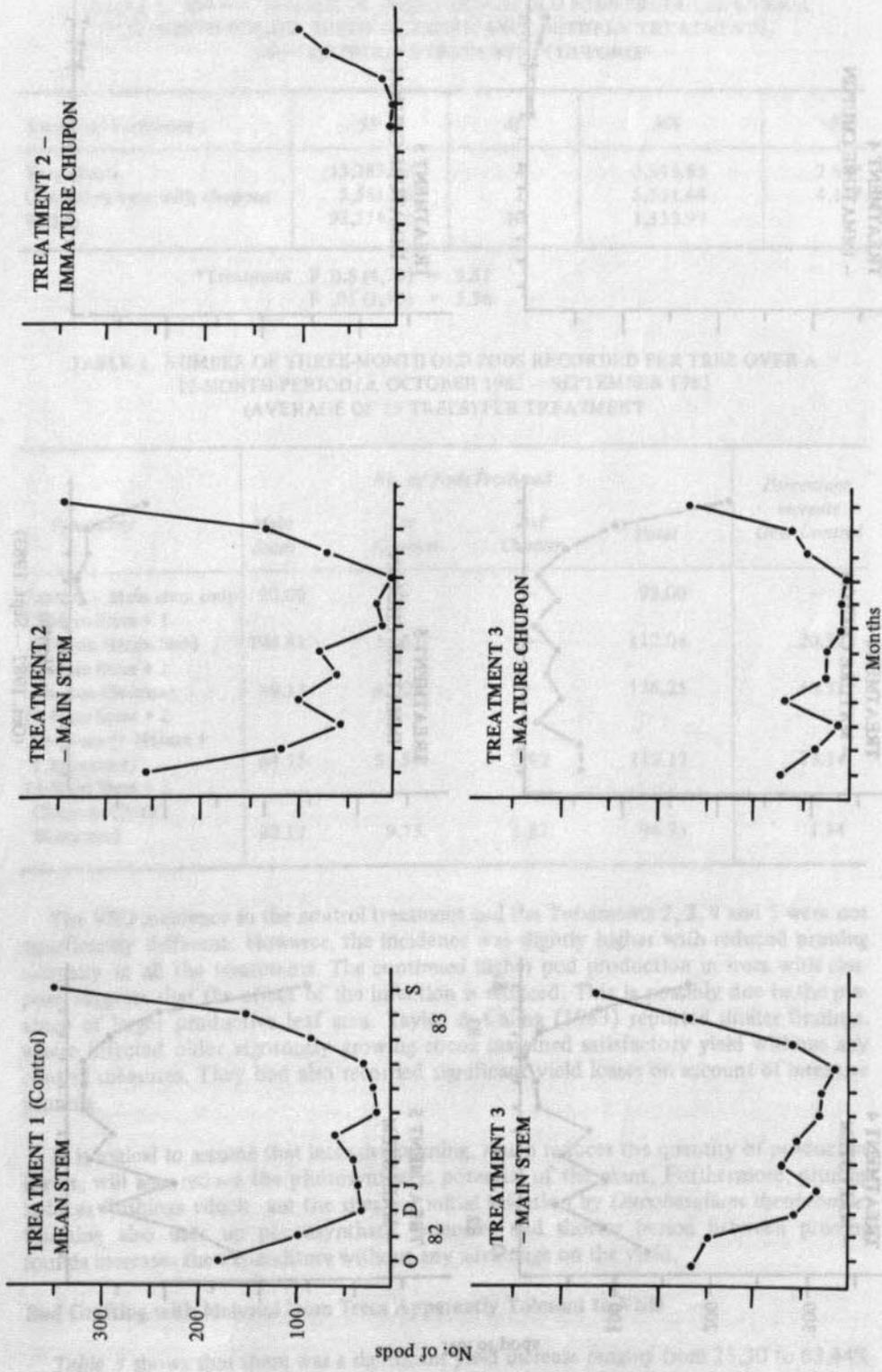
Figure 3. Total number of three-month old pods recorded from fifteen trees/bushes in control treatment, treatments 2 and 3
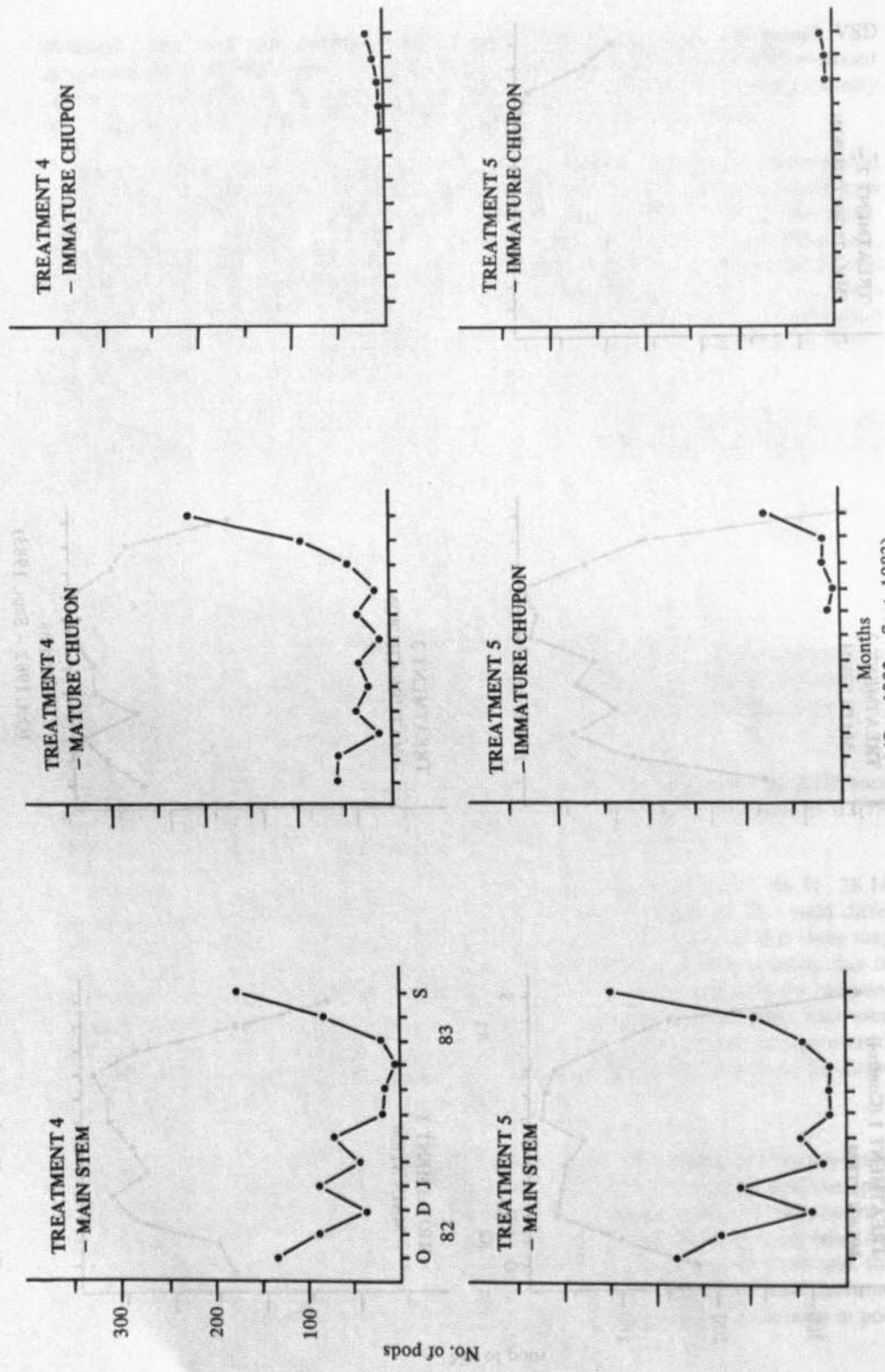
Figure 4. Total number of three-month old pods recorded from fifteen trees/bushes in treatments 4 and 5.

TREATMENT 4
– MAIN STEM

TREATMENT 4
– MATURE CHUPON

TREATMENT 4
– IMMATURE CHUPON

TREATMENT 5
– MAIN STEM

TREATMENT 5
– IMMATURE CHUPON

TREATMENT 5
– IMMATURE CHUPON

No. of pods

300

200

100

O
82

O D J

83

S

Months
(Oct. 1982 – Sept. 1983)

6

TABLE 1. ANOVA-NUMBER OF THREE-MONTH OLD PODS PRODUCED OVER A
12-MONTH PERIOD. TESTING SIGNIFICANCE BETWEEN TREATMENTS,
AND CONTROL VS TREES WITH CHUPON(S)

Source of Variations	SS	df	MS	Fs
Treatments	15,783.39	4	3,945.85	2.96*
Control vs trees with chupons	5,581.46	1	5,581.46	4.18*
Within	93,374.40	70	1,333.97	

*Treatment F 0.5 (4,70) = 2.51
F .05 (1,70) = 3.98

TABLE 2. NUMBER OF THREE-MONTH OLD PODS RECORDED PER TREE OVER A
12-MONTH PERIOD *i.e.* OCTOBER 1982 – SEPTEMBER 1983
(AVERAGE OF 15 TREES) PER TREATMENT

Treatment	No. of Pods Produced				Percentage increase Over Control
	Main Stem	1st Chupon	2nd Chupon	Total	
Control – Main stem only	93.00	–	–	93.00	–
T1-Main Stem + 1 Chupon (Immature)	105.41	16.67	–	112.08	20.52
T2-Main Stem + 1 Chupon (Mature)	89.17	47.08	–	136.25	46.51
T3-Main Stem + 2 Chupons (1 Mature + 1 Immature)	64.75	51.50	2.92	119.17	28.14
T4-Main Stem + 2 Chupons (Both Immature)	83.17	9.75	1.33	94.25	1.34

The VSD incidence in the control treatment and the Treatments 2, 3, 4 and 5 were not significantly different. However, the incidence was slightly higher with reduced pruning intensity in all the treatments. The continued higher pod production in trees with chupons suggests that the effect of the infection is reduced. This is possibly due to the presence of larger productive leaf area. Taylor & Chong (1983) reported similar findings, where infected older vigorously growing cocoa sustained satisfactory yield without any control measures. They had also recorded significant yield losses on account of intensive pruning.

It is logical to assume that intensive pruning, which reduces the quantity of productive leaves, will also reduce the photosynthetic potential of the plant. Furthermore, pruning induces flushings which are the sites for initial infection by *Oncobasidium theobromae*. Flushing also uses up photosynthate. Intensive and shorter period between pruning rounds increases the expenditure without any advantage on the yield.

Bud Grafting with Material from Trees Apparently Tolerant to VSD

Table 3 shows that there was a significant yield increase ranging from 25.30 to 63.44% over a five-year period. The larger difference in 1979 and 1980 is due to the yield from

TABLE 3. TOTAL PODS HARVESTED PER HECTARE (MEAN OF THREE REPLICATES)

Treatment	Pods harvested (No./ha)				
	1979	1980	1981	1982	1983
Unbudded Trees	12,485	12,070	11,876	8,974	7,817
Rehabilitated by budding with VSD Tolerant (apparent) bud patches	19,055	17,082	14,881	14,667	10,799
Percentage increase	52.62	41.52	25.30	63.44	38.15

both the parent trees and the scion. By about 1981/82, branches of the original trees were removed completely which reduced the yield difference in 1981 and then increased in 1982. The lower difference in 1983 is possibly due to the lower number of VSD pruning rounds, which improved yield in the control blocks also.

The VSD incidence rate was comparatively lower in the budded plots. The higher yields infer that these plants can tolerate the fungus without much effect on the yield. The VSD incidence in the budded plots may be caused by the spread from the adjacent diseased unbudded plot.

ECONOMICS OF ADOPTING TWO METHODS

Multiple-stemmed trees and rehabilitation of diseased trees both gave an increase in pod production.

In the multiple-stemmed method, the extra cost was incurred to scarify the bark of the parent tree to induce chupon growth and to select and retain the most vigorous chupon which averaged at $40/- per hectare. Thereafter, all expenditure was similar to that of maintaining an average cocoa field.

The rehabilitation method is obviously more expensive as it involves: —

(a) Budding of Mature Root Stock.
(b) Rebudding.
(c) Training of Scion.

The cost of budding of mature root stock was approximately $0.20 per tree and it would cost another $0.30 for rebudding. With the budding success rate of 35%, the average cost for budding a tree would be $0.85. However, this cost could be brought down by carrying out the multiple budding system where the success rate was 70%. At this success rate the cost of budding a mature root stock would be $0.43.

It was not always possible to obtained chupon budwood thus in our trial grafting was carried out with fan budwood. Under such circumstances, extra cost is incurred in train-ing and shaping the canopy of the scion to obtain ground clearance to carry out other maintenance operations. The cost of pruning such trees was 60% more than that incurred for normal mature seedling trees during the first three years. The tree training cost could be brought down considerably by using chupon budwood, which could be obtained by scarifying the parent tree to induce chupons.

8

In the multiple-stemmed system, the yield among plants could vary considerably depending on the shade level and density of the plantings, as the yield increase is directly related to the increase in productive leaf area, and the partitioning for vegetative growth.

Whilst in the rehabilitation method (*Figure 5*), the yield variation among the plants is minimal and a more uniform stand will be obtained. Furthermore, this is a more permanent method to reduce VSD incidence and to improve yield, as only VSD-tolerant bud patches are used in the rehabilitation.

Figure 5. A complete field showing mature scions from root stocks of mature cocoa trees approximately six years from field plantings, at time of budding.

CONCLUSION

Apart from the methods discussed, there may be other possible methods of containing yield losses due to *Oncobasidium theobromae* infection. This pathogen is widespread both in Malaysia (Keane & Turner 1972, Chan & Lee 1973, Chan & Syed Kamaruddin, 1976) and in Papua New Guinea (Keane *et al.*, 1972), which indicates the possibility of the existence of intermediate and/or alternate hosts. We have observed VSD symptoms in young cocoa plants planted under thinned jungle. Since all the plants are derived from seeds, it is not likely that the pathogen has been transported into the area through planting materials. This further strengthens the possibility of the presence of alternate hosts even in localities where cocoa has not been grown before. Attempts were made to identify the possible alternate hosts amongst the trees and shrubs in the vicinity but there was no success.

It might not be possible to eradicate the source of inoculum and therefore control could be obtained either by producing VSD-tolerant/resistant clones or by developing an integrated control measure consisting of chemical and cultural means. The inoculum potential can be reduced by removing the sporophores (*Figure 6*) of the fungus by prun-
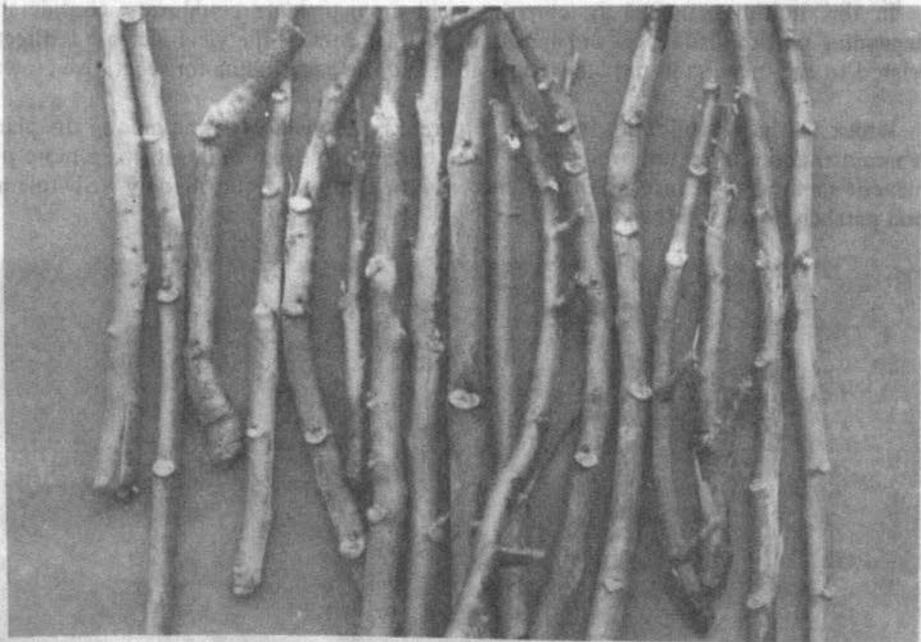
Figure 6. *Sporophores growing out of the leaf scar of branches infected with* Oncobasidium theobromae *Talbot & Keane.*

ing. With the removal of these sporophores, the frequency of pruning to control VSD may be reduced gradually.

VSD-tolerant clones have been developed by the Malaysian Agricultural Research and Development Institute and they are currently being tested at several locations.

Screening work for effective fungicides is still in progress. However, we believe that unilateral control of the disease by using chemicals may not be realistic. Fungicides will have to be used strategically, in this case perhaps to reduce the inoculum potential or to protect young flushes from being infected. Greater understanding of the epidemiology of the disease in each locality will greatly help in controlling the disease. Benlate has been shown to have some promise as a prophylactic spray for young cocoa seedlings against VSD (Chan & Syed 1976).

Knowledge in the epidemiology and control of *Oncobasidium theobromae* is still scanty and the physiological and environmental conditions predisposing the cocoa tree to disease infection should be considered in any further research. In the meantime, the methods reported in this paper could be adopted to reduce the losses due to VSD infection.

ACKNOWLEDGEMENT

REFERENCES

ARE, L.A. (1969). Methods used for rehabilitating old cocoa farms in Nigeria, Mem. *2nd. Int. Cocoa Res. Conf., Bahia Brazil, 1967*, 383.

BLENCOWE, J.W., & HUBBARD, F.T.P. (1972). Thinning and shaping of densely-planted cocoa. *Proc. Conf. on Cocoa and Coconuts in Malaysia, Kuala Lumpur, 1971*, 86–101.

CHAN, C.L., & LEE, B.S. (1972). A preliminary survey of cocoa diseases in West Malaysia. *MARDI Res. Bull.*, 1 (2), 22–31.

CHAN, C.L., & SYED KAMARUDDIN, B.S.W. (1976). Vascular-streak dieback, (v.s.d.) of cocoa in Peninsular Malaysia. *Proc. East Malaysia, Plrs. Asson. Cocoa Coconut Seminar, Tawau, Sabah*, 134–144.

JAYAWARDENA, M.P.G.S., PATMANATHAN, M. & RAMADASAN, K. (1979). Thinning and vascular-streak dieback control in high-density cocoa plantings under coconuts. *Proc. Int. Conf. on Cocoa and Coconuts, Kuala Lumpur*, 1978.

KEANE, P.J., FLENTJE, N.T. & LAMB, K.P. (1972). Investigation of vascular-streak dieback of cocoa in Papua New Guinea. *Aust. J. Biol. Sci.*, 25, 553–564.

KEANE, P.J., & TURNER, P.D. (1972). Vascular-streak dieback of cocoa in Peninsular Malaysia. *Proc. Conf. on Cocoa and Coconuts in Malaysia, Kuala Lumpur 1971*, 50–57.

LEE, A.K. (1976). Performance of cutback and multiple-stem cocoa in the field. *Proc. East Malaysia Plrs. Assn. Cocoa Cocon. Sem. Tawau, Sabah 1976*, 105–111.

TALBOT, P.H.B. & KEANE, P.J. (1971). *Oncobasidium*, a new genus of tulasnelloid fungi. *Aust. J. Bot.*, 19, 203–6.

TAYLOR, J.G., & CHONG, C.F. (1983). VSD of cocoa-practical experience, Advances in Cocoa Plant Protection in Malaysia. *Mal. Pl. Proct. Soc. Sem, Kuala Lumpur, 1983*, 10–11.

TURNER, P.D. (1967). Cocoa dieback a review of present knowledge. *FAO Pl. Prot. Bull.*, 15, 1–101.

TURNER, P.D. (1968). Dieback and other diseases of cocoa in Malaya, In *Cocoa and Coconuts in Malaya* (ed. J.W. Blencowe & P.D. Turner), pp. 32–42, Kuala Lumpur: Incorporated Society of Planters.

Factors Influencing the Production of Basidiocarps by *Crinipellis Perniciosa*, the Causal Fungus of Cocoa Witches' Broom

H.M. ROCHA

National Centre for Genetic Resources, Brasilia, Brazil

The production of basidiocarps of Crinipellis perniciosa *on dead Witches' brooms was assessed in relation to different regimes of temperature and light, the type of cocoa, age of broom and type of tissue.*

Dead brooms from Brazil and Ecuador were hung individually in specially constructed cabinets within an illuminated room (60 $\mu E/m^2/s$). Basidiocarps production was determined in the following temperature and light regimes: $20^\circ-25^\circ C$, $25^\circ-30^\circ C$, $30^\circ-35^\circ C$ and 0, 10, 100 $\mu E/m^2/s$. Brooms from different cocoa cultivars (UF 168, UF 677, Sca 6, Sca 12, ISC 1, ICS 29, ICS 95, IMC 67, EET 400 and Catongo) were used to determine the influence of genetic material on basidiocarp production. The effect of broom age on basidiocarp production was determined using 2, 3, 4 and 5 months old brooms. Basidiocarp formation was also assessed at node and internode regions of dead brooms.

Most basidiocarps formed when brooms were subjected to successive wet and dry periods and illuminated at 100 $uE/m^2/s$ at $20^\circ-25^\circ C$. Basidiocarps formed most prolifically on scavina clones 6 and 12 from Ecuador and at nodes rather than internodes. A three months period after the brooms have been dried was the minimum to start the basidiocarp production.

Infection of cocoa stem meristems by *C. perniciosa* results in the formation of swollen shoot systems, with shortened internodes and excessive branching, commonly termed 'green brooms'. These brooms subsequently die and later, in suitable environments, basidiocarps of the fungus form on them. The period over which the brooms remain green is rather variable and depends on the vigour of the plant and the pathotype of the fungus (Wheeler & Mepsted, 1982). It can vary from four to 18 weeks but is usually between five and 12 weeks. After the brooms die there is a 'dormant period before basidiocarps start to form, the length of which also varies from a minimum of six weeks to a maximum of 66 weeks with the average between 12 and 32 weeks (Baker & Holliday, 1957; Solorzano, 1977; Aranzazu, 1981). Basidiocarp production is then favoured by successive wetting and drying during a rainy season and especially by frequent, intermittent light showers (Baker & Holliday, 1957). The brooms retain their ability to produce basidiocarps for two years or more though the numbers produced tend to decline as the broom ages (Evans, 1981). Basidiocarps never form on green brooms which contain a mycelium of characteristically thick (4–20 μm wide), intercellular hyphae considered to be the monokaryotic phase of the fungus (Pegus, 1972; Evans, 1980).

The mycelium in the dead broom is composed of much thinner hyphae (1.5-4 μm wide) with clamp-connexions and is thought to be dikaryotic. It can be isolated readily

and grows well on many simple agar media but most attempts to induce basidiocarps from such mycelia in culture have failed (Delgado, 1974; Suarez Capello, 1977).

The factors which influence the formation of basidiocarps are little understood. Recently Rocha & Wheeler (1982) showed that a regime of successive 8 h wet and 16 h dry is extremely favourable for basidiocarp production on dead brooms. The present study, which is part of a research programme on the ecology of *C. perniciosa*, carried out during 1980/83 (Rocha, 1983), examined some factors which were considered likely to be important. These were regimes of temperature, light, the cocoa type, age of broom and type of tissue. The overall aim was to determine the best conditions for a regular supply of basidiocarps on brooms to aid research programmes and to provide information that might lead to a better understanding of basidiocarp formation in the field.

METHODS

Effect of Temperature

Electric heaters (Humex tubular heater) and a thermostat were installed in each of three specially constructed cabinets (Rocha & Wheeler, 1982) so that with successive periods of 8 h wet and 16 h dry three temperature regimes were obtained: 20°-25^oC; 25°-30^oC and 30°-35^oC. All cabinets were housed in a room at 20^oC illuminated (60 $\mu E/m^2/s$) during the wet period.

Ten large brooms from the Castanhal region of Brazil were hung in each cabinet and the numbers of primordia and mature basidiocarps produced were counted weekly for six months. During this period, 20 mature basidiocarps were taken from each temperature regime, the colour and diameter of their pilei and length of stipes were assessed and measurements taken of 100 basidiospores.

Effect of Light

Three cabinets were prepared, each at 20°-25^oC and with a regime of 8 h wet and dry h dry. These cabinets were kept in a room at 20^oC, illuminated at $60 \mu E/m^2/s$ for 8 h corresponding to the wet period. One cabinet was not changed in any way. Measurements with a Solartron 7040 light meter inside this cabinet indicated a light intensity of $10 \mu E/m^2/s$. Two white fluorescent tubes (Atlas warmwhite super fine, 65-80 W) were placed on each of two sides of a second cabinet and these gave a light intensity in the cabinet of $100 \mu E/m^2/s$ during the wet period. The third cabinet was enclosed in black polyethylene sheeting. This gave complete darkness during the wet period and, apart from a short period to inspect brooms, this cabinet remained in darkness because the light in the room was switched off during the dry period. Twenty large brooms from the Castanhal region of Brazil were hung individually in each cabinet and the numbers of primordia and mature basidiocarps formed on them were counted weekly over six months.

Effect on Cocoa Cultivars

Ten large brooms were collected from several trees of the following clones in the cocoa germplasm collection at Pichilingue, Ecuador: UF 168, UF 677, Sca 6, Sca 12, ICS 1, ICS 39, ICS 95, IMC 67, EET 400 and Catongo. These brooms were hung individually in cabinets at 20°-25^oC with a regime of 8 h wet and 16 h dry. The cabinets were kept in a room at 20^oC, illuminated at $60 \mu E/m^2/s$. The numbers of primordia and

mature basidiocarps which developed on each broom were counted weekly for seven months.

Effect of Broom Age

During 1981 groups of 10 brooms were labelled from their initiation within a commercial planting of cocoa hybrids (crosses between several cultivars) at Ouro Preto, Rondonia, Brazil, on four occasions: 27 March, 28 April, 28 May and 30 June. All brooms were harvested on 30 July. They were allowed to dry and were then hung on 2nd September in cabinets at 20°−25°C with a regime of 8 h wet and 16 h dry. The cabinets were housed in an illuminated room at 20°C. The time taken for the first primordium to appear and the total numbers of primordia and mature basidiocarps produced were assessed over nine months.

Effect of Broom Tissue

In the previous experiments most basidiocarps appeared to form at the nodes of the hypertrophied shoots within the dead broom. This was examined in a further experiment. Since nodes are areas from which leaves or side shoots arise and are then detached, resulting in woods, the effect of wounding brooms was incorporated in this experiment. Wounding consisted of removing a V-shaped wedge of tissue c. 1 cm long and 3−5 mm deep with a sharp scapel; usually one at a node but two to three between nodes. In terms of wounding, there were three treatments: none; wounding at the node; wounding between nodes (internodes). Seven large brooms from Pichilingue, Ecuador, were used in each treatment and they were kept in cabinets at 20°−25°C with a regime of 8 h wet and 16 h dry. The numbers of mature basidiocarps were counted over a period of nine months.

RESULTS

Effect of Temperature

Temperature appeared to be an important factor determining not only the production of basidiocarps but also their morphological features, particularly colour. Most basidiocarps were produced on brooms at 20°−25°C. Somewhat fewer were produced at 25°−30°C and none at all at 30°−35°C *(Table 1)*. Comparisons of basidiocarp populations, using the Mann whitney U Test (Siegel, 1956) indicated that the numbers of primordia and mature basidiocarps produced at 20°−25°C were significantly greater than on brooms kept at 25°−30°C at $P = 0.0136$ and $P = 0.0008$ respectively. At 25°−30°C the stipes of basidiocarps were significantly longer ($P \leqslant 0.001$) and the caps were smaller ($P < 0.05$) than those of basidiocarps produced at 20°−25°C *(Table 2)*. But, most strikingly, the pilei were white instead of usual crimson colour.

Effect of Light

The different light regimes affected basidiocarp production markedly. Significantly more primordia ($P = 0.0256$) and mature basidiocarps ($P = 0.0003$) were produced on brooms illuminated at $100 \, \mu E/m^2/s$ than on those at $10 \, \mu E/m^2/s$ *(Table 3)* although the number of brooms producing basidiocarps was similar (15 and 14 respectively). Only five primordia and one mature basidiocarp formed during the six months on brooms kept in the dark. However, on these brooms there were many mycelial aggregates like those which precede recognizable primordia. This suggests that light promotes the development of primordia and possibly their further growth.

3

TABLE 1. EFFECT OF TEMPERATURE ON THE PRODUCTION OF BASIDIOCARPS
BY *C. PERNICIOSA*

Temperature regime ($^{\circ}$C)[a]	Primordia	Mature basidiocarps	Maturity (%)
20 – 25°	96	75[b]	79
25 – 30°	43	23	53
30 – 35°	0	–	–

[a] Brooms subjected to 8 h wet/16 h dry.

[b] Each figure is the number produced on 10 brooms over six months.

TABLE 2. EFFECT OF TEMPERATURE ON THE MORPHOLOGY OF BASIDIOCARPS AND
BASIDIOSPORES OF *C. PERNICIOSA*[a]

Item	Temperature regime ($^{\circ}$C)	
	20–25°	25–30°
Pileus colour	Crimson	Whitish
Pileus diameter (mm):		
Range	4 –22	6 –12
Mean	10.6	8.0
S.D. ±	4.8	1.3
Stipe length (mm):		
Range	6 – 11	7 – 12
Mean	7.7	10.8
S.D. ±	1.5	1.4
Basidiospore (μm):		
Length	11.6	11.9
Breadth	6.4	6.5
$\dfrac{\text{Length}}{\text{Breadth}}$	1.8	1.8

[a] Means of 20 basidiocarps and 100 basidiospores in each temperature regime.

Effect of Cocoa Cultivars

There were some differences in the production of basidiocarps on brooms from different cultivars *(Table 4)*. In a general way the collection of broom could be divided into three groups related to the mean number of mature basidiocarps produced per broom: > 10, Sca 6, Sca 12 and UF 168; 8–10, IMC 67, Catongo and EET 400; < 8, UF 677, ICS 39, ICS 95 and ICS 1. This separation appeared less clear when populations of basidiocarps produced on brooms of different cultivars were compared using the Mann Whitney U Test. However, the numbers of mature basidiocarps on brooms of Sca 6 were significantly greater (P = 0.02) than on brooms of all other cultivars except

Sca 12. Zero values for four brooms of UF 168 imposed limits on the analysis and a comparsion of this cultivar indicated a significant difference in total numbers produced on 10 brooms whereas the mean number of basidiocarps per producing broom *(Table 4)* indicates no real difference.

TABLE 3. EFFECT OF LIGHT INTENSITY ON THE PRODUCTION OF BASIDIOCARPS BY
C. PERNICIOSA

Light intensity ($\mu E/m^2/s$) during wet period[a]	Primordia	Mature basidiocarps	Maturity (%)
100	165	113[b]	72
10	54	27	50
Darkness	5	1	20

[a] Regime of 8 h wet/16 h dry.

[b] Each figure is the number produced on 20 brooms over six months.

TABLE 4. BASIDIOCARPS PRODUCED ON BROOMS OF DIFFERENT COCOA CLONES
FROM PICHILINGUE OVER SEVEN MONTHS

Clone	Brooms with basidiocarps	Mean No. per producing broom	
		Primordia	Mature basidiocarps
Sca 6	10	26.4	21.0
UF 168	6	24.6	17.3
Sca 12	10	17.9	12.4
IMC 67	10	13.4	10.0
Catongo	10	13.2	8.6
EET 400	10	12.1	8.0
UF 677	8	9.7	7.6
ICS 39	10	10.2	7.2
ICS 95	8	9.6	6.0
ICS 1	9	7.2	5.3

Effect of Broom Age

As the broom takes approximately one to two months to become dry, the minimum period from this point to start the basidiocarp production which is known as 'dormant' period appears to be at least 3 months. This was clear with the brooms formed at 30 June *(Table 5)*.

The numbers of primordia and mature basidiocarps per producing brooms of different ages did not differ significantly when comparisons were made using the Mann Whitney U Test.

5

TABLE 5. BASIDIOCARP PRODUCTION ON BROOMS OF DIFFERENT AGES (OURO PRETO ISOLATE, BRAZIL)

Item	Broom formed (1981)			
	27 March	28 April	28 May	30 June
Age of broom (months):				
At harvesting	4	3	2	1
When placed in cabinet	5	4	3	2
Day from harvesting to first primordia:				
Mean	88	105	104	136
Range	95 – 158	59 – 191	98 – 188	93 – 196
Mean No. basidiocarps per producing broom[a]:				
Primordia	31	25	29	23
Mature	24	22	21	18

[a] Each figure is the total production on 10 brooms over nine months.

The total number of basidiocarps produced in each of the three treatment (110, no wounding and 147 and 127 for wounding at nodes and internodes respectively) did not differ significantly ($X^2 = 5.36$, $P \leqslant 0.1$). Therefore it appears that wounding did not affect their production.

Effect of Broom Tissue

The results *(Table 6)* confirmed that most basidiocarps are produced at nodes, the differences in numbers at nodes and internodes being very highly significant ($P \leqslant 0.001$).

TABLE 6. BASIDIOCARPS PRODUCED ON BROOM FROM PICHILINGUE (ECUADOR) AT NODES AND INTERNODES WITH OR WITHOUT WOUNDING

Treatment[a]	Site of basidiocarps	Number produced	X^2
None	Node	102[b]	80.3***
	Internode	8	
Wounding at node	Node	129	83.3***
	Internode	18	
Wounding at internode	Node	116	86.8***
	Internode	11	

[a] All brooms were kept at $20 - 25^\circ$C with 8 h wet and 16 h dry.

[b] Each figure is the number produced on 7 brooms over nine months.

*** X^2 significant at $P \leqslant 0.001$.

6

DISCUSSION

The results show that basidiocarps of *C. perniciosa* can be regularly and profusely produced if dried brooms are kept at adequate temperature and light and subjected to alternate wet and dry conditions.

There have been few observations on the effects of light and temperature on fruiting of *C. perniciosa* (INIAP, 1972; Reyes & Reyes, 1976), but the present studies indicate that these factors are important, as they are with other basidiomycetes (Wilkins & Harris, 1946; Perkins, 1969; Manachere, 1980). When the water requirements are satisfied, temperatures between 20° and 25°C and a light intensity of 100 $uE/m^2/s$ are particularly favourable for basidiocarp formation. Temperatures over 30°C were inhibitory but such temperatures are not common for prolonged periods in regions of S. America where cocoa is grown (Wood, 1975). The change in the morphology of the fungus at 25°−23°C is more interesting; especially the lack of red pigment, because such features could be taken as sufficient for designating such a form as a different species or at least as a variety of *C. perniciosa*. Few such variants have been found in nature, Pegler (1978) recognizes three: var. *perniciosa* and var. *ecuadoriensis*, both with red caps and var. *citriniceps* with a citron yellow cap. The last-named variety was recorded by Egans (1978) on a broom at Pichilingue, Ecuador. Again, it is unlikely that temperatures in this range will affect basidiocarps in the field because these develop mainly during wet periods when, at least during the night, temperatures are lower. The failure of *C. perniciosa* to produce basidiocarp in absence of light needs to be examined more closely, for this might be exploited in the field to control the flushes of basidiocarps on brooms detached from cocoa by pruning.

The fact that brooms from different cocoa clones at Pichilingue supported different numbers of basidiocarps is of particular interest. Most basidiocarps were produced on brooms of Sca 6 and Sca 12 which in other experiments (Wheeler & Mepsted, 1982) proved susceptible to the Ecuadorian isolate of *C. perniciosa* but relatively resistant to the Brazilian pathotype. Clearly such material is unsuitable for Ecuador. On the other hand, the low numbers of basidiocarps on brooms from ICS 1 suggest that more use might be made of this clone.

Experiments on the age of broom suggest that a minimum period of four months is required after brooms form before basidiocarps can develop on them. This result agrees with that of Aranzazu (1981) for field conditions in Colombia. Such data are useful in planning sanitation programmes.

REFERENCES

ARANZAZU, F. (1981). Algunos aspectos de la biologia del hongo *Crinipellis perniciosa* (Stahel) Singer en la region de Iruba. M.Sc. Thesis, Universidad Nacional de Colombia, Bogota. 82 pp.

BAKER, R.E.D. & HOLLIDAY, P. (1957). Witches' broom disease of cocoa *(Marasmius perniciosus* Stahel). Phytopathological Paper no. 2, 42 pp. Commonwealth Mycological Institute, Kew.

DELGADO, J.C. (1974). Studies on *Marasmius perniciosus*. Ph.D. Thesis., University of Florida.

EVANS, H.C. (1978). Witches' broom disease of cocoa *(Crinipellis perniciosa)* in Ecuador. I. The fungus. *Ann. appl. Biol.*, **89**, 185–192.

EVANS, H.C. (1980). Pleomorphism in *Crinipellis perniciosa* causal agent of witches' broom disease of cocoa. *Trans. Br. Mycol. Soc.*, **74**, 515–523.

EVANS, H.C. (1981). Witches' broom disease – A case study. *Cocoa Growers' Bull.*, **32**, 5–19.

INSTITUTI NACIONAL DE INVESTIGACIONES AGROPECUARIAS – INIAP. (1972). Departamento de Fitopatologia. Informe Tecnico 1977. Pichilingue, Ecuador, 32 pp.

MANACHERE, G. (1980). Conditions essential for controlled fruiting of macromycetes – A review. *Trans. Br. Mycol. Soc.*, **75**, 255–270.

PEGLER, D.N. (1978). *Crinipellis perniciosa* (Agaricales). *Kew Bull.*, **32**, 731–736.

PEGUS, J.E. (1972). Aspects of the host-parasite relationship in the *Theobroma cacao* L./*Marasmius perniciosus* disease complex. M.Sc. Thesis, University of West Indies, St. Augustine, Trinidad.

PERKINS, J.H. (1969). Morphogenesis in *Schizophyllum commune* I. Effect of white light, *Plant Physiology* **44**, 1706.

REYES, L.C. De & REYES, H. (1976). Avances en el estudio de las enfermedades del cacao en Venezuela. Caucagua, Venezuela, Estacion Experimental, 1976. 16 pp.

ROCHA, H.M. (1983). The ecology of *Crinipellis perniciosa* (Stahel) Singer in witches' broom on cocoa *(Theobroma cacao* L.) Ph.D. Thesis University of London.

ROCHA, H.M. & WHEELER, B.E.J. (1982). The water balance as an important factor in basidiocarp production by *Crinipellis perniciosa*, the causal fungus of cocoa witches' broom. In *Proceedings 8th International Cocoa Research Conference, Cartagena, Colombia* pp. 381–386.

SIEGEL, S. (1956). *Nonparametric statistics for the Behavioural Sciences.* New York: McGraw Hill, 312 pp.

SOLORZANO, G.R. (1977). Factores ambientales involucrados en la produccion de basidiocarps de *Marasmius perniciosus* Stahel. Ing. Agr. Thesis, Universidad de Manabi, Ecuador.

SUAREZ-CAPELLO, C. (1977). Growth of *Crinipellis perniciosa* (Stahel) Singer in vivo and in vitro. Ph.D. Thesis. University of London.

WHEELER, B.E.J. & MEPSTED, R. (1982). Pathogenic races of *crinipellis perniciosa?* In *Proceedings 8th International Cocoa Research Conference, Cartagena, Colombia.* pp. 365–370.

WILKINS, W.H. & HARRIS, G.C. (1946). The ecology of the larger fungi. V. An Investigation into the influence of rainfall and temperature on the seasonal production of fungi in a beechwood and a pinewood. *Ann. appl. Biol.*, **33**, 179–88.

WOOD, G.A.R. (1975). *Cocoa.* Tropical Agriculture Series, 3rd Ed. pp. 20–26. Longman, London.

Litter Production and Nutrient Cycling in a Mature Cocoa Plantation on Inland Soils of Peninsular Malaysia

LING AH HONG

Dunlop Agro-Management Sdn Bhd, Batang Melaka,
Negri Sembilan, Malaysia.

There is little information published on nutrient cycling in mature cocoa. Accordingly, a number of studies were undertaken by Dunlop Research Centre to estimate litterfall and nutrient fluxes associated with litterfall, decomposition and rainwash in a well managed Gliricidia *shaded cocoa plantation on inland soils in Peninsular Malaysia.*

Cocoa litterfall was sampled in 6 to 12-year-old cocoa plantings over a period of three years. Some 4.5 to 6.5 t of dry litter per hectare per year were produced. Of these, leaves accounted for over 90%. Further, the pattern of production was influenced by shade levels and rainfall.

Cocoa litterfall was estimated to return about 75–94 kg N, 4–5 kg P, 84–100 kg K, 28–34 kg Mg and 58–78 kg Ca per hectare per year to the soil. The rate of decomposition of leaf litter was very rapid — 75% loss in dry matter in 12 months. K was released most rapidly compared to other nutrients.

Studies with Gliricidia *showed a high level of N in the leaves and also in the root nodules. The rate of N transfer via* Gliricidia *litterfall can exceed 45 kg per ha per yr.*

Throughfall from rain leaches nutrients (particularly K) from the cocoa canopies and return them to the soil for uptake by the plant.

In addition to the above litterfall and rain-wash, mention is made of nutrient recycling via pod husks which can be left in the field after harvesting.

The studies show that considerable amounts of nutrients are in constant and rapid circulation in a mature Gliricidia *shaded cocoa plantation. The need for a total ecosystem approach towards fertiliser usage in cocoa is emphasized.*

Fertiliser input is one of the most costly items in the cultivation of cocoa especially on inland soils of Peninsular Malaysia. With the prevailing high fertiliser prices, manuring alone can account for 30–50% of the total field upkeep cost. Thus, there is an urgent need to look into all possible approaches to reduce manuring cost. In the past fertiliser requirements for cocoa grown on inland soils in Peninsular Malaysia are based mainly on immobilisation studies (Thong & Ng, 1978) and fertiliser experiments (Mainstone & Thong, 1978; Ling & Mainstone, 1982). Recent investigations by Ling (1983) however indicated that there was no significant yield response to fertiliser applications in fully matured cocoa. The lack of response has been attributed to reduced growth rates in mature trees and recycling of leaf litter and pod husks. More information on nutrient

cycling in a cocoa plantation is therefore essential if economical and efficient usage of fertiliser is to be achieved.

Of the various processes involved in the nutrient cycle of a cocoa ecosystem, litterfall represents one of the major pathways in the transfer of nutrients between plant and soil. Boyer (1972) reported that lightly shaded cocoa in Cameroun returned 6.0 to 8.5 t of dry litter per hectare per year. These correspond to nutrient turnovers of 35–45 kg N, 3–5 kg P, 35–50 K and 75–105 kg Ca per hectare per year. The rate of decomposition was found to be rapid and similar to that of tropical forests.

Shade for cocoa cultivation continues to be generally important. The possible role of shade-tree litter in the nitrogen balance of a cocoa ecosystem was first proposed by Hardy (1959). He suggested that some of the nitrogen return probably came from biological fixation in the roots of the *Erythrina* spp. shade trees. This was later supported by Cadima & Alvim (1967) who found that soils in the vicinity of the *Erythrina* shade trees had higher nitrogen level than the surrounding soils under cocoa. Recent studies in South America confirmed the important role of shade-tree litter in the nitrogen balance of cocoa plantations (Santana & Cabala-Rosand, 1982; Aranguren *et al.*, 1982).

This paper describes the studies undertaken by Dunlop Research Centre to estimate litterfall and nutrient fluxes associated with litterfall, decomposition and rainwash in a *Gliricidia* shaded cocoa plantation on inland soils of Peninsular Malaysia. The role of both cocoa and *Gliricidia* litterfall in the nutrient balance of a cocoa plantation is also assessed.

EXPERIMENTAL

Study Site

The studies were conducted at Sagil Estate, North Johore, Peninsular Malaysia. The area is one where precipitation is low relative to most parts of the Peninsula. The mean annual precipitation is 1850 mm with a dry spell of six to eight weeks duration occurring at the beginning of each year. The main wet season is from September to November. A secondary peak occurs between March and May. The mean temperature of the area is 21°C with little month to month variation.

The plantings selected range from 6 to 12 years old and are mainly of Upper Amazon hybrids. The cocoa trees were planted at 3 m x 3 m (a stand of 1074 trees per hectare) under shade provided by *Gliricidia maculata*. The shade trees were initially planted at 3.0 m x 1.5 m (2148 trees per hectare) but gradually thinned over a period of four to five years to 6 m x 6 m (268 tree per hectare). At this density, the *Gliricidia* trees provide a moderately dense shade to the cocoa.

The soils of the area are mainly Bungor and colluvium of granitic origin (Wong, 1978). The terrain is flat to gently undulating.

Methods

Litter sampling. Litterfall was collected in specially constructed traps made of wire netting of about 2 cm mesh size and with a dimension of 3.0 x 3.0 x 0.2 m. The four corners of the traps were supported by wooden stakes/cocoa trunks. The bases of the traps were raised about 15 cm above the ground to minimise any soil splash. Separate traps were used to collect the cocoa and *Gliricidia* litterfall. This was to ensure that

catchment of litter was not biased by the position of traps. The location of the traps in relation to the cocoa and *Gliricidia* trees are given in *Appendix 1.*

The litter trapped in the netting was collected at weekly intervals. At each collection, the litter was first sorted into its various fractions; cocoa leaves, twigs and branches, and cherelles in the case of cocoa litterfall and *Gliricidia* leaves and twigs and branches in the case of *Gliricidia* litterfall. These fractions were dried at 105°C and weighed. The dried samples were bulked at the end of each month and then sub-sampled for chemical analysis of N, P, K, Mg and Ca.

Three litter collection experiments were conducted. Details of the experiments are given in *Appendix 2.*

Litter decomposition. To estimate the rate of decomposition of leaf litter in the field, nylon bags measuring 20 cm x 20 cm with mesh size of 10 mm were used. Sufficient quantity of freshly fallen leaf litter was collected from the 1969, 1971 and 1973 plantings in January 1982. From the large bulked sample collected, 10 representative sub-samples of approximately 100 g each were taken for moisture and chemical determinations. Based on the average moisture content of the 10 sub-samples, 120 sub-samples equivalent to 100 g dry weight each were collected from the bulked sample. The litter was loosely packed into the nylon bags.

Five representative sites in each of the 1969, 1971 and 1973 plantings were selected and marked. At each site, eight bags of litter were placed on the top of the litter on the ground. The litter in the bags was allowed to decay. At bimonthly intervals, one bag was randomly selected from each site. The partially decayed leaves were dried at 105°C, weighed and ground for chemical analysis of N, P, K, Mg and Ca.

Soil sampling. Two soil series commonly planted with cocoa were analysed. They are Munchong series (Oxisol) and Bungor series (Ultisol). Fifteen random samples were collected from each soil type in the 1974 planting. The samples were taken from 0–15 cm, 15–30 cm and 30–45 cm depth. The chemical analyses include organic C, total N, available P, exchangeable and HCl extractable K, Mg and Ca.

Water sampling. To estimate the quantities of nutrients contributed by precipitation and rain-wash of leaves, water samples were collected from precipitation and throughfall. Precipitation was recorded at the estate meteorological station. Throughfall was measured with 20 plastic containers located randomly under a stand of mature cocoa in the 1973 planting. The water samples collected after each major storm were analysed for total N, P, K, Mg and Ca. A total of 54 samples were collected between July and December 1982.

RESULTS

Litter Production

Cocoa litterfall. The amounts of dry litter produced per annum in cocoa plantings of different age groups are presented in *Table 1.*

The total cocoa litterfall varied from 4.5 to 6.5 t dry matter per hectare per year. The highest quantity recorded was in the 1969 planting while the lowest was in the 1973 planting. The age of planting appeared to have a strong influence on the amount of litter produced.

TABLE 1. LITTER PRODUCTION UNDER 6–12 YEAR OLD COCOA

Year of Planting	Period of Sampling	Dry litter (kg/ha)			
		Leaves	Twigs & Branches	Cherelles	Total
1969	11/78 – 10/79	5556	556	89	6201
	11/79 – 10/80	5100	391	54	5545
	11/80 – 10/81	5958	491	56	6505
1971	11/78 – 10/79	5032	388	56	5476
	11/79 – 10/80	4406	315	79	4800
	11/80 – 10/81	5510	334	52	5896
1973	11/78 – 10/79	4560	457	66	5083
	11/79 – 10/80	4266	210	41	4517
	11/80 – 10/81	4669	355	95	5119
Average		5006	389	65	5460

Over the three years of sampling, leaves accounted for more than 90% of total cocoa litterfall in all three plantings. The woody materials (twigs and branches) made up about 6 to 8% while the cherelles about 1% of the total litterfall.

The weather conditions, in particular rainfall, also affected litter production (*Table 2*). The amounts of litter produced during the 1978/79 and 1980/81 periods which recorded average to below average rainfall were considerably higher than the 1979/80 period which recorded above average rainfall. The influence of rainfall on litterfall will be discussed later.

The rates of litterfall under different shade regimes were monitored in our *Gliricidia* shade density trial (*Experiment No. 2 – Appendix 2*). Results are presented in *Table 3*. The amount of cocoa litterfall in the lightly shaded 12 m x 12 m treatment plot was significantly higher than that of the densely shaded 3 m x 6 m treatment plot. It has been observed that the cocoa trees under lightly shaded conditions defoliate more rapidly

TABLE 2. INFLUENCE OF RAINFALL ON COCOA LITTERFALL

Period of Sampling	Rainfall (mm)	Dry litter (kg/ha)		
		1969 Planting	1971 Planting	1973 Planting
11/78 – 10/79	1656	6201	5476	5083
11/79 – 10/80	2016	5545	4800	4517
11/80 – 10/81	1869	6505	5896	5119

Gliricidia Stand/ha	Dry litter (kg/ha)	
	1981/82	*1982/83*
537 (3m x 6m)[a]	4130	4872
268 (6m x 6m)	5108	5429
134 (6m x 12m)	5473	5631
67 (12m x 12m)	6497	7013
MSD 5%	449	581

[a] Figures within bracket denote *Gliricidia* spacing

than under heavy shade. This indicates that the level of top shade has a profound influence on cocoa litterfall.

The seasonal variation in the amount of leaf litterfall from November 1978 to October 1981 is presented in *Figure 1*. The results show that defoliation occurred throughout the year but the main leaf-fall was observed during the months of December to March. Approximately 50% of the total annual leaf-fall occurred during this period. A second, less pronounced peak was observed between July and September.

The monthly leaf-fall is closely related to the rainfall pattern (*Figure 1*). Maximum leaf-fall was observed to coincide with low rainfall or drought period. Decreased rainfall or increased moisture stress induces leaf abscission resulting in more leaf-fall (Alvim, 1977).

Shade-tree litterfall. The amount of dry litter produced by the *Gliricidia* shade trees spaced at 6 m x 6 m (268 trees per hectare over a 12-month period was estimated to be 2.7 t per hectare (*Table 4*). Of this, leaves made up about 75% while woody materials (twigs and branches) the remaining 25%.

The rate of litterfall shows large month to month variation with two peaks. The major one was observed in October-November and the minor one in April-May. These periods coincided with the rainy months. It has been observed that the *Gliricidia* trees usually shed their leaves after the first heavy rains following an extended dry period.

Nutrient Return via Litterfall

Cocoa litterfall. The estimated amounts of nutrients contained in cocoa litterfall are presented in *Table 5*.
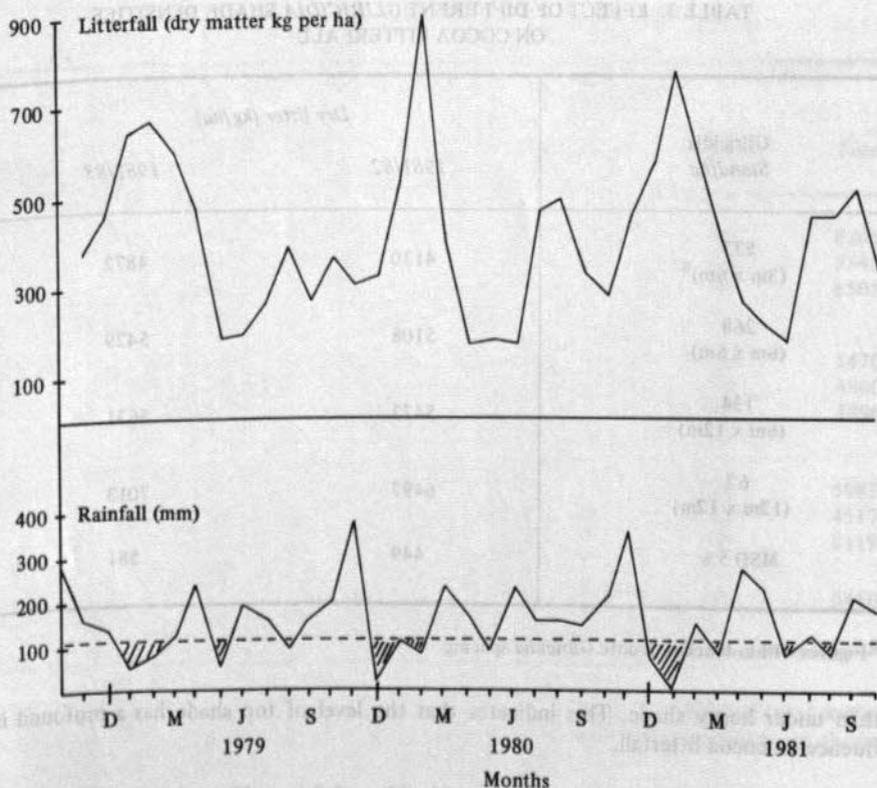
Figure 1. Seasonal Variation in Leaf Litterfall

TABLE 4. *GLIRICIDIA* LITTERFALL IN 9-12-MONTH OLD COCOA PLANTING

Month	Dry litter (kg/ha)[a]		
	Leaves	Twigs & Branches	Total
January	109	35	144
February	97	28	125
March	62	20	82
April	156	36	192
May	228	49	277
June	155	54	209
July	111	40	151
August	141	53	194
September	197	63	260
October	238	81	319
November	322	124	446
December	174	89	263
Total	1990	672	2662

[a] Based on a *Gliricidia* stand of 268 trees/ha

TABLE 5. MEAN NUTRIENT CONTENTS IN COCOA LITTER

Year of Planting	Litter Component	Dry Litter (kg/ha)	Nutrient (kg/ha/yr)				
			N	P	K	Mg	Ca
1969	A	5538	86.6	4.7	91.0	30.6	70.6
	B	479	6.1	0.4	7.0	2.5	6.3
	C	66	1.6	0.1	2.2	0.5	0.7
	Total	6083	94.3	5.2	100.2	33.6	77.6
1971	A	4982	78.3	4.0	82.0	27.7	65.7
	B	346	4.6	0.3	5.5	1.7	4.6
	C	62	1.5	0.2	2.1	0.4	0.7
	Total	5390	84.4	4.5	89.6	29.8	71.0
1973	A	4498	68.3	3.7	77.0	25.7	53.3
	B	341	4.8	0.4	5.4	1.6	4.0
	C	67	1.7	0.2	2.0	0.5	0.7
	Total	4906	74.8	4.3	84.4	27.8	58.0

Notes   A — Leaves
         B — Twigs and Branches
         C — Cherelles

The results show that considerable amounts of nutrients are returned to the soil annually via cocoa litterfall. The nutrient element that is returned in the highest quantity is K which accounts for about 33% of the total nutrients in the litterfall. This is followed by N at 30%, Ca at 24% Mg at 11% and P at only 2%.

The majority of the nutrients in the litterfall is in the leaf fraction. Leaves accounted for about 92% of the total nutrients while woody materials (twigs and branches) and cherelles about 6% and 2% respectively. It is obvious from the data that the majority of the nutrient recycling relates to cocoa leaf-fall.

Shade-tree litterfall. Table 6 presents the estimated amounts of nutrients returned via *Gliricidia* litterfall.

Nitrogen is the most abundant nutrient in the litterfall and accounts for about 37% of the total nutrients returned. This is followed by Ca (27%), K (26%), Mg (8%) and P (2%).

As with cocoa litterfall, the majority of the nutrients in the *Gliricidia* litterfall is present in the leaf fraction. The twigs and branches contributed only 19% of the total nutrients in the litterfall.

It should be noted that the values presented in *Table 6* are based on a *Gliricidia* stand of 268 trees per hectare. If the stand is reduced, it is likely that the amount of nutrients contributed by the shade trees will decrease.

TABLE 6. NUTRIENT CONTENTS IN *GLIRICIDIA* LITTER

Litter Component	Dry Litter kg/ha/yr	Nutrient (kg/ha/yr)[a]				
		N	P	K	Mg	Ca
Leaves	1990	40.8	1.6	25.0	9.1	27.6
Twigs & Branches	672	6.8	0.5	7.6	1.9	7.5
Total	2662	47.6	2.1	32.6	11.0	35.1

[a] Based on a *Gliricidia* stand of 268 trees per ha

Litter Decomposition and Nutrient Release

The rates of breakdown and the changes in the nutrient concentrations at different stages of decomposition of leaf litter are presented in *Table 7.*

TABLE 7. CHANGES IN DRY WEIGHT AND NUTRIENT CONCENTRATION
IN DECAYING COCOA LEAF LITTER UNDER FIELD CONDITIONS

Time (months)	Dry Litter (% of original)	Nutrient (% on Dry Litter)[a]				
		N	P	K	Mg	Ca
0	100	1.86	0.09	1.78	0.61	1.49
2	77	1.82	0.10	1.37	0.59	1.42
4	57	1.83	0.09	1.10	0.59	1.52
6	46	1.92	0.10	0.78	0.61	1.52
8	36	1.94	0.11	0.55	0.58	1.45
10	29	2.11	0.11	0.42	0.56	1.49
12	25	2.11	0.12	0.17	0.55	1.54
14	20	2.03	0.14	0.15	0.48	1.59

[a] Means of 15 samples

The dry weight of the leaf litter under field conditions declined rapidly. Approximately 54% of the original dry weight was lost during the first six months in the field. At the end of 12 months, only 25% of the original dry weight was left in the litter-bag. The results show that the rate of breakdown of leaf litter under field conditions is very rapid.

Analysis of decaying leaf litter shows some variations in nutrient concentrations. Both N and P concentrations increased significantly with time and the increase appeared to accelerate when the biomass loss of about 50% had occurred. This is probably due to temporary immobilisation by micro-organisms. Potassium concentration, on the other hand, declined very rapidly from 1.78% to 0.78% within six months, indicating considerable leaching of K from the litter during decomposition. The Mg and Ca concentrations in the decomposing litter did not show much variation.

The rates of release of individual nutrients from decaying leaf litter are shown in *Figure 2*. The most striking feature is the very rapid release of K. In six months, more than 80% of the K originally present in the litter was released. Mineralisation of N, P, Mg and Ca was much slower than K. N and P appear to be slightly less rapid than Mg and Ca but the differences are not significant. Although N and P concentrations increased significantly with time, no net accumulation in the litter was observed.

Nutrient Return via Rainwa

Table 8 presents the mean nutrient concentrations in precipitation and throughfall under a nine-year old cocoa planting.
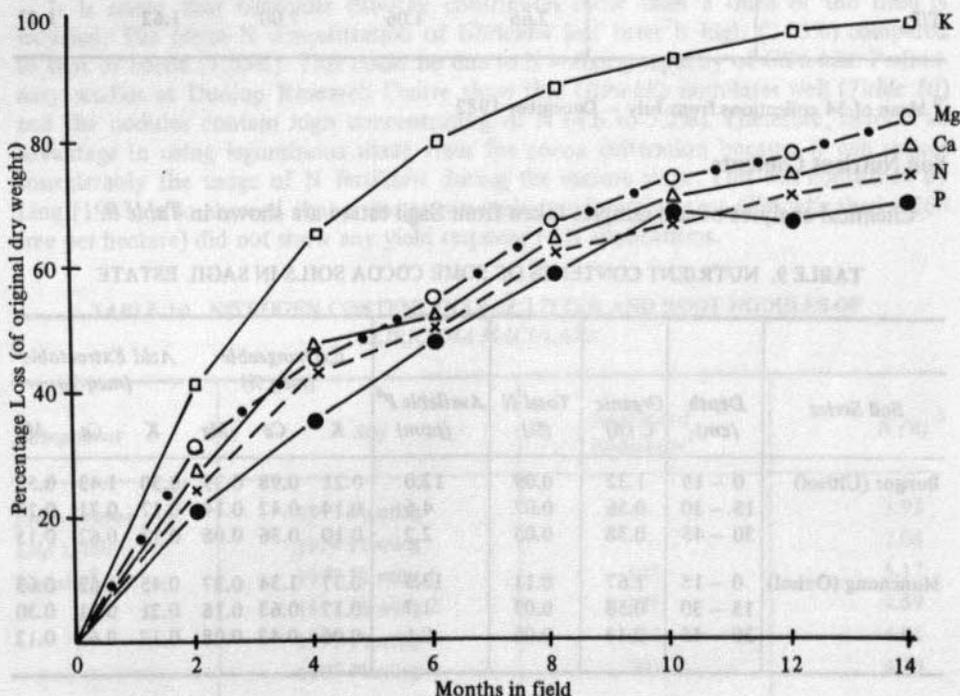
Figure 2. Rates of Release of Nutrients from Leaf Litter

Except for P, the concentrations of the other nutrients in the throughfall were considerably higher than those in the rainfall. The concentrations of N and K in the through-fall were about 2½ times and 7 times greater than those in the precipitation, respectively. The ratio of the concentration in throughfall to that in precipitation is a reflection of the extent to which leaching had occurred, that is, the greater the ratio, the greater is the leaching. It is clear from the results that there is considerable leaching of N and K from the cocoa canopy.

The amount of nutrients returned via rain-wash was calculated by assuming a mean annual precipitation of 1850 mm. The mean throughfall was estimated to be 76% that of precipitation. On this basis, the amounts (in kg per hectare per year) of nutrients were estimated to be of the following order: K–38, N–8, Mg–3, Ca–2 and P < 1. The most notable point is the large amount of K recycled by rainwash.

Source	Rainfall (%)	Concentration[a] (mg l^{-1})				
		N	P	K	Mg	Ca
Precipitation (P)	100	0.42 ±0.03	0.15 ±0.02	0.45 ±0.07	0.32 ±0.01	0.40 ± 0.02
Throughfall (T)	76 ±10	1.12 ±0.09	0.16 ±0.02	3.15 ±0.18	0.52 ±0.03	0.51 ±0.05
T/P	–	2.66	1.06	7.00	1.62	1.27

[a] Mean of 54 collections from July – December 1982

Soil Nutrient Contents

Chemical analyses of soil samples taken from Sagil estate are shown in *Table 9*.

TABLE 9. NUTRIENT CONTENTS OF SOME COCOA SOILS IN SAGIL ESTATE

Soil Series	Depth (cm)	Organic C (%)	Total N (%)	Available P[a] (ppm)	Exchangeable (meq %)			Acid Extractable[b] (meq %)		
					K	Ca	Mg	K	Ca	Mg
Bungor (Ultisol)	0 – 15	1.32	0.09	12.0	0.21	0.98	0.39	0.30	1.43	0.53
	15 – 30	0.56	0.07	4.6	0.14	0.42	0.14	0.17	0.71	0.20
	30 – 45	0.38	0.05	2.2	0.10	0.36	0.08	0.13	0.62	0.15
Munchong (Oxisol)	0 – 15	1.67	0.11	13.3	0.37	1.34	0.37	0.45	1.63	0.63
	15 – 30	0.58	0.07	1.7	0.17	0.63	0.18	0.21	0.91	0.30
	30 – 45	0.42	0.06	0.6	0.06	0.42	0.08	0.12	0.67	0.12

[a] According to NH_4F/HCl extraction

[b] According to 6N HCl extraction

The analytical results show that the soils are of low nutrient status. According to Symth (1966), the nutrient levels are low and not adequate for cocoa. For good cocoa growth, Ling and Mainstone (1983) showed that available P (NH_4F extraction) should preferably be in excess of 20 ppm. Acid extractable K and Ca should be greater than 0.4 and 2.0 meq. per 100 g soil respectively.

DISCUSSION

The results show that substantial amounts of cocoa litter (4.5–6.5 t dry matter per hectare) are returned annually to the soil under mature cocoa. The rate of production was found to vary with the age of the cocoa trees, density of shade trees and amount of rainfall. In addition, *Gliricidia maculata* shade trees contributed about 2.7 t of dry litter

per hectare per year. The total litterfall in mature cocoa works out to be about 7.2 to 9.2 t dry matter per hectare per year. These figures are higher than those reported by Boyer (1972) for lightly shaded cocoa in the Cameroun.

The large quantities of litter produced return considerable amount of important plant nutrients to the soil Of the major nutrients, both cocoa and *Gliricidia* litterfall returned 122–142 kg N, –7 kg P, 117–133 kg K, 39–45 kg Mg and 93–113 kg Ca ha^{-1} per year. These value are much higher than those presented by Boyer (1972). This could be due to (a) high nutrient levels of the cocoa plants used because of regular applications of fertilisers and (b) the type and stand of shade trees used were different.

It is noted that *Gliricidia* litterfall contributes more than a third of the total N recycled. The mean N concentration of *Gliricidia* leaf litter is high (2.05%) compared to that of cocoa (1.55%). This could be due to N – fixing capacity of *Gliricidia*. Preliminary studies at Dunlop Research Centre show that *Gliricidia* nodulates well (*Table 10*) and the nodules contain high concentration of N (4.6 to 5.2%). Therefore, there is an advantage in using leguminous shade trees for cocoa cultivation because it can reduce considerably the usage of N fertilisers during the mature stage. This was confirmed by Ling (1983) who showed that cocoa grown under moderately dense *Gliricidia* shade (268 tree per hectare) did not show any yield response to N applications.

TABLE 10. NITROGEN CONTENT IN LEAF LITTER AND ROOT NODULES OF *GLIRICIDIA MACULATA*

Component	Site	Number of nodules/m^2	N (%) [b]
Fresh Leaves	1977 Planting	–	3.93
Leaf Litter	1974 Planting	–	2.05
Nodules[a]	1977 Planting 1	143	5.17
	1977 Planting 2	437	4.59
	1977 Planting 3	130	4.61
	1977 Planting 4	103	4.79

[a] Nodules were collected from depth of 30 cm

[b] Mean of four replicates per site

Results obtained from the decomposition studies indicate that the rate of breakdown of leaf litter under Malaysian climatic conditions is very rapid. About 50% loss in dry matter was obtained in the first six months and 75% by the end of one year. The rate of release of K was very rapid. Almost all the K in the litter was released within six months. Potassium, being less strongly bound in organic combination in the litter, is less dependent on microbial action for its release. In fact, the nutrient leaches readily out of the decomposing litter (*Table 7*). N, P, Mg and Ca were also released rapidly from the litter but their rates of release depend greatly on the rates of mineralisation caused by the activities of the soil micro-organisms. The rapid breakdown of leaf litter in the present studies suggests that there is a high degree of microbiological activity in the soil under mature cocoa which could play a very important role in nutrient recycling in cocoa plantations.

11

Rainwash of leaves also returns substantial amount of nutrients, in particular K, to the soil. The rate of transfer of K was estimated at 38 kg per ha per yr. Therefore, rainwash represents an important pathway in the recycling of K in mature cocoa.

To assess the role of both cocoa and shade-tree litterfall and rainwash in the overall nutrient balance of a mature cocoa plantation, it is necessary to examine the various phases and processes involved. *Table 11* presents a summary of the nutrients stored and transfer rates in an 8 to 10-year-old *Gliricidia*-shaded cocoa planted on inland soils of Peninsular Malaysia.

TABLE 11. NUTRIENT BALANCE IN 8–10 YEAR OLD SHADED
COCOA PLANTATION IN PENINSULAR MALAYSIA

Phase/Process	Nutrient (kg per ha)					Reference
	N	P	K	Mg	Ca	
Biomass						
Cocoa[a]	423	57	607	382	370	Ling (1983)
Gliricidia maculata[b]	245	20	140	16	96	Ling (unpublished)
Total	668	77	747	398	466	
Annual Transfer						
Cocoa litter	84	5	90	30	71	
Gliricidia litter	48	2	43	11	45	
Pod husks[c]	15	2	63	4	6	Modified after Thong & Ng (1978)
Rainwash[d]	8	<1	38	3	2	
Total	155	10	234	48	124	
Annual Uptake/Losses						
Yield (Beans only)[c]	29	5	15	4	5	Modified after Thong & Ng (1978)
Immobilisation	4	2	8	6	5	Ling (1983)
Leaching losses	NA	NA	NA	NA	NA	
Annual Addition						
Rainfall (mean of 1850 mm)	8	3	8	6	7	
Soil Reserve						
Bungor series[e]	6699	59	557	233	1108	

[a] Cocoa stand of 1074 trees per hectare
[b] *Gliricidia* stand of 268 trees per hectare
[c] Based on a mean yield of 1400 kg dry beans per hectare
[d] Based on a throughfall of 76% (of rainfall) and rainfall of 1850 mm
[e] Soil parameters – Total N, Available P, Exchangeable K, Ca, and Mg, soil depth 0 to 30 cm.
NA – Not available

The amount of nutrients contained in the biomass of a stand of fully matured cocoa under *Gliricidia* is considerable and is estimated to be of the following order: N–668 kg, P–77 kg, K–747, Mg–398 kg and Ca–466 kg per ha per yr. It is estimated that about 1/5 to 1/3 of these major nutrients is recycled annually. The total annual nutrient turnovers in mature cocoa amount to 155 kg N, 10 kg P, 234 kg K, 48 kg Mg and 128 kg

Ca per hectare. These include the nutrients from pod husks. Therefore, considerable amounts of nutrients are in constant and rapid circulation under mature cocoa which can help to satisfy part of the nutritional requirements of the crop for growth and yield.

The main loss of nutrients from a mature cocoa plantation is through cropping. Large quantities of nutrients, in particular N and K, are involved in pod production (Thong and Ng, 1978). However, such a loss can be minimised if the pod husks are not removed but returned back to the field after extraction of the beans. Decomposition studies show that empty pod husks left around the base of the cocoa trees not only improved the K status in the top soil but also the K level in the plant (Ling, 1983). This technique will ensure that the actual quantity of nutrients removed from the ecosystem is relatively small. It is estimated that for a cocoa yield level of 1400 kg per hectare per year (dry beans), only 29 kg N, 5 kg P, 15 kg K, 4 kg Mg and 5 kg Ca per hectare are removed from the field annually as beans.

The amounts of nutrients immobilised in a stand of cocoa which are usually consider-ed to be fixed are extremely high in the immature and early maturity periods (Thong and Ng, 1978). However, as the trees become fully mature the growth rate declines consider-ably and the amounts of nutrients immobilised annually decreased to low values as shown in *Table 11*.

The nutrient balance sheet indicates that large quantities of nutrients are recycled annually and the actual amounts of nutrients removed as beans from the cocoa plantation are small. With appropriate agronomic practices such as uniform distribution of pod husks during harvesting and maintenance of a closed cocoa canopies through proper pest and disease control and top shade management, the fertiliser requirements for mature cocoa are small even in a high yielding cocoa stand. This finding has important bearing on the future fertiliser policy for cocoa grown on inland soils. There is the possibility that at present we may be applying more fertiliser than necessary for mature cocoa.

Since fertiliser inputs are generally costly, a more discriminatory approach to fertiliser usage for mature cocoa is advocated. However, before this can be fully realised more basic information is required and this include: the amount of N which is contributed through biological fixation through use of leguminous shade trees, the influence of shade tree management and its competition for light and water and leaching losses of nutrients from the rooting zone of cocoa.

ACKNOWLEDGEMENT

REFERENCES

ALVIM, P de T. (1977). Cacao. In *Ecopysiology of Tropical Crops* (ed. Alvim P de T & Kozlowsky, T.T.) Academic Press. New York.

ARANGUREN, J., ESCALANTE, G. & HERRERA, R. (1982). Nitrogen cycle of tropical perennial crops under shade trees. II Cacao. *Pl. Soils*, 67, 259–269.

BOYER, J. (1972). Evolution saisonniere de la production de litiere et de la decomposition des feuilles dans une cacaoyere Camerounaise. *Proc. IV Intern. Cocoa Res. Conf., St. Augustine, Trinidad, 1972.*

CADIMA, A. & ALVIM, P de T. (1967). Influence del arbol de sombra Erythrina glauca sobre algunos factores edafologicos relacionados con la production del cacaotera. *Turrialba,* 17, 330–336.

HARDY, F. (1959). La relacion carbono: nitrogeno en los suelos de cacao. *Turrialba,* 9, 4–11.

LING, A.H. (1983). Cocoa nutrition and manuring on inland soils in Peninsular Malaysia. *Proc. 2nd National Cocoa Conf., Medan, Indonesia, 1983.*

LING, A.H. & MAINSTONE, B.J. (1982). Phosphate requirements of Cocoa on Malaysian inland soils. *Proc. Int. Conf. Phosphorus and Potassium in the Tropics, Kuala Lumpur.* The Malaysian Society of Soil Science.

LING, A.H. & MAINSTONE, B.J. (1983). Effects of burning of rubber timber during land preparation on soil fertility and growth of *Theobroma cacao* and *Gliricidia maculata. Planter, Kumpur Lumpur.* 59, 52–59.

MAINSTONE, B.J. & THONG, K.C. (1978), Fertiliser responses over 6 years from planting of monocrop cocoa on a Bungor series soil. *Proc. Int. Cocoa Coconut Conf., Kuala Lumpur, Malaysia, 1978.*

SANTANA, M.B.M. & CABALA–ROSAND, P. (1982). Dynamics of nitrogen in a shaded cocoa plantation. *Pl. Soils,* 67, 271–281.

SMYTH, A.J. (1966). The selection of soils for cocoa. *FAO Soils Bull.,* 5, 76.

THONG, K.C. & NG, W.L. (1978). Growth and nutrient composition of monocrop cocoa plants on inland Malaysian soils. *Proc. Int. Cocoa Coconuts Conf., Kuala Lumpur, Malaysia, 1978.*

WONG, N.C. (1978). Detailed soil survey of cocoa growing areas in Sagil estate, Johor. Soil Survey Report 1/78, MARDI, Kuala Lumpur.

Appendix 1. Position of Litter Trap in relation to Cocoa and/or Gliricidia Shade Trees

(a)   *Cocoa Litter Trap*
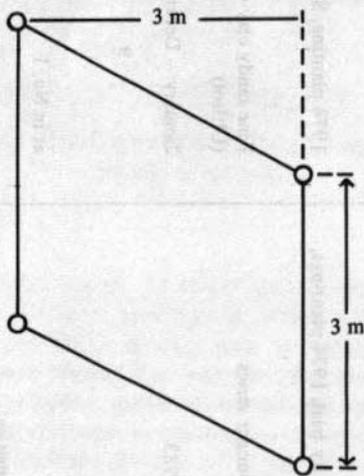
(b)   *Gliricidia Litter Trap*
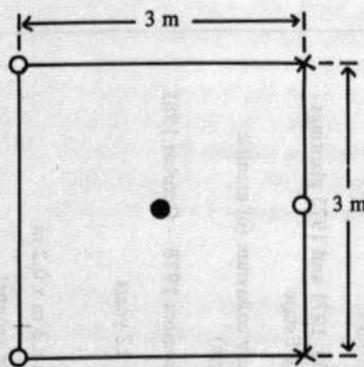
KEYS

o   — Cocoa tree
●   — *Gliricidia* tree
x   — Wooden stake
Area — 9 m^2

15

Appendix 2. Details of Litterfall Experiments

Aspect	Experiment No. 1	Experiment No. 2	Experiment No. 3
Objective	To estimate the amount of cocoa litterfall under different age of plantings	To evaluate the effect of different *Gliricidia* shade densities on cocoa litterfall	To estimate the amount of *Gliricidia* litterfall
Site	1969, 1971 and 1973 plantings Sagil Estate	*Gliricidia* shade density trial, 1974 plantings, Sagil Estate	1974 planting, Sagil Estate
Soil type	Sandy colluvium (of granitic origin)	Fine sandy clay of Bungor series (Ultisol)	Fine sandy clay of Bungor series (Ultisol)
Duration	November 1978 – October 1981	May 1981 – April 1983	January – December 1983
Age of cocoa	6 – 12 years	7 – 9 years	9
Litter collection:			
Trap size	3 m x 3 m x 0.2 m	as in No. 1	as in No. 1
Treatment	3 age groups: A. 6–8 years old B. 8–10 years old C. 10–12 years old	4 *Gliricidia* shade densities: A. 537 trees per hectare (3 m x 6 m) B. 268 trees per hectare (6 m x 6 m) C. 134 trees per hectare (6 m x 12 m) D. 67 trees per hectare (12 m x 12 m)	–
Replication	5	5	–
Total number of traps	15	20	5

16

Fertilizer and Soil Amelioration Trials on Inland and Coastal Soils in Malaysia

C.H. TEOH, A.K. CHANG AND C.F. CHONG

Harrisons Malaysian Plantations Berhad, Prang Besar Research Station, Selangor, Malaysia

Results of a 3^3 NPK factorial trial on an inland soil (Jerangau series) showed that pod and wet bean productions increased significantly within a year of application of rock phosphate (CIRP) to three and half year-old cocoa. In the third year, a significant yield response to muriate of potash applications was recorded. Improved production attributable to CIRP and muriate of potash applications was maintained until trial termination after six years. There was no response to application of nitrogen. In contrast, in a similar trial on coastal clay soil (Bernam Series), cocoa planted under Malayan Tall coconuts responded favourably to nitrogen manuring and superior yields were recorded throughout a period of nine years from planting. Application of CIRP and muriate of potash did not result in any improvement in growth nor pod production.

As application of calcium limestone has been found to raise the pH of coastal clay soil and improve cocoa growth and yields, three small-scale trials were established to monitor changes in the acidity levels of Bernam and Sedu series soils following applications of ameliorants: calcium limestone, oil palm bunch ash and quicklime. At four and half years after the trial commencement, it was observed that annual applications of limestone and bunch ash at 0.27 kg/m^2 raised topsoil pH from 4.3 to 5.4 and 5.2 units respectively. Effects of the ameliorants on sub-soil pH were less pronounced. Of the three ameliorants, limestone appeared the most desirable on account of its faster action, cheapness, availability and less detrimental side effects. Fresh bunch ash and quicklime are considerably more difficult to apply as they are hygroscopic and caustic.

In view of contrasting inherent physical and chemical characteristics of coastal and inland soils in Peninsular Malaysia, trials were established to define the optimum fertilizer requirements for cocoa grown on alluvial Bernam series soil (a Typic Tropaquept) in Lower Perak and sedentary Jerangau series soil (a Haplic Acrorthox) in Jerangau Estate in Trengganu which pioneered large cultivation in Peninsular Malaysia.

Further, as Malaysian soils are generally acidic in reaction and cocoa has been reported to respond favourably to liming, three trials were set up to monitor the effects of applications of calcium, limestone, oil palm bunch ash and quicklime for reduction of acidity.

Results of these trials are discussed in this paper.

METHOD

Fertilizer Trials

Two 3^3 NPK confounded factorial trials, particulars of which are presented in *Table 1*, were established in Bagan Datoh Estate (Trial FT 1) and Jerangau Estate (Trial FT 2) in September 1969 and April 1971 respectively. Characteristics of the soils are presented in *Appendix 1*. Nitrogen, phosphorus and potassium were applied as calcium ammonium nitrate (CAN), Christmas Island Rock Phosphate (CIRP) and muriate of potash (MOP) respectively. Actual application rates per tree are given in *Appendix II*. In order to ensure that calcium was not a limiting factor, routine liming was undertaken according to commercial practice. Fertilizers were broadcast evenly within the entire plots in both trials except during the initial 24 months from planting in Trial FT 1 when manuring was done in a ring, radius of which increased with cocoa seedling age.

TABLE 1. PARTICULARS OF FERTILIZER TRIALS

Item	Trial FT 1	Trial FT 2
Soil type	Bernam Series	Jerangau Series
Soil taxonomy	Typic Tropaquept	Haplic Acrorthox
Location	Bagan Datoh Estate, Perak	Jerangau Estate, Trengganu
Cocoa planting material	Mixed Upper Amazon Sabah hybrids	Mixed Upper Amazon Sabah hybrids
Date cocoa planted	July 1969	September 1967
Trial duration	Sept. 1969 – July 1981	April 1971 – April 1977
Cocoa planting distance	1.98 x 3.05m in twin rows within 9.14m avenues	3.05 x 3.05m
Permanent shade	1938 Tall Coconuts (9.14 x 9.14m)	Thinned jungle ($\simeq$ 70 trees/ha final stand)
Design	3^3 NPK factorial	3^3 NPK factorial
Plot size	0.07 ha	0.07 ha
No. replications	2	3
Manuring history	Area was previously under coconut monoculture where no routine manuring was done	Ex-jungle area. 454g dolomitic limestone/tree/annum and 114g CIRP/tree 6-monthly for first 3 years.

Soil Amelioration Trials

The three trials SA 1, 2 and 3 were conducted as there was limited information on continuous monitoring of soil pH response to various amounts of alternative ameliorants in the long term. Details of these are given in *Table 2*.

TABLE 2. PARTICULARS OF SOIL AMELIORATION TRIALS

Item	Trial SA 1	Trial SA 2	Trial SA 3
Soil type	Bernam series	Bernam series	Sedu series
Soil taxonomy	Typic Tropaquept	Typic Tropaquept	Typic Sulfaquept
Location	Flemington Estate, Lower Perak	Flemington Estate, Lower Perak	Sg. Sedu Estate, Selangor
Crop	Cocoa	Cocoa	Oil Palm
Treatments			
(i) Ameliorants	Ca limestone & Oil palm bunch ash	Quicklime (surface application or incorporated)	Ca limestone, Oil palm bunch ash & Quicklime (observation)
(ii) Application rates in $(kg/m^2$ or kg/tree)	0, 0.13. 0.27, 0.74, 1.48, 2.22, & 2.97 (0, 0.8, 1.6, 4.5, 9.0, 13.5 & 18.0)	0, 0.74, 1.48 & 22.2 (0, 4.5, 9.0 & 13.5)	0, 0.13, 0.27, 0.74, 1.48, 2.22, & 2.97 (0, 0.8, 1.6, 4.5, 9.0, 13.5 & 18.0)
(iii) Number of applications	6 annual applications	2 annual applications	Once only, at trial commencement
(iv) Trial duration	May 1978 to May 1983	May 1982 to May 1983	April 1980 to June 1983
Design	Split plot with ameliorants as main plots and rates as subplots	As in SA1	As in SA1
Plot size	$6.8m^2$	$6.8m^2$	$6.8m^2$
Replications	3	3	3 (Quicklime plots not replicated)
Analysis	pH of topsoil & subsoil	pH of topsoil & subsoil	pH of topsoil & subsoil. Exch. K, Ca & Mg at 9 months after application.

Trial SA 1 was established on Bernam series soil in Flemington Estate, Teluk Intan, in May 1978 to monitor effects of limestone and oil palm bunch ash on soil pH. The ameliorants were applied at the following rates: 0, 0.13, 0.27, 0.74, 1.48, 2.22 and 2.97 mg/m^2/annum. In Trial SA 2 situated beside Trial SA 1, quicklime was applied at similar rates to evaluate the influence of surface applications and incorporation (forking-in) on soil pH. In the third trial, SA3, all the three ameliorants were applied to an acid sulphate soil (Sedu series) on a coastal estate in Selangor. In this trial only one application was made, at the commencement of the trial in May 1980. At nine months after application soil samples collected were also analysed for exchangeable potassium calcium and magnesium (by the neutral ammonium acetate method, using flame photometry for K measurement and atomic absorptiometery for Ca and Mg determinations).

Small plots of $6.8m^2$ were used to ensure very uniform application of ameliorants over the entire soil surface. Soil samples were collected just prior to the first application and periodically, at three to eight-month intervals thereafter. A 3-cm diameter screw auger was used to collect samples from four representative points per plot at depths of 0—15 cm for topsoil and 15—45 cm for subsoil. The samples were dried and the pH of a suspension of 10g soil in 25 ml water was measured with a Corning 125 pH meter.

The approximate compositions of ameliorants used were as follows: Calcium limestone (50% CaO, 2% MgO), bunch ash (41% K_2O, 5% CaO, 6% MgO) after Yeow et al., (1980) and quicklime (100% CaO).

RESULTS

Fertilizer Trial FT 1

Yield and growth data recorded since commencement of the trial are presented in *Table 3*. Throughout the period of recording, plots which received nitrogen maintained superior pod production per tree over unmanured control plots. From commencement of bearing, highly significant linear response to nitrogen was obtained and the trend was maintained after fertilizer rates were increased by 50% in 1977. However, application of nitrogen did not affect the pod value (the number of pods required to produce 1 kg dry beans), indicating that pod size had not been enhanced. Cocoa growth appeared to improve following nitrogen treatment, particularly during the initial two years, but differences in girth increment over a 10-year period between "control" and manured plots were statistically not significant.

TABLE 3. GROWTH AND YIELD RESULTS IN FERTILIZER TRIAL FT1 (BERNAM SERIES)

| Factor | Av. No. Pods/Tree | | | | Pod value | Girth Increment (cm) |
	Year 1	Years 1–5	Years 6–9	Overall	Year 9	Years 1–9
N_0	18.2	24.1	37.8	30.2	33.2	18.8
N_1	29.2	33.5	44.4	38.3	33.6	19.5
N_2	30.4	35.4	48.3	41.2	33.4	19.5
Response: Linear	**	**	**	**	NS	NS
Quadratic	NS	NS	NS	NS	NS	NS
P_0	25.2	29.6	44.5	35.8	33.6	19.0
P_1	26.9	31.7	43.5	36.8	32.4	20.1
P_2	25.7	29.5	43.6	37.1	34.1	19.2
Response: Linear	NS	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS	NS
K_0	27.0	31.3	44.4	37.2	33.4	19.7
K_1	24.6	29.5	41.0	34.6	33.2	19.6
K_2	26.2	31.7	45.2	37.9	33.6	19.0
Response: Linear	NS	NS	NS	NS	NS	Ns
Quadratic	NS	NS	NS	NS	NS	NS

Fertilizer rates were increased by 50% from year 6.
NS = Not significant
** = Significant at P = 0.01

4

There were no significant improvements in pod production or growth with application of fertilizers containing phosphorus or potassium, nor were significant interactions between nutrients recorded.

Leaf samples were collected periodically but, although yield responses were obtained, no significant differences in foliar nutrient levels were detected. Considerable variation in foliar nutrient levels between samplings was apparent indicating that nutrient contents are easily influenced by climatic factors (*e.g.* droughts) and by the physiological phases of trees *e.g.* flushing, flowering and fruiting.

Coconut yields of individual plots were monitored from 1969 until 1975 but were discontinued subsequently as no differential responses in nut production were recorded.

Fertilizer Trial FT 2

Pod and wet bean production from years 1 to 6 (1971 to 1977) are presented in *Table 4.* A significant improvement in yield was obtained within a year of application of rock phosphate. Significant to highly significant linear responses to phosphorus were observed in four of the six years of recording.

Application of muriate of potash resulted in improved yields in terms of pod and wet bean production from the third year of the trial until termination. As with phosphorus, response to potassium applications was linear.

Significant P x K interaction was evident from years 3 to 5 *(Table 5),* the highest number of pods per tree and wet bean weight being obtained from the treatment combination, P_2K_1.

TABLE 5. SIGNIFICANT NUTRIENT INTERACTIONS IN FERTILIZER TRIAL FT 2
(JERANGAU SERIES)

Level	Av. pods/tree (No.)			Level	Av. wet beans/tree (kg)		
	K_0	K_1	K_2		K_0	K_1	K_2
P_0	17.6	17.1	18.0	P_0	1.95	1.91	2.00
P_1	16.7	21.7	23.2	P_1	1.91	2.54	2.68
P_2	18.7	24.9	21.2	P_2	2.04	2.72	2.36

P x K interaction (from years 3 to 5)

Yields obtained in this trial were substantially lower than those recorded in Trial FT 1. This could be attributed to inherent soil/site differences and moderate to severe vascular streak dieback disease which was endemic on the estate. However, observations of individual plots did not reveal any significant relationship between fertilizer treatment and disease incidence.

Soil Amelioration Trials

Tables 6A & 6B show the changes in topsoil and subsoil pH with time respectively in Trial SA1. At the higher application rates (1.48, 2.22 and 2.97 kg/m^2), positive responses

5

TABLE 4. POD AND WET BEAN PRODUCTIONS PER TREE IN FERTILIZER TRIAL FT2 (JERANGAU SERIES)

Factor	Year 1 pods (No.)	Year 1 beans (kg)	Year 2 pods (No.)	Year 2 beans (kg)	Year 3 pods (No.)	Year 3 beans (kg)	Year 4 pods (No.)	Year 4 beans (kg)	Year 5 pods (No.)	Year 5 beans (kg)	Year 6 pods (No.)	Year 6 beans (kg)
N_0	20.9	2.17	10.4	1.02	21.6	2.54	18.3	2.00	20.3	2.18	21.7	2.22
N_1	21.0	2.23	10.9	1.11	20.6	2.40	17.3	1.81	18.3	2.09	19.3	1.95
N_2	22.7	2.39	12.8	1.28	22.6	2.59	20.1	2.09	20.3	2.18	19.3	2.04
Response: Linear	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
P_0	19.0	1.99	10.6	1.08	19.2	2.27	16.7	1.77	16.7	1.91	16.5	1.77
P_1	22.9	2.40	11.5	1.16	23.4	2.63	19.6	2.09	20.4	2.18	21.0	2.18
P_2	22.6	2.40	11.9	1.22	22.2	2.68	19.3	2.09	21.9	2.40	22.7	2.31
Response: Linear	*	*	NS	NS	*	*	NS	NS	**	**	**	**
Quadratic	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
K_0	20.5	2.18	10.7	1.09	19.4	2.22	16.7	1.86	17.2	1.91	17.7	1.81
K_1	22.8	2.39	12.3	1.25	21.7	2.59	19.0	2.00	21.4	2.31	21.2	2.18
K_2	21.2	2.21	11.0	1.12	23.6	2.63	19.9	2.18	20.3	2.18	21.4	2.18
Response: Linear	NS	NS	NS	NS	**	**	*	*	**	**	*	*
Quadratic	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interactions	NS	NS	NS	NS	PK**	PK**	PK*	NS	NS	PK**	NS	NS

NS = Not significant
* = significant at P = 0.05
** = significant at P = 0.01

in topsoil pH improvement were detected within six months of application, particularly when limestone was used. However, at the lower rates of application, up to 0.74 kg/m^2 significant response to both ameliorants was not detected until after the third annual application.

The topsoil pH response was always greater than that of the subsoil. Significant responses in the topsoil pH to application rates were obtained at every sampling. For plots receiving the higher rates of ameliorants, the positive response in topsoil pH was maintained after each application but there was a perceptible decline at nine to 12 months after the application. The tailing off effect can be clearly seen in *Figure 1*. For the first three years, there was no significant difference in the responses between materials. Subsequently better responses were obtained from bunch ash, especially when higher rates were used. *Table 6B* shows that the time lag in responses in subsoil pH was much longer.

The pH response to quicklime application in Trial SA 2 (*Table 7*) was noticeable as early as three months after application and appeared to be more sustained than that associated with limestone and bunch ash applications. When quicklime was applied at 1.48 kg/m^2, the improvement in topsoil pH was about 1.5 units at 12 months after application. There was no difference between the effects of the two methods of application — surface application and incorporation. However, a rather thick and hard surface crust formed when quicklime was applied at 1.48 kg/m^2 or higher. When quicklime came into contact with water or absorbed moisture from the soil there was considerable heat buildup.

In Trial SA 3 on acid sulphate soil (Sedu Series), the initial pH was very low *(Tables 8A and 8B)*—about 3.7 units in both topsoil and subsoil. Throughout the trial the inherent pH in untreated plots remained constantly low. As in Trial SA 1 there was little difference between effects of the single application of limestone and bunch ash. However, quicklime applied in unreplicated observations plots appeared superior. A large increase in topsoil pH (0.18 units higher than the control) was produced by quicklime at 0.74 kg/m^2 nine months after application. At the higher rates, the topsoil pH in quicklime plots reached a peak between nine to 12 months after application and remained higher than in limestone and bunch ash plots.

The highest average pH in the limestone and bunch ash plots was recorded at nine months after application, the topsoil pH being 1.2 units higher when the ameliorants were applied at 2.22 kg/m^2. Thereafter, the soil pH declined gradually until the 38th month. In this trial, lower rates of application of limestone (*e.g.* 0.74 kg/m^2) produced a larger increase in soil pH than in Trial SA 1.

In view of the lack of responses in Trial SA 3 up to six months from application, particularly in the subsoil, soil samples were collected at the 9th month for analyses of the important exchangeable cations, K, Ca and Mg. *Table 9* shows that only bunch ash application improved the exchangeable K status significantly in the topsoil and subsoil. At an application rate of 1.48 kg/m^2 bunch ash, the exchangeable K increased 22-fold and 14-fold in the topsoil and subsoil respectively.

In the case of exchangeable Ca, limestone was more effective in raising the calcium status of the soil (*Table 9*). This is to be expected as limestone contains more calcium than bunch ash. Only at the higher rates (1.48 kg/m^2 or more) did bunch ash increase the exchangeable Ca significantly. There was an apparent anomaly in the analysis results of Ca level of the plots receiving the highest rate of bunch ash. The influence of the

7

TABLE 6A. EFFECT OF LIMESTONE AND BUNCH ASH ON pH OF TOPSOIL (0–15 CM) IN TRIAL SA1 (BERNAM SERIES)

Application rates (kg/m²)	Pre-Treat # LM	Pre-Treat # BA	1 MAA # LM	1 MAA # BA	3 MAA LM	3 MAA BA	6 MAA LM	6 MAA BA	9 MAA LM	9 MAA BA	12 MAA # LM	12 MAA # BA	15 MAA LM	15 MAA BA	18 MAA LM	18 MAA BA
0	4.3	4.4	4.1	4.1	4.1	4.1	4.6	4.4	4.3	4.3	3.9	4.2	4.2	4.3	4.4	4.3
0.13	4.4	4.5	4.1	4.0	4.2	4.2	4.5	4.5	4.3	4.3	4.1	4.0	4.3	4.3	4.5	4.6
0.27	4.4	4.5	4.1	4.2	4.3	4.2	4.6	4.9	4.4	4.5	4.2	4.0	4.7	4.3	4.5	4.7
0.74	4.4	4.5	4.2	4.1	4.4	4.1	4.7	4.9	4.6	4.7	4.4	4.4	4.8	4.7	5.0	4.9
1.48	4.4	4.4	4.3	4.3	4.8	4.2	6.0	5.2	4.9	4.9	5.0	4.6	5.6	5.3	5.5	5.4
2.22	4.4	4.4	4.8	5.1	5.2	4.8	6.0	5.4	5.1	4.8	5.2	4.9	5.6	5.8	5.8	5.8
2.97	4.4	4.4	4.7	5.4	5.5	5.6	6.3	6.0	5.3	5.0	5.6	5.3	5.7	6.1	5.8	5.5
Var. ratio & LSD																
Between materials	ns -		ns -		ns -		ns -		ns -		*(0.14)		**(0.20)		**(0.15)	
Between rates	ns -		**(0.51)		**(0.34)		**(0.30)		**(0.28)		**(0.25)		**(0.38)		**(0.37)	

Application rates (kg/m²)	21 MAA LM	21 MAA BA	24 MAA # LM	24 MAA # BA	27 MAA LM	27 MAA BA	30 MAA LM	30 MAA BA	33 MAA LM	33 MAA BA	36 MAA # LM	36 MAA # BA	39 MAA LM	39 MAA BA	42 MAA LM	42 MAA BA
0	4.2	4.3	3.5	3.5	4.6	4.3	3.8	3.7	3.8	3.7	3.8	3.7	4.1	4.0	4.4	4.4
0.13	4.2	4.7	3.7	3.6	4.5	4.2	4.3	3.8	4.0	3.5	3.9	3.6	4.3	3.9	4.5	4.6
0.27	4.3	4.4	3.7	3.6	4.6	4.3	4.3	3.5	4.2	3.9	4.1	3.8	4.3	4.2	4.6	4.7
0.74	4.2	4.5	4.1	3.9	4.7	4.5	4.1	4.7	5.4	4.7	5.1	4.5	5.2	4.7	5.4	4.9
1.48	5.6	5.7	4.3	4.5	5.0	4.9	5.6	5.9	5.5	5.7	5.5	6.1	5.5	6.3	5.6	5.4
2.22	5.1	6.5	5.0	4.0	5.6	4.8	5.5	6.2	5.8	6.6	5.7	6.8	5.9	6.8	6.2	7.2
2.97	5.1	6.8	5.4	4.1	5.9	5.0	5.6	6.9	5.7	7.2	5.8	6.5	5.9	6.7	6.4	7.4
Var. ratio & LSD																
Between materials	ns -		**(0.02)		ns -		ns -		ns -		*(0.14)		**(0.20)		**(0.15)	
Between rates	**(0.37)		**(0.25)		**(0.24)		**(0.31)		**(0.27)		**(0.18)		**(0.12)		**(0.21)	

Application rates (kg/m²)	45 MAA LM	45 MAA BA	48 MAA # LM	48 MAA # BA	51 MAA LM	51 MAA BA	54 MAA LM	54 MAA BA	57 MAA LM	57 MAA BA	60 MAA LM	60 MAA BA
0	4.5	4.3	4.2	4.3	3.8	3.9	4.8	4.4	5.0	4.7	5.0	4.9
0.13	4.6	4.7	4.6	4.5	4.2	4.7	4.6	4.9	4.8	5.3	4.6	5.0
0.27	4.6	4.5	4.2	4.6	5.2	4.8	5.4	5.2	5.6	5.3	5.7	5.2
0.74	5.1	5.7	5.1	5.6	5.7	5.6	5.9	5.8	5.8	5.6	5.8	5.0
1.48	5.6	6.5	5.3	6.3	5.5	6.3	6.7	7.0	6.0	5.5	5.9	5.2
2.22	5.4	6.8	5.3	6.9	5.7	6.6	5.8	7.0	5.8	6.2	5.7	5.8
2.97	6.0	6.8	5.4	6.6	5.8	6.7	6.6	6.9	6.6	6.8	6.2	6.2
Var. ratio & LSD												
Between materials	**(0.16)		**(0.09)		*(0.35)		*(0.23)		ns(0.37)		**(0.13)	
Between rates	**(0.11)		**(0.14)		**(0.39)		**(0.36)		**(0.22)		**(0.10)	

NOTES:

LM   = Limestone
BA   = Bunch Ash
MAA = Months after 1st application.   # = Ameliorants applied at yearly intervals, i.e. 0, 12th, 24th, 36th 48th & 60th months
ns   = Not significant
*   = significant at P = 0.05
**   = significant at P = 0.01
LSD given at P = 0.05

8

TABLE 6B. EFFECT OF LIMESTONE AND BUNCH ASH ON pH OF SUBSOIL (15-45 CM) IN TRIAL SA1 (BERNAM SERIES)

Application rates (kg/m²)	Pre-treat #		1 MAA		3 MAA		6 MAA		9 MAA		12 MAA #		15 MAA		18 MAA	
	LM	BA	LM	BA	LM	BA	LM	BA	LM	BA	LM	BA	LM	BA	LM	BA
0	4.2	4.2	4.0	4.1	4.0	4.0	4.2	4.3	4.0	4.1	3.8	3.9	4.1	4.2	4.1	4.2
0.13	4.3	4.3	4.0	4.0	4.1	4.0	4.2	4.2	4.1	4.0	3.9	3.9	4.1	4.1	4.2	4.3
0.27	4.2	4.2	4.1	4.0	4.0	4.0	4.2	4.2	4.0	4.1	3.9	3.9	4.2	4.2	4.3	4.3
0.74	4.2	4.2	4.1	4.0	4.1	4.0	4.3	4.3	4.1	4.0	3.9	3.9	4.2	4.1	4.5	4.3
1.48	4.2	4.3	4.3	4.0	4.2	3.9	4.2	4.2	4.1	4.1	4.1	3.9	4.4	4.1	4.7	4.4
2.22	4.3	4.2	4.4	3.9	4.2	3.9	4.6	4.2	4.1	4.0	4.1	3.9	4.4	4.1	4.6	4.3
2.97	4.2	4.2	4.4	3.9	4.4	3.9	4.9	4.2	4.0	4.0	4.1	4.0	4.4	4.1	4.7	5.1

Var. ratio & LSD

	Pre-treat	1 MAA	3 MAA	6 MAA	9 MAA	12 MAA	15 MAA	18 MAA
Between materials	ns —	ns —	ns —	ns —	ns —	ns —	* (0.13)	ns —
Between rates	ns —	* (0.09)	* (0.08)	* (0.33)	ns —	** (0.05)	ns —	* (0.43)

Application rates (kg/m²)	21 MAA		24 MAA #		27 MAA		30 MAA		33 MAA		36 MAA #		39 MAA		42 MAA	
	LM	BA	LM	BA	LM	BA	LM	BA	LM	BA	LM	BA	LM	BA	LM	BA
0	4.0	4.1	3.3	3.3	4.3	3.9	3.4	3.6	3.4	3.4	3.7	3.5	3.9	3.8	4.0	4.1
0.13	4.0	4.0	3.4	3.3	4.3	3.8	3.7	3.5	3.2	3.5	3.7	3.5	4.1	3.7	4.3	4.1
0.27	4.1	4.0	3.4	3.3	4.3	4.0	3.7	3.3	3.4	3.4	3.5	3.4	3.8	3.7	4.1	4.0
0.74	4.2	4.1	3.7	3.5	4.3	4.2	3.4	3.6	3.5	3.6	3.8	3.6	4.1	4.0	4.3	4.4
1.48	4.2	4.2	3.8	3.5	4.4	4.1	4.0	3.8	3.8	3.8	3.7	3.9	4.1	4.0	4.4	4.5
2.22	4.3	4.0	3.9	3.3	4.7	4.1	4.3	4.1	4.4	3.9	4.3	4.8	4.5	4.9	4.8	4.9
2.97	4.3	4.1	4.5	3.8	4.5	4.2	3.8	4.5	4.4	4.2	5.0	5.1	5.2	4.6	5.7	5.1

Var. ratio & LSD

	21 MAA	24 MAA	27 MAA	30 MAA	33 MAA	36 MAA	39 MAA	42 MAA
Between materials	* (0.04)	* (0.36)	ns —	ns —	ns —	ns —	ns —	ns —
Between rates	* (0.12)	** (0.20)	** (0.22)	** (0.38)	** (0.24)	** (0.41)	** (0.38)	** (0.17)

Application rates (kg/m²)	45 MAA		48 MAA #		51 MAA		54 MAA		57 MAA		60 MAA #	
	LM	BA	LM	BA	LM	BA	LM	BA	LM	BA	LM	BA
0	4.1	3.7	3.9	3.8	3.7	3.8	4.3	4.2	4.6	4.5	4.8	4.8
0.13	4.3	4.3	4.0	4.1	4.1	4.2	4.3	4.5	4.5	4.8	4.6	4.9
0.27	4.1	4.2	4.3	4.3	4.4	4.6	4.3	4.7	4.7	5.0	4.8	4.8
0.74	4.2	4.5	4.3	4.7	5.1	5.0	4.9	5.2	4.9	5.2	5.1	4.9
1.48	4.8	5.2	4.8	5.1	5.5	5.1	5.5	5.2	5.3	5.4	5.2	5.1
2.22	4.8	5.2	5.0	5.4	5.2	6.5	5.2	6.7	5.3	6.3	5.3	5.3
2.97	5.4	5.1	5.4	5.2	5.6	5.4	5.6	5.6	5.5	6.0	5.5	6.0

Var. ratio & LSD

	45 MAA	48 MAA	51 MAA	54 MAA	57 MAA	60 MAA
Between materials	ns —	ns —	ns —	** (0.11)	** (0.04)	
Between rates	* (0.18)	** (0.10)	** (0.28)	** (0.24)	** (0.13)	

NOTES:

LM = Limestone

BA = Bunch Ash

MAA = Months after 1st application. # = Ameliorants applied at yearly intervals, i.e. 0, 12th, 24th, 36th, 48th & 60th months.

ns = Not significant

* = significant at P = 0.05

** = significant at P = 0.01
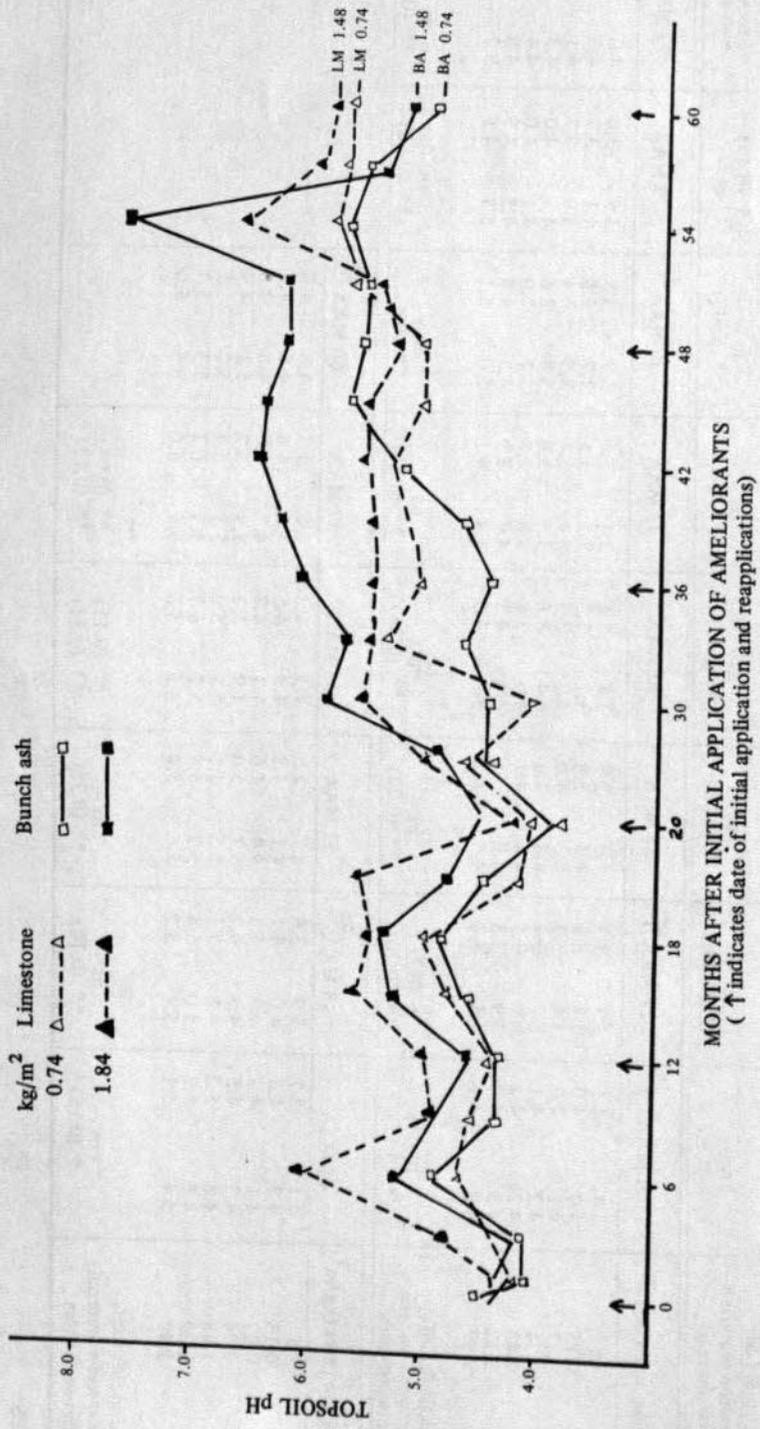
LSD given at P = 0.05

9

Figure 1. *Effect Of Limestone And Bunch Ash On Topsoil pH:Trial SA 1 (Bernam Series)*

10

TABLE 7. EFFECT OF QUICKLIME ON SOIL pH IN TRIAL SA2 (BERNAM SERIES)

pH of Topsoil (0–15 cm)

Application rate (kg/m²)	Pre-treatment #		3 MAA		6 MAA		9 MAA		12 MAA #	
	SF	INC	SF	INC	SF	INC	SF	INC	SF	INC
0	3.4	3.5	4.4	4.3	4.5	4.6	4.8	5.0	4.2	4.1
0.74	3.5	3.5	4.8	5.4	5.3	5.7	5.1	5.4	4.7	5.0
1.48	3.5	3.6	5.7	5.8	6.0	6.2	5.9	5.5	5.7	5.6
2.22	3.5	3.6	5.6	5.7	5.9	6.0	6.1	5.4	5.7	6.0

Var. ratio & LSD

	Pre-treatment #		3 MAA		6 MAA		9 MAA		12 MAA #	
Between materials	ns –		ns –		* (0.16)		ns –		ns –	
Between rates	ns –		** (0.20)		** (0.15)		** (0.75)		** (0.28)	

pH of Subsoil (15–45 cm)

Application rate (kg/m²)	Pre-treatment #		3 MAA		6 MAA		9 MAA		12 MAA #	
	SF	INC	SF	INC	SF	INC	SF	INC	SF	INC
0	3.2	3.3	4.0	4.1	4.3	4.3	4.5	4.2	3.7	4.0
0.74	3.3	3.3	4.3	4.2	4.5	4.5	4.9	4.7	4.0	3.9
1.48	3.3	3.5	4.8	5.1	5.0	5.3	4.9	5.0	4.6	4.5
2.22	3.3	3.5	5.0	5.5	5.4	5.7	5.5	5.1	5.6	5.5

Var. ratio & LSD

	Pre-treatment #		3 MAA		6 MAA		9 MAA		12 MAA #	
Between materials	ns –		ns –		ns –		ns –		ns –	
Between rates	ns –		** (0.13)		** (0.17)		** (0.25)		** (0.31)	

NOTES:

SF   = Surface application
INC = Incorporation
MAA = Months after 1st application.   # = Quicklime applied at yearly intervals, i.e. 0 & 12th months
ns   = Not significant
*   = Significant at P = 0.05
**   = Significant at P = 0.01

LSD given at P = 0.05

11

TABLE 8A. EFFECT OF LIMESTONE, BUNCH ASH & QUICKLIME ON pH OF TOPSOIL (0-15 CM) IN TRIAL SA3 (SEDU SERIES)

Application rate (kg/m^2)	Pre-treatment			1 MAA			3 MAA			6 MAA		
	LM	BA	QL	LM	BA	QL	LM	BA	QL	LM	BA	QL
0	3.7	3.8	4.1	3.7	3.8	4.0	3.8	3.9	4.0	3.7	3.7	3.7
0.13	3.6	3.7	4.1	3.8	3.8	4.0	4.0	4.0	4.1	3.7	4.0	4.7
0.27	3.6	3.9	4.1	3.9	3.8	4.0	3.9	4.3	4.3	3.9	3.9	3.8
0.74	3.6	3.9	3.9	4.2	3.7	3.9	4.1	3.9	4.3	4.3	3.9	4.2
1.48	3.8	3.8	4.1	4.1	4.2	3.9	4.4	4.5	4.8	4.0	4.3	4.4
2.22	3.6	3.9	4.1	4.2	3.8	4.2	4.6	4.3	5.7	4.3	4.2	5.4
2.97	4.0	3.7	–	4.1	3.9	3.9	4.6	4.0	–	4.6	4.4	–
Var. ratio & LSD												
Between materials	ns –			ns –			ns –			ns –		
Between rates	ns –			ns –			* (0.37)			** (0.28)		

Application rate (kg/m^2)	9 MAA			12 MAA			15 MAA			18 MAA		
	LM	BA	QL	LM	BA	QL	LM	BA	QL	LM	BA	QL
0	3.8	3.9	3.9	3.8	3.9	4.0	3.9	3.9	3.8	3.8	4.0	3.9
0.13	3.9	4.0	4.3	3.9	4.0	4.2	3.7	4.1	4.1	3.8	4.2	3.8
0.27	4.0	3.9	4.2	3.9	4.0	5.3	4.1	3.9	4.1	3.9	4.1	4.0
0.74	4.3	4.2	5.7	4.2	3.9	5.2	4.2	4.1	4.6	4.2	4.2	4.7
1.48	4.4	4.8	5.4	4.4	4.3	5.5	4.4	4.6	4.5	4.1	4.4	4.7
2.22	5.0	5.1	5.3	5.1	4.7	6.3	4.6	4.8	4.3	4.7	4.7	4.7
2.97	5.9	4.4	–	5.0	4.1	–	5.6	4.1	–	4.3	4.5	–
Var. ratio & LSD												
Between materials	ns –			ns –			ns –			ns –		
Between rates	** (0.49)			** (0.38)			** (0.32)			** (0.36)		

Application rate (kg/m^2)	21 MAA			32 MAA			38 MAA		
	LM	BA	QL	LM	BA	QL	LM	BA	QL
0	3.6	3.5	4.1	3.2	3.4	3.4	3.5	3.8	3.9
0.13	3.8	3.6	4.1	3.4	3.6	3.6	3.7	4.0	4.1
0.27	4.0	3.6	4.4	3.4	3.6	4.0	3.9	3.8	4.0
0.74	3.8	3.5	4.4	4.0	3.3	4.7	3.9	4.0	4.0
1.48	4.2	4.0	4.6	4.2	3.7	4.7	4.3	3.7	5.8
2.22	5.2	4.8	4.7	5.0	3.8	5.8	4.6	4.0	4.4
2.97	4.8	4.7	–	4.5	3.9	–	5.0	3.9	–
Var. ratio & LSD									
Between materials	ns –			ns –			ns –		
Between rates	** (0.72)			** (0.50)			* (0.49)		

NOTES:

LM	=	Limestone
BA	=	Bunch Ash
QL	=	Quicklime (observation only)
MAA	=	Months after application (One application in April 1980)
ns	=	Not significant
*	=	significant at P = 0.05
**	=	significant at P = 0.01

LSD given at P = 0.05

TABLE 8B. EFFECT OF LIMESTONE, BUNCH ASH & QUICKLIME ON pH OF SUBSOIL (15–45CM) IN TRIAL SA3 (SEDU SERIES)

Application rate (kg/m²)	Pre-treatment			1 MAA			3 MAA			6 MAA		
	LM	BA	QL	LM	BA	QL	LM	BA	QL	LM	BA	QL
0	3.8	3.7	3.9	3.6	3.7	3.9	3.6	3.7	4.0	3.5	3.6	3.8
0.13	3.6	3.7	4.0	3.6	3.6	3.9	3.7	3.7	4.0	3.6	3.6	4.3
0.27	3.6	3.7	4.0	3.8	3.7	4.0	3.8	3.8	5.1	3.7	3.5	3.9
0.74	3.6	3.7	3.8	4.0	3.7	4.4	4.0	3.6	4.1	3.7	3.8	4.2
1.48	3.6	3.7	4.0	4.0	3.9	4.5	4.3	3.7	4.8	3.7	3.8	4.1
2.22	3.7	3.6	4.0	4.0	3.9	3.9	4.2	3.9	4.9	4.0	4.0	5.8
2.97	3.8	3.6	—	3.7	4.0	—	4.7	3.7	—	4.6	3.9	—
Var. ratio & LSD												
Between materials	ns –			ns –			ns –			ns –		
Between rates	ns –			ns – (0.17)			* – (0.36)			** – (0.28)		

Application rate (kg/m²)	9 MAA			12 MAA			15 MAA			18 MAA		
	LM	BA	QL	LM	BA	QL	LM	BA	QL	LM	BA	QL
0	3.6	3.8	3.9	3.7	3.7	4.0	3.5	3.7	3.8	3.7	3.9	3.9
0.13	3.7	3.7	4.1	3.7	3.7	4.1	3.6	3.8	4.1	3.7	3.8	3.9
0.27	3.7	3.9	4.3	3.8	3.6	5.9	3.6	3.5	4.0	3.7	3.5	4.1
0.74	4.1	3.8	5.9	3.8	3.6	4.4	3.7	3.4	3.4	3.8	3.6	4.6
1.48	4.2	3.8	4.4	4.2	3.7	4.4	4.1	3.6	4.2	4.1	3.6	4.7
2.22	4.8	4.3	4.4	4.4	3.9	5.0	5.0	3.6	4.0	4.4	4.0	5.8
2.97	5.3	4.0	—	4.7	3.8	—	5.1	3.6	—	4.2	3.7	—
Var. ratio & LSD												
Between materials	ns –			ns –			ns –			ns –		
Between rates	** – (0.34)			** – (0.17)			** – (0.25)			** – (0.23)		

Application rate (kg/m²)	21 MAA			32 MAA			38 MAA		
	LM	BA	QL	LM	BA	QL	LM	BA	QL
0	3.7	3.7	3.9	3.2	3.3	3.3	3.4	3.7	3.9
0.13	3.6	3.6	4.0	3.2	3.2	3.5	3.5	3.6	4.0
0.27	3.6	3.5	4.3	3.2	3.2	3.5	3.6	3.4	3.8
0.74	3.5	3.6	4.5	3.6	3.0	3.9	3.7	3.5	4.1
1.48	4.0	3.6	5.6	3.8	3.1	3.7	4.0	3.4	5.2
2.22	4.8	4.2	4.6	4.4	3.1	5.6	3.9	3.6	4.0
2.97	4.7	4.2	—	4.3	3.1	—	4.6	3.5	—
Var. ratio & LSD									
Between materials	ns –			ns –			* – (0.11)		
Between rates	** – (0.59)			** – (0.36)			** – (0.38)		

NOTES:

LM	=	Limestone
BA	=	Bunch Ash
QL	=	Quicklime (observation only)
MAA	=	Months after application (One application in April 1980)
ns	=	Not significant
*	=	significant at P = 0.05
**	=	significant at P = 0.01
LSD given at P = 0.05		

13

ameliorants on exchangeable Mg was less obvious (*Table 9*), though bunch ash appeared to be more effective at the higher rates (from 1.48 kg/m^2) of application.

DISCUSSION

Response to Fertilizers

On the coastal alluvial clay soil (Bernam Series), the main response was to nitrogen. Significant linear response in pod production was detected since commencement of bearing. During nine years of recording, yields were increased by 29% to 36% when nitrogen was applied as calcium ammonium nitrate at Level 1 (74 kg N/ha/year during the first five years of maturity and 110 kg N/ha/year thereafter) and Level 2 respectively. It is of interest to note that the linear response was maintained even after application rates were increased by 50% from the sixth year of maturity. This finding is in agreement with those of other workers who undertook trials on similar soils in 1970/71. Ng and Chan (1980) reported 34% and 50% increase in cocoa yield following application of 145 kg and 164 kg nitrogen per hectare respectively in a 2^4 NPK Ca factorial trial established in Kangkong Series soil (since renamed Bernam Series). Khoo et al., (1980) obtained a significant quadratic response in wet bean production to nitrogen in a 3^4 NPK Ca factorial trial. However, nitrogen application did not enhance girth significantly as shown by results on Trial FT 1 and Ng and Chan (1980). In fact, Khoo et al., showed that nitrogen application depressed growth marginally.

Although Khoo et al., (1980) reported a marked response to potassium, application of muriate of potash in Trial FT 1 and the trial undertaken by Ng and Chan (1980) did not result in any significant yield improvement. There was also no response to application of rock phosphate. It should be noted that soils in these trials had adequate potassium and phosphorus reserves.

As Trial FT 1 and that of Ng and Chan (1980) were in the same locality, their results are likely to be applicable to Bernam Series soils within the Lower Perak district. The main requirement would be for nitrogen, application rates for mature cocoa being in the order of 150 kg N/ha/year.

Calcium ammonium nitrate (CAN) was used in Trial FT 1 as it also provided calcium (12% CaO). However, Khoo et al., (1980) showed that there were no yield differences when CAN or ammonium nitrate were applied. Ng and Chan (1980) concluded that urea was as efficient as ammonium nitrate or ammonium sulphate, provided the leaf litter was disturbed after fertilizer application so as to minimise volatilization losses.

Owing to the low level of available phosphorus (<6 ppm) of the Jerangau series soil in Trial FT 2, significant yield response to rock phosphate application was detected within the first year of application and highly significant linear response was recorded in four of the six years. Throughout the six years of recording, pod and wet bean production increased by 20% and 22% and 17% and 21% following application of P_2O_5 at 90 and 180 kg/ha/year respectively. In a trial on a Bungor series sandy clay loam soil with higher available phosphorus (27.6 ppm in the topsoil), Mainstone and Thong (1980) reported improved cocoa production in the second and fourth years following rock phosphate application.

Response to potassium application could be expected in many inland sedentary soils as they are inherently low in this nutrient as indicated in the following data extracted from Ng (1965) on potassium status of Malaysian soils.

TABLE 9. EFFECT ON SOIL EXCHANGEABLE CATIONS (9 MONTHS AFTER AMELIORANT APPLICATION) IN TRIAL SA3 (SEDU SERIES)

Application rate (kg/m2)	Exchangeable K (meq %)						Exchangeable Ca (meq %)						Exchangeable Mg (meq %)					
	TOPSOIL			SUBSOIL			TOPSOIL			SUBSOIL			TOPSOIL			SUBSOIL		
	LM	BA	QL	LM	BA	QL	LM	BA	QL	LM	BA	QL	LM	BA	QL	LM	BA	QL
0	0.18	0.16	0.08	0.14	0.13	0.09	0.28	0.33	0.20	0.28	0.41	0.15	0.13	0.10	0.08	0.14	0.12	0.06
0.13	0.15	0.24	0.09	0.18	0.17	0.10	1.25	0.61	1.88	1.05	0.34	1.75	0.25	0.11	0.10	0.29	0.15	0.11
0.27	0.16	0.50	0.08	0.17	0.51	0.10	1.82	0.48	0.89	1.33	0.96	1.72	0.30	0.21	0.08	0.30	0.86	0.06
0.74	0.21	1.07	0.12	0.20	0.66	0.15	4.43	0.41	15.3	3.77	0.59	19.4	0.49	0.25	0.23	0.66	0.39	0.29
1.48	0.14	3.50	0.09	0.16	1.84	0.11	4.04	1.65	1.94	5.88	1.04	3.09	0.31	1.43	0.22	0.73	1.34	0.20
2.22	0.18	4.29	0.12	0.19	2.32	0.09	11.41	3.57	4.50	9.34	1.35	4.63	0.51	2.63	0.25	1.00	1.63	0.21
2.97	0.17	3.38	–	0.17	2.04	–	22.96	0.18	–	15.13	0.62	–	0.80	1.07	–	0.95	1.07	–

Var.ratio & LSD

	Exchangeable K						Exchangeable Ca						Exchangeable Mg					
Between materials	* (1.31)			* (0.57)			* (6.31)			* (3.63)			ns (–)			ns (–)		
Between rates	** (0.99)			** (0.49)			** (5.25)			** (2.78)			* (0.87)			* (0.74)		

NOTES:
LM = Limestone
BA = Bunch Ash
QL = Quicklime (observation only)
ns = Not significant
* = Significant at P = 0.05
** = Significant at P = 0.01
LSD given at P = 0.05

15

	Mean Exchangeable K (meq %)		
	Depth (cm)		
Soil Series	0 – 8	8 – 30	30 – 60
Jerangau	0.17	0.07	0.06
Kangkong≡Bernam	0.79	0.64	0.71

In Trial FT 2, exchangeable K in the topsoil was only 0.05 meq % compared with 0.61 meq % for Bernam series in Trial FT 1.

Application of muriate of potash on Jerangau series soil in Trial FT 2 resulted in significant improvements in pod and wet bean production from the third to the sixth years, average increases being 17—20% in pod number and 16—17% in bean production for Levels 1 and 2 respectively. On Bungor series with 0.39 meq % exchangeable K, Mainstone and Thong (1980) considered potassium the most important nutrient. Potassium treatments maintained superior yields over four years of harvesting. Results of nutrient immobilization studies by Thong and Ng (1980) have also confirmed the importance of potassium in cocoa cultivation. Significant P x K interactions were obtained in Trial FT 2, highest yields being recorded in the P_2K_1 treatment (180 kg P_2O_5 and 90 kg K_2O/ha/year).

Soil Amelioration

In Peninsular Malaysia, cocoa is capable of performing satisfactorily on coastal clay soils, provided that they are adequately drained and not excessively acidic (*i.e.* soil pH not less than pH of 3.5 units). Ameliorants such as limestone and quicklime raised the exchangeable Ca status and pH in the soil whereas bunch ash similarly reduced acidity but added more K than Ca to the soil. Positive yield responses to lime applications have been reported by Khoo *et al.*, (1980) on coastal clay soils. They found that with application of 170g calcium limestone per tree the wet bean yield was about 80% better than that of the control, although they did not detect any response in early growth of cocoa. On the other hand Mainstone *et al.*, (1977) and Ng *et al.*, (1980) reported that liming improved cocoa growth on inland soils. In Brazil, Morais *et al.*, (1978) stated that cocoa seedlings grown under greenhouse conditions in an acid soil reacted positively to both lime and P applications, lime being more effective when aluminium saturation was over 50% and P when aluminium saturation was below 50%. Foster *et al.*, (1980) found that the application of ground magnesium limestone (34% CaO, 19% MgO) on many Malaysian soils raised soil pH, extractable Ca and Mg decreased extractable Al. They concluded that the main effect of liming was the reduction in Al saturation which was accompanied by an increase in soil pH and soil calcium levels. It was also suggested that the main hazard of liming was the possible inducement of Mn deficiency in some grain legume crops under test. In mature cocoa, Mn deficiency is rarely seen but in nursery seedlings Mn and Zn deficiencies could be induced by liming (Teoh, 1980).

Smyth (1966; 1975) has suggested that the topsoil pH ideal for cocoa performance should be within the range of 6.0 to 7.5. However, based on commercial experience in Peninsular Malaysia, topsoil pH within the range 5.0 to 6.0 is considered satisfactory as it is impractical to achieve a soil pH in excess of 6 units. Results from Trials SA 1 and

SA 3 indicate that on a typical coastal clay it is difficult to raise the topsoil pH to above 6.0 units unless a heavy application rate (*e.g.* 1.48 kg/m^2 of bunch ash or 2.22 kg/m^2) is repeated annually for three to four years.

It was of interest to note that limestone seemed to produce a slightly better response within the short term (three years) and at lower dosages than bunch ash. However, the latter was superior after the fourth application. At the lower rate of 0.27 kg/m^2 (about 1600 g/tree), five annual applications of either ameliorant would be necessary to raise the topsoil pH to about 5 units. Percolation in the bunch ash plots appeared to be reduced as it was known that bunch ash would breakdown soil structures and reduce porosity or aeration (Yeow *et al.*, 1980).

The application of quicklime in Trial SA 2 (*Table 7*) produced a larger response when compared with limestone and bunch ash applications. From an initial level of about 3.5 units, the topsoil pH increased to about 6 units within six months of application of quicklime at 1.48 kg/m^2. The subsoil pH also improved substantially. There was little difference in surface application and incorporation responses within the twelve-month period of recording. The better responses to quicklime application could be attributable to its higher solubility and greater chemical activity.

Trial SA 3 provided a good opportunity for monitoring the residual effects of a single application of the ameliorants. As the soil pH in untreated plots remained very constant *(Tables 8A* and *8B)*, any changes in pH in treated plots could be directly attributed to treatment effects. From three months after application, quicklime was superior to the other two ameliorants in raising topsoil and subsoil pH. A large response to quicklime applied at the highest rate (2.22 kg/m^2) was detectable at three months and responses to lower dosages (*e.g.* 0.27, 0.74 kg/m^2) at 12 months after application. Between the other two ameliorants, limestone, at the higher rates again gave faster responses and sustained higher soil pH for a longer period, up to the last recording at the 38th month. In the order of decreasing effectiveness, the ranking of the ameliorants would be quicklime, limestone and bunch ash. However, it has been found that quicklime (at 6 g/polybag) severely scorched cocoa nursery seedlings (Prang Besar Research Station, 1981). Further, detrimental effects of crusting of quicklime and destruction of soil structure of bunch ash could be encountered following their application at high rates. Bunch ash and quicklime which are very hygroscopic and caustic, could present problems in handling and cause skin irritation.

In terms of nutrients, bunch ash contributed significantly to soil exchangeable K while limestone and quicklime improved the calcium status.

The series of soil amelioration trials has shown that limestone is the most desirable ameliorant as it gives relatively quick response and is unlikely to have adverse effects on crop at realistic application rates. Limestone is very cheap, costing M$25 to $28 per tonne compared with about M$130 — $140 for bunch ash and M$150 — $200 for quicklime.

On a non-acid sulphate coastal clay soil, such as Bernam series an acceptable topsoil pH of about 5 units could be attained for five annual applications of limestone at 0.27 kg/m^2, four applications at 0.74 kg/m^2, three applications at 1.48 kg/m^2 or two applications at 2.22 kg/m^2. These annual rates are equivalent to 1.6 kg, 4.4 kg, 9.0 kg and 13.5 kg per cocoa tree respectively. The soil pH must be monitored to determine the need for reapplication.

CONCLUSION

The main nutrient requirement for cocoa planted under tall coconuts on coastal clay, Bernam series, is for nitrogen. On less fertile inland Jerangau series soil, monoculture cocoa has responded positively to application of fertilizers containing phosphorus and potassium. However, response to nitrogen manuring was not detected.

Acidity of coastal clay soils can be reduced significantly through repeated annual applications of calcium limestone or oil palm bunch ash. Application of 0.27 kg/m² (equivalent to 1.6 kg/tree) of bunch ash and limestone could raise soil pH by about 1.0 and 1.3 units respectively from an initial level of about 4.3 units.

REFERENCES

FOSTER, J.L., ABDUL RASHID, A, & ABAS, A.G. (1980). The correction of acidity in Malaysian soils. *Proc. Conf. Soil Sci. & Agr. Dev. in Malaysia, Kuala Lumpur, 1980.* (E. Pushparajah and S.L. Chin ed.) p. 157–171.

KHOO, K.T., CHEW, P.S. & CHEW, E. (1980). Fertilizer responses of cocoa on coastal clay soils in Peninsular Malaysia. *Proc. Int. Conf. on Cocoa and Coconuts, Kuala Lumpur, 1978*, pp. 208–223. Incorporated Society of Planters.

MAINSTONE, B.J., THONG, K.C. & TAN K.S. (1977). Effects of lime and rock phosphate additions upon growth of young cocoa. *Proc. Conf. Fert. Chemy. Trop. Soils, Kuala Lumpur, 1973,* 60–69.

MAINSTONE, B.J., & THONG, K.C. (1980). Fertilizer responses on six years from planting of monocrop cocoa on a Bungor Series Soil. *Proc. Int. Conf. on Cocoa and Coconut, Kuala Lumpur, 1978,* pp 243–261. Incorporated Soc. Planters.

MORAIS F.I., SANTANA, C.J.L. & SANTANA, M.B.M. (1978). Effect of lime and phosphorus application on the growth of cacao seedlings. *Centro de Pesquisas de Cacao (CEPEC), Brazil.* V. 8(2), April 1978. p. 73–85.

NG, S.K. (1965). The potassium status of some Malayan soils. The Malay Agric. J., 45(2), 143–161.

NG, S.K. (1968). Fertilizer problems in mixed cocoa-coconut plantings. *Proc. Symp. Cocoa & Coconuts in Malaya, Kuala Lumpur, 1967,* pp. 25–31. Incorporated Society of Planters.

NG, S.K., THAMBOO, S. & CHEAH, T.E. (1970). Soil and leaf nutritional status of cocoa plantings in the east and west coasts of Malaysia. *Malaysia Agr. J.,* 47(4), 390–408.

NG, S.K. & CHAN, E. (1980). Response of cocoa under coconuts to fertilizers on coastal clays in Peninsular Malaysia. *Proc. Conf. Classification and Management Trop. Soils 1977,* (K.T. Joseph ed.). pp. 436–445. Kuala Lumpur, Mal. Soc. Soil Sci.

PRANG BESAR RESEARCH STATION (1981). *Report for 1980 & 1981.* 65 pp.

SMYTH, A.J. (1966). The selection of soils for cocoa. *Soils Bulletin No. 5, FAO, U.N., Rome.* 76 pp.

SMYTH, A.J. (1975). Soils. In Wood, G.A.R. (1975) *Cocoa,* 3rd Edition, London: Longman.

TEOH. C.H. (1980). Cocoa nursery manuring investigations. *Proc. Int. Conf. on Cocoa and Coconuts, Kuala Lumpur, 1978.* Incorporated Soc. Planters.

THONG, K.C. & NG, W.L. (1980). Growth and nutrients composition of monocrop cocoa plants on inland Malaysian soils. *Proc. Int. Conf. on Cocoa and Coconuts. Kuala Lumpur, 1978*, pp. 262–286. Incorporated Soc. Planters.

YEOW, K.H., POON, Y.C. & TOH, P.Y. (1980). Effect of bunch ash on oil palm performances and soil properties of acid sulphate soils. *Proc. Conf. on Classification and Management of Tropical Soils 1977.* (K.T. Joseph ed.) pp. 536–544. Kuala Lumpur, Mal. Soc. Soil Sci.

APPENDIX I. SOIL CHARACTERISTICS

Parameters Horizon	Bernam Series (Typic Tropaquept)				Sedu Series (Typic Sulfaquept)				Jerangau Series (Haplic Acrorthox)			
	A_1	B_1	B_2	BC	A_1	A_{21g}	A_{22g}	BC	A_1	B_1	B_{21ox}	B_{22ox}
Depth (cm)	0-15	15-45	45-71	71-117	0-6	6-32	32-60	50-85	0-15	15-50	51-89	89-130
Texture	SiC	C	SiC	SiC	C	C	C	C	SCL	CL	CL	C
pH (H_2O)	4.1	3.0	3.8	3.7	3.9	3.5	3.4	3.4	5.1	4.7	4.7	4.5
C%	6.9	1.3	0.9	0.7	12.4	6.1	3.2	3.8	2.2	1.4	–	–
N%	–	–	–	–	–	–	–	–	0.17	0.11	–	–
CEC (meq)	29.6	23.5	26.6	24.2	56.3	48.6	36.4	39.8	5.4	4.1	–	–
Ex. K (meq)	0.61	0.64	0.55	0.55	0.16	0.14	0.19	0.24	0.05	0.05	–	–
Ex. Ca(meq)	21.0	23.1	23.2	24.1	1.31	0.18	0.11	0.52	0.89	0.34	–	–
Ex. Mg (meq)	11.3	17.8	15.6	16.6	0.64	0.26	0.61	3.84	0.52	0.18	–	–
Avail. P (ppm)	–	–	–	–	–	–	–	–	5.7	3.0	–	–

Texture: SiC = Silty clay, C = Clay, CL = Clay loam SCL = Sandy clay loam

20

Trial No.	Age from planting	Nutrient (Fertilizer) Application Rate (kg/ha)					
		N (CAN)		P_2O_5 (CIRP)		K_2O (MOP)	
		Level 1	Level 2	Level 1	Level 2	Level 1	Level 2
FT1	2 months	6(23)	12(46)	17(47)	34(94)	10(17)	20(34)
	4 months	6(23)	12(46)	17(47)	34(94)	10(17)	20(34)
	6 months	17(65)	34(130)	34(94)	68(188)	19(32)	38(64)
	12 months	25(96)	50(192)	46(128)	92(256)	38(63)	76(126)
	18 months	33(127)	66(254)	57(158)	114(316)	57(75)	114(150)
	24 months	37(142)	74(284)	61(169)	122(338)	68(113)	136(226)
	36 months	37(142)	74(284)	61(169)	122(338)	68(113)	136(226)
	* 4 to 7 years	74(284)	148(568)	122(338)	244(676)	136(226)	272(452)
	# 8 to 12 years	110(423)	220(846)	183(508)	366(1016)	204(340)	408(680)
FT2	3½ years	34(131)	68(262)	34(94)	68(188)	34(57)	68(114)
	4 years	39(150)	78(300)	39(108)	78(216)	39(65)	78(130)
	4½ years	39(150)	78(300)	39(108)	78(216)	39(65)	78(130)
	5 years	45(173)	90(346)	45(125)	90(250)	45(75)	90(150)
	5½ years	45(173)	90(346)	45(125)	90(250)	45(75)	90(150)
	* 6 to 10 years	90(346)	180(692)	90(250)	180(500)	90(150)	180(300)

* Split into 2 applications/year
# Split into 3 applications/year
Controls plots (Level 0) did not receive any fertilizers
CAN (Calcium ammonium nitrate)　　　=　26% N, 12% CaO
CIRP (Christmas Island Rock Phosphate)　=　36% P_2O_5, 50% CaO
MOP (Muriate of Potash)　　　　　　=　60% K_2O

Fertiliser Responses of Monocrop Cocoa in Peninsular Malaysia on a Munchong Series Soil

NAWI CHE YUSOFF AND LEONG CHENG WOH

Felda Agricultural Services Corporation, Tun Razak Agricultural Services Centre, Jerantut, Pahang, West Malaysia.

This paper presents the results on the growth and yield response of cocoa on fertiliser application on Munchong series soil (an oxisol) under inland conditions.

There was no significant response in growth and yield to N, P and K applications during the early years due to the poor growing conditions. Starting from the fourth year and continuing to the eighth year of harvest, significant yield responses were obtained with P, but not with N or K. These responses are concurrent with observations of previous workers. The responses also corresponded well with the leaf and soil nutrient levels suggesting that leaf and soil analyses could be a useful tool for fertiliser recommendations in cocoa.

When the Federal Land Development Authority (FELDA) first launched its pilot project in cocoa in 1973/74 as part of its crop diversification programme, it simultaneously spelt out the need for intensified research of the crop under inland soil conditions. Among the more important aspects looked into then were recommendations on manuring.

There was a general lack of information on fertiliser requirements of cocoa under inland soil conditions. Manurial recommendations at the time could at best be adapted from FELDA's early experiences with cocoa at the Tun Razak Agricultural Research Centre at Jerantut in Central Pahang. A 3^3 NPK factorial fertiliser trial was thus initiated in 1973 at the above Research Centre to study the response of N, P, and K fertiliser on the growth and yield of cocoa on Munchong series soil (tropeptic haplorthox, an oxisol) commonly found in FELDA. This would then provide a guide to fertiliser application of cocoa under similar field conditions and management practices.

MATERIALS AND METHODS

Site Preparation

Underbrushing and felling of the jungle were completed in March 1971 followed by pruning and stacking in May the same year. The unburnt logs were left to rot *in situ*. Cocoa was planted in December 1972. At the same time, *Flemingia* sp. and *Tephrosia* sp. were also planted in between cocoa rows to act as temporary shade. *Gliricidia* as top shade was only established in January 1973. The ratio of *Gliricidia* to cocoa was initially 1 : 2 but finally ended up in 1 : 8 after three consecutive rounds of thinning in 1978, 1979 and 1980.

Planting

Six-month-old nursery seedlings raised in 23 x 35 cm polythene bags were planted in the field at a spacing of 2.5 m x 3.0 m giving 1,333 points per hectare and 113 g of CIRP were applied during planting; half of this amount was placed in the planting hole and the remaining on top of the soil around the plant.

Planting Materials

Planting materials were obtained from a uniform mixture of the following hybrids:

UIT1 x Pa7	Pa35 x Na32
UIT1 x Na33	Pa35 x Na31
UIT2 x Pa7	Pa35 x Sca6
UIT4 x Pa7	Pa35 x Sca12

Experimental Design

The experiment was a NPK 3^3 factorial experiment in completely randomized block design and replicated four times. Each treatment plot consisted of 60 cocoa plants (5 rows x 12 plants/row) with a 30-plant core for recording.

Fertiliser Levels

Three levels of N, P and K were tested (*Table 1*). Straight fertilisers of Nitro 26, Rock Phosphate and Muriate of Potash were used for the supply of N, P and K respectively. Supplementary ground magnesium limestone was also applied at 400 g/tree/year where necessary to improve Ca and Mg status in the soil.

TABLE 1. FERTILISER APPLICATION RATES FOR COCOA (1973–1983)

Year	N (kg/ha)			P_2O_5 (kg/ha)			K_2O (kg/ha)		
	N1	N2	N3	P1	P2	P3	K1	K2	K3
1973	8.33	16.67	25.00	3.33	6.87	10.00	8.33	16.67	25.00
1974	25.00	50.00	75.00	10.00	20.00	30.00	25.00	50.00	75.00
1975	41.65	83.30	125.00	16.65	33.30	50.00	41.65	83.30	125.00
1976–1983	0	150.00	300.00	0	75.00	150.00	0	150.00	300.00

After 1976, the application rates were kept constant, and the lowest levels (N1, P1 and K1) were reduced to zero.

Fertilisers were applied in three split applications per year throughout the experiment. They were applied in a circle of diameter 0.3 to 0.5 m during the early growth phase, and in the interrows when the canopy had closed up.

Growth was measured in terms of plant height taken in 1974 and 1975, and cross-sectional area of the stem taken at six-monthly intervals from December 1973. Yield was recorded between 1977 and 1983 by the number of cocoa pods per plot obtained at each

harvesting, and the annual projected yield was calculated based on 30 pods to 1 kg of dry bean.

Leaf and soil analyses were carried out each year in June/July. Leaf number 4 from a newly-hardened flush was taken at the intensity of one leaf per alternate tree in the monitoring plot. Soil samples were taken from the interrow at six different points per plot.

The rainfall over the period of the trial is shown in the *Appendix*.

RESULTS

Early Establishment

A casualty rate of 29% among the cocoa was shown six months after planting. The casualties were probably caused by lack of shade and unfavourable weather conditions which followed after planting. Vacant points were immediately supplied by six-month-old seedlings, and in the following year, an evenly grown stand was achieved.

Growth

With the exception of N, there was no significant difference amongst treatments in stem cross-sectional area for the two-year period from December 1973 to January 1976 (*Table 2*). Plant height was also not significantly different except in the case of N (*Table 3*).

TABLE 2. CROSS-SECTIONAL AREA OF COCOA STEM MEASURED 10 CM
ABOVE GROUND FROM 1973 TO 1976

Major Treatments	Cross-sectional area (cm^2)			
	Dec 1973	Jul 1974	Jan 1975	Jan 1976
N1	1.91	6.03	13.34	28.59
N2	1.54	5.64	12.82	27.35
N3	1.63	5.56	12.76	26.69
P1	1.70	5.77	12.76	26.81
P2	1.77	5.73	12.89	27.82
P3	1.61	5.69	13.27	28.00
K1	1.79	5.94	13.40	27.80
K2	1.68	5.64	13.08	27.27
K3	1.58	5.64	12.45	27.55
Mean	1.69	5.74	12.97	27.54
se (±)	0.117	0.154	0.319	0.683
LSD 0.05	0.234	0.308	0.637	1.365
0.01	0.310	0.408	0.844	1.807

3

TABLE 3. COCOA PLANT HEIGHT IN 1974 AND 1975

Treatments	Height (m)	
	July 1974	July 1975
N1	2.77	3.00
N2	2.68	2.84
N3	2.66	2.85
P1	2.71	2.91
P2	2.70	2.88
P3	2.69	2.89
K1	2.75	2.97
K2	2.68	2.84
K3	2.68	2.87
Mean	2.70	2.89
se (±)	0.03	0.06
LSD 0.05	0.06	0.12
0.01	0.08	0.31

Yield

Yield was recorded over a seven-year period (1977–1983) but excluded harvests during the first two years. Annual and cumulative yields with respect to the major treatments are shown in *Table 4*. Individual yield response to N, P and K is illustrated in *Figure 1*.

Amongst the three major treatments, only P gave significant yield increases in the later years of production. The response was strongly linear and was manifested since the fourth year (1978). The effect of P treatment was an increase in yield ranging from 8 to 97% over the control.

With N, there was no significant yield response throughout the study period except in 1977. There was an apparent yield increase from the second level of N but this was not significant.

Results similar to N were observed with the K treatments. Yield increases were apparent at the second level of K but these were not significant.

There was no significant difference in yield amongst treatments, including the phosphate treatment, in 1983. This could be due to setback of the trees owing to the severe drought occurring in the first half of that year.

Leaf and Soil Nutrient Levels

The average foliar analysis results from 1978 to 1983 (*Table 5*) showed that the leaf nutrient contents in N, P and K significantly increased after the application of fertilisers. For the zero levels of P and K, these produced only 0.145% and 1.923% of P and K respectively in the leaf which are below the normal levels suggested by Murray (1967). The

4
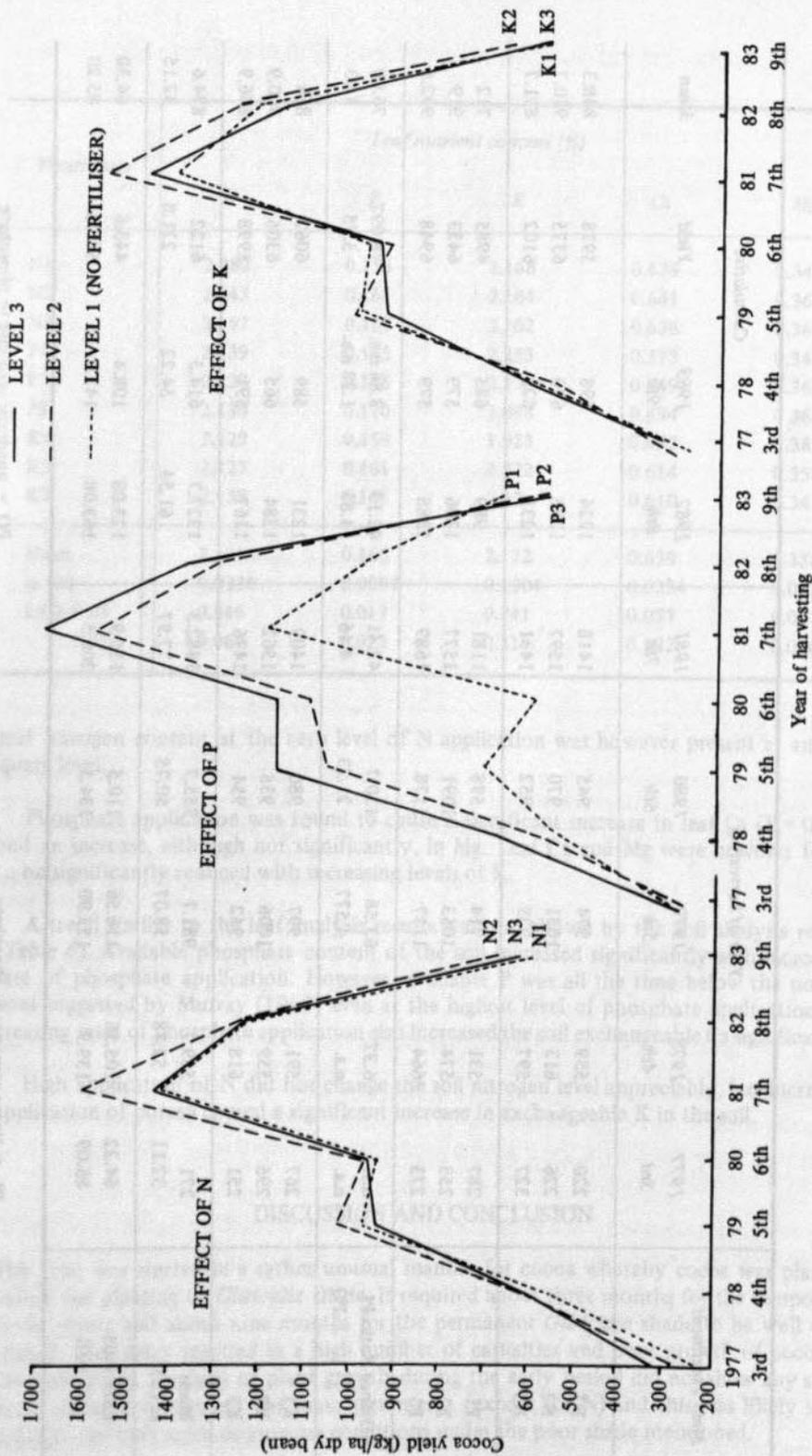
Figure 1: Fertiliser responses of monocrop cocoa on Munchong series soil.

TABLE 4. EFFECT OF MAIN TREATMENTS ON COCOA YIELD – 1977–1983
(KG/HA OF DRY BEAN EQUIVALENT)

Main Treatment	Year of harvesting							Cumulative	
	1977 3rd	1978 4th	1979 5th	1980 6th	1981 7th	1982 8th	1983 9th	Yield	Mean
N1	220	559	974	945	1418	1224	598	5938	848.3
N2	226	613	1031	970	1597	1228	670	6375	910.7
N3	327	597	939	952	1431	1231	625	6102	871.7
P1	287	531	714	598	1181	989	685	4985	712
P2	253	574	1053	1091	1577	1306	579	6433	919
P3	273	664	1177	1178	1689	1388	579	6948	992.6
Variance Ratio PL	n.s.	6.37	63.58	130.7	42.41	42.19	3.86 n.s.	78.097	76.00
PQ	n.s.	n.s.	4.577	21.23	4.46	4.83	1.28 n.s.	5.75	5.83
K1	267	591	997	980	1409	1231	589	6062	866
K2	295	559	1006	935	1562	1284	665	6306	900.9
K3	251	618	942	954	1476	1167	591	5998	856.9
Mean	271	589.7	981.7	955.7	1482.3	1227.7	614.3	6122	874.6
se (±)	32.11	52.78	58.07	50.75	77.97	61.54	54.22	221.8	32.15
LSD 0.05	64.22	105.56	116.56	110.5	155.9	123.08	108.4	443.6	64.30
0.01	85.09	139.9	153.90	134.5	206.5	163.08	143.7	587.8	85.20

PL = linear response to phosphate   PQ = quadratic response to phosphate

6

TABLE 5. AVERAGE SOIL NUTRIENT LEVEL AT 4 (1975-1976)

Treatments	Leaf nutrient content (%)				
	N	P	K	Ca	Mg
N1	2.080	0.156	2.168	0.639	0.343
N2	2.145	0.164	2.184	0.641	0.362
N3	2.167	0.160	2.162	0.636	0.368
P1	2.139	0.145	2.253	0.573	0.345
P2	2.128	0.165	2.170	0.649	0.365
P3	2.130	0.170	2.098	0.694	0.364
K1	2.129	0.159	1.923	0.692	0.381
K2	2.127	0.161	2.222	0.614	0.352
K3	2.138	0.161	2.37	0.610	0.341
Mean	2.131	0.160	2.172	0.639	0.358
se (±)	0.0228	0.0087	0.1204	0.0384	0.0137
LSD 0.05	0.046	0.017	0.241	0.077	0.027
0.01	0.061	0.023	0.319	0.102	0.036

leaf nitrogen content at the zero level of N application was however present at an adequate level.

Phosphate application was found to cause a significant increase in leaf Ca (P = 0.01), and an increase, although not significantly, in Mg. Leaf Ca and Mg were however found to be significantly reduced with increasing levels of K.

A trend similar to the leaf analysis results was also shown by the soil analysis results (*Table 6*). Available phosphate content of the soil increased significantly with increasing rate of phosphate application. However, available P was all the time below the normal level suggested by Murray (1967) even at the highest level of phosphate application. Increasing rates of phosphate application also increased the soil exchangeable Ca significantly.

High application of N did not change the soil nitrogen level appreciably, but increased application of potash caused a significant increase in exchangeable K in the soil.

DISCUSSION AND CONCLUSION

This trial was started in a rather unusual manner for cocoa whereby cocoa was planted before the planting of *Gliricidia* shade. It required about three months for the temporary shade plants and about nine months for the permanent *Gliricidia* shade to be well established. This delay resulted in a high number of casualties and poor growth of cocoa in the early years. Analysis of plant growth during the early period did not show any significant difference between the main treatments (except for N) and this was likely attributed to the unfavourable growing conditions under the poor shade mentioned.

TABLE 6. AVERAGE SOIL NUTRIENT LEVELS AT 0–15 CM (1978–1982)

Treatments	N (%)	Avail. P (ppm)	m.e./100 g soil		
			Exch. K	Exch. Ca	Exch. Mg
N1	0.180	13.192	0.260	1.352	0.372
N2	0.183	12.551	0.263	1.450	0.378
N3	0.184	10.590	0.251	1.351	0.404
P1	0.183	7.226	0.280	1.347	0.394
P2	0.179	11.226	0.240	1.360	0.395
P3	0.184	17.850	0.254	1.445	0.366
K1	0.186	11.042	0.197	1.338	0.369
K2	0.178	12.431	0.154	1.397	0.404
K3	0.182	12.828	0.324	1.414	0.380
Mean	0.182	12.101	0.258	1.384	0.385
se (±)	0.00306	2.8066	0.0337	0.0442	0.0148
LSD 0.05	0.006	5.613	0.067	0.088	0.030
0.01	0.008	7.438	0.089	0.117	0.039

The phosphate treatment was consistently returning highly significant differences in yield beginning from the fourth year of harvesting (*i.e.* 1978) although 1983 was an exception as the treatment could then be confounded by the effects of the long drought in the early part of the year (see *Appendix*). These responses also corresponded well with the leaf and soil nutrient levels, particularly the phosphate levels, for the period under study.

Significant yield responses to phosphate application have in fact been reported in many cocoa growing areas; in Ghana by Ahenkorah & Akrofi (1975), in Nigeria by Wessel (1971) and Egbe & Omotoso (1971), and in Brazil by Cabala, *et al.* (1975, 1981). In Sabah, cocoa responded to the application of phosphorus on Table and Kinabutan series soil (Wyrley-Birch 1972). On the inland soils of West Malaysia, the response to P on Bungor series soil was demonstrated by Ling and Mainstone (1982). From the work of Egbe and Omotoso (1971), effects of the fertiliser on yield were also found to become significant three years after fertiliser application, and this appeared to be related to the P content of the soil.

In this trial, response to N was only noted up to level N2 (150 kg/ha N). This may be attributed to the beneficial effects of *Gliricidia*, itself being a leguminous plant and thus a contributor of N. Khoo *et al.* (1980) suggested that the high rate of N application could be counter-productive on Kangkong series soil. Adverse effect of high N application on yield was also reported in Sabah by Wyrley-Birch (1972).

Similarly for K, yield responses in this trial were noted only to the second level. This is probably true as the soil (Munchong series) already has an inherently ample supply of K. Adequate supply of K from this soil is also reflected in the K level of the leaf. Several

workers (Egbe & Omotoso 1971, Morais *et al.*, 1978) have also demonstrated the lack of response of K due to its inherent fertility in the soil.

The results of this trial thus further strengthen the observations made by the previous workers. As the responses in yield were also found to relate closely to the leaf and soil nutrient level, leaf and soil analyses could provide a useful guide to fertiliser recommendations in cocoa despite the limitations generally accepted (Thong, 1976).

ACKNOWLEDGEMENT

REFERENCES

AHENKORAH, Y. & AKROFI, G.S. (1975) Amazon cocoa (*Theobrama Cacao* L.) shade and manurial experiment (K2-01) at Cocoa Research Institute of Ghana. III. Cumulative Yield Analysis. *Proc. 5th Int. Cocoa Res. Conf. Ibadan, Nigeria 1975.*

CABALA-ROSAND, F.P., DE SANTANA, C.J.L. & MIRANDA, E.R. (1975) The response of cocoa to fertilisers in Bahai, Brazil. *Proc. 5th Int. Cocoa Res. Conf. Ibadan, Nigeria, 1975.*

CABALA-ROSAND, E.P., DE SANTANA, C.J.L. & MIRANDA, E.R. (1981) Respostas do cacaueiro n sul da Bahai a doses crescentes de Nitrogenio Fosforo e Potassio. *Proc. 8th Int. Cocoa Res. Conf. Cartagena, Colombia 1981*, 137.

EGBE, N.E. & OMOTOSO, T.I. (1971) Results of a 2^3 NPK factorial fertiliser trial on farmers' Amelonado cacao in Nigeria. *Proc. 4th Int. Cocoa Res. Conf. St. Augustine, Trinidad 1971.*

KHOO, K.T., CHEW, P.S. & CHEW, E. (1980) Fertilizer responses of cocoa on coastal clay soils in Peninsular Malaysia. *Proc. Int. Conf. on Cocoa and Coconuts, Kuala Lumpur 1978*, 208.

LING, A.H. & MAINSTONE, B.J. (1982) Phosphate requirements of cocoa on Malaysian inland soils. In *Phosphorus and Potassium in the Tropics* (ed. E. Pushparajah & Sharifuddin H.A. Hamid), pp. 365–381. Kuala Lumpur: Malaysian Society of Soil Science.

MORAIS, F.I., DE SANTANA, C.J.L. & CHEPOTE, R.E. (1978) Respostas do cacaueiro ao Nitronenio, Fosforo em Solos da regiao cacauera da Bahai, Brazil. *Revista Theobrama*, 8(1), 31.

MURRAY, D.B. (1967) Leaf analysis applied to cocoa. *Cocoa Growers' Bull.*, 9, 25–31.

THONG, K.C. (1976) Problems associated with leaf and soil analyses techniques in relation to cocoa. *Proc. Seminar on Soil and Leaf Analytical Methods – their Techniques and Interpretation, Serdang, Malaysia 1978*, 96.

WESSEL, M. (1971) Fertiliser requirements of cacao (*Theobroma cacao* L.) in South-Western Nigeria. *Tropical Communication, Dept. Agric. Res. Royal Tropical Inst.*, 61, 35–36.

WYRLEY-BIRCH, E.A. (1972) The manuring of cocoa. In *Cocoa and Coconuts in Malaysia* (ed. R.L. Wastie & D.A. Earp), pp. 136–142. Kuala Lumpur: Incorporated Society of Planters.

APPENDIX. MONTHLY RAINFALL AT TUN RAZAK AGRICULTURAL SERVICES CENTRE FROM 1972 TO 1983

Year	Rainfall (mm)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
1972	49.1	137.0	12.1	133.2	72.6	85.8	56.6	149.6	255.2	200.2	104.8	155.6	1411.8
1973	30.6	29.6	19.3	302.2	196.7	128.3	48.8	194.7	188.8	148.0	129.2	304.5	1720.7
1974	12.4	156.9	75.7	375.2	206.3	112.8	108.3	177.3	152.1	109.1	227.5	176.4	1890.0
1975	121.3	160.9	204.2	176.7	167.7	180.9	58.0	89.1	205.6	142.0	313.6	178.6	1998.6
1976	15.1	4.1	140.6	107.2	169.0	174.7	105.3	236.4	174.6	234.8	216.1	293.9	1871.8
1977	43.1	112.3	12.6	57.8	82.0	176.2	17.2	232.4	154.9	270.0	212.7	124.0	1495.2
1978	174.3	100.1	206.6	184.6	127.1	105.7	174.3	65.0	115.2	181.6	262.6	249.9	1947.0
1979	63.0	42.2	67.1	157.2	125.1	242.1	227.7	62.3	141.9	444.6	341.7	21.6	1936.5
1980	66.9	34.0	215.1	289.6	88.7	127.5	125.8	115.5	178.6	237.9	207.9	242.7	1930.2
1981	97.0	76.7	115.4	180.0	312.4	57.4	59.6	74.8	329.0	287.4	155.2	122.6	1867.5
1982	43.2	14.6	114.5	358.2	235.4	52.1	186.7	107.8	88.3	188.7	175.6	253.9	1819.0
1983	26.7	15.0	30.7	94.7	248.1	134.5	89.5	124.8	130.8	178.5	222.4	322.7	1618.4
Total	1494.1	1026.0	1700.3	2838.4	2740.8	1867.5	1690.6	2338.8	2557.4	3371.8	3138.8	3743.9	28508.4
Average	106.5	73.3	113.4	189.2	182.7	124.5	112.7	155.9	170.5	224.8	209.3	249.6	1900.6

A Survey of Ghanaian Cocoa Farmers Fermentation and Drying Practices and their Implication for Malaysian Practices

R.J.E. DUNCAN

Cocoa Chocolate and Confectionery Alliance, London, England.

Historical beliefs of the way the Ghanaian cocoa farmer ferments his product to give a consistent high quality flavour were investigated. A wide variety of conditions was used and it was found that it was the blending of cocoa that gave good and consistent flavour. The paper discusses their implication for the Malaysian producer and his product suggests that to improve cocoa flavour a degree of variability in fermentation practice should be introduced on Malaysian cocoa estates. Suggestions are also made to enable the specific variation in practice required to be decided.

The first recorded recommendations for cocoa fermentation in Ghana were made by Knapp (1934). He stated that the most suitable fermentation practice for the Ghanaian cocoa farmer was the 'heap method' where the cocoa beans are heaped onto leaves on the ground and covered with more leaves.

He recommended that the optimum duration of the fermentation was six to seven days during which time the cocoa beans should be turned on two occasions, after 48 and 96 h. The requirement for the cocoa to be turned after 48 and 96 h fermentation was said to be necessary to ensure even fermentation, good aeration and absence of defective beans. This recommendation was adopted by the cocoa extension services in Ghana (Anon, 1950) and continues to be quoted in the literature (Wood, 1975) as the optimum cocoa fermentation regime not only for Ghana but also for most other West African countries. However, Knapp (1934) considered daily turning and the use of cascades of wooden boxes in preference to heaps as the ideal.

Ghana cocoa is generally recognised by chocolate manufacturers as the premier bulk cocoa with respect to flavour. Researchers into cocoa fermentation have therefore accepted the recommended 'heap method' along with 48 and 96 h turning as a standard. This was the case between 1979 and 1981 when scientists from the U.K. Cocoa, Chocolate and Confectionery Alliance, in co-operation with scientists from MARDI and members of the Rubber Growers Association, undertook research into differences in flavour between Malaysian and West African cocoa beans, (Anon, 1980; 1981; 1982). This research was designed to investigate how the course of cocoa fermentation and drying in Malaysia might be controlled by simple and practical means in order to produce cocoa closer in flavour to that of West Africa, and thus, of increased acceptability to the U.K. confectionery industry.

The Alliance team has carried out about 70 fermentation trials in the course of this study and in a comparable one with the Ivory Coast authorities (Anon, 1983).

In these trials variations were made to the duration of fermentation and turning regimes, parameters which could easily be varied by farmers. Additionally, variations

to the size of ferments and other treatments, such as pressing the wet beans prior to box fermentation, were investigated, since these were of importance and of practical application to Malaysian cocoa estates.

Eighteen of these fermentation trials were performed in Ghana using the standard practice recommended by Knapp (Anon, 1980; 1981) None of these trials produced cocoa of a flavour comparable with beans from commercial Ghanaian or Nigerian shipments, or which were fully acceptable to the confectionery industry. Further, the best flavour results obtained from both the West African and Malaysian trials came from fermentations of much shorter duration, where the beans had either not been turned or had been turned only once. It was concluded from these results, and from direct observation, that Ghanaian farmers probably did not follow the reported method of fermentation, and it was strongly recommended (Anon, 1981; 1982) that a survey of Ghana cocoa farmers be performed to establish exactly how the commercial Ghana cocoa flavour was achieved.

GHANA COCOA FARMERS SURVEY

This survey was performed during the 1983–84 main crop. Eighty-nine Ghanaian cocoa farmers were interviewed throughout the cocoa-growing regions of Ashanti, Brong Ahafo, Western, Eastern and Central. Questions were posed regarding the normal cocoa harvesting, fermentation and drying practices, of each farmer. In 30 per cent of the cases the replies on fermentation and splitting were confirmed by observation.

Harvesting

Farmers in Ghana generally harvest their cocoa three or four times during the main crop period, which lasts about four months.

Figure 1 shows the range of harvesting durations encountered during the survey, which were clearly very variable. Harvesting was normally composed of three phases, viz.
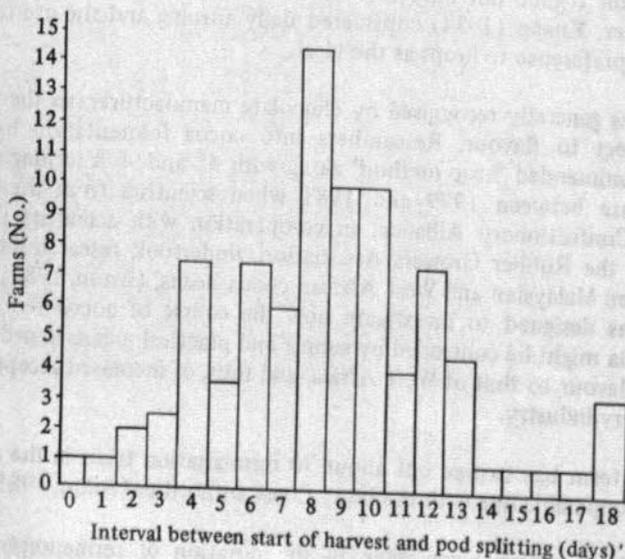
Figure 1. The Distribution of Harvesting Duration Encountered In Ghana.

2

- Cutting the pods from the trees took on an average of five days.
- Collecting the pods into a central area of the farm for splitting, was on an average of two to five days.
- A delay of one to three days between collection and splitting of the pods, with an average of one and half days.

The reasons for these three stages were mainly social. The full time labour employed on the farm would cut the pods from the trees and then, sometimes with help from their families, collect them. A delay was normal between pod collection and splitting. This enabled the farmer to obtain extra voluntary labour to assist at splitting and also food to feed them. It is generally believed that a delay of some days between cutting the pods from the trees and splitting has a beneficial effect on both the fermentation and the flavour of the cocoa. During such a delay the moisture content of the pulp falls and after splitting, the fermentation proceeds more rapidly. This is reflected in the temperature which after the first 24 h can be as much as 13°C higher than that of a ferment constructed with the beans from freshly harvested pods. A similar temperature effect and flavour enhancement were also observed in some Malaysian ferments constructed from fresh wet beans which had been pressed prior to fermentation, as practiced on certain estates (Anon, 1982).

Pod Splitting

Pods were always split using machettes. A high degree of skill was exhibited by farmers such that damage to the beans in the pods was rare.

During splitting, farmers and labourers demonstrated quality awareness, rejecting germinated beans and certain other diseased or discoloured beans which through their experience they knew would lead to defects in the final cocoa and reduce its value.

Size and Construction of Ferments

As reported in the literature (Knapp, 1934; Wood, 1975) it was found that the 'heap method' of cocoa fermentation was generally used by Ghanaian farmers although the variation in size encountered during this survey was considerably greater than anticipated. Heaps containing up to 2 tonnes of wet beans were observed, and some farmers indicated that ferments considerably larger (up to 5 tonnes wet beans) were common. Conversely, ferments of less than 20 kg wet beans were observed. However, on average ferments were of 200 to 500 kg in size.

Ferments were always very well constructed and much care was taken to ensure that the beans were well insulated with a close covering of two or more layers of banana or plantain leaves. The same leaves were also used for the base of ferment. It was interesting to note that many farmers suggested such a close covering of leaves was necessary to ensure the ferment was 'airtight', rather than to insulate. This, of course, is contrary to the normal belief that a ferment must be well insulated but should still allow easy access of air to drive the fermentation.

Duration and Turning Regime of Ferments

None of the farmers interviewed during the survey carried out their cocoa fermentations according to the regime recommended by Knapp (1934). This was despite many being aware of the recommended practice, since it is also the practice promoted by the extension services in Ghana (Anon, 1950). Instead, farmers choose to follow traditional

practices which were less demanding of their time and flexible enough to fit into their day-to-day life style.

Only one farmer out of the 89 interviewed, fermented his cocoa for the recommended full six days. The remainder fermented for much shorter periods, between 72–120 h as shown in *Figure 2*. In periods of excessive rain some farmers indicated that they would shorten the duration of fermentation by one day, moving the distribution towards shorter durations as shown in *Figure 2*. This was necessary as beans would obviously take longer to dry in the rainy season and therefore drying had to be started earlier. Otherwise, the beans might turn black during drying and the incidence of mould would increase.

Fermentation durations were irrespective of the size of the ferment, although the durations reported were probably not strictly adhered to, as farmers were controlled more by social events such as market day, Sunday etc., than by a strict fermentation timetable.
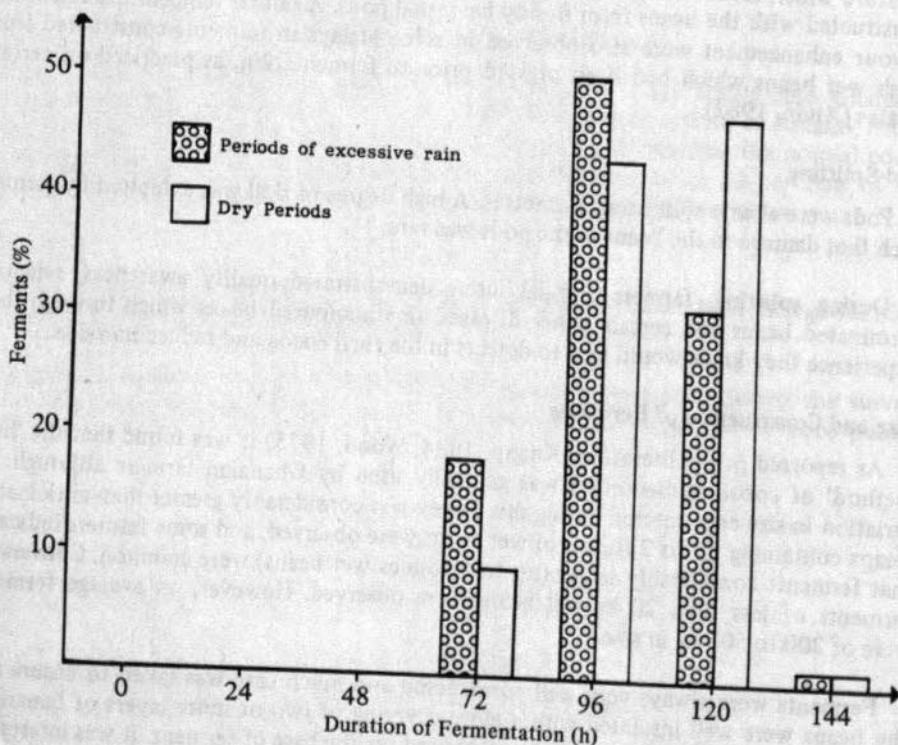
Figure 2. Distribution Of Fermentation Duration In Ghana.

The range of fermentation turning regimes reported by Ghanaian cocoa farmers is given in *Figure 3*. As shown, slightly less than 50 per cent of farmers ever bothered to turn their cocoa during fermentation. Of these about 20 per cent indicated that they only turned the ferment occasionally, usually to remove the beans from the placenta which had been left in during splitting due to labour shortage. This turn was normally performed after 48 or 72 h fermentation. No ferment was ever reported to be turned more than once and, as with the duration of fermentation, the turning regime used by a farmer was irrespective of ferment size.

4
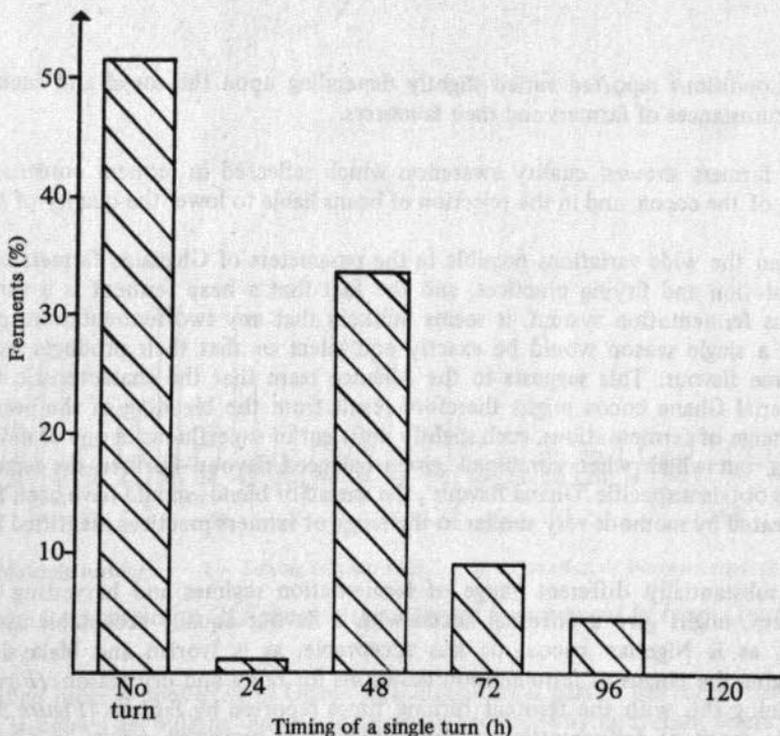
Figure 3. Percentage Of Ferments Turned And Timing Of The Turn.

Drying

As expected all cocoa in Ghana was sun dried on bamboo drying tables. Farmers showed exemplary care of cocoa during drying and were often to be seen working with the beans on the tables removing germinated, mouldy, flat and other defective beans as well as placenta and husk debris not previously removed.

In the evenings and in the event of rain, the beans were always covered on the table. The beans were always fully dry (moisture below 7.5 per cent) before being removed from the table for sale.

CONCLUSIONS FROM THE GHANA SURVEY

Farmers in Ghana harvest, split, ferment in heaps and sun dry their cocoa beans in very similar ways. The durations and specific parameters of these processes do vary from farm to farm such that:

- 60 per cent of farmers completed harvesting and split within 10 days while 90 per cent completed the process in 14 days;

- The size and shape of ferments varied between 20 and 5000 kg of wet bean with 200 to 500 kg being the most common;

- The duration of fermentation varied between 72 and 120 with 50 per cent of farmers fermenting for about 96 h;

- Fifty per cent of ferments were never turned and the remainder were only turned on one occasion, usually after 48 or 72 h.

- Fermentation parameters were independent of ferment size;

5

● Conditions reported varied slightly depending upon the social and economic circumstances of farmers and their labourers.

All farmers showed quality awareness which reflected in ferment construction and drying of the cocoa, and in the rejection of beans liable to lower the quality of the cocoa.

Given the wide variations possible in the parameters of Ghanaian farmers harvesting, fermentation and drying practices, and the fact that a heap ferment is a very heterogeneous fermentation system, it seems unlikely that any two fermentations performed during a single season would be exactly equivalent or that their products would have the same flavour. This suggests to the Alliance team that the characteristic flavour of commerial Ghana cocoa might therefore result from the blending of the beans from a large range of fermentations, each slightly deficient or superfluous in one or more flavour aspects, but which when combined, give a balanced flavour. Further, the team suggests that to obtain a specific 'Ghana flavour', the spread of blends should have been fermented and treated by methods very similar to the range of farmers practices identified here.

A substantially different range of fermentation regimes and harvesting or drying practices, might give a different cocoa with a flavour equally acceptable as Ghanaian cocoa, as is Nigerian cocoa, or less acceptable, as is Ivorian and Malaysian cocoa. Averaging the ranges of fermentation durations for rainy and dry seasons *(Figure 2)* and combining this with the ferment turning times reported by farmers *(Figure 3)* give the specific range of fermentation regimes which it is suggested, results in Ghana cocoa *(Figure 4)*. A comparison of this with the range of fermentation regimes reported by Ivory Coast farmers (Anon, 1983), clearly demonstrates that Ivorian cocoa farmers employ a much wider range of fermentation regimes than Ghanaian cocoa farmers *(Figure 5)*.
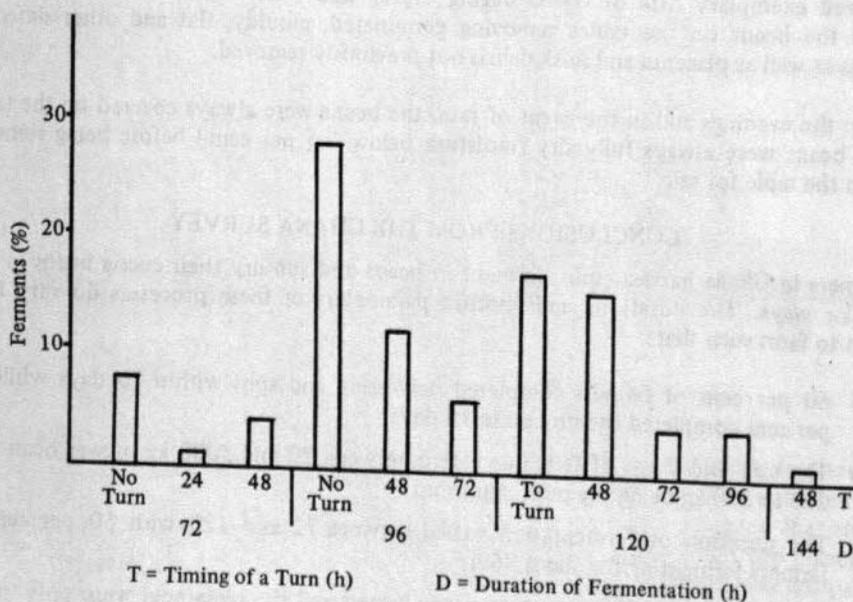

T = Timing of a Turn (h)   D = Duration of Fermentation (h)

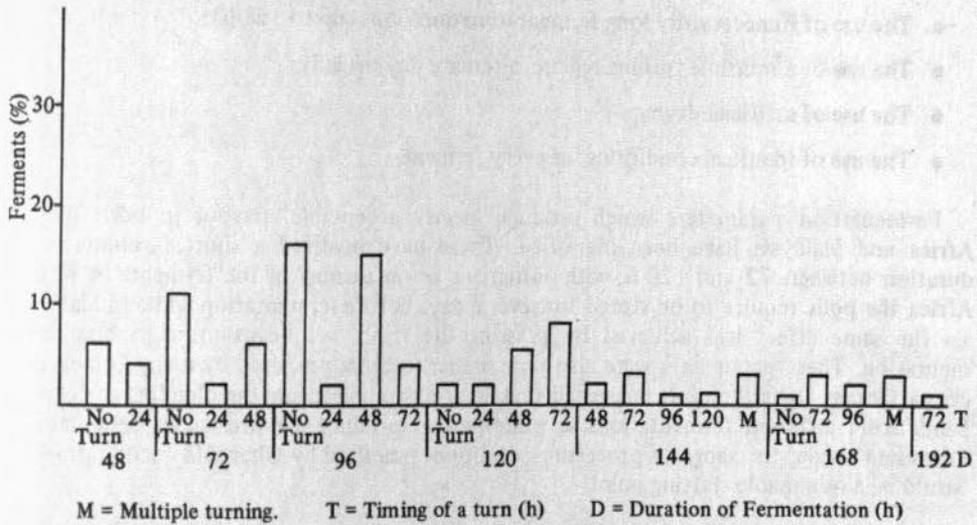*Figure 4. Distribution Of Fermentation Regimes Encountered In Ghana.*

Figure 5. *Distribution Of Fermentation Regimes Encountered In Ivory Coast.*

A blending process does exist in Ghana as a fundamental part of the cocoa marketing system. It is known as 'bulking' and occurs in every produce-buying station where beans, purchased from different farmers, are thoroughly mixed together prior to bagging. Additional blending also takes place when bags of beans are mixed during transportation, and in the cocoa bean silos and cocoa liquor storage tanks of the bean user.

IMPLICATIONS FOR COCOA RESEARCH AND MALAYSIAN ESTATE PRACTICES

The conclusions drawn above imply that it would be rare for a single set of cocoa fermentation parameters to produce beans wholly acceptable and recognisable as commercial Ghana cocoa. At best, the results of a single fermentation trial might only point to conditions likely to produce objectionable flavours in cocoa or those which consistently produce 'nearly acceptable' flavour. This suggestion is borne out by the results of early work in Ghana (Anon, 1980; 1981).

The Alliance team believe that the concept of blending cocoa beans which are treated and fermented under different conditions to produce a more acceptable product could be of particular relevance to the Malaysian situation and is worthy of proper controlled investigation.

The present Malaysian estate practice is such that all cocoa produced by a particular estate or estate company, will have been harvested, fermented and dried by a single method. Any tendency of this method to produce either an excess, deficiency or an objectionable flavour characteristic in the cocoa may be amplified by the repetitive nature of the processing on the estate(s). It is possible that acidity and certain off-flavours such as liquorice, which are common in almost all Malaysian cocoa, are symptomatic of defects in cocoa processing common to all estates. The results of the research work in Malaysia (Anon, 1982) outlined possible processing defects common to Malaysian estates and these are summarised below:

- The use of beans from freshly harvested pods in the ferment;

7

- The use of unnecessarily long fermentation durations (up to 168 h);
- The use of a multiple turning regime, alternate day or daily;
- The use of artificial drying;
- The use of identical conditions for every ferment.

Fermentation parameters which produce 'nearly acceptable' flavour in both West Africa and Malaysia have been identified. These have involved a short fermentation duration between 72 and 120 h, with either one or no turning of the ferment. In West Africa the pods require to be stored for several days before fermentation while in Malaysia the same effect was achieved by pressing the fresh wet beans prior to box fermentation. These parameters were also very similar to those practised by many Ghanaian cocoa farmers. It is therefore suggested that in order to investigate the blending of cocoa beans from different fermentations as a method to produce a more widely acceptable Malaysian cocoa, the range of processing conditions practised by Ghanaian cocoa farmers would be a reasonable starting point.

If blending proved to be a successful means of improving the acceptability of commercial Malaysian cocoa one implication would be the recommendation that no one fermentation regime be practised exclusively on any estate. Variation in processing would require to be introduced such that the cocoa beans produced had been processed using a specific range of conditions. The U.K. Cocoa Chocolate and Confectionery Alliance will be interested to explore with the Malaysian cocoa producing industry and MARDI, the concept of cocoa bean blending.

REFERENCES

ANON (1950) *Kofi The Good Farmer*, pp. 15-19. Accra: The Gold Coast Cocoa Marketing Board.

ANON (1980) *A comparative Study of the Fermentation of Amelonado and Amazon Cocoa*, pp. 1-73. London: Cocoa Chocolate and Confectionery Alliance.

ANON (1981) *The Relationship between Oxygen Temperature Acetic and Lactic Acid during Cocoa Fermentation*, pp. 1-73. London: Cocoa Chocolate and Confectionery Alliance.

ANON (1982) *Fermentation Trials in Malaysia 1981*, pp. 1-56. London: Cocoa Chocolate and Confectionery Alliance.

ANON (1983) *CCCA Scientific Team Ivory Coast Report*, parts 1 & 2. London: Cocoa Chocolate and Confectionery Alliance.

KNAPP, A.W. (1934) Cocoa fermentation in West Africa, *J. Soc. Chem. Ind.* 53, 151.

WOOD, G.A.R. (1975) *Cocoa*, 3rd ed., chapter 12. London: Longman.

Commercial Production
of Low-Acid Beans

R. SHEPHERD, C.F. CHONG, J.G. TAYLOR AND J.D. MENNEER

Harrisons Malaysian Plantations Berhad

The technique of pulp reduction, reported in the 1978 International Conference on Cocoa and Coconuts, remains one of the most promising methods for reducing the acid level of Malaysian beans. Investigations had since been undertaken to define the pressing technique and fermentation regime. It was established that in order to produce acceptable low-acid beans, fresh beans should be pressed intermittently for about 10 min and the pressure be held for 6h or more. The beans are then fermented at 35–40 cm bean depth.

This paper provides details of the pressing technique, fermentation and drying practices curently adopted in five Harrisons Malaysian Plantations Berhad cocoa factories for commercial production of low-acid beans, describes the characteristics of the cured beans and reports on the responses of processors/manufacturers to the improved product.

For many years manufacturers have expressed concern over the excessive acidity of Malaysian cocoa beans and the extent to which the flavours of derived chocolates differ from those perpared from beans of West African origins. Using cured nib pH as an index of acid level, the problem of excessive bean acidity (pH 5.0 units or less) occurs throughout South-East Asia where Upper Amazon hybrid beans are fermented on a large scale and are artificially dried. Within Malaysia the problem is acute in coastal environments of the mainland where substantial areas have been planted with the crops (Shepherd, 1976).

Investigations undertaken by national and private sector research establishments in Malaysia have shown that it is possible to reduce the acid levels in beans by modifying fermentation and drying practices. The main techniques reported, some of which have been adopted in commercial practice include:

- Partial removal of pulp juices prior to fermentation (Chong *et al.*, 1980)

- Bean maturation process (Liau, 1980)

- Fermentation in shallow boxes (Shahrir *et al.*, 1980)

- Inoculation of fresh beans with yeast (Chick *et al.*, 1982)

- Addition of yeast and enzyme to fermenting beans (Yap, 1983)

As the presence of excessive acidity usually correlates with poor development of chocolate flavour and may also be responsible for off-flavours in chocolates (Anon, 1984), it is highly desirable that proven technologies are more widely adopted in commercial practice whereby bean acidity can be reduced *and* their flavour potential improved, even though there may still be scope for improving the flavour characteristics of derived products. Although worthwhile premia over prices offered for unimproved beans may

not be obtained until manufacturers become fully satisfied that the beans can be used more extensively in their process, it is vital that Malaysian producers take positive steps to improve their bean quality without further delay, for the following reasons:

- There is an urgent need to improve the image of the Malaysian cocoa industry.

- Many chocolate manufacturers are not prepared to utilize more than 10% un-improved Malaysian beans in their blends, as higher incorporation rates could adversely affect the flavour characteristics of their products.

- Malaysian cocoa bean production is expected to rise from the present level of 70,000 tonnes to about 200,000 tonnes by the turn of the century, at which level Malaysia would contribute almost 10% of the projected world bean supply.

- Increasing quantities of Malaysian beans will be processed locally. The market appeals of cocoa liquor, cocoa butter and cocoa powder are determined largely by the quality of beans processed.

The technique whereby pulp juices are partially removed prior to bean fermentation (Chong *et al.*, 1980) has been adopted, with minor modifications, in five cocoa fermentaries operated by Harrisons Malaysian Plantations Berhad (HMPB) in Peninsular Malaysia to produce more than 5,000 tonnes low-acid beans per annum. This paper describes the current bean harvesting, collection, fermentation and drying practices in these factories, considers the characteristics of cured beans and reports on consumer reactions.

FIELD PRACTICES

Harvesting

Ripe pods are harvested at 7–10 day intervals. Pods are split in the field within a few hours and, after the placenta removal, beans are put into clean non-porous polythene bags (capacity 50 kg fresh beans) which are taken to the roadside for weighing and collection later in the day.

Collection

Special cylindrical mild steel boxes (termed 'press boxes'), which are designed to enable uniform application of perssure to remove a proportion of the pulp surrounding beans, are used for conveying beans from the field to the fermentary. The design and specifications of the boxes, which have a capacity of 700 kg fresh beans, are shown in *Figure 1*. A plate of marine plywood is placed on the floor of each box and two other plates are inserted during the course of bean transfer from polybags, when boxes are one-third and two-thirds full. The plates ensure more uniform pressure distribution throughout the bean mass when pressure is subsequently applied and also facilitate emptying of beans from the press boxes after a period of pressure retention. Up to six boxes may be transported on specially designed tractor-drawn trailers.

FACTORY PRACTICES

Bean Pressing

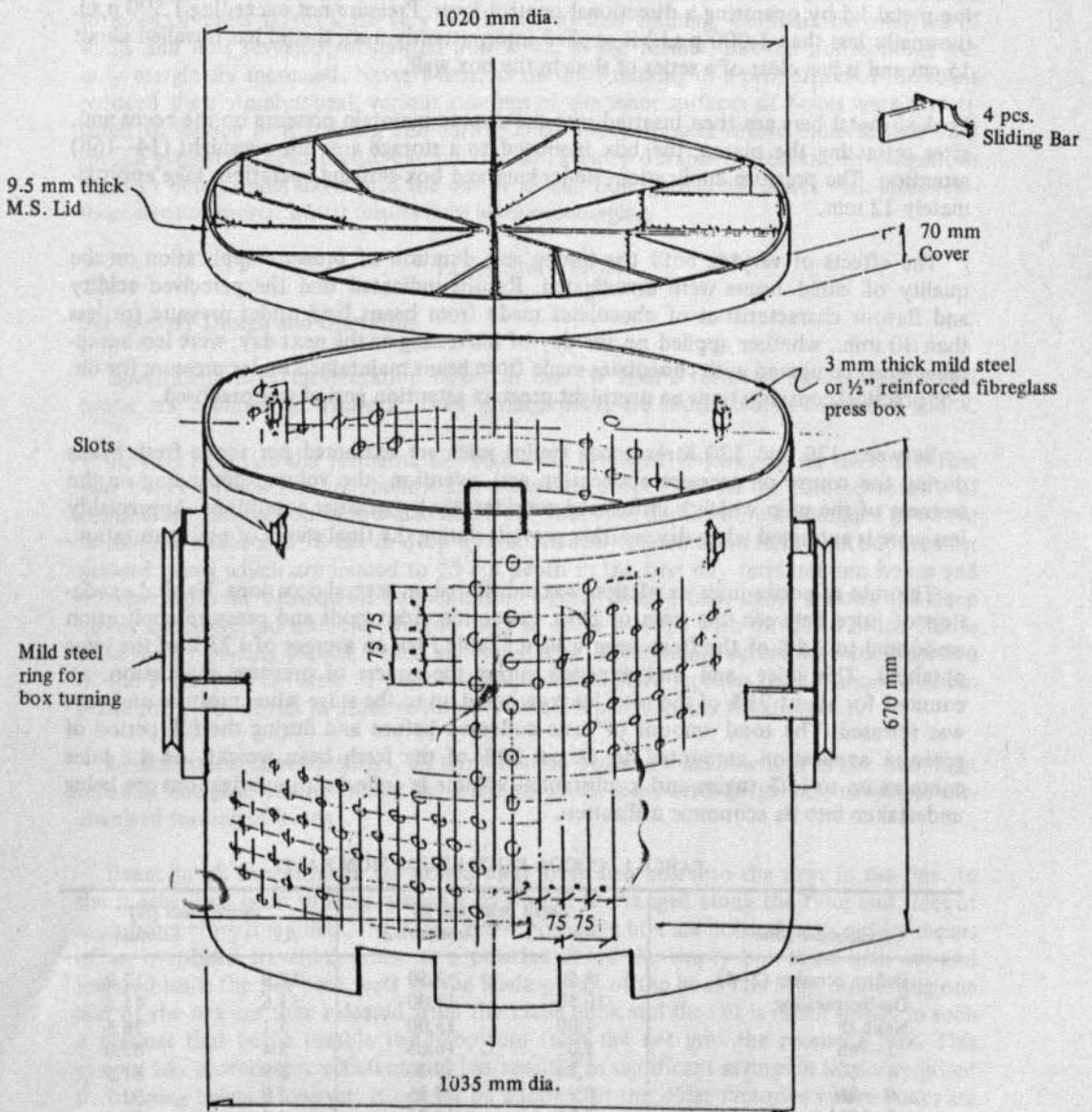Beans are usually delivered to the factory within 6h of extraction from pods. At the

Figure 1. Press box design and specification (isometric view).

The figure is labeled with the following specifications:

- 1020 mm dia.
- 9.5 mm thick M.S. Lid
- 4 pcs. Sliding Bar
- 70 mm Cover
- 3 mm thick mild steel or ½" reinforced fibreglass press box
- Slots
- 75 75
- 670 mm
- Mild steel ring for box turning
- 75 75
- 1035 mm dia.

factory the beans in press boxes are levelled off to a pre-determined capacity mark. A 3.5-cm diameter nylon rope gasket is then fitted over the beans, against the full inner circumference of the press box and a fourth pressure plate is placed on top of the beans and gasket. Thereafter a heavy metal lid (diameter 0.75 cm less than the press box inner diameter) is fitted over the pressure plate and, using a forklift truck or pallet truck, the box is moved directly below a hydraulic press. The press platen is then lowered onto the metal lid by operating a directional control lever. Pressure not exceeding 1,500 p.s.i. (normally less than 1,000 p.s.i.) is applied intermittently until the lid has travelled about 15 cm and is just clear of a series of slots in the box wall.

Locked metal bars are then inserted into the slots to maintain pressure on the beans and, after retracting the platen, the box is moved to a storage area for overnight (14–16h) retention. The pressure application, lid-locking and box-shifting operations take approximately 12 min.

The effects of varying both the timing and duration of pressure application on the quality of cured beans were investigated. Results indicated that the perceived acidity and flavour characteristics of chocolates made from beans held under pressure for less than 30 min., whether applied on the day of harvesting or the next day, were less acceptable when compared with chocolates made from beans maintained under pressure for 6h. For practical considerations an overnight pressure retention period was practised.

Between 120 and 170 litres cocoa (pulp) juice are extracted per tonne fresh beans during the course of pressure application and retention, the volume depending on the wetness of the pulp which is influenced considerably by weather conditions. Appreciably less juice is extracted when dry weather prevails during the final stages of pod maturation.

The rate of cocoa juice exudation was monitored on several occasions. Natural exudation of juice between the time of bean extraction from pods and pressure application amounted to 3.5% of the fresh bean weight (*Table 1*) or an average of 17.9% of the juice obtained. This juice, and that expelled during the course of pressure application, accounted for about 71% of the total juice gathered up to the stage when pressure on beans was released. The total amount of juice collected before and during the full period of pressure application amounted to almost 20% of the fresh bean weight. As the juice contains up to 17% sugars and a substantial volume is collected, investigations are being undertaken into its economic utilization.

TABLE 1. COCOA JUICE EXUDATION RATE

Exudation time	Fresh bean wt. (%)		Juice yield (%)	
	Av.	Cumulative	Av.	Cumulative
Before pressing (2–4)	3.50	3.50	17.9	17.9
During pressing	10.50	14.00	53.6	71.5
Next 2h	1.00	15.00	5.1	76.6
2– 4h	1.05	16.05	5.4	82.0
4– 6h	1.15	17.20	5.9	87.9
6– 8h	0.95	18.15	4.8	92.7
8–10h	0.90	19.05	4.5	97.2
10–12h	0.35	19.40	1.8	99.0
12–14h	0.20	19.60	1.0	100.0

Bean Transfer from Press Boxes

Following overnight storage, the press boxes are returned to the hydraulic press to

4

enable extraction of the lid locking bars. After removal of the lid and top pressure plate, the press boxes are hoisted over the first day fermentation boxes and inverted slowly to discharge beans. The empty boxes and pressure plates are subsequently cleaned for transportation to the field.

Despite the higher pressure applied, beans displayed no evidence of being flattened or damaged. However, the pulp and shell of beans that were in direct contact with steel surfaces of press boxes were very black due to iron staining. Comparative analyses of shells and nibs revealed substantial iron levels in the former, but nib iron content was only marginally increased. Nevertheless, as the iron staining of a proportion of the beans reduced their visual appeal, various coatings of the inner surfaces of boxes were investigated to reduce iron staining and corrosion of boxes. Results todate indicate that only special glass reinforced plastic can provide sufficiently durable protection. Investigations are also being undertaken into the use of special fibre glass press boxes with steel reinforcement supports. Initial results have been encouraging.

FERMENTATION

Fermentary Design and Operation

Specifications of fermentation boxes in the five HMPB factories producing low-acid beans are otulined in *Table 2*. Their arrangements are illustrated in *Figures 2* and *3*.

In two factories the fermentation boxes are arranged stepwise in six tiers. The first two boxes in each line are shallow and others are deep. Prior to the commencement of commercial production of low-acid beans in 1980, bean depths were maintained at 50 cm in shallow boxes and 90 cm in deep boxes. Shallow fermentation have been adopted for pressed beans which are loaded to 25 cm depth in the first day fermentation boxes and 40 cm depth in subsequent fermentation boxes. During high crop seasons the deep boxes are converted into two shallow tiers in order to cope with increased crop. This is achieved by placing planks, which are removable, horizontally across the middle section of the box. A 10 cm strip of perforated aluminium plate replaces the top-most wooden plank of the lower tier in order to improve air flow between and within boxes.

In the other three factories, all fermentation boxes are shallow and in the two most recently constructed the boxes are arranged at the same level (*Figure 3*) to enable mechanised turning of beans.

Beans in all fermentaries are turned daily from one box into the next in the line. In the mechanised bean turning system a nylon net is arranged along the floor and sides of each box before it is filled. The beans in the preceding box are hoisted in its net by means of an over-head travelling crane to a position above the empty box lined with net and lowered until the net base rests on the leading wall of the box. The rings supporting one end of the net are then released from the crane hook and the net is raised slowly in such a manner that beans tumble top-to-bottom from the net into the receiving box. This system has proved very efficient and has resulted in significant savings in labour required for turning beans. However, it cannot be adopted in the older factories where boxes are arranged step-wise, as the factory designs are such that a travelling crane cannot be introduced.

After beans are transferred they are covered with a single layer of hessian to minimise surface evaporation and conserve heat.

5

TABLE 2. FERMENTATION BOX AND SPECIFICATIONS

Item	Fermentary No. 1 & 2 (Bagan Datoh and Flemington estates rep.)	Fermentary No. 3 (Bukit Blimbing Estate)	Fermentary No. 4 & 5 (Cashwood and North estates rep.)
Year constructed	1971 and 1974	1980	1982 and 1984
Processing capacity (tonnes dbe/day)	25 and 15	2.5	5 each
Construction material	chengal	chengal	chengal
Arrangement	step-wise	step-wise	horizontal : 1.3m from ground level
Box per series	6	6	6
Box size	1 & 2 (shallow) − 1.7 x 4.8 x 0.6m 3 to 6 (deep) − 1.7 x 2.5 x 1.0m	1.5 x 1.9 x 0.5m	1 − 1.8 x 3.0 x 0.55m 2 to 6 − 1.8 x 1.8 x 0.55m
Capacity (wet bean)	3,600 kg	1,300 kg	1,500 kg
Perforation − walls − floors	1.2 cm holes on 10 cm grid 0.6 cm slats 5 cm apart	1.2 cm holes on 10 cm grid 0.6 cm slats 10 cm apart	1.2 cm holes on 10 cm grid 0.6 cm slats 10 cm apart
Turning and mixing beans	Manual	Manual	Mechanised

6
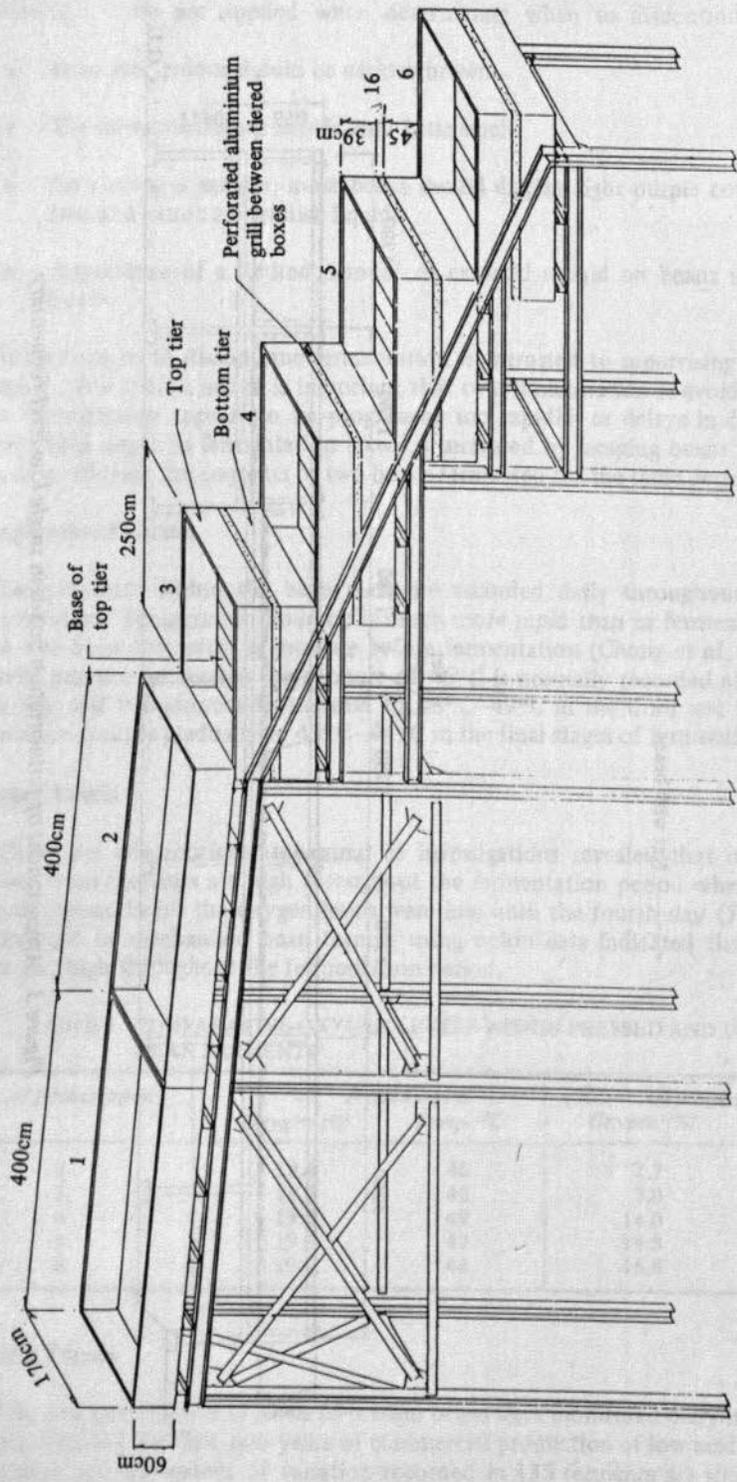
Figure 2. Arrangement of step-wise fermentation boxes
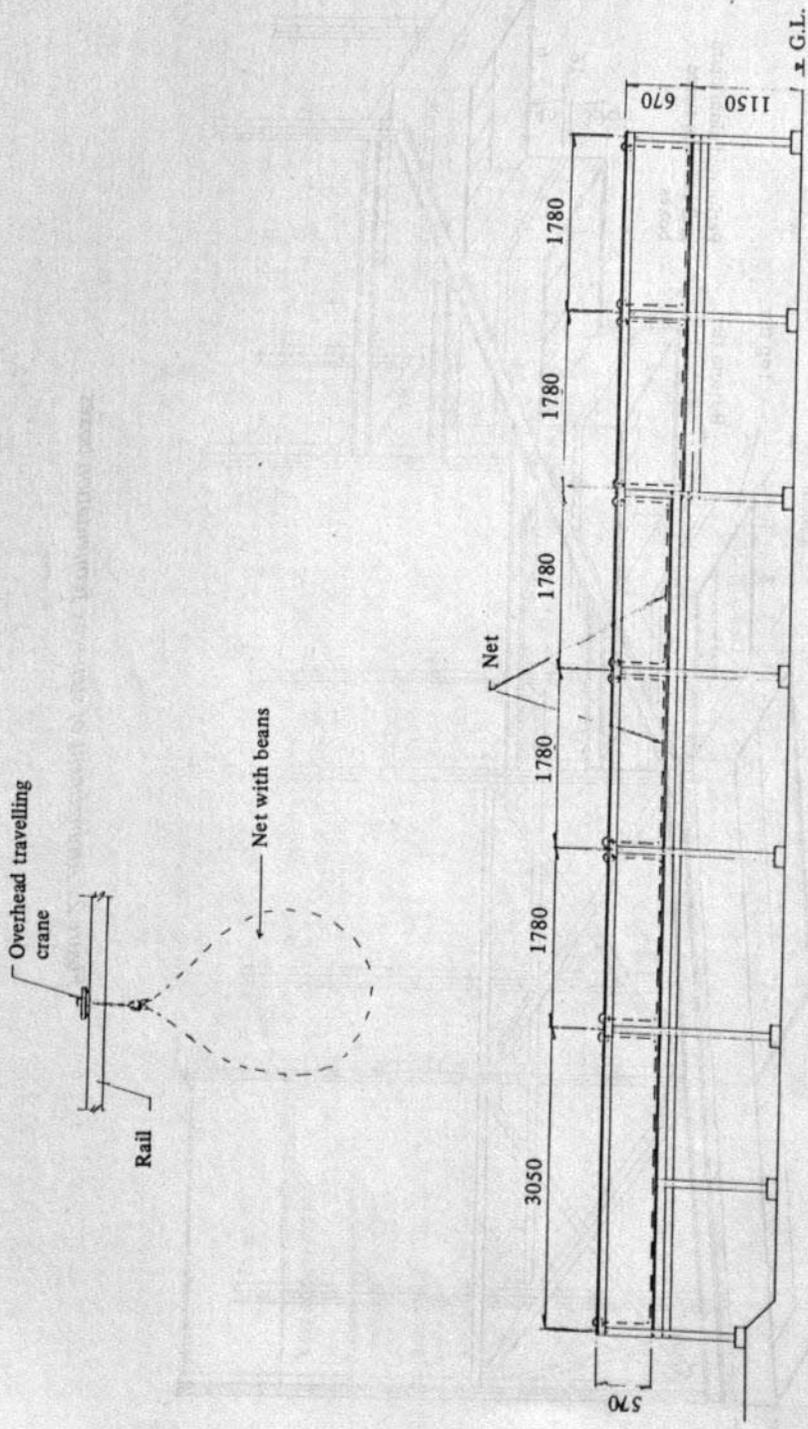
Figure 3. Arrangement of fermentation boxes in single low-level fermentary

8

Beans are normally ready for drying after approximately six days of fermentation. The following criteria are applied when determining when to discontinue fermentation:

- Bean shell colour should be darkish brown.

- The fermented beans should emit little smell.

- On cutting a sample, most beans should display light purple cotyledon colouration and exude a brownish liquid.

- Appearance of a limited amount of external mould on beans in the corners of boxes

Judgement as to discontinue fermentation is entrusted to supervising staff as the end point is quite critical and it is important that over-fermentation is avoided. In the event that fermentation appears to be progressing too rapidly, or delays in drying are anticipated, bean depth in fermentation boxes is increased by heaping beans within the same box or combining the contents of two boxes fermented for the same period.

Temperature Patterns

Temperatures within the bean mass are recorded daily throughout the course of fermentation. Temperature build-up is much more rapid than in ferments of beans that have not been subjected to pressure before fermentation (Chong et al., 1980). In commercial practice an average temperature of 46°C is normally recorded at the end of the first day and it continues to increase to 48°C–49°C in the third and fourth days and thereafter declines gradually to 43°C–44°C in the final stages of fermentation.

Oxygen Levels

These are not routinely measured as investigations revealed that oxygen levels in pressed bean ferments are high throughout the fermentation period whereas in ferments of non-pressed beans the oxygen levels were low until the fourth day (Table 3). Checks subsequent to mechanised bean turning using nylon nets indicated that oxygen levels were also high throughout the fermentation period.

TABLE 3. COMPARATIVE OXYGEN LEVELS WITHIN PRESSED AND UNPRESSED BEAN FERMENTS

| Day of fermentation | Pressed beans | | Unpressed beans | |
	Oxygen (%)	Temp. °C	Oxygen (%)	Temp. °C
2	19.6	46	2.7	42
3	19.2	48	3.0	46
4	19.6	49	14.0	48
5	19.6	47	16.8	50
6	19.8	44	16.8	49

Acidity Trends

Pulp and cotyledon acid levels of pressed beans were monitored daily in representative ferments during the first two years of commercial production of low acid beans. Average pH values and the extent of variation recorded in 135 ferments are shown in Table 4.

TABLE 4. PULP AND COTYLEDON pH VALUES DURING THE COURSE OF FERMENTATION

Day of fermentation	Pulp pH	S.D.	Cotyledon pH	S.D.
1	3.9	0.09	6.1	0.15
2	3.8	0.05	5.4	0.19
3	4.1	0.08	4.7	0.15
4	4.4	0.10	4.5	0.10
5	4.6	0.12	4.7	0.19
6	5.0	0.11	4.9	0.23

After a small decline in the second day, pulp pH progressively increased and reached 4.9–5.1 units at the end of fermentation. The cotyledon pH, however, fell rapidly from 6.1–6.2 units to 4.4–4.6 units in the first four days and thereafter rose gradually to reach 4.7–5.1 units at the end of fermentation.

A fairly strong acetic acid odour is detected from about 24h fermentation until the end of the third (occasionally fourth) day. Thereafter the odour diminishes and is hardly detectable in the final stages of fermentation. This situation contrasts with that in ferments of non-pressed beans in which acetic acid build-up is slowest but the odour is much stronger and continues to be detectable until virtually the end of fermentation.

It is noteworthy that metal corrosion in the factories has been greatly reduced following the introduction of bean pressing in commercial practice.

DRYING

A three-stage drying procedure was adopted in all five factories.

Pre-drying

Pre-drying is done in a circular bin dryer equipped with a revolving agitator and heater/fan unit. Beans are transferred from the final fermentation box by conveyor belts in the older factories and by means of nylon nets in the two factories equipped with travelling cranes. Beans are filled to 40 cm depth, equivalent to 4.2 tonnes dry beans, and are levelled by a continuous stirring movement of the agitator. Drying is done by means of a stream of hot air (inlet-temperature 65°C) which passes at high speed through the perforated aluminium floor of the dryer. Pre-drying is discontinued after 5–6h, when the bean moisture content has been reduced to about 23 percent.

Resting

Partially dried beans are either loaded into steel boxes of 520 kg capacity (two oldest factories) or into a trough surrounding the dryer (at factories built in recent years) for 12–20h to allow equalisation of moisture gradients within beans. Extension of the resting period beyond 20h is not permitted as activities of putrefactive micro-organisms could result in unacceptable off-flavours in cured beans.

Rotary Drying

The final drying is done in large rotary dryers (capacities 2.5–3.3 tonnes dry beans). Beans are transferred from resting boxes to the rotary dryer by means of a fork-lift

truck and from the bin dryer trough by a conveyor belt. Hot air (65°C inlet temperature normally, but may be raised to 70°C during peak cropping periods) is blown through a central spindle of the drum which rotates continuously (one revolution in 3 min). After 7h the rate of decline in bean moisture content is monitored by means of a portable electronic moisture meter. Application of heat is discontinued when the moisture content is approximately 8 percent as experience has shown that on cooling the moisture content continues to decline and registers 6.5% to 7.0% at ambient temperature. Generally rotary drying is completed within 8h of commencement.

Drying Investigations

The drying regimes adopted were based on a series of investigations with fully loaded dryers. For pressed beans it was established that in both pre-dryers the rotary dryers, most economical drying was obtained when inlet air temperature were within the range of 60°C to 65°C. Whereas low temperature (below 50°C) drying resulted in unacceptable increases in drying time and power consumption, high temperature (above 70°C) drying increased fuel consumption and tended to roast beans.

Investigations were also conducted into the feasibility of using only circular bin dryers or rotary dryers for drying pressed beans. Drying time, fuel consumption and the proportions of broken beans are compared in *Table 5* with corresponding statistics for partial drying in the circular bin dryer and final drying in the rotary dryer. The combined circular/rotary and exclusively rotary drying systems proved superior to complete circular bin drying in all respects and rotary drying was marginally more efficient than circular bin drying. However, the dual dryer system is adopted in commercial practice for the following reasons :

TABLE 5. COMPARATIVE PERFORMANCES OF VARIOUS DRYING SYSTEMS

Drying Systems	Drying duration h/3.5 tonnes dbe	S.D.	Fuel consumption 1/tonne dbe	S.D.	Broken beans %	S.D.
Circular/rotary	13.4	1.2	98.1	10.4	1.2	0.3
Circular throughout	19.5	2.5	144.4	14.1	2.3	0.6
Rotary throughout	11.8	1.3	87.6	9.1	1.0	0.2

- Bean shrinkage during drying could reduce efficiency of rotary dryers during low-cropping periods when insufficient beans are available to 'top-up' dryers.

- Efficient drying is only possible when rotary dryers are fully loaded.

- Incomplete loads in rotary dryers could increase the proportion of broken beans.

More recently, the use of solid fuel burners to supply heat for drying beans was investigated. Results have been highly encouraging. Based on present costs of solid fuels and diesoline, a solid fuel burner installed at one factory achieved a 59% fuel cost saving. A second solid fuel burner is being installed at another factory where abundant supplies of cheap wood are available. Consideration is being given to using only solid fuel burners in a new cocoa factory to be constructed in the near future on an estate in Sabah.

Fuel and power consumption are closely monitored at all cocoa factories. In the older factories which prior to 1981 processed non-pressed beans, fuel and electrical power consumption have declined by about 35% and 50% respectively, due largely to the fact that there is less moisture in the pressed bean pulp and as a consequence drying time has been virtually halved, from 25h to less than 14h. Besides the fuel/power cost savings, the shorter duration of drying also results in a lower proportion of residue (1.3% c.f. 2.5%) collected under dryers and during winnowing of pressed beans.

BEAN SIZE GRADING AND WINNOWING

After discharge from the rotary dryer, beans are mechanically winnowed/size-sorted to remove broken beans, very small beans and agglomerated beans. The incidence of agglomerated beans is much lower than that obtained before bean pressing was introduced, and those grouped together can normally be manually parted without undue difficulty.

BEAN CHARACTERISTICS

The characteristics of cured low-acid beans differ in several respects from those of beans produced in commercial practice prior to the adoption of the bean pressing technique described in this paper.

Bean configuration. The plumper appearance of cured pressed beans is attributed to reduced nib compactness and the shell adhering less strongly to the nib.

Bean weight. Average bean weights are about 2% less than those of non-pressed beans, due largely to less pulp adhering to the shell. As the nib weight is not affected by the bean pressing operation, the yield of nib is accordingly about 2% higher. This has been confirmed by a local secondary processor.

Shell. The shell is cleaner, smoother and darker brown than that of non-pressed beans and is easily separated from the nib. The proportions of shell of cured pressed and non-pressed beans of differing average weights are compared in *Table 6.* An inverse relationship between the proportion of shell and average bean weight is apparent, but it is also noteworthy that for bean weights within the range 0.8g–1.1g, the pressed beans yield 2.2% less shell.

TABLE 6. AVERAGE SHELL CONTENTS IN RELATION TO BEAN WEIGHTS

Bean weight	No. samples	Non-pressed % shell	S.D.	No. samples	Pressed % shell	S.D.
0.70 – 0.79g	66	18.4	0.7	70	16.6	0.8
0.80 – 0.89g	85	17.5	0.6	50	15.4	0.9
0.90 – 0.99g	93	16.2	0.5	100	14.1	0.6
1.00 – 1.09g	80	15.9	0.6	85	13.5	0.7

Nib pH. The nib pH values of 1193 batches of cured pressed beans produced since 1981 are compared in *Table 7* with those of cured non-pressed beans produced in the same factories in the preceding three years. The nib pH of cured pressed beans, averaging 5.26 units, was about 0.6 units higher than that computed for cured non-pressed beans

12

which were marginally less variable. The frequency distribution of nib of pH of the 1193 batches of cured pressed beans is indicated in *Table 8*. Virtually 80% of the batches had nib pH values within the range 5.1 units to 5.4 units and none was less than 5.0 units or exceeded 5.5 units.

TABLE 7. COMPARATIVE NIB pH VALUES

Bean	Samples analysed	Mean pH	Standard deviation
Pressed	1193	5.26	0.16
Non-pressed	743	4.65	0.07

TABLE 8. FREQUENCY OF pH DISTRIBUTION

pH	5.0	5.1	5.2	5.3	5.4	5.5
Percentage of 1193 samples	9.2	15.8	23.1	21.9	18.5	11.5

Introduction of stricter monitoring during the later stages of fermentation, to obviate possible overfermentation, has reduced in recent months the incidence of batches with nib pH values exceeding 5.4 units to less than 5%.

Cocoa butter. Results of analyses indicate that the yield of cocoa butter, expressed as a proportion of dry nib, is not influenced by pressing of beans prior to fermentation (*Table 9*). However, by virtue of the lower proportion of shell in cured pressed beans, the yield of cocoa butter expressed as a percentage of the whole bean is higher than that of cured non-pressed beans.

TABLE 9. AVERAGE COCOA BUTTER CONTENTS

Bean	Sample analysed	Fat content (%)	S.D.
Pressed	521	56.4	0.82
Non-pressed	91	56.3	0.73

MANUFACTURERS' RESPONSE

Most manufacturers are able to provide potential Malaysian suppliers with details of their required raw bean specifications. These essentially relate to acidity, yield of nib, been size and flavour. In the eyes of European manufacturers, Malaysian beans have fallen far short of requirements being rather small and variable in size with a high shell content. The chocolate flavour is weak and there is evidence of off-flavours due to acidity (Export Trade Centre). As a consequence manufacturers became rather indifferent in attitude; they purchased Malaysian beans at a discount and did not welcome suggestions of improvement. Initial attempts to market low acid beans in Europe met with polite acceptance although enthusiasm declined when it was suggested an improved quality warranted an improved price. Latterly however interest has been revived and, with uncertainty surrounding supplies from West African origins, it is evident a useful market can be established for good Malaysian beans.

13

Against this background, manufacturers in the U.S.A., Japan and Australia responded well to consignments of low acid beans which had been subjected to winnowing and grading. Sales to these areas increased from 1982 to 1984 and a reputation for quality became firmly established. This enabled a higher price to be obtained when compared to sales of non-pressed beans.

It is commercially attractive to outturn low-acid beans although most estate factories have shown a reluctance to adopt such a practice due primarily to doubts on profitability. At present manufacturers in consuming countries outside South-East Asia continue to use only a small percentage of Malaysian beans in their base blends. There is evidence that the percentage will be increased if good quality low-acid beans become more readily available. Manufacturers in the Far-East will replace uncertain supplies of Ghana and Bahia beans with consistent quality supplies from Malaysia. This in turn will uplift the image of the Malaysian cocoa industry and producers will enjoy the benefits of such improvements by way of increased profitability.

CONCLUSION

The pulp reduction technique whereby cocoa juices are partially removed by pressing over an extended period has been successfully adopted in five cocoa factories operated by Harrisons Malaysian Plantations Berhad in Peninsular Malaysia to produce more than 5,000 tonnes of bean with nib pH values within the range of 5.1 units – 5.5 units annually since 1981.

Since the commencement of commercial production of low-acid beans, fuel and electricity power consumption for bean drying were reduced by 35% and 50% respectively and the drying time was virtually halved. The shorter duration of drying resulted in a considerable reduction in broken beans.

It is noteworthy that the working environment in the factory also considerably improved as objectionable acid fumes emitted from the fermentary mass and exhausted from dryers were reduced to negligible levels. Corrosion of factory roof, floors and walls were minimised which led to reduced factory upkeep and maintenance costs.

Responses of processors and manufacturers, both local and overseas particularly those in the U.S.A., Japan and Australia to low-acidity beans have been very encouraging. A higher price is generally obtained for the improved product, which more than compensates for the loss in shell weight associated with pre-fermentation pressing. Nevertheless, as the nib weight is not affected, the yield of nib is accordingly about 2% higher.

ACKNOWLEDGEMENT

REFERENCES

ANON. (1984). Cocoa Beans, Chocolate Manufacturers' Requirements. Rep. The Cocoa, Chocolate and Confectionery Alliance.

CHICK, W.H, MAINSTONE, B.J. & WAI, S.T. (1982). DEB investigations into control of aspects of cocoa bean acidity. Preprint of paper presented at the IKM Conference in Kuala Lumpur, Nov. 1982.

CHONG, C.F., SHEPHERD, R. & POON, Y.C. (1980). Mitigation of cocoa been acidity – fermentary investigations. *Proc. Int. Conf. on Cocoa and Coconuts, Kuala Lumpur, 1978*, pp. 387–414.

EXPORT TRADE CENTRE OF THE MINISTRY OF TRADE & INDUSTRY (1984). Mini Market Survey on cocoa beans and cocoa products in the Netherlands by the Embassy of Malaysia.

LIAU, H.T.L. (1980). The criteria and mechanism for removal of cocoa bean acidity. *Proc. Int. on Cocoa and Coconuts, Kuala Lumpur, 1980.*

SHAHRIR, S., AHMAD, I. & MOHD HASHIM, H. (1980). Preliminary efforts to improve the quality of cocoa bean. *Proc. Int. Conf. on Cocoa and Coconuts, Kuala Lumpur, 1978.*

SHEPHERD, R. (1976). Large scale processing of cocoa beans — Temperature and acidity trends. *The Planter,* **52 (605),** 311–322.

YAP, T.N. (1983). Control of cocoa fermentation technique to enhance quality. Preprint of paper presented at SASS Seminar in Tawau, May 1983.

Cocoa Fermentation — Effect of Surface Area, Frequency of Turning and Depth of Cocoa Masses

MAMOT BIN SAID

Malaysian Agricultural Research and Development Institute, Serdang, Selangor.

AND

RODNEY JAYASIRI SAMARAKHODY

Cocoa and Coconut Research Division, Hutan Melintang, Perak

Understanding the kinetics of cocoa fermentation is important in formulating new means to solve the problems of poor quality of Malaysian cocoa beans. Thus, the objective is to study the effect of surface area, frequency of turning and depth of ferment on the quality of fermented cocoa beans.

Fermentation trials were carried out in wooden boxes of different surface areas (0.56 m², 1.10 m², 1.67 m², 3.34 m²) and depths (15.2 cm, 22.9 cm, 30.5 cm, 45.7 cm, 61.0 cm). The beans were turned after 24, 48, 72 and 96 h. The changes in pH and temperatures were monitored daily. The degree of fermentation was determined after drying.

Generally, surface area does not have a significant effect on the pH of the dried beans. Nevertheless, there was an indication that the uniformity and degree of fermentation decreased as the surface area increased. It was also observed that the temperature rise was slower in cocoa masses with a greater surface areas.

The temperature in the middle of the cocoa masses became higher as the depth was increased. This indicated a larger loss in heat as the ratio of surface area to cocoa mass was increased. Using deeper fermentation boxes with depths of 45.7 cm and above, the resulting bean masses still developing the typical vinegar smell during drying, indicating incomplete fermentation in the deeper boxes. The effect of the frequency of turning was more pronounced as the depths were increased.

The patterns of temperature development and degree of fermentation were very much affected by the frequency of turning, especially at depths more than 15.2 cm. Generally, the rise in temperature is slower in the less frequently turned cocoa masses with a consequent decrease in the degree of fermentation and a lower pH of the dried cocoa beans.

Cocoa production in Malaysia has increased steadily, from 1,000 tonnes in 1967/68 to 60,000 tonnes in 1981/82 (Gill & Duffus, 1984). At present, Malaysia produce about 4% of the world's cocoa market. Despite a rapid growth in production, the quality of the cocoa beans, especially those from smallholders and smalltime processors is still considered poor. High residual acidity and weak chocolate flavour are characteristic of Malaysian cocoa (Powell, 1983). Improper methods of fermentation and drying practised by the smallholders are the major factors that affect the quality of the product. Due to their

ignorance in the fermentation requirement such as aeration and drainage of sweating, fermentation is carried out in various containers, for example baskets and wooden boxes. As a result, the quality of the fermented beans is inconsistent and sometimes totally unacceptable.

A survey carried out recently showed that most of the cocoa beans produced by the smallholders in Peninsular Malaysia were underfermented with the average degree of fermentation below 60% and pH above 5.5 (Husin et al., 1982). Since about 60% of the cocoa production is from smallholders (Said & Shamsudin, 1983), a positive measure has to be taken to eradicate their malpractices or else the quality of cocoa beans exported from this country will remain poor and unacceptable.

It is an accepted fact that the method of fermentation determines the quality of the product produced especially in flavour (Powell, 1983). Certain methods of fermentation can influence the acidity level of the product (CEPEC, 1980). Turning regimes and depth of ferment are the most determining factors of acidity. The delay in turning causes a delay in the onset of acetic acid production resulting in higher level of acid at the end of fermentation. While early mixing during the fermentation period tends to favour ethanol production and discourages lactic acid production (Lehrian & Patterson, 1983). Dougan (1981), however, concluded that a reduction in the degree of aeration of the fermentation by reducing the number of turns and shortening the duration of fermentation would decrease the acetic and lactic acid levels of the cured cocoa. Overaeration will lead to a further increase in pH, sometimes to around 5.8 (Liau, 1976). A strong aeration may also cause an earlier overfermentation (Biehl, 1984).

The mass of cocoa, which is fermenting, influences the degree of aeration and, to a certain extent, the amount of heat produced by the organism (Said, 1982; Lehrian & Patterson, 1983). Chick et al., (1981) found that by using half-depth ferment the non-volatile acidity could be reduced by 31%. In fully fermented beans, acetic acid appears to be the principle free acid, while the non-volatile acids play a secondary role. However, in the case of underfermented cocoa, the situation is probably reversed (Lopez, 1983).

Studies on the effects of turning, size of batches and duration of fermentation during fermentation have attracted many workers. Most of them have described the factors influencing the pH of the beans, temperature of the mass and to some extent the flavour of the product (Biehl, 1961; 1965; 1968; Howart et al., 1957; Rohan, 1958a and b; Vander-Forst, 1984). However, very little studies have been done on the kinetics of the fermentation. Statistical analysis on the effects of such treatments should be done in order to have a clearer understanding of the fermentation itself. This information is very important so as to formulate a remedy to the poor quality Malaysian cocoa, especially those from smallholders.

METHODS

Chemicals

All chemicals used were of analytical grade, unless otherwise stated.

Fermentation

Fresh cocoa beans were obtained from the MARDI's Station at Hilir Perak. The beans were fermented in boxes of various sizes (0.61 m x 0.91 m, 1.22 m x 0.91 m, 1.83 m x

0.9 m and 1.83 m x 1.83 m), depths (0.15 m, 0.23 m, 0.3 m, 0.45 m and 0.61 m) and turning regimes (24, 48, 72 and 96 h). The boxes were made of a hardwood of 10 cm wide and 2.5 cm thick arranged 0.5 cm apart to facilitate drainage of the sweating. About 24 kg wet beans could accommodate 16.4 cm^3 (1 cubic feet) of such box. The beans were fermented for six to eight days depending on the sizes of the boxes and turning regimes used. Temperature of the mass was recorded daily before and after turning at the top and centre of the mass by using a glass-mercury thermometer. pH was determined potentio-metrically by using a pH-meter according to O.I.C.C. (1972). The degree of fermentation was determined by the cut test method (ISO, 1977) of the dried beans.

Chemical Analysis

Samples of cocoa beans were taken every morning from the top and middle of the masses. The following analyses were carried out.

Total sugar. The mucilage from cocoa beans was removed by abrasion with the help of saw-dust. Then the testa was removed by using a knife. Total sugar content of the cotyledon was determined by the anthrone method of Scott & Melvin (1953 and the extraction procedure used as in Quesnel and Lopez (1975).

Soluble nitrogen, total nitrogen and nitrogen index. Soluble and total nitrogen were determined by the method of Rohan and Stewart (1966). From these values, the nitrogen index was calculated (Rohan & Stewart, 1967; Bracco *et al.*, 1969).

Total anthocyanin. Total anthocyanin was determined by the differential pH method of Fuleki and Francis (1968) with a few modifications (Said, 1982).

Total polyphenol. Total polyphenol was determined by Folin — Ciocalteu reagent as reported by Cros *et al.* (1982a and b) with modification, whereby 20% solution of Na_2CO_3 was replaced by 5.0 M ethanolamine. (–) Epicatechin was used as standard. The $E^{1\%}$ for (–) epicatechin colour complex was found to be 1240.

Statistical analysis. The analysis of variance namely Duncan Multiple Range Test and Multiple Regression Analysis was done by Computer IBM System OS/451 Model 4341.

Sensory evaluation. Sensory evaluation of chocolate made from the roasted samples was done according to O.I.C.C. (1974).

RESULTS

The effects of surface area, depth on ferment and frequency of turning on temperature and the final pH of the beans are shown in *Table 1* and *Table 2* respectively.

Statistical analysis showed that the treatments had no significant effect on the degree of fermentation. However, there is an indication that the uniformity and degree of fermentation decrease as the surface area and depth of ferment increase. According to the results obtained from the Duncan Multiple Range Test, a box size of 1.83 x 0.91 m with a depth of 0.15 m and frequency of turning at every 48 h would give a better degree of fermentation.

3

TABLE 1. STATISTICAL ANALYSIS OF THE EFFECT OF TREATMENT ON TEMPERATURE

Sources	Level of Significance	Regression Equation	Coefficient of Correlation (r)
Model	***		
Size	*		
Depth	***	$Y = 46.76 - 0.15x$	-0.26*
Turning	***	$Y = 43.26 + 0.12x$	0.70***
Size * Depth	NS	$Y = 48.73 - 0.04x$	-0.53***
Depth * Turning	***		
Surface Area/Depth	**	$Y = 47.54 - 14.86x$	-0.4**

$R^2 = 0.9669$
$CV = 1.5693$

* = significant at 0.1%
** = significant at 0.05%
*** = significant at 0.001%
NS = not significant

TABLE 2. STATISTICAL ANALYSIS OF THE EFFECT OF TREATMENT ON pH

Sources	Level of Significance	Regression Equation	Coefficient of Correlation (r)
Model	**		
Size	NS		
Depth	***		
Turning	NS	$Y = 5.35 - 0.011x$	-0.63***
Size * Depth	NS		
Size * Turning	NS		
Depth * Turning	NS		

$R^2 = 0.9088$
$CV = 2.6351$

** = significant at 0.05%
*** = significant at 0.001%
NS = not significant

The treatments, however, had significant effects on the final pH of the beans (P < 0.05) and also the temperature of the cocoa mass (P < 0.001). Further results are described below.

Effect of Surface Area

As shown in *Table 2*, the sizes of the boxes did not affect the final pH of the beans significantly. According to Rohan (1958a), the pH of the cotyledon was related to the size of the batch rather than the mixing and tended to be lower at any given time in

4

larger batches. Reduction in size of fermentation mass was belived to be proportionally accompanied by greater air penetration, and hence would aid in the oxidation of acetic acid formed, resulting in higher pH.

The build up of temperature in the cocoa mass was significantly affected by the size of the container ($P < 0.1$). Regression analysis showed a linear relationship between surface area and temperature (*Table 1*). A more significant relationship ($P < 0.05$) was obtained when the ratio of surface area/depth was plotted against temperature. Both cases showed negative relationship, thus indicating a greater loss in temperature as the surface area to mass ratio increased. This was in agreement with the finding of Rohan (1958b) who found somewhat lower temperature in the smaller batches.

Effect of Depth

The depth of cocoa mass affected the pH of the beans very significantly ($P < 0.001$) as shown in *Table 2*. The negative correlation suggested that the deeper the mass, the more acidic the beans would be as penetration of air became poorer in a deeper box. Hence the oxidation of acetic acid to carbon dioxide and water becomes slower, resulting in a lower pH.

The temperature of the mass was also greatly affected by the depth ($P < 0.001$). Positive correlation indicated a higher temperature in a deeper box. The reduction in the depth of a given mass of cocoa would result in an increase in surface area and potentially greater heat losses (Rohan, 1958b). The combination of depth and turning would also affect the temperature significantly ($P < 0.001$) as turning can cause heat loss.

Effect of Frequency of Turning

From our studies, we found that the frequency of turning did not have a significant effect on pH. This is in agreement with the finding of Rohan (1958a) who found that the pH of the cotyledon was independent of the frequency of mixing. He also found that the frequency of mixing had no noticeable effect on quality. Biehl (1968) demonstrated that the unmixed cocoa mass had an earlier increase in pulp pH compared to the mixed mass. In this study, the less frequently turned beans demonstrated a higher pulp pH.

Turning would affect the temperature development in the mass very significantly ($P < 0.001$). The negative correlation indicated a greater temperature losses in a frequently turned masses. It was also found that the less frequently turned beans had a slower increase in temperature. Biehl (1961; 1968) had also similar conclusion. Duncan Multiple Range Test showed that turning at every 24 and 48 h had no significant difference.

Effect of Frequency of Turning and Depth on Chemical Changes in the Beans during Fermentation

Since the size had no significant effect on the pH and degree of fermentation, further work was concentrated on the effect of turning and depth on some chemical changes during fermentation. The results are illustrated in *Figures 1-6* and discussed below.

Total polyphenol. The degradation of polyphenol was faster in frequently turned beans (*Figure 1*) compared to that in the lesser frequently turned beans. Turning obviously increased aeration and hence facilitated the oxidation of polyphenol by enzyme polyphenoloxidase. However, overaeration as in the case of a shallow ferment (*Figure 2*), encouraged earlier tanning which inhibited enzymatic oxidation of polyphenol (Forsyth et al., 1958). So, the destruction of polyphenol became slower in a shallower ferment.
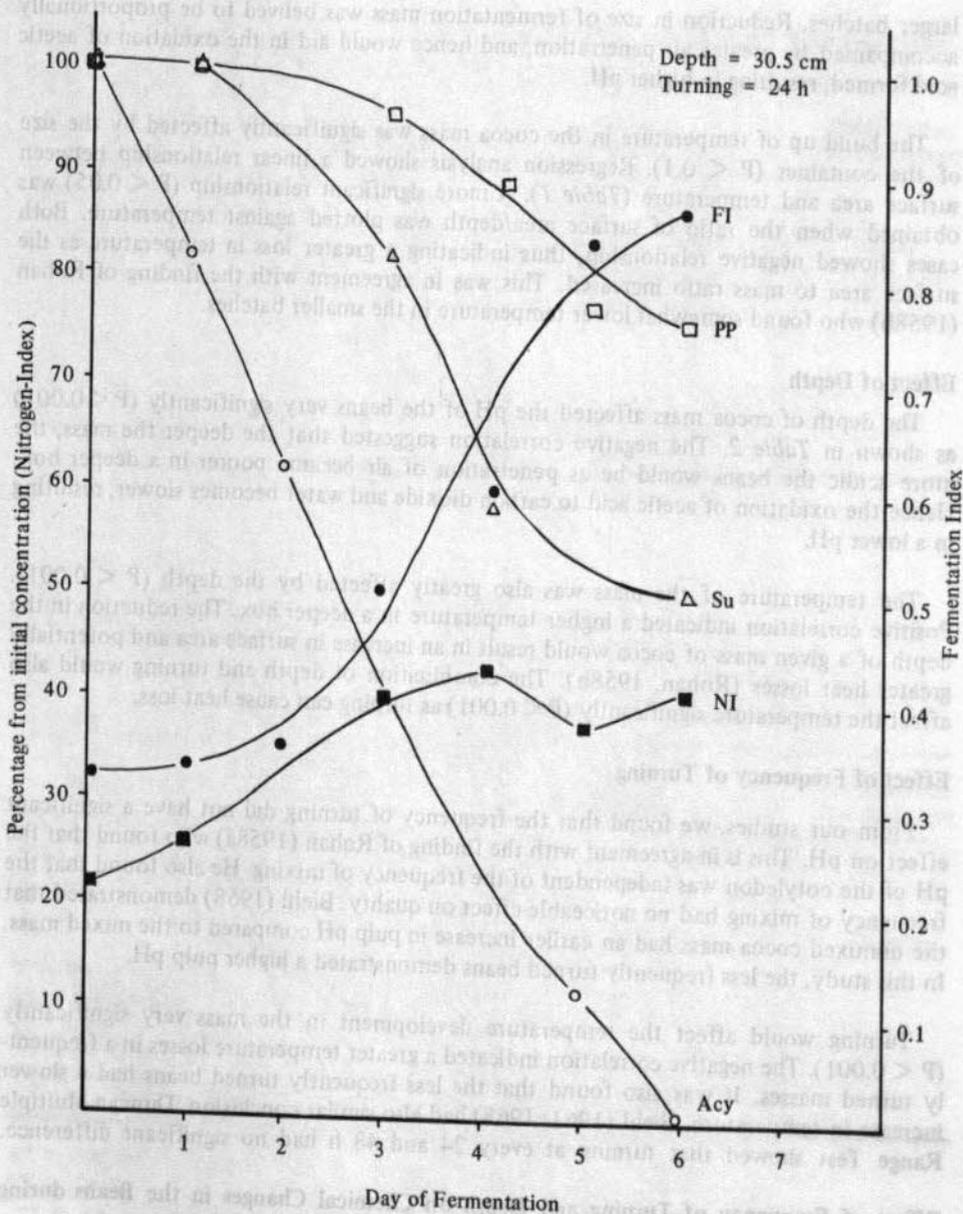
5

Figure 1. Chemical changes during fermentation. The depth of the beans was 30.5 cm frequency and turning was 24 h.
Acy = anthocyanin, FI = fermentation index, NI = nitrogen index, PP = polyphenol, Su = Sugar.

The same phenomenon was also observed in the earlier work (Said, 1982). In a deeper box (*Figure 5*), the oxidation of polyphenol was hampered by the anaerobic conditions of the cocoa mass. Daily turning at the depth of 30.5 cm (*Figure 1*) favoured the oxidation of polyphenol as seen by the rapid decrease in total polyphenol.
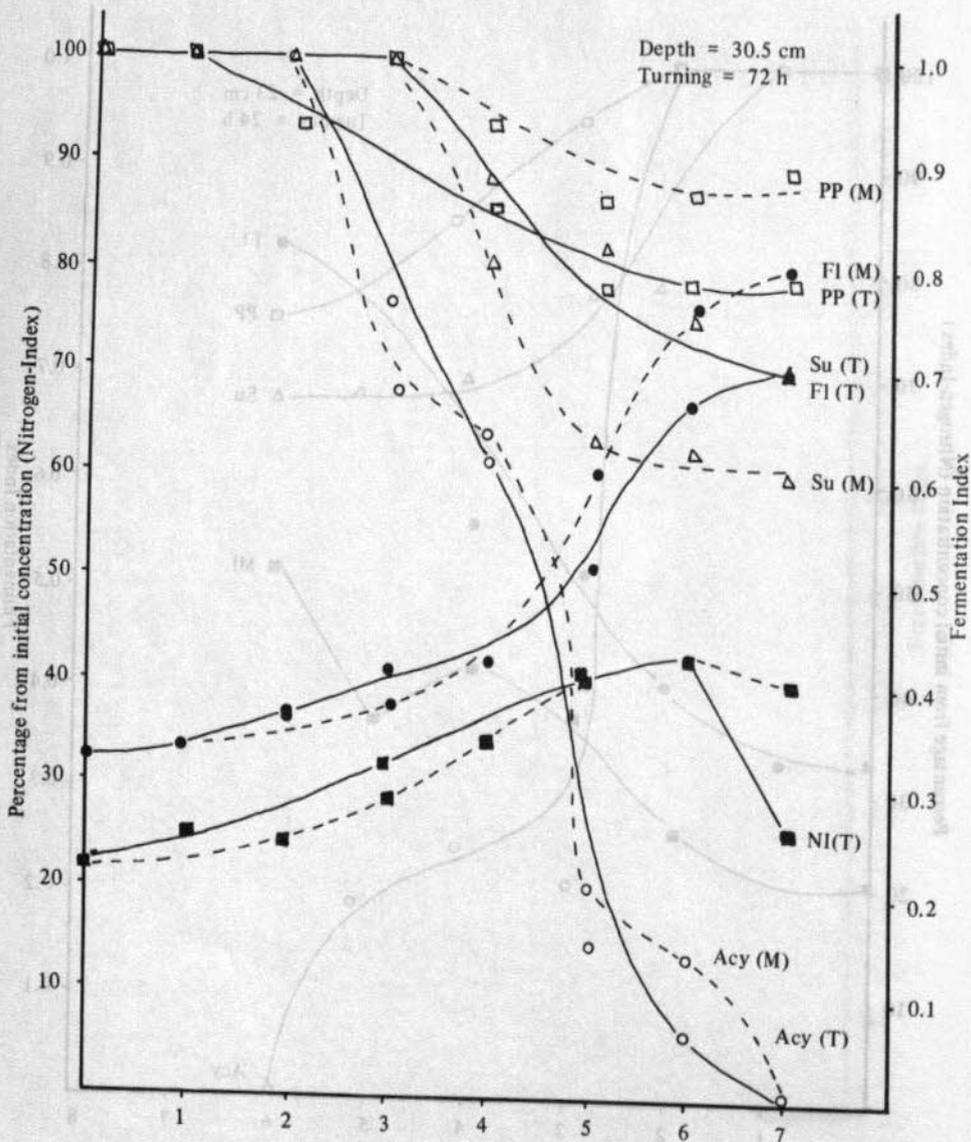
6
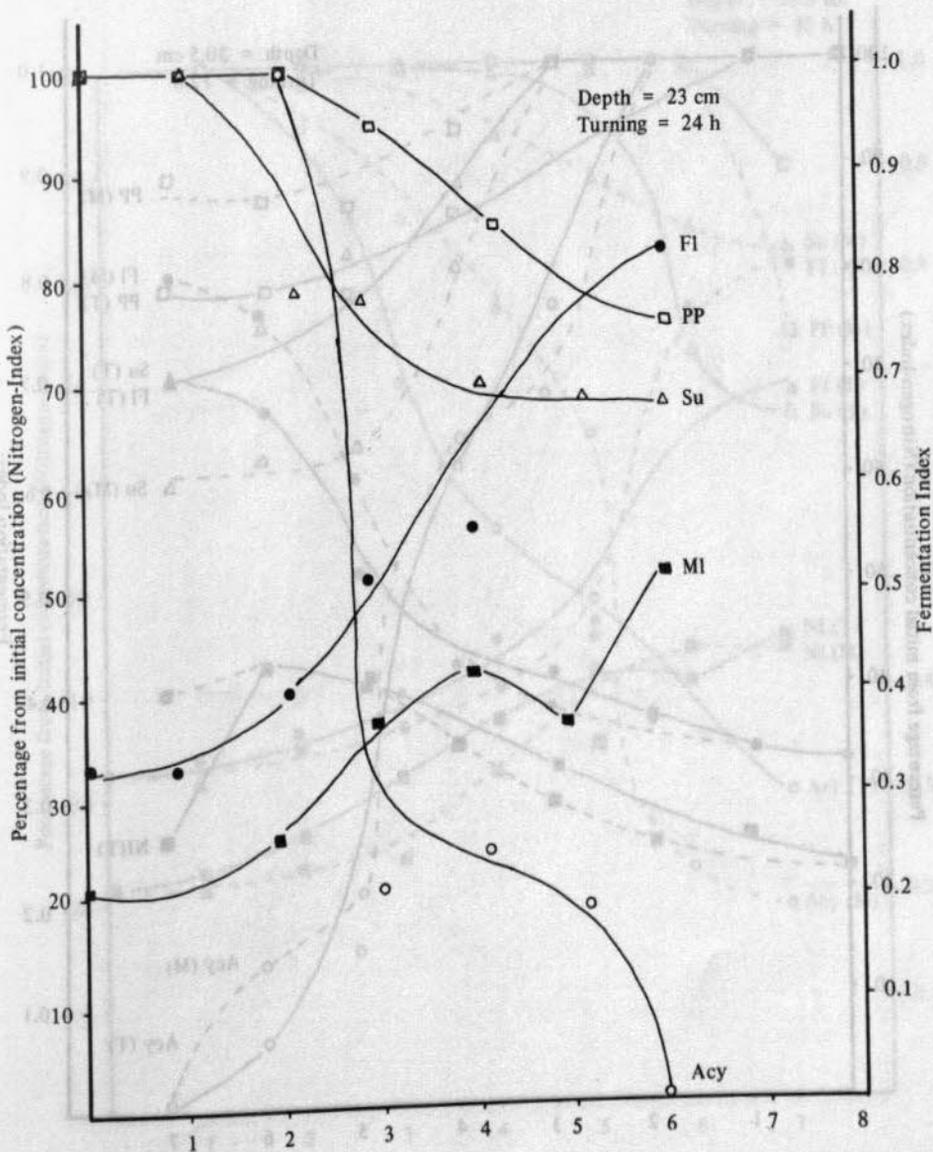
Figure 2. *Chemical changes during fermentation. The depth of the beans was 23 cm and frequency of turning was 24 h. (Legends as in Figure 1).*

Total anthocyanin. In daily turned ferment irrespective of depth, almost all of the anthocyanin had been degraded (*Figure 1, 2* and *6*). If the beans turned at 48 h and 72 h (*Figure 5* and *Figure 3* respectively), hardly about 10% anthocyanin was left. However in the 96-h turned beans (*Figure 4*), the degradation of anthocyanin was slower with the residual content of about 30%. Cut test method showed that at a depth of 30.5 cm, the daily-turned beans had 83% brown beans, while the 96-h turned beans only had 64% brown beans.
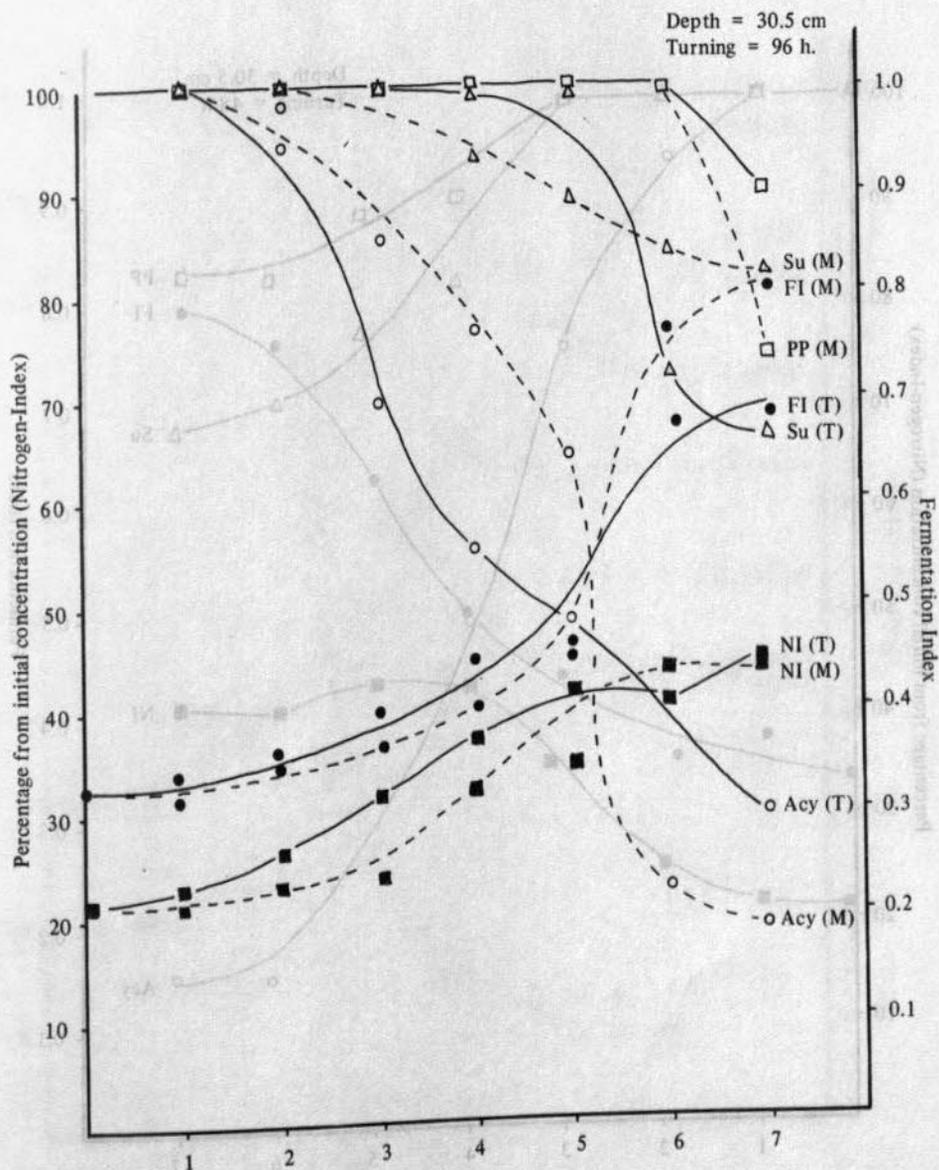
Figure 3. Chemical changes during fermentation. The depth of the beans was 30.5 cm and the frequency of turning was 72 h. (Legends as in Figure 1) (M) = middle (T) = top.

Total sugar. The assimilation of sugar of the cotyledon was also faster in daily turned beans (*Figures 1, 2* and *6*) followed by 72 h, 48 h and 96 h. At the end of fermentation, the residual sugar content were 44% in daily turned beans, 59% in 72-h, 69% in 48-h and 85% in 96-h turned beans. The results indicated a slower fermentation in less frequently turned beans. This effect had also been observed in the earlier work (Said, 1982). According to Berbert (1979), the total sugar content in fermented beans decreased to approximately 1/4 of its initial amount.
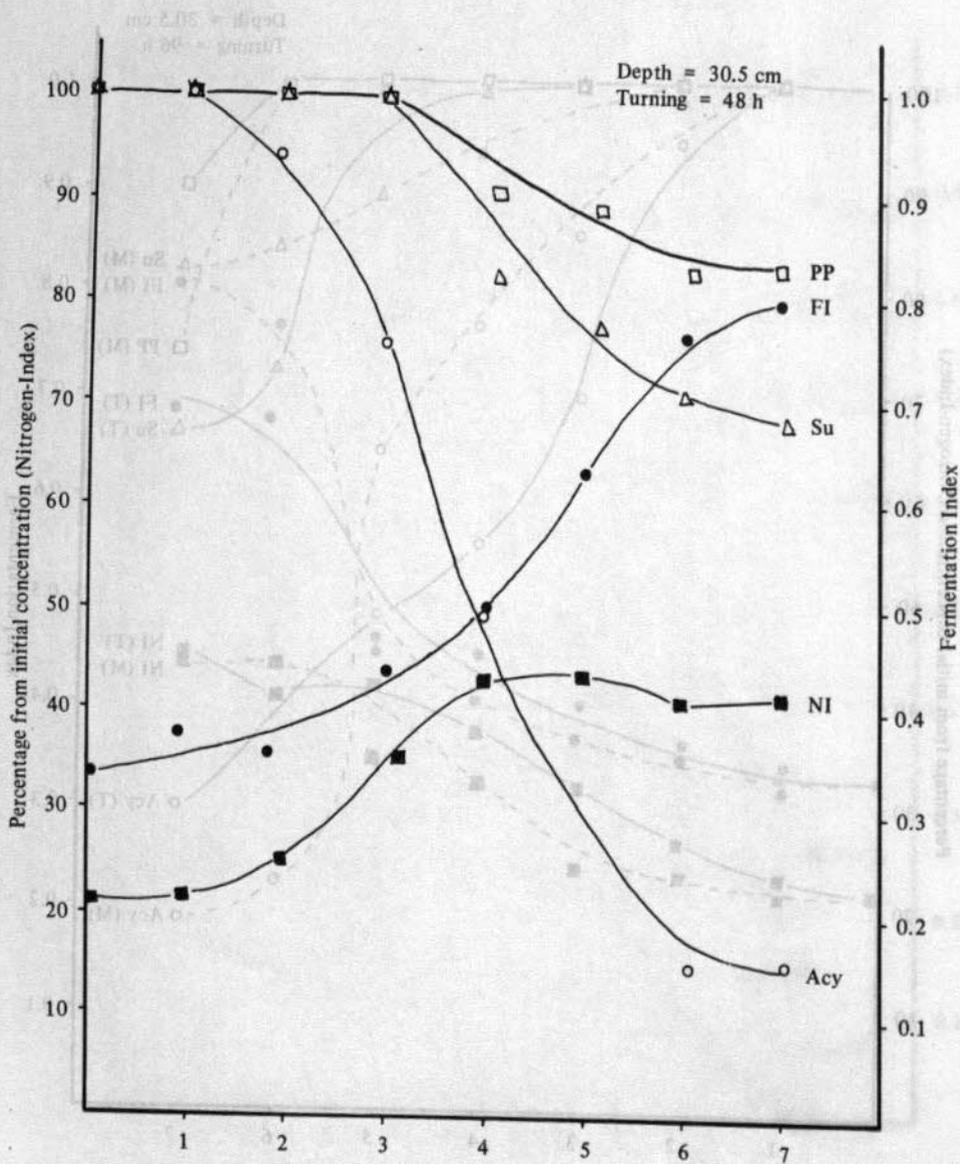
Figure 4. *Chemical changes during fermentation. The depth of the beans was 30.5 cm and the frequency of turning was 96 h, legends as in Figure 3.*

Fermentation index. Similar trend was also observed with the more frequently turned beans whereby faster fermentation and higher fermentation index were observed. The daily turned beans demonstrated an index of > 0.9, while the less frequently turned beans showed an index of < 0.8.

Nitrogen index. Similarly, it was shown that the daily-turned beans had a higher nitrogen index. Shallower box and daily turned beans demonstrated the highest index

Figure 5. *Chemical changes during fermentation. The depth of the beans was 30.5 cm and the frequency of turning was 48 h. Legends as in Figure 1.*

(*Figure 2*), indicating a higher proteolysis as a result of earlier acidification (Biehl and Adomako, 1983). Similar pattern was reported in the changes of nitrogen index as in Bracco *et al.* (1969), whereby the index reached its highest value after four days of fermentation. The decrease in the nitrogen index after this period might be due to the condensation reaction between quinones and amino compounds (Purr, 1972) to form additional products which would further darken the colour of the cotyledon.
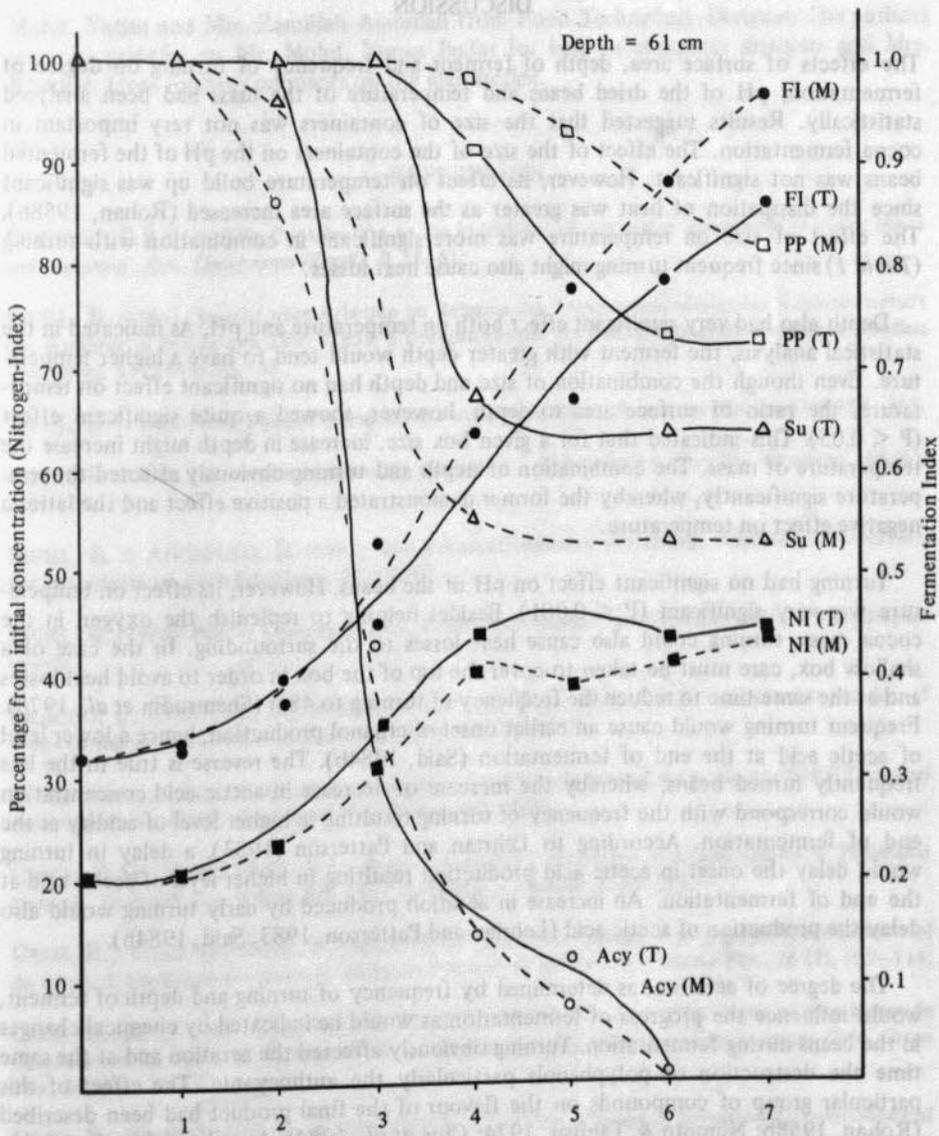
Figure 6. Chemical changes during fermentation. The depth of the beans was 61 cm and the frequency of turning was 24 hours. (Legends as in Figure 3).

Sensory evaluation. Sensory evaluation of the chocolate prepared from the dried beans showed that those fermented at a depth of 22.86 cm and turned daily was preferred. Flavour analysis by using the head space technique showed a higher proportion of isovaleraldehyde in fermented beans which were turned daily and at 48 h and also a higher proportion of ethanol, methanol, 2-methylfuran and diacetyl in fermented beans which were turned at 72 h and 96 h (Said, 1984a). The significance of these highly volatile compounds in cocoa flavour and their formation as a function of fermentation and roasting had been discussed by Ziegleder (1982).

DISCUSSION

The effects of surface area, depth of ferment and frequency of turning on degree of fermentation, pH of the dried beans and temperature of the mass had been analysed statistically. Results suggested that the size of containers was not very important in cocoa fermentation. The effect of the size of the containers on the pH of the fermented beans was not significant. However, its effect on temperature build up was significant since the dissipation of heat was greater as the surface area increased (Rohan, 1958b). The effect of size on temperature was more significant in combination with turning (*Table 1*) since frequent turning might also cause heat losses.

Depth also had very significant effect both on temperature and pH. As indicated in the statistical analysis, the ferment with greater depth would tend to have a higher temperature. Even though the combination of size and depth had no significant effect on temperature, the ratio of surface area to depth, however, showed a quite significant effect (P < 0.05). This indicated that for a given box size, increase in depth might increase the temperature of mass. The combination of depth and turning obviously affected the temperature significantly, whereby the former demonstrated a positive effect and the latter a negative effect on temperature.

Turning had no significant effect on pH of the beans. However, its effect on temperature was very significant (P < 0.001). Besides helping to replenish the oxygen in the cocoa mass, turning could also cause heat losses to the surrounding. In the case of a shallow box, care must be taken to cover the top of the box in order to avoid heat losses and at the same time to reduce the frequency of turning to 48 h (Shamsudin *et al.*, 1978). Frequent turning would cause an earlier onset of ethanol production, hence a lower level of acetic acid at the end of fermentation (Said, 1984b). The reverse is true in the less frequently turned beans, whereby the increase or decrease in acetic acid concentration would correspond with the frequency of turning resulting in higher level of acidity at the end of fermentation. According to Lehrian and Patterson (1983), a delay in turning would delay the onset in acetic acid production resulting in higher level of acetic acid at the end of fermentation. An increase in aeration produced by early turning would also delay the production of acetic acid (Lehrian and Patterson, 1983; Said, 1984b).

The degree of aeration, as determined by frequency of turning and depth of ferment, would influence the progress of fermentation as would be indicated by chemical changes in the beans during fermentation. Turning obviously affected the aeration and at the same time the destruction of polyphenols particularly the anthocyanin. The effect of this particular group of compounds on the flavour of the final product had been described (Rohan, 1958b; Niimoto & Tanitsu, 1974; Cros *et al.*, 1984). As indicated in the results, daily turning would encourage the oxidation of polyphenol. However overaeration would tend to slow down the process due to early tanning of the enzymes involved. As indicated by fermentation index, better fermentation was expected from the daily turned beans. Nitrogen index was also higher in the daily turned beans, suggesting a better proteolysis in the well-aerated beans. According to Biehl and Adomako (1983), proteolysis of protein would occur faster in highly acidified beans, as in the case of earlier turning and would facilitate aeration in a shallower box (*Figure 2*).

Mohd. Yatim and Mrs. Zamillah Abdullah from Food Technology Division. The authors are also grateful to Mr. Mohd. Yunus Jaafar for help in computer analyses and Mrs. Khatijah Idrus for her comments on the manuscript.

REFERENCES

dsf

t

HOWAT, G.R., POWELL, B.D. & WOOD, G.A.R. (1957). Experiments on cocoa fermentation in West Africa. *J. Sci. Fd. Agric.*, 8, 67–72.

HUSIN, A.B., SAID, M.B., SHIBANI, S.B. & MOHD. KHALID, N.B. (1982). Quality aspect of Penn. Malaysia smallholder cocoa beans. *MCGC-FAMA Workshop on Cocoa Quality and Grading, Kuala Lumpur, 1982.*

ISO (1977). Cocoa beans-Cut Test. *International Standard Organization (180) 1114–1977 (E).*

LEHRIAN, D.W. & PATTERSON, G.R. (1983). Cocoa fermentation. In *Biotechnology* (ed. H. – J. Rehm and G. Reed), Chap. 12, pp. 531–575. Weinheim: Verlag Chemie.

LIAU, H.T.L. (1976). Raw cocoa processing: Acidity and flavour, *Proc. East Malaysian Plrs. Assn. Cocoa-Cocou. Sem., Tawau, Sabah.* 1976, 184.

LOPEZ, A.S.F. (1983). Factors associated with cocoa bean acidity and possibility of its reduction by improved fermentation *Rev. Theobroma*, 13, 233–248.

NIIMOTO, H. & TANITSU, K. (1974). The quality assessment of cocoa beans produced in Nigeria, Sabah and Papua New Guinea. *Meiji Seika Kaisha Ltd., Tokyo.*

O.I.C.C. (1972). Electrometric pH determination of cocoa and chocolate product. *Anal. Method of O.I.C.C. 9 – E/1972.*

O.I.C.C. (1974). Small-scale preparation of sample of chocolate. *Anal. Method of O.I.C.C. 15 – E/1971.*

POWELL, B.D. (1983). Changes in cocoa bean availability. *Manuf. Conf.*, 9, 63–69.

PURR, A. (1972). Enzymatische vorgange in Kakobohnen wahrend der Fermentation bei anwendung der vakuum infiltration. *Ann. Technol. Agric.*, 21 (3) : 457–472.

QUESNEL, V.C. & LOPEZ, A. (1975). A sweat-box for fermenting small sample of cacao. *Trop. Agric. (Trinidad)*, 52, 309–316.

ROHAN, T.A. (1958a). Processing of raw cocoa. I Small-scale fermentation. *J. Sci. Fd. Agric.*, 9, 104–111.

ROHAN, T.A. (1958b). Processing of raw cocoa. II. Uniformity in heap fermentation and development of methods for rapid fermentation of West African Amelonado Cocoa. *J. Sci. Fd. Agric.*, 9, 542–551.

ROHAN, T.A. & STEWART, T. (1966). The precursors of chocolate aroma: Changes in the free amino acids during the roasting of cocoa beans. *J. Fd. Sci.*, 31, 202–205.

ROHAN, T.A. & STEWART, T. (1967). The precursors of chocolate aroma: Production of free amino acids during fermentation of cocoa beans *J. Fd. Sci.*, 32, 395–398.

SAID, M.B. (1982). Cocoa fermentation trials in Malaysia. *Report submitted to the Rubber Grower Association. Kuala Lumpur.*

SAID, M.B. & SHAMSUDIN, S.B. (1983). Cocoa fermentation practices in Malaysia. *Proc. MARDI – MIFT Seminar on Towards better Acceptance of Malaysian Cocoa, Serdang, Selangor. 1983,* 13.

SAID, M.B. (1984a). Studies on the formation of highly volatile compounds in cocoa beans (submitted for publication).

SAID, M.B. (1984b). Unpublished results.

SCOTT, T.A. JR. & MELVIN, E.H. (1983). Determination of dextran with anthrone. *Anal. Chem.*, 25, 1656–1661.

SHAMSUDIN, S., IDRUS, A.Z. & HASSAN, M.H. (1978). Preliminary efforts to improve the quality of cocoa beans. *Proc. Intn. Conf. Cocoa – Cocons. Kuala Lumpur. 1978*, 415.

VANDER-FORST, N. (1984). Calculation of the optimum time and number of turns in the fermentation of cocoa in boxes. *9th. Intn. Cocoa Res. Conf. Lome, Togo, 1984.*

ZIEGLEDER, G. (1982). Highly volatile cocoa flavour constituents as indicators during cocoa processing. *Rev. Choc. Conf. Bakery*, 7, 17–22.

Current Practices of Primary Processing and the Quality of Cocoa Beans in Sabah

K. LI AND LEE MING TONG

Department of Agriculture, Kota Kinabalu, Sabah.

This paper presents the results of a survey conducted on the current practices of primary processing and the quality of cocoa beans collected from 174 fermentaries in the seven major cocoa growing districts of Sabah.

The majority of the fermentaries were well constructed and managed. Variations observed in the different stages of processing were identified.

The quality of the cocoa beans were found to be satisfactory in bean size and high in butter content. They were well fermented and contained very few defective beans. However, some samples were high in moisture content and the major drawbacks were high shell content, large variation in size and high bean acidity.

Comparing the cotyledon pH of beans processed under various conditions, the results indicated that partial sun drying or maturation when practised alone or in combination with some other procedures were effective in providing a satisfactory cotyledon pH.

The State of Sabah is the major producer of cocoa in Malaysia. In 1982, Sabah produced 29,605 t of dry cocoa beans (Department of Statistics, Malaysia, 1984) amounting to about 49% and 1.7% of the total Malaysian and world production respectively (Gill & Duffus, 1984). Estimated from the total planted area of 117,542 ha in 1982 (Department of Agriculture, Sabah, 1983), the annual production of dry cocoa beans in Sabah would likely exceed 120,000 t by the turn of the century which is over 5% of the estimated total world production (Holdorff & Magiera, 1983).

At present, there is only one established secondary cocoa processing factory in Sabah consuming about 5% of the cocoa. The bulk of the beans is exported to various countries including Singapore, Australia, U.S.A. and the Netherlands. In the world market, Malaysian cocoa was generally traded at a price discount against the quality African cocoa because of some weaknesses in quality and inconsistency in supply. Sabah beans are sometimes acknowledged to be less acidic and bigger in bean size when compared with the beans from Peninsular Malaysia. However, improvements in quality are very much required to establish the confidence of the buyers and thus our competitive position in the world trade. This study is an assessment of the primary processing methods practised and the quality of the dry cocoa beans produced in the State. It is hoped that it will serve as a basis for further research towards the achievement of a better cocoa bean quality.

METHODS

Cocoa bean samples were collected from the fermentaries of the seven major cocoa growing districts of Sabah, namely Tawau, Semporna, Kunak, Lahad Datu, Sandakan, Tenom and Kudat (including Kota Marudu and Kota Belud) during the period Mar 1982 to Jan 1984. Each sample was submitted with a detailed questionnaire on the facilities at the fermentaries and the methods of processing. The quality of the samples was assessed according to the methods described previously (Li & Lee, 1983). Of the 475 samples tested, about 15% were randomly selected for the determination of butter content. In the analysis, 3 g of cocoa nib were briefly digested in HCl and then extracted with petroleum ether $40^{\circ}-60^{\circ}C$ (O.I.C.C., 1972).

A Student's t-test was used to compare the pH of samples subjected to some fermentation and drying conditions which were usually related to the reduction of bean acidity. These included the drainage of pulp juice in rattan baskets prior to fermentation, the use of comparatively shallow boxes (<0.76 m in depth), maturation, skin drying, partial and complete sun drying. Samples not subjected to any of these treatment conditions served as the "control".

RESULTS AND DISCUSSION

Fermentation and Drying Practices

A total of 174 fermentaries was assessed in this study which was estimated to cover over 60% of the fermentaries in the State. It was reported that 60% of the Malaysian cocoa was produced by smallholders (Mamot Said & Shahrir Shamsuddin, 1983). In contrast, the majority of cocoa land in Sabah was owned by estates occupying more than 40 ha per holding. In 1982, only 28% of the areas were planted with cocoa were classified under smallholding, settlement schemes and cooperatives (Department of Agriculture, Sabah, 1983). A large proportion of the smallholdings did not possess any fermentation facilities and they resorted to selling wet beans to commercial processing centres mostly operated near town areas. Similar to places outside Sabah, bigger estates usually practised a regular schedule of field management, harvesting and processing and produced a more consistent bean quality compared with that from smallholdings which was more likely to be variable. Some of the inferior wet beans would inevitably be passed on to the processing centres. Owing to reasons such as the availability of finance and expertise, the structure and the practice of fermentaries varied with the size, location and nature of the holdings.

Harvesting. Cocoa pods were mostly opened in the fields and transported to fermentaries in woven plastic sacks (65%) and rattan baskets (23%). Smallholders normally practised centralized pod splitting and metal containers were sometimes used to hold wet beans. The majority (51%) of processors opened the cocoa pods within 24 h after harvesting and 90% managed to do so within four days. However, a minority (5%) delayed splitting by up to a duration of seven to 11 days, a period likely to cause some adverse effects on the bean quality. After pod splitting, the wet beans were put directly into fermentation boxes unless a preliminary drainage process in rattan baskets was desired. The drainage of pulp juice in rattan baskets, prior to fermentation was practised by 38.4% of processors ranging from a period of 1 to 48 h and with an average of 16½ h.

For the smallholders who sold wet beans, an extended period of storage of wet beans was not uncommon due to the lack of proper arrangements for transportation.

Fermentation. The amount of wet beans fermented varied considerably from 46 kg

to 33,000 kg per batch. Essentially all the fermentaries under survey fermented the beans in wooden boxes of various sizes. The average box dimensions measured 1.45 m (length) x 0.91 m (width) x 0.76 m (depth). Almost all the boxes were physically well constructed and provided with some drainage and ventilation openings. The actual efficiency of ventilation, however, varied according to the total spaces available and the frequency of clearing the holes or slits. The boxes were either arranged horizontally on flat ground (60%) or in tiers (40%), the latter being more popular in bigger estates and newly constructed fermentaries.

In general, many of the fermentation boxes were over-sized and under-ventilated. Only 7% of the boxes were under 0.45 m in depth whereas 47% were deeper than 0.76 m, the upper limit recommended by the Department of Agriculture (Wyrley-Birch, 1978). The arrangements of boxes might also limit the degree of ventilation, this is especially true when the boxes were all fixed together leaving very little surface for ventilation and drainage. An over-sized and under-ventilated box would inevitably enhance the build-up of acids imposing a problem of their removal afterwards.

The schedule of fermentation was rather standardized. The majority of fermentaries (60%) practised seven days of fermentation in boxes whereas 22% and 14% performed six and eight days of fermentation respectively. Most of the beans were covered with gunny or plastic sacks throughout or during the initial stage of fermentation. Turning was carried out by moving the beans from one box into the next box and the turning schedule was mostly daily (64%). Sixteen per cent of processors turned less frequently such as every 48 h and the remaining 20% turned more frequently. Metallic spades and shovels were often seen in the fermentaries giving a common source of metal contamination which should be avoided.

The maturation process has been introduced as a means of reducing bean acidity (Liau, 1976a; 1976b). The conditions of this process could be achieved by performing five turns a day in a box or on a platform during the last two days of fermentation. In this study, maturation is grossly classified as frequent turnings (three turns or more) during the later stage of fermentation without the introduction of any form of heating. Of all the fermentaries, 21% practised some degree of maturation either in a box (45%), on a platform (52%), or in both (3%). The majority (73%) carried out these extra turnings only for one day and the rest for two days.

Drying. Complete sun drying was practised by 8% of the processors which were all located in Kudat district where the holdings were small. The rest of the processors either performed partial sun drying (22%) or complete artificial drying (70%).

Artificial drying was mostly (80%) carried out on single rectangular platforms under the indirect heating of hot air. Some of the driers were fitted with ventilation fans to enhance air circulation. In some fermentaries, one burner was built to serve two platforms heated concurrently or alternatively (Hiew, 1983; Kassim Chow, 1983; Yee, 1983). The multistage drier was also used by some processors (16%). The cocoa beans were subjected to three stages of temperature regime, the initial one-third of the drying time being under a slow residue heating (skin drying) and the rest of the time under progressively higher temperatures (Anselmi, 1976). Some of these multi-stage driers were modified with an extra platform for performing maturation prior to skin drying. Skin drying under artificial heating was practised by 19% of fermentaries mostly for a period of one day.

Both solid and diesel fuels were used in the fermentaries depending on the design of the burners, the former being preferred by most (78%) as firewood or coconut husks were

3

readily available and economical. Some of the artificial driers were built with removable roofs to facilitate sun drying and artificial drying to be carried out concurrently during sunny days. In some cases of partial sun drying, the beans were firstly dried in the sun and subsequently transferred to an artificial drier for the completion of drying.

The total drying time for cocoa beans depended largely on the amount of beans and the type of drier used. Some processors practised continuous drying while the others rested at night. The majority (88%) required one to three days. The drying temperature was usually not recorded.

After drying, the beans were put into new jute sacks for storage and exportation. Mechanical grading of beans was carried out by a small number of estates. Some processors used plastic or wiremesh sieves to sort out double beans, flat beans and debris. With the recently introduced policy of buyers to price the beans according to bean size, the processors have notably resorted to some forms of bean sorting and grading.

Cocoa Bean Quality

Results of bean quality assessments are summarised in *Tables 1 — 4*. As a result of the unusually long drought experienced in Sabah for the first six months of 1983 and the infestation by the cocoa pod borer *Acrocercops cramerella* Sn., some bean quality parameters were adversely affected during the second year of sampling. For comparison, results of the 190 samples collected during the first year (Mar 82 to Feb 83) are also presented.

Bean size, shell content and size variation. Bean size was generally satisfactory but shell content was high. These observations were in good agreement with those reported by Holdorff & Magiera (1983). The variability of bean size was also high. All these three factors appeared to have deteriorated because of the drought. Furthermore, many of the young cocoa trees coming into production also contributed to some extent on the observed high bean count and size variation. In order to comply with the grading requirements, many processors would likely carry out sorting of beans to provide the desirable bean and as a result, the size variation would be reduced. Attempts on the reduction of shell has not been reported in Sabah. However, shell content can be decreased by the technique of pulp reduction (Shepherd & Chick, 1983). Mechanical reduction of shell during the process of drying has also been suggested.

Moisture content. Mean moisture content values were generally acceptable except for Kudat district where the majority of samples were not dry enough as a consequence of the common practice of complete sun drying. In Sabah, sole dependence on solar energy as such is not practical because the main cocoa cropping seasons usually coincide with the rainy periods of the year. Those processors who could not afford to install an artificial drier would be better off selling wet beans.

In general, 18% of the samples possessed moisture contents over 7.5% suggesting that the process of drying and the existing storage conditions needed improvement.

Cotyledon pH. The mean cotyledon pH of 5.08 observed was in good agreement with reported values (Shepherd, 1976; Holdorff and Magiera, 1983). Although simple measurements of pH did not necessarily reveal the acidity aspect of the flavour, it has generally been felt that the pH range of 5.0 to 5.6 was acceptable for Malaysian beans as a prerequisite for a satisfactory chocolate flavour (Upali Malaysia, 1982; Shepherd, 1982). Of all the beans assessed, 39% fell into this acceptable range whereas the majority (52%) were still considered as acidic (pH <5.0).

4

TABLE 1. BEAN SIZE AND SIZE VARIATION OF SOME SABAH COCOA BEANS

District	Tawau	Semporna	Kunak	Lahad Datu	Sandakan	Tenom	Kudat	Total
No. of Fermentaries[a]	55	15	14	21	29	18	22	174
No. of Samples	136	32	47	41	110	75	34	475
Bean Count (No. per 100g)								
Mean	100.1 (96.6)[b]	108.3 (98.4)	103.3 (96.0)	118.2 (NB)	103.1 (103.4)	110.0 (104.3)	104.0 (95.3)	105.1 (100.2)
Range	64.8-156.8	79.9-172.5	57.3-157.8	83.7-160.8	79.0-130.0	75.2-186.8	64.0-136.2	–
S.D.	16.9	18.8	18.5	19.0	9.2	18.9	15.7	–
No. of Samples with Bean Count > 120	17 (0)[b]	5 (0)	8 (0)	16 (NB)	5 (2)	12 (0)	7 (0)	70 (2)
Bean Above 1/3 Av. Bean Wt. (% No.)								
Mean	12.4	13.8	15.2	18.1	13.6	16.2	11.0	14.0
Range	0-28	4-25	4-29	5-28	1-31	2-31	3-23	–
S.D.	6.1	6.4	5.6	5.9	5.2	6.0	5.1	–
Beans Below 1/3 Av. Bean Wt. (% No.)								
Mean	8.8	11.6	9.3	11.6	11.0	12.5	10.2	10.5
Range	0-39	3-22	0-23	2-22	3-28	3-28	1-21	–
S.D.	6.6	5.4	5.5	5.1	4.7	5.2	5.2	–
Total Size Variation (% No.)								
Mean	21.2 (17.2)[b]	25.4 (17.5)	24.5 (19.3)	29.7 (NB)	24.6 (22.8)	28.7 (26.8)	21.2 (16.8)	24.5 (21.1)
Range	0-47	7-46	5-44	12-48	8-45	14-53	5-43	–
S.D.	10.4	10.1	9.7	9.4	6.8	8.6	8.1	–

a These figures also apply to *Tables 2* and *3*.
b Figures within brackets are mean values of samples collected during the period of March 1982 to February 1983.
NB No bean samples were collected from Lahad Datu before March 1983.

5

TABLE 2. SHELL CONTENT, MOISTURE CONTENT, COTYLEDON pH AND BUTTER CONTENT OF SOME SABAH COCOA BEANS

District	Tawau	Semporna	Kumak	Lahad Datu	Sandakan	Tenom	Kudat	Total
No. of Samples[a]	136	32	47	41	110	75	34	475
Shell content (%)								
Mean	15.3[b] (14.9)	16.9 (15.6)	16.1 (15.2)	17.4 (NB)	15.4 (15.3)	15.8 (15.5)	15.9 (13.9)	15.8 (15.1)
Range	11.4-21.5	13.4-25.6	13.4-21.7	11.0-21.1	12.7-20.2	11.0-23.1	12.4-21.6	—
S.D.	1.56	2.52	1.92	2.06	1.46	1.89	2.01	—
Moisture Content (%)								
Mean	6.66	6.73	6.80	7.26	6.49	6.64	7.70	6.76
Range	5.29-12.2	5.10-10.2	4.13-9.70	4.66-11.7	4.76-9.79	4.71-9.93	3.99-10.3	—
S.D.	0.96	1.07	0.90	1.25	0.79	1.03	1.53	—
No. of samples with Moisture Content < 5.0%	2	0	1	1	1	2	2	9
No. of Samples with Moisture Content > 7.5%	19	5	7	13	10	11	20	85
Cotyledon pH								
Mean	5.01	5.09	4.91	5.19	5.03	5.05	5.65	5.08
Range	4.52-6.30	4.48-6.20	4.63-5.60	4.67-6.34	4.50-5.88	4.50-6.75	4.61-6.93	—
S.D.	0.28	0.38	0.24	0.38	0.28	0.41	0.64	—
No. of Samples with pH < 5	78	15	31	15	55	45	6	245
No. of Samples with pH > 5.6	6	5	0	7	4	6	17	45
Butter Content (% dry nib)								
No. of Samples	22	6	8	6	20	12	6	80
Mean	58.4	58.2	59.1	56.8	58.8	59.0	60.5	58.7
Range	55.8-62.7	57.2-59.3	56.7-61.7	55.6-59.0	56.5-62.7	56.9-61.7	58.8-63.0	—
S.D.	1.88	0.97	1.47	1.29	1.92	1.29	1.82	—

[a] These figures do not apply to Butter Content,
b, NB – Refer to *Table 1*.

6

TABLE 3. RESULTS OF CUT TEST OF SOME SABAH COCOA BEANS

District	Tawau	Semporna	Kunak	Ladah Datu	Sandakan	Tenom	Kudat	Total
No. of Samples	136	32	47	41	110	75	34	475
Degree of Fermentation (% No.)								
Fully Brown								
Mean	97.1	96.3	99.0	97.2	98.0	96.0	96.8	97.3
Range	32-100	85-100	87-100	78-100	87-100	13-100	79-100	—
S.D.	7.2	4.6	2.7	5.1	3.0	13.5	5.5	—
Partly Brown								
Mean	2.0	3.1	1.1	2.3	1.7	3.6	2.6	2.4
Range	0-35	0-12	0-13	0-18	0-11	0-76	0-15	—
S.D.	4.0	3.7	2.6	4.1	2.4	12.1	3.8	—
Purple								
Mean	0.6	0.6	0.04	0.5	0.3	0.4	0.7	0.4
Range	0-15	0-3	0-2	0-7	0-4	0-11	0-8	—
S.D.	2.0	1.1	0.3	1.3	1.2	1.5	1.9	—
Slaty								
Mean	0.2	0	0	0	0.02	0.04	0.03	0.07
Range	0-24	—	—	—	0-1	0-2	0-1	—
S.D.	2.1	—	—	—	0.13	0.28	0.17	—
No. of Samples with >5% Purple Beans	4	0	0	1	0	2	2	9
No. of Samples with >3% Slaty Beans	1	0	0	0	0	0	0	1
Mouldy Beans (% No.)								
Mean	0.4	0.6	0.09	0.6	0.2	0.6	0.5	0.4
Range	0-4	0-3	0-2	0-17	0-5	0-15	0-6	—
S.D.	0.8	0.9	0.4	2.6	0.8	2.0	1.3	—
No. of Samples with >3% Mouldy Beans	2	0	0	2	2	2	2	10
Insect Infested Beans (% No.)								
Mean	0.1	0.3	0.2	0.2	0.09	0.2	0.09	0.14
Range	0-3	0-3	0-6	0-6	0-1	0-4	0-3	—
S.D.	0.4	0.8	1.0	0.5	0.3	0.6	0.5	—
No. of Samples with >3% Infested Beans	0	0	1	1	0	1	0	3
Flat and Shrivelled Beans (% No.)								
Mean	1.5 (0.8)b	1.8 (0.3)	1.4 (0.3)	2.7 (NB)	0.6 (0.4)	2.7 (1.4)	2.4 (0.9)	1.7 (0.7)
Range	0-14	0-10	0-14	0-11	0-5	0-20	0-8	—
S.D.	2.4	2.6	2.8	3.0	1.0	4.0	2.3	—
No. of Samples with >3% Flat and Shrivelled Beans	20b (5)	5 (0)	7 (1)	12 (NB)	2 (1)	16 (5)	9 (0)	71 (12)

b, NB – Refer to *Table 1*

TABLE 4. COMPARISON OF COTYLEDON pH OBTAINED UNDER VARIOUS PROCESSING CONDITIONS

Processing Conditions	No. of Samples	Mean	Cotyledon pH Range	S.D.	Percentage of Samples with pH < 5.0	5.0 – 5.6	> 5.6	Level of Significance[a]
Control[b]	91	5.01	4.50 – 6.93	0.39	55	37	8	NS
Drainage (of pulp juice)	50	4.98	4.68 – 5.60	0.24	60	40	0	NS
Box depth < 0.76 m	19	5.01	4.54 – 6.40	0.37	58	37	5	NS
Maturation	17	5.07	4.86 – 5.40	0.14	35	65	0	NS
Skin drying	42	4.96	4.68 – 5.90	0.28	69	26	5	NS
Partial sun drying	19	5.33	4.87 – 6.75	0.47	32	42	26	1%
Drainage + Partial sun drying	12	5.10	4.62 – 5.78	0.32	33	58	9	NS
Drainage + Maturation + skin drying	17	5.23	4.85 – 6.37	0.39	29	53	18	5%
Drainage + Maturation	11	5.07	4.70 – 5.90	0.32	55	36	9	NS
Drainage + Skin drying	14	4.98	4.81 – 5.77	0.30	71	22	7	NS
Box depth < 0.76 m + Partial sun drying	20	5.16	4.73 – 5.75	0.26	25	70	5	NS
Box depth < 0.76 m + Complete sun drying	15	5.85	5.18 – 6.78	0.50	0	40	60	0.1%

[a] Comparison with the control using a Student's t-test,
[b] Control samples were not subjected to any of the treatment conditions.
NS Statistically not significant.

8

The mean pH of samples from Kudat district was notably higher than those reported for other districts. Possible reasons were that the majority (70%) of the fermentation boxes used in Kudat measured less than 0.6 m in depth and that 68% of the processors practised partial or complete sun drying. Some of the beans possessing a high pH would likely be due to infestation by putrefactive micro-organisms as a result of prolonged wet conditions. Similar problems also arose during the peak cropping seasons when some of the under-facilitated fermentaries failed to cope with the large quantity of in-coming beans.

Butter content. The butter contents of the beans assessed were consistently well in excess of the normally required 55%. The mean value of 58.7% was slightly higher than the 57.5% reported by Wadsworth and Bondt (1980). Previous assessments on 39 cocoa clones in Sabah showed a mean fat content of 59.7% ranging from 53.5 to 63.6% (Liau, 1979).

Degree of fermentation. The beans were essentially well fermented with very few slaty beans. Only 2% of the samples contained more than 5% of fully purple beans, a level suggested by Selvaraj (1983) as the upper limit of the acceptable under-fermented beans in terms of their effects on the chocolate flavour.

Other defects. The degree of mouldiness and insect infestation was very low. The number of flat and shrivelled beans was rather high; however, they would be much lower if expressed in terms of weight as they carried less than one-third of the mass of the otherwise normal beans. The amount of flat beans has notably increased after the drought. Furthermore, the presence of clustered beans, a defect normally not serious in Sabah, was high in bean samples not protected from the infestation by the pod borer. Other defects such as germinated beans, broken beans and the presence of foreign matter were negligible.

Effects of Some Processing Conditions on Cotyledon pH

Acidity has been one of the focal points of cocoa research in Malaysia. Various methods have been suggested to reduce cocoa bean acidity. These have included the reduction of pulp, use of shallow boxes, application of enzymes, forced aeration, inoculation of yeast, maturation and sun drying (Li, et al., 1983; Mamot Said & Shahrir Shamsuddin, 1983). In Sabah, apart from maturation and sun drying, the use of other methods has not been reported. A few procedures such as the drainage of pulp juice prior to fermentation, skin drying and partial sun drying were practised in some fermentaries although the intention might be more of a matter of convenience and fuel economy.

In this study, the cotyledon pH obtained under these processing conditions or a combination of them was compared with the control and the results are summarized in *Table 4*. Results of the conditions not commonly practised (<10 samples) were not presented. It has to be considered that this was not a trial designed to compare the methods concerned but a collection of observations from fermentaries each having its own features and management characteristics.

Results indicated that three conditions namely, (A) partial sun drying, (B) drainage of pulp juice plus maturation plus skin drying and (C) box depth less than 0.76 m plus complete sun drying produced beans with pH values significantly higher than that of the control samples. Apart from the mean values, both box depth less than 0.76 m plus partial sun drying and maturation alone gave the highest percentages of beans within the pH range of 5.0 to 5.6. On the other hand, complete sun drying or any of its combination

9

did not produce a single acidic sample (pH<5.0), however, the majority (56.7%) of samples possessed pH above 5.6. Maturation was defined as the oxidation of cocoa acids under a moist, warm and aerated environment (Liau, 1980). In principle, both sun drying and skin drying should provide a similar condition. However, results appeared to show that skin drying was not as effective in reducing acidity. The various environmental regimes for the removal of acids at the later stage of fermentation needed to be more specifically defined.

In general, the study appeared to indicate that partial sun drying or maturation when practised alone or in combination with some other conditions was effective in improving cotyledon pH. This finding was in agreement with the study on the adoption of the maturation process in two slightly different systems of processing which revealed that the maturation method incorporated into and integrated processing system was effective in producing a satisfactory cotyledon pH. (Li, et al., 1983).

CONCLUSION

The present study revealed that in Sabah the majority of fermentaries especially those in estates were well constructed and managed. However, considerable variations existed in the different stages of processing and these have inevitably led to some inconsistency in the resulting bean quality. As for the bean quality factors assessed, the bean size, butter content, degree of fermentation and most aspects of defective beans were satisfactory. The high percentages of flat beans and under-dried beans, however, needed attention. There were also drawbacks because of high shell content, size variation and bean acidity.

To overcome the quality poblems so far discussed is essentially a matter of awareness and adoption of the appropriate precautions and techniques already available through research studies. Since most of the cocoa beans were processed in large holdings, it is anticipated that the introduction of changes to the existing systems or the adoption of the appropriate structure and techniques in newly built fermentaries may not be an impossible task. At the same time, the development of cocoa machinery such as more controllable driers and bean sorters would likely evolve into a competitive industry supportive to the effort of achieving a desirable bean quality.

Besides the economic aspect of the quality, the acceptance of cocoa beans would ultimately be dependent on the flavour developed in the end product. The flavour of Malaysian beans has not been specifically defined nor its potential fully exploited under the presently adopted processing procedures. The development of a more defined and controllable primary processing system for the improvement of flavour would be of significant importance towards the total acceptance of Malaysian cocoa beans in the future.

ACKNOWLEDGEMENT

REFERENCES

ANSELMI, J.A. (1976). New Barico drier and fermentary. *Proc. East Malaysia Plrs. Assn. Cocoa-Cocon. Sem. Tawau, Sabah 1976*, 173.

DEPARTMENT OF AGRICULTURE, SABAH (1983). *Agricultural Statistics of Sabah 1982*, Kota Kinabalu. Unpublished.

DEPARTMENT OF STATISTICS, MALAYSIA (1984). *Monthly Statistics, Sabah* p. 33. Kota Kinabalu.

GILL & DUFFUS (1984) . *Cocoa Market Report No. 311*, London.

HIEW, K.S. (1983). Planter's hot-air solid fuel dryer. *SASS Seminar on Primary Cocoa Processing and Quality Control, Tawau, Sabah 1983.*

HOLDORFF, C. & MAGIERA, E.J. (1983). Market prospects for cocoa in the 1980's with specific regard to Malaysian cocoa. *Bengkel Perlaksanaan Skim Mengred Dan Pengesahan Koko, Kuala Lumpur 1983.*

KASSIM CHOW (1983). G.E.S. solid fuel dryer. *SASS Seminar on Primary Cocoa Processing and Quality Control, Tawau, Sabah 1983.*

LI, K. & LEE, M.T. (1983). Study of the processing practices and the quality of cocoa beans in Sabah, some preliminary results. *SASS Seminar on Primary Cocoa Processing and Quality Control, Tawau, Sabah 1983.*

LI, K., LIAU, H.T.L. & LEE, M.T. (1983). A brief account of the reduction of cocoa bean acidity and recent experience in two fermentaries in Sabah. *SASS Seminar on Primary Cocoa Processing and Quality Control, Tawau, Sabah 1983.*

LIAU, H.T.L. (1976a). *Raw Cocoa Processing.* Technical Bulletin No. 2. Kota Kinabalu: Department of Agriculture, Sabah.

LIAU, H.T.L. (1976b). Raw cocoa processing, acidity and flavour. *Proc. East Malaysia Plrs. Assn. Cocoa-Cocon. Sem. Tawau, Sabah 1976*, 184.

LIAU, H.T.L. (1979). Unpublished results. Department of Agriculture, Sabah.

LIAU, H.T.L. (1980). The criteria and mechanism for the removal of cocoa bean acidity. *Proc. Int. Conf. on Cocoa and Coconuts, Kuala Lumpur 1978*, 425.

MAMOT SAID & SHAHRIR SHAMSUDDIN (1983). Cocoa fermentation practices in Malaysia. *Proc. MARDI/MIFT Sem. on Towards Better Acceptance of Malaysian Cocoa, Kuala Lumpur 1983*, 13.

O.I.C.C. (1972). Analytical methods of the Office International du Cacao et du Chocolat. *Rev. Int. Choc. (RIC)27*, 8a-E/1972.

SELVARAJ, D. (1983). Technical problems faced by Malaysian chocolate manufacturers. *Proc. MARDI/MIFT Sem. on Towards Better Acceptance of Malaysian Cocoa, Kuala Lumpur*, 37.

SHEPHERD, R. (1976). Large scale processing of cocoa beans, temperature and acidity trends. *Planter, Kuala Lumpur 52*, 311–322.

SHEPHERD, R. (1982). Some highlights of cocoa bean quality improvement investigations co-ordinated by the Rubber Growers' Association Cocoa Quality Sub-committee. *MCGC-FAMA Workshop on Cocoa Quality, Grading and Specifications, Kuala Lumpur 1982.*

SHEPHERD, R. & CHICK, W.H. (1983). Prospects and problems of Malaysian cocoa beans. *Proc. MARDI/MIFT Sem. on Towards Better Acceptance of Malaysian Cocoa, Kuala Lumpur 1983*, 23.

UPALI MALAYSIA (1982). Manufacturers' quality requirements of cocoa beans. *MCGC-FAMA Workshop on Cocoa Quality, Grading and Specifications, Kuala Lumpur 1982.*

WADSWORTH, R.N. & BONDT, D. (1980). Malaysian cocoa — some observations on its quality and value. A report issued to the plantation groups in Malaysia on 18th Apr 1980.

WYRLEY–BIRCH, E. (1978).*Cocoa Planting Manual*, p. 51. Kota Kinabalu: Department of Agriculture, Sabah.

YEE, G.L.F. (1983).AGRI–GP5 hot air dryer. *SASS Seminar on Primary Cocoa Processing and Quality Control; Tawau, Sabah 1983.*

Cocoa Fermentation and Problem of Acidity, Over-Fermentation and Low Cocoa Flavour

B. BIEHL

*Botanisches Institut, Technische Universitat Carolo Wilhelmina Braunschweig,
West Germany*

*On the basis of simplified description of the complex fermentation and the flavour
forming reactions, some alternative views of the causes of high acidity and overfermenta-
tion during large-scale box fermentation and strongly aerated fermentations are given.
The changes in the internal bean pH are considered. pH decreases to about 4.5 in both
conventional box fermentation and strongly aerated fermentation, especially by absorp-
tion of acetic acid in high amounts. The increase of pH at the end of fermentation by
aeration in order to reduce acidity is assumed to be caused by a microbial process which
initiates overfermentation and destroys flavour precursors. A slow decrease of internal
pH during fermentation to not less than pH 5.0 to 5.5 without final increase and a slow
increase in temperature would be preferable. The results of own studies about germina-
tion-like reactions, pH dependent proteolysis and flavour potential are cited in order to
support the views described.*

In this paper an attempt is made to explain why strong acidity or hammy off-flavour in
cocoa beans results from conventional large-scale fermentations of cocoa beans and why
cocoa flavour is not developed in full extent under such conditions. The explanation is
based on literature on the process, especially aeration, and on own results about proteo-
lysis and premortem reactions in the seeds.

Although much knowledge has been accumulated in the last 90 years about the tech-
nology of cocoa fermentation and about biochemical reactions in the seeds, especially
during the Fifties and Sixties, it is still difficult to describe definitely the compounds
which are specific to cocoa flavour, the differences in flavour in beans from various pro-
ducing countries and the optimal run of fermentation in order to produce the best
possible flavour.

Advanced methods today allow the separation or identification of hundreds of flavour
components (Van Straten, 1977; Maniere & Dimick, 1979), but thus far, those which
are specific to cocoa flavour are not well defined.

It is well known that flavour is not developed during roasting without foregoing
fermentation. Flavour precursors are formed during fermentation. Reducing sugars,
amino acids and peptides (Rohan, 1963; 1972), (Mohr *et al.*, 1971) and in some unclear
way polyhydroxyphenols (Rohan, 1972) are flavour precursors as substrates for Maillard
reactions. This reaction takes place in the course of much food processing and is not
unique to cocoa.

There are still some serious problems involving the quality of raw cocoa. Alternative
devices and procedures different from traditional heap or box fermentation have been
tried out in an attempt to overcome these problems on a practical scale, *e.g.* the tray
fermentation developed by Allison & Rohan (1958), rotary systems designed by Halifax

& Goebel in Brasil in the Sixties (Biehl, 1965), and postaeration, pulp pressing and shallow box fermentation, developed in Malaysia in the Seventies (Liau, 1978), (Chong et al., 1978).

Although promising in certain respects, they do not seem to have solved adequately such main problems as acidity, hammy off flavours or low cocoa flavour. Besides other possible reasons, most significant is the fact that we do not know enough about the reactions of flavour development during fermentation. Further, there is no concrete definition and no unequivocal way of estimating flavour and quality.

The cut test allows only the detection of fungi, insects and unfermented beans and gives an unsatisfactory indication of the progress of fermentation by counting purple and brown beans. These are indirect indicators, giving no idea of the flavour characteristics.

It was recognized about thirty years ago that during heap fermentation (Rohan, 1957) and box fermentation (Biehl, 1961), the complex process runs very heterogeneously, resulting in heterogeneous raw cocoa beans. It was shown that non-uniform aeration was responsible. The alternative devices mentioned above are all suitable for reducing this heterogeneity by more uniform aeration. The most essential observation was that aeration controls fermentation (Biehl 1961; 1965; Quesnel, 1968). Heat development, acetic acid formation and consequently the degradation of the pulp, the death of the seeds and postmortem reactions in the beans, which are known to be responsible for the formation of flavour precursors, all depend on aeration. Thus, one should assume that the regulation of aeration could solve serious problems mentioned above. This has not been achieved up to now. Why?

- Although aeration controls fermentation we do not have satisfactory means to control aeration.

- There are some peculiar pre- and postmortem reactions affecting proteolysis within the seeds which have not been considered but which are assumed to be important to flavour and quality (Biehl & Adomako, 1983).

These two points are considered further and an attempt is made to explain our own implications.

Aeration and bean pH

It has been generally assumed up to now that the formation of flavour precursors does not start before the death of the seeds (destruction of the cotyledon cells) and is due to postmortem enzymatic acid hydrolysis (proteolysis, glycolysis) (Forsyth & Quesnel, 1963). Consequently, the period of fermentation before the death of the seeds would not be essential but is necessary only to develop heat and acetic acid by the pulp fermentation in order to kill and to acidify the seeds. This period is considerably reduced by strong aeration of the pulp which accelerates acetic acid production and heat generation (Biehl 1965; 1969). Even strong aeration of the pulp during the first period of fermentation does not cause aerobic conditions with the beans (Quesnel, 1960). The enzymatic reactions producing flavour precursors are complete within a short time after cell death (Rohan, 1957). Thus it might be assumed that the duration of fermentation could be reduced.

However, fermentation running in this way does not necessarily result in high flavour potential of the cocoa beans. In contrast, especially after box fermentation on a large scale, acid or off-flavoured beans are produced. Therefore this assumption has to be critically reviewed.

In order to illustrate these problems, a simplified graph (*Figure 1*) shows the pH changes in the cotyledons during fermentations differing in the extent of aeration (Biehl, 1961).
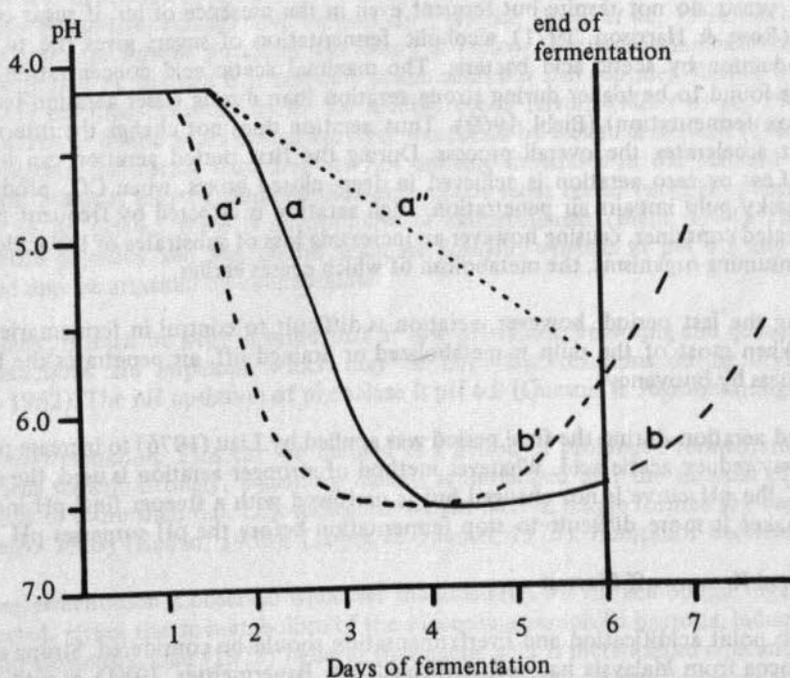
Figure 1. *Simplified Model of pH Changes in the Seeds During Fermentation*

Legend to Figure 1.

Average pH of random samples of a box fermentation (upper layer) (　　　), of a strongly aerated fermentation (- - - - - -) and of a fermentation with limited aeration (. . . . . . .) are schematized.

The pH of the living seed decreases as soon as the seeds die. Acids (predominantly acetic acid) penetrate into the cotyledons during conventional fermentation (a). Generally, when the pulp is aerated, the pH decreases to about pH 4.5 and does not change very much as long as the metabolism of yeast, acetic acid bacteria and lactic acid bacteria dominates and acid is produced. However, when the pulp substrates of these organisms are exhausted, the pH increases. This change can be recognized by shell darkening and the change of smell. The mass is now accessible to air and the development of several aerophilic bacteria were recognized in this period which succeed the acidophilic organisms of the first period (Ostovar & Keeney, 1973). Stronger aeration causes a similar decrease in internal pH down to 4.5, but the process is quicker (a') and an earlier pH increase is observed in the second period (b, b') (Biehl 1961; 1964). Thus, after six days' fermenta-

3

tion the internal pH may be still low after conventional fermentation, but considerably higher after strong aeration.

An earlier increase of pH at the end of fermentation is caused especially by the strongly aerated rotary fermenters (Biehl, 1965; 1969), but is to be expected also during shallow box fermentation especially after pressing off pulp before fermentation (Chong et al., 1978), since pressing increases air penetration. Aeration causes more intensive pulp metabolism.

Since yeasts do not respire but ferment even in the presence of air, if sugar content is high (Rose & Harrison, 1971), alcoholic fermentation of sugars gives rise to acetic acid production by acetic acid bacteria. The maximal acetic acid concentration in the pulp was found to be higher during strong aeration than during lesser aeration (conventional box fermentation) (Biehl, 1969). Thus aeration does not change the internal pH level but accelerates the overall process. During the first period aeration can be controlled. Low or zero aeration is achieved in deep, closed boxes, when CO_2 production in the sticky pulp impairs air penetration. High aeration is affected by frequent turning in perforated container, causing however an increasing loss of substrates of the acidophilic sugar-consuming organisms, the metabolism of which ceases earlier.

During the last period, however, aeration is difficult to control in fermentaries used today. When most of the pulp is metabolized or drained off, air penetrates the heated porous mass by buoyancy.

Forced aeration during the final period was applied by Liau (1976) to increase pH and in this way reduce acetic acid. Whatever method of stronger aeration is used, the overall shape of the pH curve is not changed but is narrowed with a steeper final pH increase, which makes it more difficult to stop fermentation before the pH surpasses pH $>$ 5.5.

Acidity and Hammy off Flavour

At this point acidification and overfermentation should be considered. Strong acidity in raw cocoa from Malaysia has been criticized (e.g. Bauermeister, 1984), as well as low flavour and hammy off flavours.

Acidification. Liau (1978) found that the internal pH was directly correlated to the acetic acid concentration in the beans, but not to lactic acid. It is unknown how lactic acid bacteria are influenced by aeration during the first phase. Acetic acid in contrast to lactic acid penetrates membranes of the living cells and contributes to the death of the seeds (Quesnel, 1965). The fact that after fermentation acetic acid concentration in the beans is higher than lactic acid concentration is at least partly due to the lipid solubility of acetic acid and thus to its penetration through membranes and lipid bodies within the cotyledon cells.

After acidification (around pH 4.5) we have found quite differing acetic acid concentrations although the pH-values were similar (Biehl et al., 1984). This can easily be explained by the pKa of acetic acid (4.77) and the buffering capacity of the seed proteins. At low pH ($<$4.5) absorption of acetic acid decreases the pH to a lesser extent than at higher pH.

The quantity of acetic acid accumulated in the cotyledons depends on the outer concentration of acetic acid and on the time it is allowed to diffuse into the seed. During box fermentation high concentrations are formed in the aerated layer. By turning, they

4

are transferred to the lower, anaerobic layer and new acetic acid is formed in the upper layer in the pulp of the seeds turned up. The seeds stay in the medium containing acetic acid for a long time allowing the slow diffusion (Biehl et al., 1982b) to increase acetic acid concentration in the beans. In strongly aerated fermentations, this time is shorter, allowing diffusion of acetic acid into the surface layer of the cotyledon cells only, but in high concentrations. Strong acidification is not necessary for good flavour potential (Biehl et al., 1984). Although maximal liberation of amino acids by proteolysis is found at pH 4.0 to 4.5, we have found that the flavour potential was better (stronger cocoa flavour was developed following the flavour profile, analysed by the "Fraunhofer Institut fur Lebensmitteltechnologie und Verpacking", Munich (Biehl et al., 1984). After strong acidification the flavour potential was found to be low. The reason is unknown but can be interpreted by the fact that not only amino acids but also peptides, formed by proteolysis, are essential components of the specific cocoa flavour (Mohr et al., 1976). The destruction of amino acids during roasting was found by Rohan & Stewart (1966) not to be complete, indicating that they are not limiting substrates in the Maillard reaction, however peptides may be. Endopeptidases in cocoa seeds reveal two pH optima (pH 3.5 and 5.5). At pH 4.5 there is an optimum of exopeptidases. (Biehl, 1984). Thus at pH 5.5 more peptides and less amino acids are formed, whereas at pH 4.5 any peptides formed may be attacked by exopeptidases.

Finally, it must be kept in mind that at low pH values, browning and quinone-amino acid reactions are impaired, which may be important reactions during drying (Purr et al., 1962). The pH optimum of phenolase is pH 6.0 (Quesnel & Jugmohunsingh, 1970).

Overfermentation. This can be defined as a period of prolonged fermentation; when the shells darken strongly, a hammy flavour is developed and the internal pH usually increases to more than 6.0. Low-molecular-weight fatty acids are formed (by degradation of amino acids) (Kaden, 1955), (Lopez & Quesnel, 1973). Aerophilic bacteria develop.

Overfermentation is observed whenever the substrates for the acidophilic organisms are exhausted, giving rise to metabolism of the succeeding aerophilic bacteria, inducing putrifaction. Obviously Liau (1978) believes that acetic acid is metabolized concomitantly to pH increase during aeration (maturation) in the final period. In some cases we found high concentrations of acetic acid in the beans after fermentation (Biehl et al., 1974), although the internal pH was > 6.0. Neutralisation of free acids (for instance by NH_4^+ from amino acid degradation) could be responsible for pH increase. The idea that acetic acid is metabolized via activation by Coenzyme A from the seed tissue (Liau, 1978) is not plausible, since this would need energy (ATP) and the intact respiration pathway in a postmortem process. Acid degradation is most probably due to the activity of aerophilic organisms. The participation of over-oxidising acetic acid bacteria (Ostovar & Keeney, 1973) cannot be ruled out but is less probable than the activity of other (putrefactive) bacteria which develop concomitantly to pH increase.

Own experiments (Biehl et al., 1984) revealed that significant degradation of amino acids and proteolytic peptides occurs and cocoa flavour is lost when the internal pH increases. Flavour was lost not only when the pH increased to more than 6.0 but also was reduced during pH increase in the range of pH 4.5 to 5.3.

In conclusion, any attempt to reduce acidity by increasing the pH at the end of fermentation results in destruction of flavour precursors by putrefactive aerophilic organisms. As shown in *Figure 1*, there is a dilemma in conventional box fermentations as well as in more strongly aerated fermentations. When the fermentation is terminated

prior to pH increase, the beans are strongly acid but when it is terminated after the pH increase, flavour precursors are lost. In the case of strongly aerated fermentation, especially the termination of the process is critical. The pH increase is more rapid and steeper. Overfermentation may proceed after fermentation, when initial drying is slow.

Significance of the Period before Seed Death

In contrast to the view described earlier, the period before the beans die is not unimportant for the postmortem formation of flavour precursors. A slow rise of temperature (from 30°C to 45°C) in the first period of fermentation before the seeds die improves postmortem proteolysis and flavour potential (Biehl et al., 1984). Similar to germination at this temperature the protein vacuoles of the cotyledon cells absorb water and swell (Biehl et al., 1982a; 1982b). Subsequent postmortem proteolysis degrades vacuolar storage proteins predominantly (Biehl et al., 1982c) and is enhanced under this condition in contrast to direct heating to 50°C. It is probable that specific proteolytic peptides are formed from vacuolar storage proteins by the activity of endopeptidases (Biehl et al., 1982c). Water absorption before the seeds are killed may – as in other seeds – (Chrispeels et al., 1979) prepare intravacuolar proteolysis by uptake by the vacuole of proteinases, which are enabled to digest vacuolar proteins even after fusion of the lipid bodies (Biehl et al., 1982a). These reactions should be allowed during fermentation before the seeds die. A slow temperature increase and a slow acidification would presumably promote these premortem reactions.

CONCLUSION

A steep increase of the temperature and a strong acidification during the first period of fermentation by forced aeration should be avoided. Any subsequent elevation of the internal pH by metabolic activity of aerophilic organisms which succeed the activity of yeasts, acetic acid bacteria and lactic acid bacteria after cessation of pulp sugars should be prevented. It would be preferable to increase temperature slowly, and to reduce consequently acetic acid accumulation. The internal pH should decrease smoothly to not less than pH 5.0 – 5.5 at the end of the fermentation (*Figure 1* a''), when the succession of the acidophilic organisms ceases because of exhaustion of the pulp sugar content.

It is the task of fermentation technology to find out how to allow a fermentation of this type (*Figure 1*, a'') without causing other defects like the well-known heterogeneity during box fermentations.

REFERENCES

ALLISON, H.W.S. & ROHAN, T.A. (1958) A new approach to the fermentation of West African Amelonado cocoa. Trop. *Agric. Trin.*, 35(4), 279–288.

BAUERMEISTER, J. (1984) Rohstoffland Malaysia. *Susswaren*, 84(4), 113–114.

BIEHL, B. (1961) Untersunchungen der Kakofermentation in Bahia, *Gordian*, 61 (1443), 26–35.

BIEHL, B. (1964) Unpublished results.

BIEHL, B. (1965) Neue Kakao–Fermentationsverfahren in Bahia, *Susswaren*, 7, 358–363.

BIEHL, B. (1969) Uber die Bildung fluchtiger Sauren in der Pulpa und in den Kakaokernen wahrend der Kakaofermentation in Bahia. *Z. Lebensm. Unters. Forsch.*, 139, 76–85.

BIEHL, B. & ADOMAKO, D. (1983) Die Kakaofermentation (Steuerung, Acidation, Proteolyse). *Lebensmittelchem. Gerichtl. Chem.*, 37, 57–63.

BIEHL, B., BRUNNER, E., PASSERN, D., QUESNEL, V.C. & ADOMAKO, D. (1984) Acidification, proteolysis and flavour potential in fermenting cocoa beans. (submitted for publication in *J. Sci. Food Agric.)*

BIEHL, B., PASSERN, D. & SAGEMANN, W. (1982a) Effect of Acetic Acid on Subcellular Structures of Cocoa Bean Cotyledons. *J. Sci. Food Agric.*, 33, 1101–1109.

BIEHL, B., QUESNEL, V.C., PASSERN, D. & SAGEMANN, W. (1982b) Water uptake by Cocoa Seeds during Fermentation–like Incubation. *J. Sci. Food* Agric., 33, 1110–1116.

BIEHL, B., WEWETZER, CHR. & PASSERN, D. (1982c) Vacuolar (Storage) Proteins of Cocoa Seeds and their Degradation during Germination and Fermentation. *J. Sci. Food Agric.*, 33, 1291–1304.

CHONG, C.F., SHEPHERD, R. & POON, V.C. (1978) Mitigation of cocoa bean acidity – fermentary investigations. *Proc. Int. Conf. Cocoa and Coconut.*

CHRISPEELS, M.C., BOLLINI, R. & HARRIS, N. (1979) Biosynthesis, accumulation and catabolism of reserve proteins in legume seeds. *Ber. Dtsch. Bot. Ges.*, 92, 535–551.

FORSYTH, W.G.C. & QUESNEL, V.C. (1963) The Mechanism of Cacao Curing, *Adv. Enzymol.*, 25, 457–492.

KADEN, O.F. (1955) Die organischen Sauren des Rohkakaos. *Gordian*, 55, (1391), 13–14.

LIAU, H.T.L. (1976) Raw Cocoa Processing Techn. Bull. No. 2, Dept. Agric., Sabah Malaysia.

LIAU, H.T.L. (1978) The criteria and mechanism for the removal of cocoa bean acidity, *Proc. Int. Conf. Cocoa and Coconut.*

LOPEZ, A. & QUESNEL, V.C. (1973) Volatile Fatty Acid Production in Cacao Fermentation and the Effect on Chocolate Flavour. *J.Sci. Food Agric.*, 24, 319–326.

MANIERE, I.Y. & DIMICK, P.S. (1979) Effect of conching on the flavour and volatile components of dark semi-sweet chocolate. *Lebensm. – Wiss. Technol.*, 12, 102–107.

MOHR, W., ROHRLE, M. & SEVERIN, TH. (1971) Uber die bildung des Kakaoaromas aus seinen Vorstufen, Fette Seifen. *Anstrichmittel*, 73, 515–521.

MOHR, W., LANDSCHREIBER, E. & SEVERIN, TH. (1976) Zur Spezifitat des Kakaoaromas, Fette, Seifen, *Anstrichmittel*, 78, 88–95.

OSTOVAR, K. & KEENEY, P.G. (1973) Isolation and characterization of Mikroorganisms involved in the Fermentation of Trinidad's Cocoa Beans. *J. Sci. Food Agric.*, 38, 611–617.

PURR, A., HELFENBERGER, A. & NADAI, J. (1962) Verwendung der Vakuum Infiltration bei der Fermentierung der Kakaobohnen unter Berucksichtigung enzymatischer Vorgange im Hinblick auf die Bildung von Aroma und Aromavorstufen. *Int. Choc. Rev.*, 27, 3–14.

QUESNEL, V.C. (1960) The anaerobic phase in cocoa fermentation. *Chem. Ind.*, 101–102.

QUESNEL, V.C. (1965) Agents inducing the death of cocoa seeds during fermentation. *J. Sci. Food Agric.*, 16, 441–447.

QUESNEL, V.C. (1968) Oxygen consumption and heat production during the fermentation of cocoa, Turrialba, *Rev. Interam. Ci. Agric.*, 18(2), 110–114.

QUESNEL, V.C. & JUGMOHUNSING, K. (1970) Browning Reaction in Drying Cacao. *J. Sci. Food Agric.*, 21, 537–541.

ROHAN, T.A. (1957) Observations on the Fermentation of West Aftican Amelonado Cocoa. *Rept. Cocoa Conf. London 1957*, 203–210.

ROHAN, T.A. (1963) Processing of Raw Cocoa for the Market, *FAO Techn. Bull. No. 16*

ROHAN, T.A. & STEWART, T. (1966) The precursors of Chocolate Aroma: Changes in the Free Amino Acids During the Roasting of Cocoa Beans. *J. Food Sci.*, **31**(2), 202–205.

ROHAN, T.A. (1972) Aromas in Food Processing. *Dechema Monogr.*, **70**(1327–1330), 301–322.

ROSE, A.H. & HARRISON, J.S. (1971) (ed.) Physiology and Bio-chemistry of Yeasts. In *The Yeasts*, Vol. 2, Acad. Press, London, New York.

VAN STRATEN, S. (1977) *Volatile Compounds in Food*, 4th ed. Zeist: Central Institute for Nutrition and Food Research, TNO.

INFLUENCE OF STEAM AND HOT-AIR TREATMENT

AND THE EFFECT TO THE WINNOWING AND THE

BACTERIOLOGY OF COCOA BEANS

F. KOLLER

SUMMARY

A study was carried out on the improvement of the yield of
cocoa beans in the winnowing section. The final results led
to a new preparation system for the processing of cocoa beans.

Extensive tests were carried out on cocoa beans from Ghana
as well as on Arriba beans, some of them with similar behaviour
as Malaysian cocoa beans. The pilot plant for these tests
consists of a steaming screw, a hot-air fluid-bed dryer and
the subsequent new winnowing installation. This winnowing
installation allows the dehulling and winnowing of hot cocoa
beans. The capacity for the tests was at 400-500 kg/h of beans.

Comparative tests were carried out on a conventional compact
winnowing machine, that means, crushing of predried and cooled
beans with subsequent winnowing on flat oscillating sieves.
The results showed clearly that the steam treatment with
subsequent hot-air treatment on the fluid-bed dryer leads to
a significantly better loosening of the shells from the kernels
of the beans.

Beans treated in such a way can then be dehulled more smoothly
which results in a smaller amount of fine nibs. This facilitates
the separation of the shells from the nibs since it is easier

to separate big husks from big nibs than small husks from
small nibs. As a result, the amount of shells in the nibs
and the nibs in the shells can be reduced to a minimum. Also,
the loss of fat into the shells can be minimised by this new
method.

A further advantage of the steam and hot-air treatment is the
reduction of the plate-count by a factor of about 100.

As a conclusion, it can be said that, thanks to this new
treatment, the effect of the winnowing system is substantially
improved, specifically on cocoa beans which are difficult to
dehull. In early 1985, the first industrial plant with a
capacity of 2.5 t/h will be commissioned and, afterwards, more
long-term results will be made available.

INTRODUCTION

It is a well-known fact that one of the most important requirements for the successful running of a cocoa plant depends strongly on the achieved yield in the cocoa bean winnowing system. Our company has therefore, particularly in the last few years, made tremendous efforts to investigate possibilities to improve the cocoa bean winnowing system. These investigations were also made with special regard to beans which are known to be difficult to dehull and winnow.

The yield of the winnowing system can basically be increased by improving the loosening of the shells from the kernels and by adjusting the crusher in such a way that it produces a minimum of fine particles. This is because it is much more difficult to separate small shell pieces from small nibs than big shell pieces from big nibs.

To loosen the shells from the kernels, we developed a cocoa bean treatment which consists of dampening and drying the bean shells within a short period of time in order to produce a so-called "popping" effect. To achieve a uniform and big nibs size, an impact-huller with variable speeds was utilized to dehull the hot cocoa beans.

After conducting numerous small pilot tests on these individual processing steps, Buhler built the following large test plant.

METHODS

The continuous operating plant on which most of the tests have been carried out is shown in Appendix II.

The hourly capacity of the plant is 400-500 kg/h and it consists of the following main machines:

Steaming Unit

In the steaming screw which is of a special sanitary design, the cocoa beans are pre-heated, dampened and homogenized.

In the first half of the screw, the beans are treated with saturated steam of about $150^{o}C$ to dampen the surface of the beans, i.e. the shells.

In the second half of the screw, the beans are mixed to achieve a homogeneous moisture content in the bean shell.

During this step of the process, with a duration of about one minute, the average temperature of the beans increases by about $20^{o}C$ and the average moisture content of the bean increases by about 1-2%, the latter due mainly to the increased moisture content of the shells. Additionally, the steaming and pre-heating results in a slight expansion of the bean-shell.

Drying Unit

In the hot-air fluid-bed dryer, the beans are, for a short while, exposed to a pulsating hot-air stream of about $220^{o}C$, which

creates a very good drying of the bean shells due to the high
heat transfer. This results in shrunk and brittle shells
which are very easy to crush in the subsequent hulling unit.
This drying process needs, depending on the origin of the beans,
about 1-3 minutes and the average moisture content of the beans
is reduced by 3-4%. The temperature of the bean surface reaches
up to 130°C which is, together with the steaming of the beans,
the main reason for the plate-count reduction of the cocoa beans.

Hulling/Winnowing Unit

The hot cocoa beans with a temperature of about 100°-110°C
leave the fluid-bed dryer and are continuously fed into a
pre-sieving machine where the broken beans are separated
from the whole beans. The whole beans are directly fed into
a specially designed impact-crusher, whereas the broken beans
bypass it. The whole quantity is then brought to the first-
stage winnowers which are directly underneath the crushers.

In the first winnowing stage, about 95-98% of the nibs are
separated from the shells and small nibs. The remaining mixture
of shells and small nibs is aspirated through the top of the
aspiration channel and fed into the second-stage winnowers.
The coarse nibs which are separated in the first winnowing stage
are almost free of shells and have a temperature of about 90-100°C.

The second winnowing stage consists of two drum sieves which sepa-
rate the mixture of shells and fine nibs into five size fractions.
The drum sieves, with their automatic sieve-cleaning device,
are perfectly suitable for achieving, over a very long working

period, the same good and gentle grading. This is not always
obtained when using the conventional flat sieves.

The sieves are followed by four aspiration channels with
special cascades to separate the rest of the nibs from the
shells. The very small quantity of the fifth fraction - the
fine particles smaller than 1 mm - is directly bagged off.

All the shells are collected in a cyclone and all the nibs
on a belt conveyor.

The nibs with a temperature of about 90-100°C can be fed either
directly into the grinding machine in cases where no further
roasting is necessary or where liquor treatments are foreseen,
or into the alkalizing and roasting machine with the positive
side-effect that the nibs do not need a long pre-heating.

RESULTS

For all our tests, we ran the plant continuously at a
capacity of 400-500 kg/h for about 5-20 hours.

A large number of measurements have been made during the
tests at the various stages of the process, to analyse the
efficiency of the cocoa bean treatment as well as to optimize
the various processing steps. Tests have also been carried
out for different cocoa bean origins and qualities.

Some average figures which are of main interest are given in
the table below:

1. Nibs size

   Nibs > 4 mm   :   50 - 70%

         > 3 mm   :   85 - 95%

         > 2 mm   :   95 - 98%

         < 2 > 1 mm   :   1 - 3%

   Fine < 1 mm   :   0 - 2%

2. Shell content in the nibs   :   0,5 - 1%

3. Nibs loss into the shells and fine   :   0,1 - 0,3%

4. Plate-count reduction by   : $10^2 - 10^3$

5. Fat loss into the shells   :   0,1 - 0,2%

These figures changed very little between the various bean origins, once the necessary adjustments had been made. They also changed very little between large and small cocoa beans. However, they can be quite different when the beans at the inlet already contain too much broken beans.

Since it is more difficult to separate small shells from small nibs, a higher content of broken beans at the inlet leads consequently to either a higher nibs content in the shells or a higher shell content in the nibs.

More broken beans at the inlet lead also to a higher fat loss to the shells and a higher plate-count of the nibs.

It is also of a big advantage when the beans are pre-cleaned and destoned before being treated on such a processing plant.

DISCUSSION

We would like to comment on the abovementioned results as follows:

Nibs size spectrum

The nibs size spectrum varied during the tests within the range shown, depending on the content of broken beans at the inlet and the bean origin. The results show clearly that it is possible to achieve a very big portion of big nibs, e.g. 97% > 2mm, which is of advantage for the shell separation.

The fine fraction below 1 mm could normally be kept at around 1%. Whether these fine particles can be added to the nibs or have to be separated from the shells depends on the customers' requirements. According to the fat analysis of the fine particles, we can say that its relative nibs content was mostly between 15 and 30%, compared to approximately 50% in the conventional processing.

Shell content in the nibs

The shell content in the nibs is generally an indication of the nibs quality. It is, in many countries, limited to 5% calculated on the dry matter.

In our tests, we could reach, relative easily, values of between 0,5-1% shells in the nibs. With this plant, it is absolutely no problem to obtain results within the inter-national standards, i.e. shell contents of the nibs less than

5% calculated on the dry matter (as per EEC or IOCC specifi-
cations for cocoa nibs), and it seems to be possible to fulfil
even the highest customer requirements concerning the shell
content of the nibs.

Nibs loss into the shells

The nibs loss into the shells is very important since it
represents directly an economic loss. Therefore, it is of
vital interest to keep this figure as small as possible. The
figure depends on the amount of broken beans at the inlet and
especially on the content of fine particles after the crusher,
since it has been proven that the smaller the particles, the
more difficult the separation of the nibs from the shells is.

Another observation we made was that the shells of flat and
shrivelled cocoa beans are more difficult to separate from the
kernels and that, in cases where its percentage in a product
is high, the shell content in the nibs is consequently higher.

The nibs loss of 0,1-0,3% consists normally of 0-0,15% nibs loss
into the shells and 0,1-0,2% nibs loss into the fine particles,
which means that, if it is possible to add the fine particles
to the nibs, the nibs loss into the shells becomes marginal.

Plate-count reduction

Since it is specially the shells which contain the bulk of the
bacteria, it is important to have a minimum of broken beans in
the intake product and also a minimum of shells in the nibs.

The figure shown indicates the reduction between intake product and nibs without fine particles. The plate-count of the fine particles is about 10^1-10^2 times higher than the one of the nibs. This has to be taken into consideration when adding the fine particles to the nibs.

Increase of fat content in the shells

The figure shown represents a loss of about 0,1-0,2% of fat into the shells. The increase of the fat content in the shells seems to depend on the percentage of broken beans at the inlet and of fine particles produced by the crusher. It seems that it is not mainly a fat diffusion from the kernel to the shell but a transfer of fat from the nibs particles to the shells which come into contact with these nibs.

Therefore, it is advantageous to separate, in the first winnowing stage, 95-98% of the nibs, and this might be the main reason that it was possible to reduce the fat loss quite substantially as compared to fat losses of 0,3-0,6% in conventional systems.

CONCLUSION

Regarding the results which could be achieved with the plant, we can say that the following advantages are obtained by such steam and hot-air treatment of cocoa beans.

- The steam treatment with subsequent hot-air treatment produces very brittle bean shells which are easy to crush.

- The system also reduces the plate-count of the shells drastically.

- Due to the pre-treatment, the impact-crusher produces a very small quantity of fine particles.

- Due to the small quantity of fine particles and the pre-separation of a very big portion of coarse nibs in the first stage of the winnowing, the fat loss to the shells can be kept small.

- Due to the steam and hot-air treatment and the efficient winnowing system, the plate-count of the nibs can be kept within 10^4-10^5.

- The system is specially energy-saving when we make use of the latent heat in the nibs in the following processing steps, like direct grinding of the hot nibs, etc.

- In this system, the risk of fire is minimized since it works with steam and hot air.

Taking all the advantages and inconveniences into consideration, we believe that this kind of cocoa bean treatment is a further step to efficient cocoa processing and high quality end-products.

The system is of a big advantage for a cocoa processing plant which produces cocoa powder and cocoa butter, as well as for a chocolate factory which has its own cocoa processing facility.
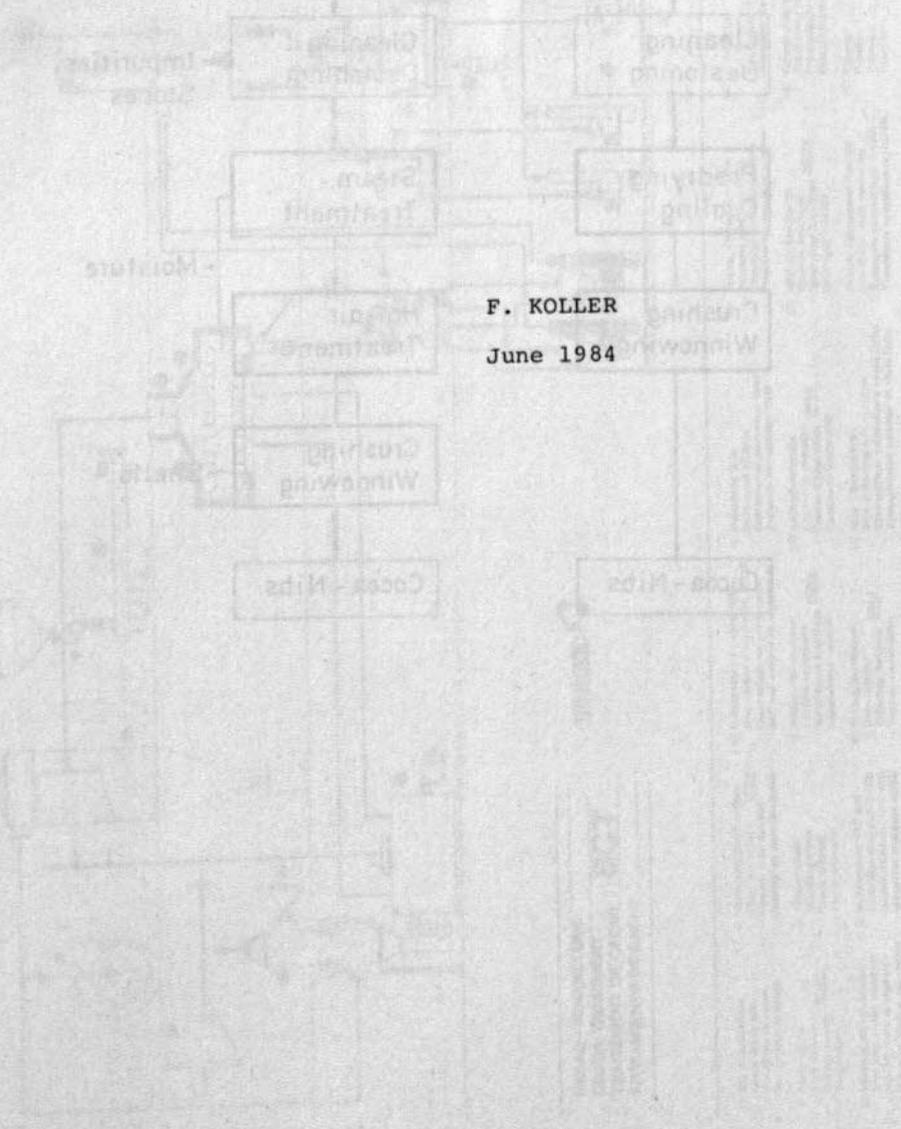
F. KOLLER

June 1984

WINNOWING - SYSTEMS

Conventional   New

Conventional	New
Cocoa-Beans	Cocoa-Beans
Cleaning Destoning	Cleaning Destoning → Impurities, Stones
Predrying Cooling	Steam-Treatment
Crushing Winnowing	Hot-air Treatment ← Moisture
	Crushing Winnowing → Shells
Cocoa-Nibs	Cocoa-Nibs

FLOWSHEET

SUDS-30836-01
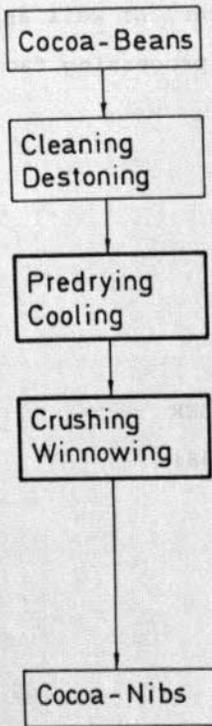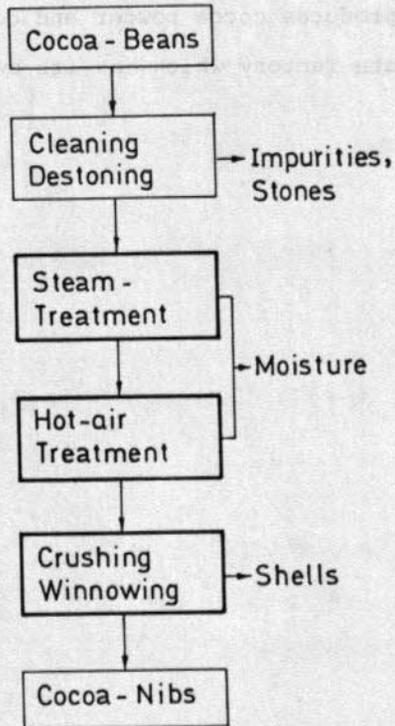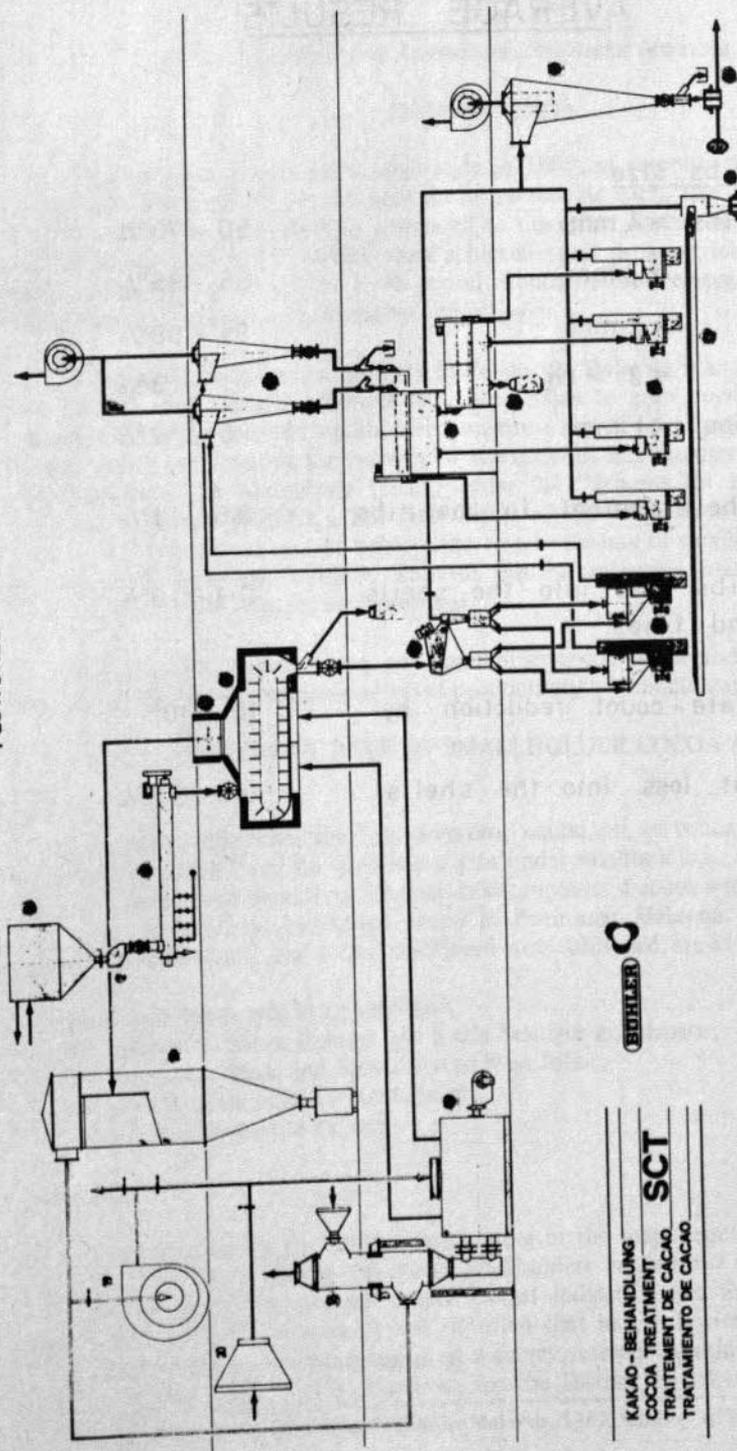
KAKAO – BEHANDLUNG
COCOA TREATMENT **SCT**
TRAITEMENT DE CACAO
TRATAMIENTO DE CACAO

BÜHLER

1) Silo Kakaobohnen
   Cocoa beans silo
   Silo fèves de cacao
   Silo granos de cacao

2) Dosiergerät MZAC
   Flow balancer
   Doseur autom.
   Dosificador

3) Beaufumpung-Schnecke
   Steaming screw conveyor
   Vis doseuse (à vapeur)
   Rosca de tratam. por vapor

4) Wirbelschicht-Trockner SCTW
   Fluid bed dryer
   Sécheur à lit fluidisé
   Secador de capa fluidizada

5) Vibrator-Sieb
   Vibrating sieve
   Tamis vibrant
   Tamis vibrante

6) Warfbrecher SBC mit
   Aspiration/mit Aspiration SBC with
   impact aspiration SBC avec
   aspiration channels MVSE

7) Zyklon - Abscheider MCXB
   Cyclone separators
   Séparateurs à cyclone
   Separadores - ciclón

8) Trommelsortierer DHFZ
   Drum grader
   Calibreur tambour
   Tambor clasificador

9) Absacking Grus
   Sacking - off of germ
   Quebradora de particulas finas
   Ensacado de partículas finas

6) Quetscheun à impact SBC
   avec canaux d'aspiration MVSE
   Quebradoras por impresión
   SBC con canales de aspiración

7) Zyklon - Abscheider MCXB
   Cyclone separators
   Séparateurs à cyclone
   Separadores - ciclón

10) Aspirationskanäle MVSE
    Aspiration channels
    Canaux d'aspiration
    Canales de aspiración

11) Nibs - Sammelband DHFZ
    Nibs collecting belt conveyor
    Transporteur collecteur à rubán
    Transportador colector de cáscara

12) Pneum. Akttransport Nibs
    Pneumatic nibs conveying
    Transport pneumatique alba
    Transporte neumático p./alba

13) Zyklon - abscheider MCXB
    Cyclone separator
    Séparateur à cyclone
    Separador - ciclón

14) Pneum. Akttransport Schalen
    Pneumatic shell conveying
    Transport pneumatique à robe / cáscara
    Transporte neumático cascarilla

15) Lufterhitzer Nihe
    Air heater
    Réchauffeur d'air
    Calentador de aire

16) Vorwärmung Frischluft
    Pre-heating of fresh air
    Préchauffage d'air frais MCXB
    Precalentamiento aire fresco

17) Pulsator
    Pulsator
    Pulsator
    Pulsador

18) Heissluftfilter PGFA
    Hot air filter
    Filtre à air chaud
    Filtro de aire caliente

19) Heissluftventilator HFE
    Hot air fan
    Ventilateur à air chaud
    Ventilador de aire caliente

20) Kühlluft-Eintritt
    Cooling air inlet
    Air de refroidissement
    Aire de entramiento

AVERAGE   RESULTS

1. Nibs size

Nibs	> 4 mm	: 50 - 70%
	> 3 mm	: 85 - 95%
	> 2 mm	: 95 - 98%
	< 2 > 1 m	: 1 - 3%
Fine	< 1 mm	: 0 - 2%

2. Shell content in the nibs   : 0.5 - 1%

3. Nibs loss into the shells   : 0.1 - 0.3%
    and fines.

4. Plate - count reduction by   : $10^2 - 10^3$

5. Fat loss into the shells   : 0.1 - 0.2%

Production and Extension of Smallholder Cocoa in Peninsular Malaysia

Department of Agriculture, Peninsular Malaysia

INTRODUCTION

Cocoa was first planted on a large scale in 1965, in response to the Government's policy of diversification in the agricultural sector. As such, this industry is relatively new to the nation's economy as compared to the other plantation crops. Nevertherless, the cocoa industry has in recent years achieved rapid progress, stimulated by the high cocoa prices during the 1974–1978 period. Cocoa has now emerged as the third significant export crop after natural rubber and oil palm.

The mainstay of the cocoa industry in Peninsular Malaysia is as an intercrop in coconut holdings but recently attempts have been made to grow cocoa as a monocrop in inland soils. As the coconut smallholders constitute one of poverty groups in the country, efforts aimed at redressing the poverty of the coconut smallholders were undertaken by the Department of Agriculture (DOA) under the "Scheme for the Rehabilitation of Coconut Holdings" (RPSKK). The main thrust of this programme is towards rehabilitation of areas under coconut to achieve increase in income of smallholders by increasing the productivity of the holdings. Towards this end intensive intercropping with more profitable crops like cocoa is being stressed.

This paper attempts to review the smallholder cocoa sector and the extension effort undertaken by DOA to achieve increased productivity of smallholder cocoa.

PRESENT STATUS OF SMALLHOLDER COCOA AREA

Area

In Peninsular Malaysia, the total sole crop equivalent of cocoa in 1982 was 50,599 hectares* Of this 47% of the area is the area under smallholdings, 41% under estate and the rest under government land schemes. Intercropping of cocoa with coconuts represents the major bulk of the cultivated cocoa in Peninsular Malaysia. The five main cocoa growing areas with coconut as the traditional crop cultivated, are as follows:

(a) Bagan Datoh area in Lower Perak;
(b) Districts of Sabak Bernam and Kuala Selangor in Selangor;
(c) Districts of Muar and Batu Pahat in West Johor;
(d) Seberang Prai in Pulau Pinang; and
(e) Jerantut District in Pahang

Farm Size

The average size of the cocoa smallholding in the major cocoa growing area ranges from 1.5–3.0 ha. A survey of cocoa smallholders carried out by FAMA in 1974 in Hilir Perak, Sabak Bernam and Kuala Langat indicated that the average cocoa farm size was about 1.77 hectares. It was reported that in the Lower Perak District, where 83% of the smallholders participated in a survey, the cocoa holdings ranged from 0.8–1.6 ha (Abdul Kadir, 1977). However, for the District of Sabak Bernam, the average

---

* Acreages of Miscellaneous Crops, Peninsular Malaysia, 1982. Ministry of Agriculture.

size of cocoa smallholdings was reported to be 1.68 hectares (Shaaban Shahar, *et. al.*, 1980). It is felt that holdings that are below 1.5 ha are not economic production units and as such farmers prefer to leave their land idle and search of alternative employment outside their holdings.

Yields

Yields per hectare from cocoa smallholdings are relatively low when compared to the potential yields which can be obtained if farmers were to follow recommended practices. There is much scope for improvement through better management and cultural practices. Wide variations in yields occur not only between estates and smallholdings but also within the smallholdings in the different states and districts depending on the management/inputs. Cocoa intercropped with coconuts on estate basis is estimated to produce an average annual yield of 1,000–1,350 kg of dry beans per hectare whereas the average annual yield of cocoa under coconuts is only one half of that of the estate. The survey in Sabak Bernam district reported an average annual yield of only 330 kg dry beans per ha with considerable variation in yield among smallholdings ranging from 210 kg to 574 kg dry beans per ha (Shaaban Shahar *et al.*, 1980). In a survey carried out by the RPSKK on coconut/cocoa smallholders before participation in the Rehabilitation programme in the three major states, the annual cocoa yield varies from 217 kg to 245 kg dry bean per ha for 4–5 year old cocoa holdings (*Table 1*). These yield figures were rather poor and yield variations recorded in this survey ranged from 100%–200% among holdings of similar sizes.

TABLE 1.   SMALLHOLDER COCOA YIELD UNDER COCONUT REHABILITATION PROGRAMME AREAS

State	Age of Holding (year)	Yield Dry bean (kg/ha/yr)
Perak	4–5	245
Johore	4–5	237
Selangor	4–5	217
Average	4–5	220

In the farm record keeping programme carried out by DOA on 15 smallholders in Endau, Rompin, Pahang, it is shown that there are potential benefits from inter-cropping cocoa and coconut in smallholding less than 2 ha in size. The average yield figures are shown in *Table 2*.

TABLE 2.   AVERAGE COCOA YIELD OF SELECTED SMALLHOLDINGS IN ENDAU, ROMPIN 1981–1983

Age of Cocoa (year)	Yield Dry bean (kg/ha/yr)
1½–2	74.1
2–3	350.5
3–4	617.5

Therefore, if these yield trends are maintained it is possible to achieve a yield level of 800–1000 kg per ha when the holdings attain maximum production.

There are several reasons for the low yields of smallholder cocoa. Poor drainage and the resulting flooding of the fields along the West Coast of Peninsular Malaysia is one of the main causes. Although most smallholdings appear to be adequately drained, the occurrence of floods causing water levels to rise up 15 cm or more for periods of at least 3 days during the wet season are common. Temporary flooding by moving water does not cause much harm to mature cocoa trees but stagnant water in the field for more than 3 days would adversely affect the cocoa trees as evidenced in the February 1984 flood in Lower Perak. The Drainage and Irrigation Department has undertaken systematic drainage schemes in the major cocoa growing areas, and in many instances farmers have complemented the Government's drainage work with internal field drains.

Another reason for poor yield is that field maintenance and cultural practices are of a low standard as overshading is evident in smallholdings with low cocoa yields. Overshading is commonly caused by high coconut density ranging from 148 trees — 247 trees per hectare. Apart from the overshading caused by coconut palms, a number of the poorly managed smallholdings have as much as 120—250 banana and other fruit trees per hectare. Apart from this, insufficient labour inputs for maintenance and the general inexperience and lack of knowledge regarding pruning techniques accentuate the overshading problem.

The lack of/incorrect usage of fertilizers is another reason causing low yields. From experiences in the Coconut Rehabilitation Programme under the RPSKK, it is found that smallholders do not continue to apply fertilisers from the fourth year onwards, that is when the fertilizer subsidies come to an end.

Another contributing factor to the low yields is the use of sub-standard planting materials by smallholders especially during the late 70s, when there was a upsurge in cocoa planting caused by high cocoa prices.

Income and Profitability

Cocoa/coconut smallholders obtain their income from two main sources namely from their holdings (farm income) and outside their holding (non-farm income).

In smallholdings that are of uneconomic sizes, the farm income could constitute less than 40% of the total family income. It was reported (Fuad and Sharif 1979) that with an average farm size of 1.2 ha in the Mukim of Hutan Melintang, Lower Perak, only 33 percent of the total family income was derived from farm income. With increase in farm size, the proportion of household income that is derived from farm sources correspondingly increases. In the District of Sabak Bernam, Selangor where the average size of cocoa holdings is 1.68 ha, the farm provides about 67 percent of the total family income (Shaaban Shahar et al., 1980). In the Mukim of Bagan Datoh, 76% of the total household income is provided by the farm with an average farm sizes of 1.6 ha (Fuad and Sharif, 1979).

The farm household annual gross income varies in different cocoa/coconut growing areas. Gross incomes of $2,500—$5,000 per household are commonly reported in farm management record keeping exercises. These great variations make detailed analyses rather difficult.

Table 3 illustrates the gross and net income derived from one hectare of cocoa under coconut for different cocoa yields and price levels based on the cost of production as

3

TABLE 3: ESTIMATED GROSS/NET INCOME FROM 1 HECTARE OF COCOA UNDER
COCONUT AT DIFFERENT COCOA YIELDS AND PRICE LEVELS

Cocoa Yield (kg dry bean/ha/yr)	Cocoa Price ($/kg dry bean)		
	2.50	4.50	6.50
220.0	779.69 (187.07)	1,219.69 (597.07)	1,659.69 (1,067.07)
617.0	1,773.44 (751.84)	3,008.44 (1,986.84)	4,243.44 (3,221.84)
850.0	2,354.69 (1,082.17)	4,054.69 (2,782.17)	5,754.69 (4,482.17)

detailed in *Appendix 1*. Gross income derived from the holding takes into consideration
the returns to family labour, whilst net income assumes that the labour is hired.

The gross income ranges from $779.69 for the low yield and low price level to $5,754.69
for the high yield and high price level. If the minimum economic farm size were
taken to be 1.5 ha then a gross income level of $4,512.66 can be achieved using medium
yield level of 617.50 kg dry bean/ha/yr and a medium price level of $4.50 dry bean/kg.
This income level is above the poverty line. It can be seen that increase in productivity
of the cocoa/coconut holdings can be achieved by proper management/inputs under-
taken by the Smallholders themselves. It must be emphasised that for full potential of
the mixed cocoa-coconut cropping to be realised in smallholdings, there is the need for
further extension efforts.

THE ROLE OF EXTENSION SERVICE OF THE DEPARTMENT OF AGRICULTURE
IN THE DEVELOPMENT OF SMALLHOLDER COCOA

The provision of effective extension services constitutes one of the major programmes
of DOA. Extension on crops including cooca for smallholders is being conducted with the
following objectives:

(i) To provide an effective transfer of appropriate technology and research findings
to the farmers so as to transform research results into farm benefits; and

(ii) To change the outlook of farmers to be dynamic and receptive to new technology,
and to be able to assume greater responsibility in activities pertaining to the
improvement of their farm business and homes.

Strategy and Approach in Extension

In the past, the extension activities of the DOA were focussed on all crops and there
was no special extension programme for cocoa *per se*. However with the introduction of
the new agricultural policy, emphasis will be on commodity development. All relevant
aspects in development of the smallholder sector would be incorporated into a 'package'
programme as in the case of rubber and oil palm.

The current emphasis in Malaysia's agricultural extension is the integrated approach in
which all aspects of development (of any particular area or community) are taken into
consideration and embodied in a balanced programme. Thus the development of the

4

farm, the home, the institutional and infra-structural facilities are factors to be consi-
dered. The socio-economic needs of the small farmers are also reflected in the pro-
gramme.

Programme Emphasis

Extension work of the Department of Agriculture is conducted at two levels. The
Federal Department of Agriculture (FDOA) supervises and coordinates the extension
efforts of the State Departments of Agriculture (SDOA) by providing financial assistance,
technical expertise and material aids as well as organizing in service training of personnel.

The SDOA operates a comprehensive network of extension services which includes:

(a) providing technical advice to farmers through regular field visits;

(b) providing formalised training of farmers at the Rural Agricultural Training Centres
(RATCs);

(c) Conducting demonstration plots and local vertification trials (LVTs) in crops
relevant to the area in order to get farmers interested in a particular technology;
and

(d) providing a wide range of other services pertaining to the development of the
community as a whole.

The responsibility for extension at the farm level lies with the Agricultural Technician
who covers one service area which includes villages/mukim and is supervised by the
Agricultural Assistant or Agriculture Offices.

SCHEME FOR THE REHABILITATION OF COCONUT HOLDINGS (RPSKK)

The development for cocoa in coconut holdings is the major programme under the
RPSKK. In the years 1985–2000, a total of 17,139 ha of cocoa will be developed under
the coconut replanting and rehabilitation programmes.

TABLE 4: THE PROPOSED PHYSICAL HECTARAGES FOR THE COCOA INTERCROPPING
PROGRAMME UNDER THE RPSKK

| Programme | Hectares | | | | | | |
	1985	1986	1987	1988	1989	1990	Total
Intercropping existing coconut with cocoa	470	360	564	696	828	1,116	4,034
Rehabilitation of existing cocoa under coconut	1,105	840	1,316	1,624	1,932	2,604	9,421
Replanting of both cocoa and coconut	714	300	470	580	690	930	3,684
Total	2,289	1,500	2,350	2,900	3,450	4,650	17,139

Three (3) management approaches will be utilised for the development of the above programme in the coconut growing areas. However, the approach to be adopted will depend on the prevailing conditions of that particular area.

- *Mini-estates* where the management of the individual holdings are carried out collectively by a central body coporate *e.g.* Farmers' Organisation. The farmers are the shareholders and they can also elect to work in these estates as paid workers.

- *Block system* where participants operate and maintain their own holdings in contiguous areas organised into blocks or units. Dissemination of information can be effected through appointed block leaders. Each block comprises 50 farmers and will be served by one extension agent (Agricultural Technician).

- *Individual approach* where scattered holdings will continue to receive assistance and services through the normal channels.

The cocoa intercropping programme calls for intensification of extension and technical support services. Extension in coconut smallholdings encompasses technology transfer for both coconut as well as the intercrops. The relevant types of technology are incorporated into the extension programme implemented under the extension delivery system. This system shall be the main mechanism for promotion campaign at the initial stages of project development and implementation.

The major emphasis in the cocoa intercropping programme is the rehabilitation of the existing cocoa plants under coconut holdings. This rehabilitation programme involves a technical package made available to farmers taking cognizance of the current problems and constraints. It will be tailored to meet the specific needs of individual farmers. The improvement of the existing cocoa can be effected through the following steps:—

- improvement of drainage;

- improvement of cultural practices such as weeding, fertilizer application, pest and disease control;

- shade adjustment (including thinning and/or replanting as required);

- pruning;

- mature budding with budwood from recommended clones;

- field budding; and

- training of farmers using the biweekly visit.

The cocoa improvement programme is aimed at improving the productivity of the coconut smallholdings. The programme would also provide employment in terms of intensive cocoa cultivation in smallholdings. The return of higher farm income may be sufficient incentive for the labour resources to remain in the farm, and consequently reduce the migration of rural labour to urban areas in search of employment. The increase in farm productivity would enable farmers to operate holdings smaller than 1.5 ha and yet earn income above poverty level.

6

REFERENCES

ABDUL KADIR BIN ABDUL HADI (1977). Rancangan Tanaman Koko Hilir Perak. In-service course, Dept. of Agriculture, Perak, 2nd Edition 48 pp.

C.Y. CHUNG (1984). Potensi Tanaman Koko di bawah kelapa sebagai satu sumber pendapatan utama petani — Satu pengalaman di Mukim Endau, Rompin. Farm Management Unit, Department of Agriculture, Kuantan, Pahang.

DENAMANY, GET. AL (1978). Coconut intercropping systems in Peninsular Malaysia. Prof. Int. Conf. on Cocoa and Coconuts Kuala Lumpur 1978.

FAMA, (1975). A survey report of cocoa production and marketing in Hilir Perak, Sabak Bernam and Kuala Langat.

MINISTRY OF AGRICULTURE, MALAYSIA (1978). The coconut smallholder in Peninsular Malaysia. Proc. Int. Conf. on Cocoa and Coconuts Kuala Lumpur 1978.

NIK FUAD & MOHD SHARIF (1978). The socio-economic status of coconut smallholders in Lower Perak. *Proc. Int. Conf. on Cocoa and Coconuts Kuala Lumpur,* 1978.

SHAABAN SHAHAR, *et al.* (1980). Report of the coconut-based farming system survey in Sabak Bernam, MARDI Report.

Appendix 1. Cost of Production for 1 hectare of Cocoa Under the Coconut

Type of Work	Material Cost	Labour Requirement Man-day		Total Cost
1. Manuring	$207.48	7.4	$ 59.20	$ 266.68
2. Weeding	69.16	7.4	59.20	128.36
3. Pest and Disease Control	27.17	14.8	118.40	145.57
4. Pruning	—	14.8	118.40	118.40
5. Harvesting	—	59.3	474.40	474.40
6. Processing/Transportation	—	24.0	192.00	192.00
Total	$303.81	127.7	$1,021.60	$1,325.41

1 manday = $8.00
Cocoa yield per hectare = $617 kg drybean
Harvesting and Processing/Transportation costs are proportional to yield.
Coconut yield per hectare = 5,928 nuts
Net income from coconut = 5,928 x 9¢ = $533.50

Source: Adapted from Farm Management
           Record Keeping data, DOA

Pre-Shipment Inspection of Malaysian Cocoa Beans

OTHMAN BIN MOHD RIJAL

Federal Agricultural Marketing Authority, Malaysia

The Federal Agricultural Marketing Authority (FAMA) has undertaken to inspect and certify the grade of all cocoa beans to be exported from Peninsular Malaysia, in compliance with specifications drawn up by the Standards and Industrial Research Institute of Malaysia (SIRIM). Cocoa submitted by exporters and large producers will be inspected, initially at Grading Centres at Port Kelang, Pasir Gudang and Prai, to ensure that packing, moisture levels, foreign matter content, and insect counts conform to requirements. Grades based on the level of defective beans, and on bean size will be determined for each lot received, after the cut-test and the bean count are carried out on randomly drawn samples. Bags will be grade-marked and sealed after grading, and Certificates of Grade issued before export is permitted. Rigorous control procedures to ensure effective implementation of the scheme, including laboratory tests on retained samples, form the basis for a "quality audit" system. Close monitoring of grading results and coupled with follow-up extension work with producers, fermentaries and exporters is expected to bring about increased awareness and a commitment to improve the quality of cocoa exports.

While statutory compliance in Peninsular Malaysia took effect on the 16th of August, 1984, it is expected that grading and certification of beans as Standard Malaysian Cocoa (SMC) in Sabah and Sarawak will be initiated on a voluntary basis in the near future. Meanwhile efforts are being made to promote the grading scheme amongst consumers and the response has been favourable. Such acceptance of the SMC grades and the successful implementation of the grading scheme is dependent on the joint efforts of the government, the producers, and the traders.

Inspection of Malaysian cocoa prior to export is designed to give effect to the Standard Malaysian Cocoa (SMC) Grades as drawn up by the Standards and Industrial Research Institute of Malaysia (SIRIM), in order to determine or verify the grade of the cocoa, as well to ensure that the moisture level, insect count and packing are conducive to shipment and storage without deterioration of quality. It has been recognized that the effectiveness of the grading and certification scheme is dependent on the reliability of the grades, both in terms of their representativeness of the actual cocoa shipped and in terms of being fair and free from any hint of improper practice, in speed and ease of the procedures involved, so that shippers are not unduly inconvenienced, and on the cost of grading in relation to the benefits accruing to the industry from the implementation of the scheme. A set of procedures has been designed bearing these factors in mind, where a balance has been sought between the rigorous system required for infallibility in grading and the flexibility that will facilitate speedy handling of the large volume of cocoa expected during the main seasons. To complement the grading and certification procedures, a "quality audit" system has been introduced which will provide checks on graded cocoa at shippers' premises, port godowns and during transit (internal). A central

laboratory, with facilities and staff for carrying out detailed and varied tests is also a part of the overall grading and certification system.

The Federal Agricultural Marketing Authority (FAMA) has been entrusted to implement the grading scheme (by virtue of regulation 7 (i) and (ii) of the Cocoa Marketing Regulations, 1980 — see *Appendix I*), and to carry out grading and certification of cocoa beans for export. Where statutory compliance with the grading requirement is applicable, the Malaysian Customs and Excise Department shall not allow the export of cocoa which has not been graded and grading will be evidenced by a Certificate of Grade (*Appendix II*) and a licence stamped on the relevant Export Declaration document. Customs officers are also empowered to inspect any consignments of cocoa for export to ensure that the particulars indicated on the Certificate (such as the grade, Lot No., and number of bags) correspond to the actual shipment, before they validate the Certificate of Grade. Where inspection and grading are voluntary (at the request of the shipper) the Certificate of Grade shall also be issued, but without the Customs validation.

PROCEDURES FOR INSPECTION AND CERTIFICATION

Preliminary Inspection

The inspection of a consignment of cocoa prior to export begins with a preliminary inspection, where the cocoa is checked to ensure that requirements pertaining to packing, moisture, insects and foreign matter and waste are met. During such a preliminary inspection, 10 percent of the total number of bags in the lot are randomly selected and weighed, to confirm that the bags weigh 62.5 kg nett, with an allowance of ½ kg more or less per bag, given that the total weight of the lot is as stated in the delivery note. The bags should also to be marked with the words "PRODUCE OF MALAYSIA" in addition to any identification mark the shipper may require. The selected bags are then opened and their contents poured on to an insect sieve. While this is being done, samples are drawn from the bags for moisture tests, and any waste material or foreign matter is separated from the cocoa. The insects which are found on the drawer or floor of the insect sieve are counted, and if more than 10 insects are found in any bag, that lot of cocoa has to be fumigated. If waste (including flat beans) or foreign matter is found to be excessive, if the moisture content of the samples taken is found to be over 7.5 percent, the cocoa is returned to the shipper or owner for further cleaning or drying as the case may be. Any discrepancy in packing, incidence of insects infestation, high moisture, excessive waste and foreign matter, or objectionable odour will be indicated on an Advice Note, which will be given to the owner or shipper for him to take remedial action. If the cocoa is found to be clean, dry and properly packed, it is accepted for grading or grade confirmation.

Grading

Grading of a particular lot of cocoa is carried out on the basis of samples randomly drawn from 30 percent of the bags in that lot. A probe is used to obtain samples from three points at the top, the bottom and the middle of each randomly selected bag, and these primary samples are bulked and successively quartered to obtain the test samples. A cut-test is carried out on about 200 beans, to determine the level of defective beans, *i.e.* the percentage of mouldy, slaty, insect-damaged/infested or germinated beans in the sample.

That lot of cocoa is categorised into Grade I, II or Sub-standard based on the results of the cut-test.

A bean count is also done on two of the test samples of approximately 200 g each, where the total number of whole beans in each sample is counted and weighed in order to arrive at the number of beans per 100 g. This is to determine whether the beans fall into category A ($\leqslant$ 100 beans per 100 g), B ($>$100$\leqslant$110 beans per 100 g), C ($<$110$\leqslant$ 120 beans per 100 g) or Sub-standard ($>$120 beans per 100 g). This, cut-test and the bean count will determine if the cocoa is of SMCIA, IB or IC, SMCIIA, IIB or IIC or Sub-standard (*Appendix III*).

If any ambiguity or doubt arises as to the grade of the beans, then the tests are repeated on the remaining test samples; however, if there is doubt as to whether the grade is applicable to the whole lot, or when the primary samples are found to differ in quality or bean size, then all the bags should be sampled in order to isolate particular bags of off-grade beans or to separate the cocoa into different lots of differing grades.

Certification

On determining that a lot of cocoa is of a particular grade, the authorized officer will issue a Certificate of Grade (in three copies), which states that consignment of cocoa has been inspected and found to be of the specified grade at the time of inspection. The Certificate will identify the consignment by the lot number or numbers, and any other identification marks as given. In addition, the officer will attach a metal seal to the stitching at the top of the bag, and fix a stamp issued by SIRIM to a plastic label which will be on each bag.

The exporter or owner will also be provided with a "lot form" containing details of the grading results, including the cut-test, the bean count, overall fermentation level, and moisture level. While the Certificate of Grade must be submitted to the Customs together with the other export documents, the lot form is for the exporters' information only, and he may transmit it to the buyer if he so wishes. (See flow chart at *Appendix IV*).

FACILITIES FOR INSPECTION

Initially FAMA set up three Grading and Certification Centres at the main ports in Peninsular Malaysia, *i.e.* at Penang, Port Kelang and Johor Bahru. Each of these three Centres has the capacity to grade up to 4000 tonnes of cocoa per month, and to store up to 2000 tonnes at any one time. These Centres are equipped with forklifts and other handling equipment, equipment required for inspection and sampling (such as insect sieves, weigh-bridges and weighing scales, probes, quartering tools and moisture meters) and also have a small laboratory. A larger and more sophisticated laboratory has been set up at Port Kelang, where samples from all the Centres are received and tested.

Each Centre is staffed with trained graders, a manager and three assistant managers, other clerical staff, a store-keeper, a weighman and drivers and labourers. A chemist is in charge of the main laboratory, at Port Kelang, with laboratory assistants stationed at the other centres. Much attention has been paid to training of the staff concerned, with a basic course provided by MARDI (Malaysian Agricultural Research and Development Institute) followed by in-house training on grading procedures. Some of the staff were sent to Papua New Guinea to observe the inspection of cocoa for export in that country, and the staff have also received the benefit of lectures and papers presented by various experts, both foreign and local, at seminars and workshops.

While much of the cocoa to be exported will be inspected at these three Centres, it is not unlikely that FAMA will also carry out check-grading, or inspection at the premises of major producers or exporters. Large fermentaries with proper stores, and godowns with facilities as specified by FAMA, may be recognized as authorized premises for pre-shipment inspection. FAMA grading inspectors may on request, visit these authorised premises, and carry out the inspection procedures and issue Certificates for the graded cocoa.

INSPECTION REQUIREMENTS

Scheduling of Grading

Owners or exporters of cocoa to be inspected are required to apply for grading at least a week before the anticipated date of grading. This is necessary to ensure that proper scheduling of inspection can be done, and to prevent shippers from being inconvenienced by delays in inspection. Given the likelihood that shipments of cocoa might occur only twice or three times a month (when a suitable vessel calls) and a number of shippers might seek to ship at the same time, it would be to the advantage of the shippers to plan to have their cocoa inspected well in advance. There would also be less strain on the resources at the Grading Centres. Provision is made for cocoa requiring urgent inspection, but a higher fee is charged for consignments which have to be graded within seven days of the date of application.

On confirmation of the application date, the exporter should prepare his cocoa for grading and export, by ensuring that clean, dry and insect-free cocoa is packed into clean new gunny bags, weighing 62.5 kg nett each. Plastic labels should be sewn into the mouth of the bags (the labels will be provided by FAMA on confirmation of the grading application) and the bags should be securely sewn. The cocoa should be received at the Grading Centre on the scheduled date and the Centre should be informed well in advance in the event of any cancellation or postponement of the inspection.

Applications for inspection are accepted from all licensed dealers, wholesalers or exporters, or from registered producers who wish to export their cocoa. It is expected that most applications will be received from exporters themselves, but there is a likelihood that exporters may seek to buy graded cocoa from wholesalers or the larger processors. Exporters who do not have facilities to handle, store or transport cocoa, may take delivery of cocoa they have purchased from their suppliers at the Grading Centres, or they may instruct their forwarders to take delivery at the Grading Centres and transfer to the port godowns or direct to the wharf for shipment. Any person other than the applicant for grading, however, will require authorisation in writing before he is permitted to remove any cocoa from the Grading Centre.

Grading and Other Fees

The grading fee for normal inspection at Grading Centres has been set at 70 ct per bag or $11.20 per tonne, while a fee of $2.00 per bag will be charged for late applications (deemed as emergency grading). Grading fees are expected to cover direct costs incurred during grading, initially at least, while indirect costs such as staff salaries, utilities, communication, maintenance and other services will be met from Government funds. The cost of the SIRIM stamps, the metal seals, plastic labels, and other materials and supplies, direct labour costs, and charges for services directly related to grading activities (such as printing of Certificates, postage and transport of samples, and preparation of stencils for

marking of bags) are estimated to be about 70 ct per bag. The $2.00 per bag charged for late or emergency applications is meant as a deterrent and it is not expected that any exporter will place himself in the position of having to pay such a high fee.

The other fees charged at the Grading Centres will be for storage and for fumigation. While storage fees are designed to aid the exporter to store cocoa at the Centres for short periods prior to shipment, the charges become progressively higher to discourage storage for long periods. Fumigation charges are levied at cost, i.e. the charged incurred by FAMA are passed on to the exporter or owner.

IMPLEMENTATION OF PRE-SHIPMENT INSPECTION

While much care and planning have gone into the formulation of the SMC grades and into the procedures for inspection and certification it remains true that the whole exercise of providing a standard for exports of cocoa and ensuring that exports match the standards which have been specified, will only be effective if they are proven to be effective. Doubts as to the efficiency of the system, the integrity of the staff and the reliability of the grades, will be voiced until it is shown that the scheme works, and can bring about an overall improvement in the quality of cocoa exported from Malaysia and thereby increase the returns realised by producers and reduce the incidence of claims and deductions against Malaysian cocoa. To this end, emphasis has been placed on the careful selection of staff to operate the scheme, on devising a rigorous system of checks and security devices, and on instituting a monitoring and feedback programme to ensure that producers and processors are speedily informed of any serious quality defects in their output. In addition, concerted efforts are being made to inform buyers and potential users of Malaysian cocoa about the SMC grades.

A "quality audit" system, designed to check on the reliability of the grading procedures, is seen as the focus of efforts to ensure that the grading scheme does not diverge from set procedures and standards, as a result of either negligence, external influences or bad practices. This system requires that a sample of all cocoa inspected at the Grading Centres or at the authorised premises be sent to the Central Laboratory. At least a third of all samples received would be tested and checked to make sure that they conform to the grades as determined by the grading staff. In addition an "audit" team would draw samples from graded cocoa at the ports, at exporters' premises and in transit, and submit them to the Central Laboratory for confirmation of grade. While the statistical possibility of having different results has been considered, such variations will be monitored closely and any grading unit or officer whose work is suspected will be placed under supervision. In this way, incidences of variation can be related to the grader, the Grading Centre (or authorised premise) and owner or exporter, and any repeated instances where grade differences are noted can be investigated quickly and effectively.

The use of the SIRIM stamp on the labels, which state that the cocoa has been graded to the Malaysian Standard for cocoa beans, and of the metal seals on the stitching thread or twine across the mouth of the bag, is essentially to reduce the likelihood of any unscrupulous persons tampering with the graded cocoa. These security devices, though cumbersome and time consuming, are considered necessary especially during the early stages of implementation, when exporters are less familiar with the benefits and objectives of the Scheme and may attempt to circumvent the requirements or misuse the Certificate and grade markings. In addition, the SIRIM stamp on the label gives some authority to the grades as marked on each bag, and it is hoped, will serve as an assurance of quality insofar as users are concerned.

A programme has been written to monitor grading activities and results, and data pertaining to each inspection exercise are recorded for reference and follow-up action. Monitoring of the prevalence of any type of defect and of bean characteristics will help to locate and ensure remedial action is taken against any problems which may arise, such as insect infestation, before they become widespread. Furthermore, such monitoring can also speedily identify the source of any cocoa against which queries are raised, and make available data on previous shipments from the same source. The compilation of statistics on export of cocoa and the quality of exports will also become readily available. The monitoring programme should also facilitate extension activities to help determine which areas need greater attention and which aspects need greater emphasis.

Efforts to acquaint traders and manufacturers in consuming countries with the grades and to make them aware of the emphasis the government places on improving the quality of cocoa exports from Malaysia are ongoing. Advertisements in trade journals, pamphlets, audio-visual presentations, and personal contacts are being used extensively by FAMA and Malaysian trade representatives to increase awareness of the implementation of the Standard Malaysian Cocoa Grades.

IMPLICATIONS OF PRE-SHIPMENT INSPECTIONS

The effect of implementing statutory inspection of cocoa beans for export has been far-reaching. The trial period which allowed for voluntary inspection and grading of cocoa from May to July 1984 gave some indications as to the changes which are likely to take place in marketing practices at various levels.

At the farm level, producers, especially those who have facilities for processing wet beans, are becoming more conscious of bean quality. Farmers who do not have proper fermentation boxes or drying facilities are turning to selling wet beans, as they are aware that they may obtain lower prices because of poor quality. At the same time, farmers who do possess facilities for processing wet beans are paying more attention to proper fermentation and drying, winnowing or sieving of dry beans, using good packing material and ensuring proper storage of dried cocoa. Dry bean collectors are beginning to use SMC grades when purchasing dry beans, and price differentials, particularly for bean size, are becoming standard practice. The major bean dealers-cum-processors have set up price boards which give some indication of prices they are willing to pay for the grades available in that area. There is a reluctance to accept cocoa which is not adequately dried, and undesirable characteristics such as high external mould, foul odours and high content of foreign matter are being penalised. While mixing or "blending" of beans of different sizes is still practised, bean dealers are exercising greater care and being more circumspect when doing so.

While inspection of cocoa prior to shipment cannot be expected to eliminate all mal-practices which lead to quality problems, it will act as a deterrent to the more blatant practices. Wholesalers or bean dealers who may possibly be the crucial link in the chain, now have to ensure that cocoa which they submit for inspection is acceptable and is able to obtain a required grade marking before they are able to place on board as per contract requirement. While exporters may leave it to their suppliers and forwarding agents to ensure that any consignment due for shipment receives the required documents, they will be responsible for the quality of the cocoa they deliver to overseas buyers. As local dealers begin to sell graded cocoa to exporters, it is likely that the practice of withholding part of the payment to offset possible claims, will become less prevalent.

6

There have been fears that farmers will be affected adversely by the implementation of pre-export grading, as when dealers take advantage of the complexities of the Grading Scheme to make unjustified deductions and give lower-than-representative grades for cocoa they purchase, but effective enforcement of the licensing regulations and close monitoring of invoices issued by dealers, complemented by widespread extension to farmers, processors and dealers has curtailed such fears. The extent of competition among cocoa buyers is fairly high, and this has also helped to limit the activities of any unscrupulous dealers; finally, farmers may take advantage of the FAMA offices in their vicinity and obtain advice as to the grade of their cocoa before sale if they are dissatisfied with the price or grade offered by a particular buyer.

A desirable effect of the implementation of the Grading Scheme would be the use of SMC grades in contracts and quotations by both local and overseas buyers. This, however, would be dependent on the extent to which the exporters use the grades in their dealings and their commitment to promoting the use of the grades. While promotion overseas by the authorities and the use of the grades by agencies like FAMA, SAMA and FELDA are effective to some extent, private sector promotion of SMC in day-to-day dealings with their counterparts at the terminals is essential for acceptance of the grades, particularly by dealers.

CONCLUSION

Pre-shipment inspection of Malaysian cocoa was begun on mid-August 1984. The response of the industry has been encouraging, and while initial problems do exist, the Centres have been able to cope with the workload and the markets have reacted favourably to Standard Malaysian Cocoa.

The implementation of voluntary grading in Sabah will also contribute towards the effectiveness of the Grading Scheme as a whole. The overall benefits of pre-shipment inspection far outweigh any immediate inconveniences which may be experienced, and the need for support for this scheme from all sectors of the industry cannot be overemphasized. Effective implementation of quality control measures must be a complement to increased productivity, improved processing, storage and transport, and efficient marketing for cocoa in Malaysia.

FEDERAL AGRICULTURAL MARKETING AUTHORITY
ACT 1965

COCOA MARKETING REGULATIONS 1980

IN exercise of the powers conferred by section 3 and 12 of the Federal Agricultural Marketing Authority Act 1965, the Authority, with the approval of the Minister, makes the following regulations:

Act 141.

1. (1) These Regulations may be cited as the **Cocoa Marketing Regulations 1980** and shall apply throughout Malaysia with effect from the 1st August 1980.

Citation, application, commencement and exemption.

(2) The Minister may by notification in the *Gazette* exempt any State or part of a State or person or persons from any or all of the provisions of this Scheme.

2. In these Regulations, unless the context otherwise requires —

Interpretation.

"Authority" means the Federal Agricultural Marketing Authority (FAMA);

"cocoa bean" means of a seed of *Theobroma Cacao* L. which has not passed through a fermentation or drying process and includes a cocoa pod, and/or the dry fermented bean of the plant *Theobroma Cacao* L.;

"cocoa farmer" means a person who cultivates cocoa on land which belongs to him or in which he has an interest as lessee, tenant, occupier, licensee, assignee, chargee, successor in title, agent or in any other manner or capacity and includes any person who cultivates his land through persons employed or otherwise engaged by him for the purpose, notwithstanding that he does not reside on the land or is not personally present when the physical cultivation of the land takes place;

"processing" in relation to cocoa beans means the performance of any one or more activities involved in fermenting, drying, cleaning, grading, mixing, blending, or grinding of cocoa beans;

"purchase" includes to acquire for a consideration other than money;

"this scheme" means the Cocoa Marketing Regulations 1980.

3. (1) No person shall, for the purpose of trading, storage, transport or processing,

Licensing.

    (a) purchase from a cocoa farmer any cocoa beans;
    (b) purchase from any other person any cocoa beans; unless he is licensed in that behalf by the Authority.

(2) A person who, not being a cocoa farmer,

    (a) is found in possession of cocoa beans; or
    (b) arranges for or obtains the transportation at any one time, other than as a carrier, of cocoa beans;

shall be deemed to have purchased the cocoa beans from a cocoa farmer, unless the contrary is proved.

4. (1) An application for a licence mentioned in paragraph 3 or the renewal thereof shall be in such form as the Authority may from time to time prescribe.

(2) Any such licence issued or renewed under sub-paragraph (1) may be subject to such terms, conditions and restrictions as may from time to time, and at any time, be imposed by the Authority.

(3) Without prejudice to the provisions of sub-paragraph (2), the following provisions shall apply with respect to every licence issued or renewed as aforesaid:

(a) each licence shall expire twelve months from the date on which it was issued or renewed; and

(b) there shall be paid to the Authority such fee in respect of the licence as the Authority may from time to time impose.

5. (1) The Authority may by way of conditions in the licence require a person licensed under paragraph 3 to issue —

(a) a purchase invoice to the cocoa farmer or any other seller; and

(b) a sale invoice to the buyer.

(2) A purchase invoice and a sale invoice shall be in such form and contain such information as the Authority may require.

(3) The licensee shall keep in the premises specified in the licence, a register, in the form approved by the Authority, in Bahasa Malaysia or in English, in which shall be made within seventy-two hours of each purchase, receipt, or sale of cocoa beans, proper entries of particulars relating to the name and address of the seller, supplier, or purchaser of cocoa beans, the date, the quantity so purchased, received or sold, the amount remaining in store and such other particulars as the Authority may from time to time require.

(4) The licensee shall exhibit in a conspicuous place —

(a) in the premises or place of business specified in the licence a board showing the prevailing price at which he purchases cocoa beans from the cocoa farmers or any other sellers for the day, and the deductions from the price or weight thereof which may be permitted under the terms of the licence issued to him; and

(b) over the door of the premises or place of business specified in the licence, and in such manner as can be easily read by members of the public, his full name as appearing in the licence, in Roman letters, and the words —

PEMBELI KOKO BERLESEN
LICENSED COCOA BUYER

8. (1) No person offering cocoa bean for export shall use any distinguishing mark or identification in respect of such cocoa bean unless

9

(5) The licensee shall —

    (a) furnish to the Authority such other information or returns as the Authority may require; and

    (b) display such other information in such manner as the Authority may require.

(6) The licensee shall, on demand by an authorised officer of the Authority, permit the officer to enter the premises and shall, if required, produce for the inspection of the officer his licence and the register aforesaid.

6. (1) If it appears to the Authority that any person duly licensed under these Regulations has contravened or failed to comply with any rule or any of the terms, conditions or restrictions imposed with respect to a licence issued to him thereunder, the Authority may call upon such person to show cause why such licence held by him should not be cancelled.

<div align="right">Cancellation of licençe.</div>

(2) Any person called upon to show cause under sub-paragraph (1)—

    (a) shall be supplied by the Authority with particulars, in writing, of the contravention or non-compliance complained of; and

    (b) may, if so desires, appear in person or be represented by any person authorised by him in writing at a hearing before the Authority.

(3) If, after such hearing, the Authority considers that the person called upon to show cause has contravened or failed to comply with any of the provisions of these Regulations or contravened any of the terms, conditions or restrictions of the licence issued to him, the Authority may cancel the licence.

(4) The Authority, upon calling a licensee to show cause pursuant to sub-paragraph (1) or at any time thereafter, and pending its decision as respects the cancellation or otherwise of the licence, may suspend such licence provided that the Authority may at any time withdraw such suspension.

7. (1) No cocoa bean shall be exported unless it has been graded, packed and sealed in such manner as the Authority may determine and the Authority has, with respect to any cocoa bean graded, packed and sealed as aforesaid, issued a certificate or certificates certifying such fact.

<div align="right">Grading and export of cocoa.</div>

(2) Where the Authority finds that any cocoa bean sent to it for the purpose of the issue of a certificate under sub-paragraph (1) is unfit to be issued with such a certificate, it may require the person who sent the cocoa bean to remove the cocoa bean from the premises of the Authority within such time as the Authority may specify and if he fails to remove the cocoa bean within the time so specified the Authority may destroy the said cocoa bean.

8. (1) No person offering cocoa bean for export shall use any distinguishing mark or identification in respect of such cocoa bean unless

<div align="right">Distinguishing mark or identifications.</div>

such mark or identification is registered with the Authority as the distinguishing mark or identification used by such person.

(2) An application for the registration of a distinguishing mark or identification aforesaid shall be made in such form as the Authority may prescribe.

(3) The registration of any distinguishing mark or identification aforesaid may be subject to such terms and conditions as may be imposed by the Authority from time to time.

Register of identification marks.

9. The Authority shall keep and maintain a register of all distinguishing marks and identification registered with the Authority pursuant to paragraph 8.

Exemptions of cocoa beans used or intended to be used as planting material and burden of proof.

10. (1) The provisions of these Regulations relating to cocoa beans do not apply to or in relation to cocoa beans used or intended to be used as planting material.

(2) The burden of proof that any cocoa beans are or have been used or intended for use at any particular time as planting material lies on the person alleging it.

Made the 22nd July 1980.

SHAMSURI BIN MD. SALEH,
Chairman,
Federal Agricultural Marketing
Authority

Approved the 25th July 1980.
[KP. Sulit O. 339/126; PN. (PU²) 145.]

DATUK SHARIFF BIN AHMAD,
Minister of Agriculture

11

FAMA

Certificate of Grade

MALAYSIAN COCOA BEANS

Issued by:

Federal Agricultural Marketing Authority, Malaysia.

(Cocoa Marketing Regulations 1980, Regulation 7(1))

This is to certify that the consignment of cocoa received from ....

....

Licence/Registration No. ...., details of which appear below,

has been inspected on .... in accordance with the MALAYSIAN

STANDARD MS293: Specification for Grading of Malaysian Cocoa Beans, and found at

the time of inspection to be of the following grade:

....

Total number of bags: ....

Lot number(s): ....

Other marks: ....

Intended date of shipment: ....

Destination: ....

Signature: ....

Grading

Centre: .... Name: ....

Date: .... Position: ....

For Customs Use Only

Date of Export ....
    Date/Month/Year

Export Declaration No. ....

Exporting vessel ....
    Proper Officer of Customs

SCHEDULE OF SMC GRADES

Grade	Bean Count (per 100 gms)	Mouldy	Slaty	Insect-damaged and germinated
SMC 1A	≤100	≤3%	≤3%	≤2.5%
SMC 1B	>100 ≤110	≤3%	≤3%	≤2.5%
SMC 1C	>110 ≤120	≤5%	≤3%	≤2.5%
SMC IIA	≤100	≤4%	≤8%	≤5.0%
SMC IIB	>100 ≤110	≤4%	≤8%	≤5.0%
SMC IIC	>110 ≤120	≤4%	≤8%	≤5.0%
Sub-standard	>120	>4%	>8%	>5.0%

Other aspects of quality which should be given attention are as follows:—

(i) The cocoa must be free from live insects.

(ii) The cocoa must be reasonably free from waste, dust and flat beans and virtually free from foreign matter such as stones, placenta, bits of string, etc.

(iii) The moisture content of the cocoa must not exceed 7.5%.

(iv) The cocoa beans should be adequately fermented.

(v) The cocoa should not be contaminated or have any foreign odours.

(vi) The cocoa should be packed in new, clean gunny bags of 62.5 kg nett each.

Issue advice note

72

If bags not acceptable for grading, request removal of cocoa.

Reload bags   Permit removal of cocoa by owner/shipper   REJECTION

70 — 71 — 73

Owner does not want fumigation

62

If bags require fumigation, give owner option to fumigate at the Center.

If fumigation requested, mark on lot form.   Send bags to fumigation bay   Issue stores receipt to owner/shipper   Fumigation   Continue grading activities as from 50.   FUMIGATION

60 — 61 — 63 — 64 — 65 — 66

Weigh each bag as selected.

32

Prepare grading sheet and enter lot identification no.

38

Record seals used/spoilt/returned

83

For immediate shipment load bags on to lorry

84   Permit removal of bags from premises

Issue seals for no. of bags recorded

86

| Receive Application | Confirm Receiving Date | Weigh Full Lorry | Issue Lot Identification no and lot form | Unload Bags at Grading Bay | Select 10% of bags | Pour beans into insect screen/flow sampler. | Check For Insect/Foreign Matter | Mark Result On Grading Sheet | Select Further 20% of bags and sample | Bulk and Mix Sample | Reduce bulk sample to test sample | Weigh test sample | Count no of beans and mark beans/100 gms on grading sheet. | Cut 2000 beans | Read cut-test results and mark on grading sheet. | Determine grade and mark on lot form. | Issue seals for no. of bags recorded. | Seals bags apply grade marks and SIRIM mark. | Remove bags to store | Issue copy of lot form to owner | Retain cocoa in store | Allow removal of bags for export on request | Collect storage fees/issue delivery note | Obtain confirmation from custom | copy of c of c |

10 — 11 — 20 — 21 — 22 — 30 — 31 — 33 — 39 — 50 — 51 — 52 — 54 — 56 — 57 — 58 — 59 — 80 — 81 — 82 — 83 — 85 — 87 — 88 — 01 — 02

Register Application

12

Obtain sample for moisture test.

Grind beans for moisture test.   Read moisture meter result.

34 — 35 — 37

Check For Foul Odour

36

Mark results on grading sheet.

If cocoa acceptable for grading and storage is requested, issue Delivery acceptance note.   Lorry permitted to leave.

53 — 55

Copy of lot form to registry

90

Register all lot forms for consignment.   Obtain copies of C of G from Sr. Grader   Collect grading fees from owners/shippers   Issue 2 copies C of G to shippers/ owner of graded cocoa

92 — 95 — 96

Register particular of C of G

CERTIFICATION AND REGISTRATION

Weigh empty lorry   Calculate nett load   Mark on Lot form.

40 — 41

Sr. Grader retain one copy of lot form and grading sheet.   Compile all lot forms for one consignment

91 — 93   Issue C of Grade for the consignment in 4 copies, 3 for registry.   94

APPLICATION   PRELIMINARY INSPECTION   GRADING   SEALING, STORAGE AND DOCUMENTATION   EXPORT CONFIRMATION

QUALITY CONTROL OF PAPUA NEW GUINEA COCOA BEANS

R.B. DUNCAN

Cocoa Board of Papua New Guinea, P.O. Box 532,

Rabaul, PNG

J.C. BOND

Department of Primary Industry, P.O. Box 417,

Konedobu, PNG.

SUMMARY

The world market for cocoa beans cannot be described as a
dynamic growth industry when the average annual increase
of grindings is about 2.5%

As almost all of the world production is used by the
confectionary trade, which is highly competitive, it is of
utmost importance that the farmer produces a consistently
high standard of quality in cocoa beans and to do this
requires adequate fermentation and drying facilities.

Papua New Guinea has a reputation for supplying good quality
beans and this achievement is assisted by a two tier
inspection system.

Firstly the farmer must have a more or less standard
well equipped fermentary which is capable of satisfying
the second level of inspection which is carried out on all
dry beans before sale.

This paper describes how the two levels, one controlled by
the Cocoa Board of Papua New Guinea and the other by the
Department of Primary Industry, operate under the powers
given by the Cocoa Act 1981.

REGISTRATION OF FERMENTARIES

Under Section 25 of the Cocoa Act, 1981 the Cocoa Board may, on payment of the prescribed fee, register premises, or proposed premises, as premises permitted to be used for processing or fermenting cacao beans.

The Cocoa Board, when registering premises, may make the registration subject to such conditions and restrictions as it considers appropriate in the circumstances.

Registration fee is K30 per annum and the restrictions are:-

(a)   Only export quality cocoa is to be produced.

(b)   All cocoa processing facilities to be kept in a clean and hygienic condition and be kept free of cocoa storage pests.

(c)   Minimum fermentary production must be in excess of two tonnes export standard cocoa per annum.

(d)   Fermentary numbers are registered in the name of the owner of the fermentary and are for his use only. They must not be used by any other person.

(e)   An unregistered fermentary must not be used to process cocoa beans.

With assistance from the Department of Primary Industry's field staff all fermentaries are inspected at least once per year.

Fermentaries are expected to have two well constructed timber fermenting boxes with drainage facilities, a hot air drier and clean waterproof storage area. Dealers in wet bean require a minimum of four fermenting boxes and correspondingly more drying capacity.

All registered fermentaries are given an identifying mark which must be stencilled on the cocoa bag of beans.

The Cocoa Board may cancel a registration if it is
satisfied that -

(a)   the registration was obtained -
       (i)   by means, or partly be means, of a false or
             misleading statement or
       (ii) by other improper means; or
(b)   the owner of the registered premises -
       (i)   has failed, in the Board's opinion, to
             comply with a condition or to observe a
             restriction noted on the Certificate of
             Registration; or
       (ii) has been convicted of an offence against
             this Act:

The Cocoa Board may refuse an application for registration
of a fermentary if the Board is not satisfied -

   (i)   that the premises or proposed premises are or
          will be constructed, equipped or operated in an
          efficient manner; or
   (ii)   that the proposed method of processing will in
          general produce cocoa beans which will conform
          to the prescribed quality for export cocoa
          beans; or
   (iii) that additional facilities are required.

A person aggrieved by the Cocoa Board's decision may appeal
to the Minister for Primary Industry in writing within
twenty-one days.

Under this Subsection of the Cocoa Act, 1981 a person is
guilty of an offence if -
(a)   he uses or permits premises owned or occupied by
       him, other than premises in respect of which he
       holds a Certificate of Registration, to be used
       for processing or fermenting cacao beans or
       partly processed cocoa beans; or

(b) he fails to comply with a condition or to observe a
     restriction endorsed on the Certificate; or

(c) for the purpose of obtaining a registration he gives
     false or misleading information to the Cocoa Board.

PENALTY

A fine not exceeding K1,000.00, imprisonment for a term
not exceeding six months or both.

Where a person is convicted of an offence under this
Subsection in relation to any cacao beans or cocoa beans
the court which convicts him may, in addition to, or
instead of imposing any other penalty, order that the
beans be forfeited to the Cocoa Board. These beans
would thus be the property of the Board.

A fermentary registration is usually cancelled if non-
export quality cocoa is produced on more than two
occasions within a period of two months.

On the first occasion that non-export quality beans are
produced Produce Inspectors offer advice to the farmer
and the Department of Primary Industry extension staff
are requested to visit the fermentary.

REGISTRATION OF COCOA DEALERS

Cocoa dealers are registered fermentary owners who purchase
wet cacao beans from farmers.

A dealer is registered subject to the conditions and
restrictions applicable to fermentaries plus the following:

(a) Only cacao beans of good quality to be purchased
     or received for fermenting.

(b) Fermented or fully processed beans must not be
     purchased.

(c) Wet beans from immature pods and containing
     placenta or other foreign matter must not be
     purchased or received.

(d) Cacao or cocoa beans suspected of being stolen are
     not to be purchased.

(e) Only Buying Points approved by the Board Inspector
     can operate.

(f) Wet beans must be placed in fermenting boxes within
     24 hours of purchase.

(g) Dry bean storage area to be kept insect free and
     be of sound weather proof construction.

Registration fee is K50.00 per annum.

The Cocoa Board may refuse an application for registration
as a cocoa dealer if in the Boards opinion the applicant
has not adequate finance, facilities or organisation
for the storage or control of quality of cacao beans
or cocoa beans.

Registered Dealers are given a maximum fermenting
capacity which is related to the drying capabilities.
When this capacity is reached no further wet bean is to
be purchased. This restriction is to prevent fermentation
in containers other than those approved.

REGISTRATION OF EXPORTERS

Only registered exporters can purchase dry cocoa beans and
then only after they have been graded by the Produce
Inspectors.

The Cocoa Board may refuse an application for registration
if in the Board's opinion the applicant has not adequate
finance, facilities for the storage, control of quality,
handling or marketing of cocoa beans.

Registration fees for an exporter are calculated at the
rate of -

(a) K500.00 for each major port; and

(b) K200.00 for each minor port, through which the cocoa
     exporter is permitted to export cocoa.

A major port is one from which more than 2,000 tonnes of cocoa was shipped in the previous year.

An Exporter is registered subject to the following conditions -

(a)   The store or stores referred to in this certificate will be constructed and maintained at a standard approved by the Inspectors of the Department of Primary Industry and/or of the Cocoa Board.

(b)   Floors of storage sheds must be kept clean of any material likely to stain or mark cocoa bags.

(c)   All bags of cocoa must be stored on pallets.

(d)   All cocoa storage sheds must be kept free of insect storage pests.

(e)   An adequate space must be left between stacks of bags and shed walls to allow access for insect control.

(f)   All cocoa sales contracts must be registered with the Cocoa Industry Board within (14) days of the establishment of such contracts.

(g)   Monthly Returns of Shipments, including nil returns, must be submitted, on the forms provided, within fourteen (14) days of the end of the month. Copies of relevant Export and Cocoa Levy forms must accompany the returns. The latter forms relate to payments into the Cocoa Stabilisation Fund.

(h)   Return of Contracts forms must be submitted within fourteen (14) days of the end of the month, detailing all registered contracts which are wholly or partially unfilled.

(i)   A return of stock on hand and in transit at the 30th September each year is to be submitted, on the form provided, by the 14th October of the same year.

(j)   Off-Grade cocoa beans and cocoa residue are to be stored separately to Export Quality beans.

(k)   All Off-Grade beans and residue must be fumigated before being shipped.

A person is guilty of an offence if -

(a)   not being a person registered as a Registered
        Exporter be exports cocoa beans or

(b)   being a person to whom a Certificate of Registration
        as a Cocoa Exporter has been issued he fails to
        comply with a condition or to observe a restriction
        endorsed on the Certificate or

(c)   for the purpose of obtaining a registration he gives
        false or misleading information to the Cocoa Board.

PENALTY

This is the same as for fermentaries and dealers, a
maximum of K1,000.00 and or the forfeit of cocoa to the
Cocoa Board.

Section 32 of the Cocoa Act is worth noting.
A person is guilty of an offence if he sells or agrees
to sell cocoa beans for export by sample and subsequently,
wilfully or negligently exports, on the basis of that
sample, cocoa beans which do not substantially conform
to that sample.

The penalty is a fine not exceeding K500.00.

Once registered, a fermentary can commence operations
and sell dry cocoa beans to the registered exporters
after having the beans inspected and graded by the
Department of Primary INdustry Produce Inspectors who
operated in a central depot.

The Cocoa Regulations, 1982 specify the manner of sampling,
quality standard for export, weight of contents, marking
of bags, inspection mark, sealing and quality of bags.

MANNER OF SAMPLING

The Cocoa Inspector estimates the total weight of each consignment by weighing at least one bag of cocoa beans and draws samples of beans as follows -

a)　　Where a flow sampler is available the sample shall be be obtained by tipping into the flow sampler the contents of -

    (i)　　in the case of a consignment consisting of not more than three bags - all bags and

    (ii)　　in any other case - the bags taken at randon in accordance with the following schedule.

No. of bags in a Consignment	No. of bags to be Sampled
Not less than 4 and not mroe than 10	3
Not less than 11 and not more than 17	4
Not less than 18 and not more than 30	5
Not less than 31 and not mroe than 42	6
Not less than 43 and not more than 56	7
Not less than 57 and not more than 72	8
Not less than 73 and not more than 90	9
Not less than 91 and not more than 110	10
Not less than 111 and not more than 132	11
Not less than 133 and not more than 156	12
Not less than 157 and not more than 182	13
Not less than 183 and not mroe than 210	14
Not less than 211 and not mroe than 240	15
More than 240	

The number being the square root of the number of containers in the consignment taken to the nearest whole number.

From this a subsample being 10% by weight of the cocoa beans is extracted; and

b)　　a flow sampler is not available - a sample shall be obtained by taking 25% of the bags at random and extracting not less than 0.25 Kg of beans from each bag by using a stabber approved by the Board.

It is a recommend that a bagging slide be constructed under the flow sampler to allow foreign matter to be collected by the Inspector as the beans are rebagged. The foreign matter is weighed.

The use of a bag stabber is not recommended as it cannot extract clusters of beans and pieces of string etc. Where a stabber has to be used the tip out bagging slide is absolutely essential.

TESTING OF SAMPLES

The Produce Inspector selects 100 beans at random that are cut length wise to expose the cotyledon and inspected to ascertain if they conform with the following requirements for Export Standard.

a) be beans that have been through fermenting and drying processes approved by the Board.

b) contain not more than 1% by count of slaty beans; or

c) not more than 5% by count of flat, double, broken or germinated beans; and

d) not more than 5% by count of defective beans; and

e) be evenly dried; and

f) contain a moisture content of 5.5% and 7.5% by weight; and

g) have not more than 1000 beans per kilogram.

A slaty Bean means a bean that shows a slate colour on 50% or more of its surface exposed by a cut lengthwise through its centre. Defective Bean means a cocoa bean that is affected by internal mould or internal insect infestation.

Some of the sample is pulverised in a electric grinder and sniffed to detect off-flavours caused by over fermentation, smoke and contact with foreign odours.

When any doubt exist about the moisture content of beans a moisture metre is used.
To judge whether cocoa has been through a fermenting and drying process approved by the Board is sometimes difficult and relies on the training and experience of the Inspector.

The staining on the inside of the testa is a major indicator of unfermented beans.

It is very important that the Primary Industry Inspectors become involved in fermentary inspections.

MARKING OF BAGS

Section 6 of the Cocoa Regulations state -

(1)   Marking of bags of cocoa beans intended for
       export shall be in black indelible ink, each
       letter or symbol being not less than 60mm and not
       more than 80mm high, and 6mm thick.

(2)   A bag of cocoa beans shall be clearly marked with
       the following in separate lines one beneath the
       other at a space of 26mm.

       (a)   the letters PNG and
       (b)   the words Cocoa Beans and
       (c)   the identification mark.

(3)   A clear space of 150 mm shall be left between the
       top of the bag and the letters PNG in which the
       inspection mark shall be applied by the Produce
       Inspector.

The identification mark enables the buyer to identify
the fermentary, in which the beans were produced, should
it be necessary.

INSPECTION MARK

The inspection mark to be applied to bags of cocoa beans
conforming to Papua New Guinea export quality shall be -
(1)   in red indelible ink; and
(2)   in the form of a solid equilateral triangle, each
       side being not less than 100mm long; and
(3)   made with the apex of the triangle pointing to
       the top of the bag.

The inspection mark to be applied to bags of cocoa beans
rejected as not conforming to Papua New Guinea export
quality shall be
(1)   in green indelible ink; and
(2)   in the form of a stripe along the mouth, including
       the stitching, of the bag:

SEALING BAGS

Bags of cocoa beans that have been passed as Papua New
Guinea export quality are be sealed by means of a metal
plomb attached to the top of the bag in a manner to
prevent the bag being opened without obviously
disturbing the seal.

All bags must be securely sewn.

QUALITY OF COCOA BAGS

Bags for cocoa beans must be clean, sound and new.

Dirty or broken bags are condemned by the Produce
Inspectors and must be changed. If a bag is damaged
after inspection the contents are re-bagged and
submitted, with the broken bag, for re-inspection.

CERTIFICATE OF INSPECTION

After examination of a consignment of cocoa beans
intended for export, the Cocoa Inspector issues a
signed Certificate of Inspection in triplicate. The
original is attached to shipping documents by the
registered exporter for the Comptroller of Customs,
the duplicate is retained by the grower and the
triplicate is sent to the Cocoa Board.

A Certificate is valid only for three months from the
date the cocoa was examined.

ADVICE NOTE

When a consignment of cocoa beans is found to be non-export quality an Advice Note is issued stating the reason for rejecting the beans. If the consignment contains more than 1% slaty beans or have foul or foreign odours or contain more than 5% of defective beans the fault or faults is noted on the Advice Note and the owner of the cocoa beans instructed to deliver the consignment to a registered exporter. A copy of the Advice Note is attached to each of the Inspection Certificates.

It is an offence if the owner of the cocoa beans obliterates, removes or tampers with an inspection mark or removes from, adds to, or in any way tampers with the contents of, the cocoa bag without a Cocoa Inspector's approval.

The penalty is K500.00.

If the consignment of beans can be reconditioned by further drying or removal of foreign matter the farmer does so and submits the beans for re-inspection. The Advice Note must be presented with the beans.

APPEAL AGAINST INSPECTORS DECISION

A cocoa grower can appeal to the the Cocoa Appeal Committee if he is aggrieved by a Cocoa Inspectors decision.

The Cocoa Appeal Committee of a province consists of
(a)   an officer of the Department of the Province responsible for primary industry, who shall be Chairman; and
(b)   two persons, not being officers, who represent cacao growers in the Province, appointed by the Cocoa Board after consultation with the Head of the Department of the Province.

Papua New Guinea exports about 30,000 tonnes of cocoa
beans annually. This cocoa is inspected at twelve
inspection depots, shipped by eleven exporters through
twelve ports and is produced in 1800 fermentaries of
which 1150 are dealers.

The system could be made more efficient by combining
the grading, winnowing and inspection in central
depots but because of transport difficulties this
would reduce the return to farmers.

There is no doubt that the final effectiveness of any
inspection system depends entirely on its staffing and
administration. In PNG the Inspection Service is a
government organisation and has the usual public service
malaise but despite this the Service has a good
reputation with overseas cocoa buyers.

UTILIZATION OF BY-PRODUCTS OF COCOA BEAN PROCESSING

by

R. Shepherd, Harrisons Malaysian Plantations Berhad
& Yap Tuan Ngan, Sime Darby Plantations

SUMMARY

This paper reviews possible uses for cocoa pod husks and juice or sweatings that exude from beans during primary processing. Pod husks contain significant amounts of plant nutrients, especially potassium and nitrogen, values of which have been computed. Alternatively, pod husks may be incorporated at controlled rates in ruminant and non-ruminant diets. Mention is also made of the possibility of generating biogas from pod husks by anaerobic digestion.

The economic utilization of cocoa juice or sweatings also merits consideration. Cocoa juice, extracted from the pulp of fresh beans by application of pressure or enzyme, contains up to 16 percent sugars and is expected to be suitable for conversion into economic products. Of the various uses received, its utilization as an ingredient of non-alcoholic drinks or as feedstock for vinegar production is considered particuarly worthy of investigation.

INTRODUCTION

World production of cocoa beans in 1983 exceeded 1,530,000 tonnes, of which Malaysia contributed 68,000 tonnes or 4.4 percent (Gill & Duffus, 1984). Although global output of cocoa beans is expected to increase at a very modest rate (between two and three percent per annum), a three-fold increase in Malaysian production by the turn of this century could prove realistic if the recent pace of cocoa planting is maintained and increasing use is made of cocoa clones which are capable of outyielding hybrid seedlings by significant margins. The foregoing projection also presumes that pests and diseases do not pose untoward problems.

Two by-products of consequence are produced during crop collection and primary processing — pod husks and juice/sweatings arising from the pulp surrounding beans. Apart from leaving pod husks in the field to recycle nutrients, by-products have been utilized only to a very limited extent. The purpose of this paper is to consider availability of the two main by-products and the prospects for their economic utilization.

POD HUSK UTILIZATION

Typical yields of pod constituents are shown in <u>Table 1.</u>

TABLE 1.   POD CONSTITUENTS

Constituents	Percent by weight	
	Fresh basis	Dry basis
Husk	68.5	47.2
Placenta	2.5	2.0
Beans	29.0	50.8

Based on these figures, 5.900 kg fresh husk or 930 kg dry husk would be available for every 2,500 kg fresh cocoa beans or 1,000 kg dried beans produced.

1.   Source of Plant Nutrients

In cocoa estates the beans are usually removed from pods at distributed points in the field and husks are scattered over the soil surface near pod breaking points in an effort to recycle nutrients.   The alternative estate practice of centralised pod breaking and subsequent distribution of husks involves additional transport costs.

For proper evaluation of the feasibility of these recycling systems <u>vis</u> a <u>vis</u> alternative economic uses for husks, the values of contained nutrients should be ascertained.   Based on prevailing prices of inorganic fertilizers and concentrations of nutrients in husks, the values of major nutrients per tonne dry husks are shown in <u>Table 2</u>.

TABLE 2. POD HUSK NUTRIENT CONTENT AND ESTIMATED VALUE

Element/ oxide	Percent on D.M.	Kg per tonne	Nutrient value*(M$) per tonne husks
N	1.66	16.6	27.69
P205	0.17	1.7	1.04
K20	5.54	55.4	29.17
MgO	0.30	3.0	3.55
CaO	0.23	2.3	0.23
			61.68

*Based on the following fertilizer prices per tonne delivered to field :-

Sulphate of ammonia (20.5% N)	=	$342
Christmas Island rock phosphate (34.5% P205)	=	$212
Muriate of potash (60% K20)	=	$316
Kieserite (26% MgO)	=	$308
Calcium limestone (54% CaO)	=	$ 54

Although nutrient levels are comparatively low, at prevailing fertilizer costs the value of husk nutrients amounts to M$61.68 per tonne dried husks or M$57.36 per tonne dry cocoa beans produced. No values are ascribed to the micro-nutrients (Mn 50 ppm, Fe 121 ppm, Cu 9 ppm and Zn 54 ppm on a dry basis) in husks as these nutrients are not routinely applied in cocoa plantations.

Nitrogen and potassium, especially the latter, are the main nutrients in dried cocoa pod husks. As cocoa beans also remove appreciable amounts of nitrogen and potassium Table 3, (based on Thong & Ng, 1980), and positive yield responses to both nutrients have been demonstrated in most Malaysian soils, particularly in inland situations, the nutrient value of pod husks should be recognized and every effort should be made to ensure they are reasonably well distributed so that cocoa trees can derive maximum benefit from the nutrients and organic matter.

TABLE 3.   NUTRIENT REMOVAL IN 1,000 KG DRY COCOA BEANS
(INCLUSIVE NUTRIENTS IN MUCILAGE)

Element	Kg	Oxide	Kg
N	20.4		
P	3.6	P205	8.4
K	10.5	K20	12.7
Mg	2.7	MgO	4.5
Ca	1.1	CaO	1.5
Mn	0.03		

A potential limitation in Sabah to mulching with fresh cocoa pod husks is the presence of the cocoa borer moth. If cocoa moths are present, the pod husk must be appropriately treated before mulching. Currently the pod husks are put in plastic bags for several days, which effectively kills the larvae, before mulching (Wood, 1980; Day & Mumford; 1983).

Adomako (1978) has reported that pod husks may be dried and ashed to concentrate nutrients and facilitate transportation. Although the ashing would attain these objectives and eliminate cocoa pod borer moth larvae, the organic matter, much of the nitrogen, and part of the potassium would be lost in the process. As husk collection and ashing would entail significant expenditure, it is unlikely that the production of ash will prove economic unless high value uses for it are found.

Where centralised pod splitting is done, the costs of returning pod husks to the field are likely to be high in relation to their nutrient value and alternative uses for the husks could prove more remunerative. Of the various possible applications reported in the literature, their utilization as a component of animal feeds is considered the most worthwhile, though the production of biogas or extraction of pectin might also be economic. Only these applications will be considered further in this paper.

2.   Animal Feed

During 1980, the costs of animal meat and feedstuffs imported into Peninsular Malaysia amounted to M$126.7 million and M$175.6 million respectively (Dept. of Statistics, 1981). In view of the desirability of restricting imports, there is clearly a strong case for intensifying efforts towards self-sufficiency and lowering meat production costs. If cocoa husk meal can be successfully incorporated into livestock rations, the benefits to both the livestock and cocoa industries should be considerable.

A comparison of analyses undertaken in Malaysia (Devendra, 1975; Hutagalung & Chang, 1980) on dried cocoa pod husks and cakes derived from copra and oil palm kernels is presented in Table 4.

Cocoa pod husk meal has higher ash and crude fibre than both oil cakes and contains less crude protein and crude fat. Its composition indicates that it may be more suitable as a component of ruminant diets (Devendra, 1980).

To prevent biodegradation and retain their nutritive value, pod husks must be dried soon after beans are removed. Investigations in Costa Rica (de Alba & Basadra, 1952; de Alba et al, 1954) have indicated that the quality of rapidly dried pod husks was superior to that of sun-dried samples and was virtually comparable with that of good quality maize meal. With due regard to the desirability of minimising artificial drying costs, consideration could be given to utilizing surplus or waste heat from palm oil mills. The possibility of ensiling pod husks to conserve their nutritive value is also worthwhile investigating, especially for producers who may not have access to an inexpensive source of heat for drying.

In ruminant feeding investigations, cocoa pod meal has been incorporated at 35 to 60 percent in feeds for cattle (de Alba et al, 1954: Bateman & Larringan, 1966; Bacon & Anselmi, 1984) and at 25-40 percent in feeds for sheep and goats (Adeyanju at al, 1975; Devendra, 1975). In the case of non-ruminants, tolerance levels in diets have been lower. Pigs have been fed with up to 20 percent pod husk meal (Adeyanju & Ilori, 1979; Hutagalung & Chang, 1980) while chick diets have contained up to 10% of the products (Hutagalung & Chang, 1980).

TABLE 4. COMPOSITION OF COCOA POD HUSK, COPRA CAKE AND PALM KERNEL CAKE (DRY MATTER BASIS)

Constituent	Cocoa pod husk		Copra cake	Palm kernel cake
	*	**	*	**
Dry matter %	90.4	89.5	94.0	90.3
Ash %	16.4	10.6	4.5	3.5
Crude protein %	6.0	6.4	18.3	15.0
Crude fibre %	31.5	27.6	13.0	14.2
Crude fat %	n.a.	1.5	n.a.	5.0
N-free extract %	45.2	43.9	36.8	52.6
Ether extract %	0.9	n.a.	7.0	n.a.
Ca %	0.67	0.35	0.13	0.30
P %	0.10	0.09	0.34	0.60
Mg %	0.64	n.a.	0.32	n.a.
Gross energy (kcal/g)	3.51	3.48	3.89	2.91
Metab. energy (kcal/g)	n.a.	2.10	n.a.	2.04

* Devendra (1975)
** Hutagalung & Chang (1980)

Due to the low nutrient concentration and low digestibility of pod husks, incorporation at relatively high rates (30-60 percent) in diets of non-ruminants has depressed feed efficiency (Devendra, 1980; Hutagalung & Chang, 1980).

Low rates of pod husk meal in animal feeds have been reported to act as a mild myocardial stimulant and a diuretic (Devendra, 1980; Hutagalung & Chang, 1980), possibly due to the presence of the alkaloid theobromine, concentration of which is 0.2 percent in dry pod husks. Theobromine at low rates of incorporation in feedstuffs is reported (Trout et al, 1978) to stimulate the appetites of ruminants, in particular young lambs and calves, causing them to eat more than their metabolic needs and gain weight more rapidly.

It may be concluded that cocoa pod husks or meal can usefully be incorporated in diets of both ruminants and non-ruminants, but feeding rates should be carefully regulated to obviate possible adverse reactions.

3. Biogas Production

Another possible use for the cocoa pod husks is the generation of biogas from anaerobic digestion. Cocoa farmers in Brazil have been reported (Wood, personal communication) to utilize the biogas as a heat source. As husks are comparatively rich in nitrogen and potash, the effluent should also have potential as a liquid fertilizer.

4. Pectin Source

The pod husk contains 6-12 percent pectin on a dry basis (Anon, 1972; Adomako, 1974). Comparative chemical properties of pectins from cocoa pod husk, cocoa sweatings, lemon rinds and apples have been reported by Adomako (1974) and are shown in Table 5.

TABLE 5. PROPERTIES OF PECTIN (ADOMAKO, 1974)

Source	Yield % DM	N	Ash	Anhydro-uronic acid	Acetyl content	Methoxyl content	Degree of esterification
Cocoa husk	9.0	0.8	13.3	34.6	5.4	4.2	70.2
Cocoa sweatings	n.a.	0.2	5.0	53.5	1.0	8.1	86.0
Lemon	10.1	0.4	3.6	71.1	0.2	10.3	82.9
Purified apple	n.a.	0.2	0.0	65.5	0.0	2.4	20.8

Although the yield of husk pectin was quite satisfactory, its chemical properties are quite different from those of pectins normally used in the sugar industry. The high acetyl content was expected to affect adversely the texture of jellies and it has been considered unlikely that husk pectin could compete with pectins of commerce for conventional uses (Adomako, 1974).

UTILIZATION OF COCOA JUICES

The pulp surrounding fresh cocoa beans contains about 80 percent water and between 10 percent and 16 percent (w/v) sugars, mainly glucose. Analyses of pulp in Peninsular Malaysia have indicated cultivar differences in both the amount in relation to bean weight and the concentration of sugars in the pulp (Chong et al, 1980). It was also noteworthy that Upper Amazon hybrid beans had a higher proportion of pulp than Amelonado beans and also had more sugars per unit weight of pulp.

During fermentation, enzymes from yeasts and bacteria liquify the pulp and 'sweatings' flow out of the fermentation boxes. The volumes measured daily over a period of four days are shown in Table 7 (Anon 1977).

TABLE 7.   VOLUME OF SWEATINGS DURING COCOA FERMENTATION

	Day 1	Day 2	Day 3	Day 4
Litres/tonnes fresh beans	110.5	5.7	0.1	0
Litres/tonnes dry beans	276.3	14.3	0.3	0
Percent of total	95.0	4.9	0.1	0

These sweatings are not usually utilized and damage concrete surfaces over which they flow. Moreover, although the volume of sweatings is much less than that of liquid wastes from rubber and oil palm factories, in large cocoa factories they could constitute a pollution hazard unless appropriately treated.

Investigations by Lim (1980) have indicated that the COD, BOD and total solids of fresh cocoa sweatings were generally very high, but considerable variation was also apparent (Table 8).

TABLE 8.   CHARACTERISTICS OF COCOA SWEATINGS

	Mean	Range High	Low	Standard Deviation	Coefficient of variation
pH	3.64	3.90	3.31	0.16	4.62
COD	112,015	172,727	29,291	36,990	33.02
BOD	73,203	130,000	26,500	36,655	50.07
VFA	13,838	21,540	6,708	4,096	29.59
TKN	713	1,050	468	18	25.37
AN	51	140	10	33	63.35
TS	66,740	90,664	22,293	17,282	25.89
TVS	50,113	68,461	16,221	12,974	25.88
SS	2,249	4,591	157	1,731	76.99
VSS	1,888	7,467	114	1,677	88.80

It was concluded that a high level of technical input would be necessary for successful treatment of the cocoa effluent, in view of the recorded quality variation and need to add large quantities of nitrogen to adjust the BOD/TKN ratio to about 30:1 which was considered desirable for anaerobic digestion. This problem would be of reduced magnitude if cocoa factory effluent could be discharged into an oil palm effluent treatment plant.

As treatment of cocoa sweatings as an effluent is difficult and, moreover, is wasteful of a resource that is comparatively rich in sugars, it is felt that consideration ought to be given to their economic utilization. Potential uses are listed and considered below.

i.   **Non-Alcoholic Beverage**

The hydraulic press method used to decrease acidity build-up in fermenting beans (Chong et al, 1980) can express 130 litres of juice from each tonne of fresh beans and two large factories with a combined throughput capacity of 5,000 tonnes dry beans per annum would produce more than 1.6 million litres fresh juice. This juice has a characteristic, pleasant taste and, subject to prompt pasteurisation and subsequent treatment (e.g. clarification & addition of flavourings) might find appeal as a non-alcoholic drink.

Rapid juice removal from fresh beans using enzymes is also possible (Yap, unpublished data).

ii. Production of Sugar

Recovery of sugar from a solution with up to 16 percent sugars requires availability of a very cheap source of heat energy. However, processes that can utilize the sugar solution to produce a value-added product, such as monosodium glutamate, may be feasible.

iii. Production of Pectin

The pectin from cocoa sweatings has been rated more useful for preparation of conventional pectin-sugar-acid-water jellies, but doubts have been expressed on the economics of extracting the pectin, due to the low yield and high extraction costs (Adomako, 1974; Poon, 1977).

iv. Jelly Constituent

A form of jelly is made in Brazil (Wood, 1976) from sweatings produced on the day pods are opened. Sugar is added to raise the concentration to 40 percent and the mixture is allowed to cool to form a jelly.

A pleasant jelly, having a flavour similar to that of apple juice, may also be produced simply by adding agar-agar to fresh cocoa juice (Taylor, 1980).

v. Alcoholic Beverage

On theoretical considerations, with high conversion efficiency, it should be possible to produce from fresh cocoa juice a wine with between 6 percent and 8 percent v/v ethyl alcohol content, the level depending on the initial amounts of fermentable sugars in the juice.

In Mexico the sweatings are sometimes allowed to ferment to produce wine (Wood, 1975). The production of alcoholic products from juice expressed from fresh cocoa beans has also been investigated in Ghana (Adomako, 1975).

Although the cocoa wine could be attractive if the production technology is appropriate and strict standards of hygiene are applied, demand for wine is expected to be small in relation to the potential volume of fresh cocoa juice that would be produced in Malaysia if the bean pressing technique is introduced in all primary processing factories.

An alternative method of utilizing this alcoholic product would be to recover the alcohol by distillation for commercial applications. However, the economics of the process would have to be investigated carefully as the product would have to compete with others produced by traditional and more efficient methods.

vi. Vinegar Production

Currently Malaysia imports more than 750,000 litres vinegar and vinegar substitutes annually. The possibility of increasing local production of vinegar, using cocoa juice as a feedstock is considered worthy of investigation, especially as retail prices of natural vinegars may exceed M$4 per litre.

Using a prototype acetator operating on the quick process concept, 30 litre batches of vinegars with between 5.5 percent and 6.5 percent w/v acetic acid have been produced consistently within 24 hours from cocoa juice that had previously been fermented for about two weeks and contained corresponding levels(v/v)of alcohol. The resultant vinegar had a pleasant smell and taste. However, slight turbidity and light brown colouration reduced its appeal and after exposure to air (as in a partially filled bottle) the vinegar turned dark brown. The brown colour and its intensification with storage may be attributed to the oxidation of polyphenols in the juice. Although treatment with activated carbon resulted in a pale straw colour, it did not prevent darkening with storage.

Yap (unpublished data) found that if the cocoa juice was enzymatically removed from contact with the beans within a short time of pod breaking, the resultant vinegar did not have brown colouration.

In the event that a satisfactory vinegar can be produced commercially, there would be a surplus if all large cocoa

factories were to embark on the venture. Accordingly other uses for the vinegar would have to be sought. Distillation to produce acetic acid is unlikely to be worthwhile as it is improbable that it could be produced at a cost competitive with industrial acetic acid.

vii. Biological/Chemical Coagulation of Rubber Latex

Both fresh cocoa juice and vinegar might be useful for coagulating rubber; however, as alternative coagulants are comparatively inexpensive, higher value uses for the juice and vinegar would be preferred. Before large-scale use of either product is considered, it is necessary to establish that the characteristics of the rubber will not be adversely affected.

Limited investigations by McIntosh (1975) have indicated that partially fermented cocoa juice with 1 1/2 percent acetic acid, added at 2 1/2 litres per 100 kg dry rubber content, resulted in satisfactory fractionation of latex for sole crepe production and the appearances of the resulting sole crepe and lower grade crepe were reported to be indistinguishable from those of crepes prepared using commercial acetic acid.

In another investigation (Yap, unpublished data) a sample of cocoa sweatings initially diluted 1:10 was found to have 800 ppm volatile acids and pH 3.6 after 7 days. This was used to coagulate latex in a ribbed smoked sheet factory. Four litres of the organic acid were required to achieve the same results as obtained with one litre commercial formic acid used in standard factory practice. The product was found not to differ from the control (Table 9).

TABLE 9. QUALITY OF RIBBED SMOKED SHEETS COAGULATED WITH DIFFERENT ACIDS

Treatment		Dirt %	VM%	Po	PRI	N2%	Ash
Formic Acid	1	0.032	0.46	61.5	84	0.44	0.30
	2	0.029	0.36	62	85	0.39	0.29
Cocoa Juice	1	0.023	0.28	62	85	0.40	0.32
	2	0.032	0.25	61.5	85	0.38	0.31
Trade Specific. (SMR 5)	1	0.005	0.5	30	70	0.55	0.5

CONCLUSION

There is scope for more efficient utilization of by-products of primary cocoa processing, both in relation to enhancing the earnings of cocoa growers and optimising exploitation of resources.

Cocoa pod husk is a major by-product. Where soils are comparatively infertile and economic responses to nitrogen and potassium are likely, the pod husks should be distributed uniformly over the land surface. However, in circumstances where soil nutrient reserves are such that economic responses to nitrogen and potassium are unlikely, consideration should be given to preparing a feedstuff from pod husks.

Pod husk utilization as a component of livestock diets should also be considered where retention of pod husks in the field might aggravate the pest and disease situations.

There is evidence that pod husks can be incorporated at higher rates in the diets of ruminants than non-ruminants, but care should be taken not to feed excessive amounts, otherwise less efficient digestion of feedstuffs will result and undesirable side-effects could occur.

Pod husks may be fed fresh to animals, or may be ensiled or dried. Both ensiling and drying should be done as soon as possible after beans are removed. This is expected to be facilitated when pod splitting is done at a centralised point and on a large scale. The economics of using pod husks will depend on production costs, of which collection and drying costs are major components. The possibility exists that spare heat energy generated in palm oil mills could be exploited to reduce drying costs.

The extraction of pectin from pod husks also merits further investigation although, for conventional, uses husk pectin has been rated inferior to pectins extracted from citrus fruits and apples.

In large scale processing the sweatings that exude from beans in the early stages of fermentation constitute a potential source of environmental pollution. Their biological treatment as an effluent is difficult and economic

utilization should be considered. A higher quality juice, more suitable for conversion into economic products, can be obtained by application of pressure or addition of enzyme to fresh beans before they are loaded into fermentation boxes. A yield of 325 litres high quality cocoa juice with approximately 16 percent sugars can be obtained for every tonne dry beans produced.

Of the potential uses considered for cocoa juice, the production of a pleasant non-alcoholic beverage, with or without flavour additives, is possibly the most promising. However, it will be necessary to undertake research to ensure the juice is entirely acceptable for human consumption.

With due regard to the large potential volume of cocoa juice that can be produced, active market promotion would also be essential to increase its popularity and stimulate consumption.

The extraction of sugar from fresh cocoa juice is also possible, but the economics of this process depends on availability of a cheap source of heat.

Although it is feasible to produce an alcoholic beverage from cocoa juice, offtake may be comparatively small.

Cocoa juice may also be used for production of a vinegar with about 6 percent acetic acid content. The derived vinegar has a pleasant aroma and taste. However, further research is desirable to improve its visual appeal for human consumption, with particular attention given to its colour characteristics.

Many of the by-products will have to compete in established markets. Accordingly, efforts should be made to lower production costs and to increase public awareness of their existence and virtues. While further research is necessary to improve the quality of cocoa by-products, the extent to which their production can be justified will depend largely on the effectiveness of market promotion.

ACKNOWLEDGEMENT

REFERENCES

ADEYANJU, S.A. OGUTAGA, D.B.A., ILORI, J.O. & ADEGBALA, A.A. (1975). Cocoa husk in maintenance rations for sheep and goats in the tropics. Nutr. Rep. Int., 11, 351-357.

ADEYANJU, S.A. & ILORI, J.Q. (1979). Growth, economics and carcass characteristics of pigs fed on cocoa husk diets. Trop. Agr. Trin. 56 (3), 253-257.

ADOMAKO, D. (1974). Chemical characteristion of cocoa pectin. Chemistry and Industry, 2, 873-4.

ADOMAKO, D. (1978). A review of researches into the commercial utilization of cocoa by-products, with particular reference to the prospects in Ghana. C.M.B. Newsletter No. 61.

ALBA, J. de & BASADRE, J. (1952). Trials of fattening pigs with rations based on cacao pod meal, maize and ripe bananas. Turrialba, 2 (3), 106-9.

ALBA, J. de, GARCIA, H., CANO, F.P. & ULLOA, G. (1954). Nutritive values of cacao pods in milk production in comparison with ground maize and cassava meal. Turrialba, 4 (1), 29-34.

ANON (1972). Pectin studies of cacao 'sweatings' and cacao pod husks. In. Rev. Theobroma 2 (2), 50-51.

ANON (1977). Yield of cocoa sweatings in estate practice. Internal Harrisons & Crosfield report.

ANON (1981). Department of Statistics : Peninsular Malaysia - Preliminary figures of external trade 1980.

BACON & ANSELMI, J. (1984). Cocoa pod rations in feed lot cattle production. Proc. Seeds & Seeding Systems for Livestock, 13-14 March 1984, Genting Highlands.

BATEMAN, J.V. & LARRANGAN, A. (1966). The use of cocoa pod husks for feeding steers. Turrialba, 16 (1), 25-28.

CHONG, C.F., SHEPHERD, R. & POON, Y.C. (1980). Mitigation of cocoa bean acidity - Fermentary investigations. Proc. Int. Conf. on Cocoa & Coconuts Kuala Lumpur 1978, 387-414.

DAY, R.K. & MUMFORD, J.D. (1983). Control of the cocoa pod borer (Acrocercops cramerella) in Sabah. 10th Int. Congress of Plant Protection (3) 1025.

REFERENCES (contd.)

DEVENDRA, C. (1975). Agricultural by-products for animal feeding in Malaysia, MARDI Rept. No. 31, 14 pp.

DEVENDRA, C. (1980). The feeding value of by-products from cocoa and coconuts in diets for farm livestock. Proc. Int. Conf. on Cocoa & Coconuts Kuala Lumpur 1978, 457-471.

GILL & DUFFUS (May, 1984), Cocoa Market Report Vol. (9).

HUTAGALUNG, R.I. & CHANG, C.C. (1980). Utilization of cocoa by-products as animal feed. Proc. Int. Conf. on Cocoa & Coconuts Kuala Lumpur 1978, 447-456.

LIM, K.H. QUAH, S.K., GILLIES, D. & B.J. WOOD (1984). Palm oil mill effluent treatment & utilization in Sime Darby Plantations - The current position. Workshop on review of palm oil mill effluent treatment technology, Kuala Lumpur.

McINTOSH, J.B. (1975). Internal Harrisons & Crosfield (M) Sdn. Bhd. memorandum.

POON, Y.C. (1977). Extraction of pectin from cocoa sweatings. In Anon. Rept. H&C Oil Palm Research Station 1977, p 56.

TAYLOR, J.G. (1980). Personal communication.

THONG, K.C. & NG, W.L. (1980). Growth and nutrients composition of monocrop cocoa plants on inland Malaysian soils. Proc. Int. Cocoa & Coconuts Conf. Kuala Lumpur, 1978, pp 262-286.

TROUT, A.G., ZOUMES, B.L. & TARKA., S.M.(1978). Method of stimulating appetite in ruminants and ruminant feed containing appetite stimulant. United States Patent 4070487, Jan. 24. 1978.

WOOD, B.J. (1980). The cocoa pod borer moth in Malaysia. Perak Planters Association Journal 28-36.

WOOD, G.A.R. (1975). Cocoa. Tropical Agricultural Series. Longman, 292 pp.

WOOD, G.A.R. (1976). Personal communication.

Chocolate and Cocoa Manufacturers Quality Requirements for Cocoa Beans

B.D. POWELL

Cadbury Limited Bournville Birmingham, England.

Cocoa beans are used mainly for the manufacture of chocolate and cocoa powder and their suitability for this purpose and their value to the market are determined by manufacturers against the criteria of purity, flavour, yield, and cocoa butter hardness, to mention the most important. These criteria are examined and the values sought are described.

There is a close relationship between the properties of the cocoa bean and the properties of the chocolate which can be made from it. Good quality cocoa beans are the starting point for good quality chocolate. At the present state of knowledge good chocolate cannot be made from poor beans. Indeed chocolate cannot be made at all without cocoa beans, either physically or legally.

The chocolate manufacturer is looking for cocoa which enables him to make pure and wholesome chocolate which will appeal to his current and future customers to an increasing degree in its flavour and texture; and be at a competitive price. Thus he wishes to purchase cocoa beans relatively richer in its more valuable component — cocoa butter and relatively poorer in its less valuable or even waste components, *e.g.* shell. He is looking for a high yield. Additionally, he wishes to be able to make his particular chocolate formulation on standard plant at standard throughputs, or at most with but modest effects on output and with any needed modifications to plant being inexpensive.

The factors of purity, flavour, cocoa butter hardness (which is a major influence on texture) and yield are embraced in the word 'quality', and they will be dealt with below. They are the criteria by which the value of a consignment of cocoa beans will be judged, and thus lead to the price which it will be appropriate for the purchaser to pay for it.

While this paper deals mainly with the needs of the chocolate manufacturer it must not be forgotten that there is a significant use for cocoa powder (the cocoa butter reduced cocoa bean) in cocoa based drinks, ice cream, pudding mixes, baked goods *etc.* Similar considerations regarding purity, flavour, yield *etc.* will also apply.

Cocoa producers and chocolate and cocoa powder manufacturers alike would neglect the importance of cocoa bean quality at their peril! Chocolate sells in a very competitive food market, and is a food which is eaten because people like it — no one has to eat chocolate! If ever the appeal of chocolate were to be lost, there would be no chocolate manufacturing industry, and no agricultural industry producing cocoa beans. The two parts of what is a really single overall industry advance or decline together.

The requirements of the manufacturer with regard to the quality of cocoa beans can be met by sound methods of cultivation, fermentation, drying, storage and transport —

methods which are well established and generally known. Sometimes they are not applied with sufficient diligence and rigour. These points are noted as they are important, but it falls outside the scope of the paper to detail such methods and the problems which can arise through their neglect. Such methods are dealt with in the literature (CCCA, 1984).

PURITY

Chocolate and indeed all products made from the cocoa bean must be pure and whole-some and like all food products must not harm the consumer. The manufacturer must meet the appropriate legal requirements in the countries where he has his factories and in the countries where he has his markets. These legal requirements are becoming more detailed and more onerous as the scientific knowledge of foods increases, and as the attitudes of consumers and legislators change. The principal sources of impurities are described below.

Pesticides

The use of pesticides on cocoa trees and in cocoa stores can lead to the presence of residues in the dried beans and some of these residues are toxic. There is a growing body of knowledge on this subject which has led to limits being set for the level of certain pesticides in raw materials including cocoa beans. *Table 1* gives a list of limits proposed by the Codex Alimentarius Commission of FAO. This commission makes recommendations which Governments may adopt in national legislation.

TABLE 1. LIMITS OF PESTICIDE RESIDUES

Item	Limit in cocoa beans (mg/kg)
Insecticides	
gamma – HCH	1.00
fenitrothion	0.10
propoxur	0.05
dichlorvos	5.00
Fungicides	
fentin	0.10
Fumigants	
hydrogen phosphide	0.01
methyl bromide (as bromide ion)	50.0[a]

[a] This figure is a guideline, not a maximum limit

Source: Guide to Codex Maximum Limits for Pesticide Residues, first issue. Codex Alimentarius Commission CAC/P21–1978. Some countries may wish to impose lower limits.

Chocolate manufacturers need to ensure that their supplies of cocoa beans comply with these limits and therefore they must monitor their intake for pesticide residues.

Bacteria

All cocoa beans carry a bacterial population which is derived originally from the

2

fermentation process. However, faulty methods of drying and subsequent handling can lead to significant increases in numbers and types of micro-organisms, including the possibility of infection with pathogenic organisms such as *Salmonella.*

Normal manufacturing processes will destroy a large proportion of the bacteria. However, the higher the initial level of contamination, the higher the resulting levels in the final product. High levels of pathogenic organisms on cocoa beans increase the risk that contamination of finished products may occur.

Insects

Cocoa beans can be infested by several species of insects, and the most troublesome from the manufacturers' point of view is the Tropical Warehouse moth *(Ephestia cautella).* This insect is frequently found breeding in cocoa beans arriving in Europe. It can thrive inside cocoa and chocolate factories if stringent control measures are not undertaken and can spoil finished goods.

Foreign Matter

The presence of foreign matter in a shipment of cocoa may contaminate the product, affect flavour or cause damage to plant and machinery, besides reducing the proportion of edible material.

Free Fatty Acid

Beans which have been fermented and dried thoroughly and without delay will contain a low level of free fatty acid (f.f.a.) typically about 0.5% in the bean. The level must be less than 1.0% so that the f.f.a. in the cocoa butter produced from these beans will be less than 1.75%. This is the legal limit for cocoa butter within the EEC and the limit proposed by Codex.

Higher levels of f.f.a. may be due to the use of beans from diseased pods, the activity of moulds inside the beans due to incomplete or delayed drying or to prolonged storage under humid conditions.

Heavy Metals

Limits on the amounts of heavy metals are being introduced more commonly into national legislation.

FLAVOUR

The manufacturer needs cocoa beans which can be processed into chocolate with a good flavour, which consumers will enjoy. This property of the cocoa bean, the possession of good flavour potential, is their most important property providing, of course, the bean is safe to eat (the over-riding requirement of all food ingredients). Flavour potential can only be fully assessed by actually manufacturing chocolate on a factory scale. Even then the flavour, as with most other foodstuffs, is a matter of subjective judgement and at the present state of knowledge cannot be described in analytical and numerical terms.

The impracticalities of assessing flavour by large scale processing are obvious so alternatives must be followed. The IOCC small scale laboratory method of making chocolate

is a guide to flavour but has disadvantages. The usual alternative is the cut test, largely based on the appearance of the interior of cocoa beans. It is a measure of overall quality and the degree of the fermentation and drying process.

With all cocoas, flavour is affected by the genetics of the tree, the cultural practices of the farmer, but above all by the method of fermentation and drying employed and the care with which it has been carried out. One cannot over stress the importance of thorough fermentation and drying since they comprise one of the most important processes involved in the manufacture of chocolate and cocoa. If not carried out properly, the subsequent flavour will be unacceptable to the consumer. Not only is thorough fermentation and drying necessary to obtain a good chocolate flavour, but also to avoid the occurrence of off-flavours in the subsequent chocolate. Off-flavours can arise from the misuse of pesticides.

In the cut test a predominance is sought — 50% or more, of fully fermented beans — beans with chocolate brown cotyledons — together with a smaller proportion, 20% or more, of partly brown-partly purple beans. The cut test also reveals slaty and mouldy beans which can be tolerated up to 3% each (see below). The presence of mould is one of the most serious sources of off-flavours experienced in cocoa. It can impart a flavour which persists through all aspects of manufacture and there is no known way of removing it. It must be acknowledged that the cut test, while revealing much about the quality of preparation, suffers from limitations, but it is the best that is currently available and when used with traditional methods of fermentation and drying is a good guide.

Practically all the cocoa in the world today is of the Forastero Amelonado or Amazon type and their crosses referred to as bulk cocoa which meets the needs of all manufacturers in whole or in part. This type of cocoa has a good chocolate flavour, but there are differences from country to country resulting from differences in say, soils, agricultural practices, microflora in the fermentation process, methods of fermentation and drying. It is important with beans from a particular country that there is uniformity of flavour, not only from shipment to shipment but also from crop to crop.

The special contribution from the fine cocoas has fallen over the years to a very low level looked at on a world basis. Even so they do make a worthwhile contribution and those who use them to introduce a particular flavour have a concern with their preparation for the market. In recent years little attention has been paid to these varieties by plant breeders. Demand for good fine grade beans is present worldwide and would be honoured by the appropriate prices being paid.

It is not possible to describe good quality chocolate flavour satisfactorily in words or numbers alone. Chocolate must be made and tasted against the requirements of a particular market, and it must be acknowledged that there are differences of opinion in the finer shades of what "good" means. This must follow as not everyone likes the same chocolate to the same degree. For example, in the United Kingdom the most popular chocolate is milk chocolate with relatively low content of cocoa, a mild chocolate flavour and a relatively high content of milk solids. On the continent of Europe the preference is for a plain chocolate, or a milk chocolate with a relatively high cocoa solids content, a stronger chocolate flavour and relatively lower in milk.

While the positive aspect of the flavour is the requirement for a good chocolate flavour, it is important to ensure that 'off flavours' are absent, and that some other flavours are not present to an excessive degree. 'Off flavours' may be classified as follows:—

4

Mouldy Off-flavours

These arise from the presence of moulds inside the beans and samples with a few per cent only of internally mouldy beans can impart a mouldy flavour to chocolate. This type of off-flavour cannot be removed during processing.

The presence of mouldy beans is revealed by the cut test.

Smoky Off-flavours

Contamination by smoke during drying or during storage causes a characteristic off-flavour in chocolate in which can be reminiscent of smoky bacon. This is another off-flavour which cannot be removed during chocolate manufacture.

The presence of smoky beans in a sample may be detected by crushing some beans in the hand, or preferably in a mortar, and sniffing them. This is a quick test but it is not as reliable as making up into chocolate on a small scale. There is no satisfactory objective method of detecting the presence of smoky beans.

A smoky off-flavour is sometimes referred to as "hammy". Hammy off-flavours can also arise from over-fermentation.

Acidic Off-flavours

These are due to excessive amounts of certain acids which arise during fermentation. Two acids are involved: acetic acid which is volatile and lactic acid which is non-volatile. During manufacture the acetic acid present in dried beans will normally be reduced to an acceptably low level, but the non-volatile lactic acid is not removed and if present in excess will cause an off-flavour in chocolate. Furthermore, the presence of excessive acidity usually correlates with poor development of chocolate flavour. The presence of acetic acid is readily detected by smelling the beans, but acidity due to lactic acid can only be detected by tasting the chocolate made from them. High acidity has been a feature of some Malaysian beans.

A high degree of acidity is usually associated with a pH of 5.0 or less in the dried bean, while the pH of beans from West Africa in which the perceived acidity is very slight or absent is around 5.5. The measurement of pH is not, however, a guide to chocolate flavour and if measures are taken to raise pH, by neutralising for instance, they will not eliminate the acid flavour nor achieve an acceptable chocolate flavour. With cocoa powder, excessive alkali addition can cause unacceptable flavour and ash contents above legal limits.

It should also be stressed that there is no connection between the presence of acetic and/or lactic acids and the f.f.a. content which has been dealt with earlier.

Pesticides

Certain pesticides have been shown to cause off-flavours in chocolate and these cannot be removed. Only those pesticides which have been approved as safe on cocoa (*Table 1*) and cleared by taint tests (*Table 2*) should be used.

TABLE 2. PESTICIDES APPROVED BY TAINT TESTS CONDUCTED BY COCOA, CHOCOLATE AND CONFECTIONERY ALLIANCE, LONDON.

Common name	Trade name
Gamma – HCH	Grammalin, Lindane
difolotan	
dioxacarb	Elocron
bufencarb	Orthobux
acephate	Orthene
carbaryl	Sevin
fenitrothion	Sumithion, Agrothion
metalaxyl	Ridomil
promecarb	Carbamult
propoxur	Baygon, Unden

This list was correct at January 1984

Contamination

Cocoa beans can absorb off-flavours from other products such as copra when stored in close proximity, *e.g.* in a ship's hold.

Bitterness and Astringency

Some bitterness is part of the complex of chocolate flavour but if present in excess it becomes objectionable. Similarly astringency when present in excess is also objectionable. Excessive amounts of these flavours cannot be removed by normal factory processing.

These flavours are associated with poor fermentation. Unfermented or slaty beans, as revealed in the cut test, give rise to strong astringency and samples with more than 3 per cent of slaty beans can impart unwanted astringency to chocolate. Fully purple beans also produce bitter and astringent flavours.

COCOA BUTTER HARDNESS

Cocoa butter is unusual among fats in that it is hard at room temperature (in temperate climates), can be handled by the fingers, but melts readily in the mouth. It is the component which determines largely the hardness, snap and mouth feel of chocolate, although other ingredients — milk fat, for example — and factory processes also play a part. Scientific work of recent years has given methods for measuring the hardness of chocolate and of cocoa butter, its snap, and its chemical composition, with a precision unknown hitherto.

This work has confirmed in numerical terms that there is a natural variation in cocoa butters in both chemical and physical properties, and in some instances, this variation is seasonal indicating that climatic conditions may be a determining factor. Some butters are "soft" and others are "hard" (*Table 3*); harder butters are preferred and have an obvious advantage in warm climates and seasons. The spread of central heating in the main temperate zone consuming countries has meant that the homes in which chocolate is kept, and shops from which it is sold, are maintained at higher temperatures than they were. Thus any tendency for chocolate to be soft becomes apparent to the consumer.

TABLE 3. COCOA BUTTER HARDNESS

Country	Solid fat content at different temperatures (%)				
	$20^{\circ}C$	$25^{\circ}C$	$27.5^{\circ}C$	$30^{\circ}C$	$35^{\circ}C$
Malaysia	85.0	83.1	79.9	69.6	12.3
Ghanaian	82.0	78.0	73.9	61.3	2.9
Brazilian	71.7	68.8	62.5	49.3	3.0

Source: – private communication.

Most chocolate manufacturers will be looking for beans which will yield a harder cocoa butter. The extent to which hardness/softness is determined by genetic selection, cultural practice or climatic conditions is not fully understood. It is important to take account of this relatively new factor of cocoa butter hardness in plant selection and breeding.

Some butters are processed to bring down a high free fatty acid content in order to comply with the legal limits set in most countries. Such processing can have the effect of making such butters softer.

YIELD

The yield of the useful part of the bean significantly affects its value to the manufacturer and hence the price he is willing to pay for the cocoa. A number of factors which can be measured objectively affect the amount of edible material (cocoa nib) and the amount of the most valuable portion, the cocoa butter, that can be obtained from a parcel of cocoa.

Shell

Shell is virtually a waste product to the manufacturer and a level of 11.5% to 12% is typical of cocoa from West Africa. The shell should be loose to aid its subsequent removal but strong enough to remain unbroken during handling and transportation, thereby reducing risk of damage by insects. The practice of washing so that the shell percentage is reduced is, however, not to be encouraged. The shell of washed beans is brittle and cracks easily allowing access for insects and mould. Pieces of extraneous matter like dried pulp and double beans should be absent.

Moisture Content

Moisture content should be in the range of 6% – 7%. A level above 8% may encourage mould growth and a lower one lead to very brittle beans, easily broken and leading to less efficient factory processing. The presence of water is unavoidable, but it has no role in chocolate!

Fat Percentage

The relative value of the cocoa butter and non-cocoa butter portion of the cotyledon varies from time to time according to market forces, but generally it is the former which is the more valuable. Hence, other things being equal, a butter content in the nib over 56% expressed on a dry basis is desired.

Foreign Matter

The presence of foreign matter will also affect the yield of edible material.

Flat and Shrivelled Beans

Shrivelled beans contain very little nib and hence reduce the yield. Plant can 'see' them as shell and rejects them.

Insect Damaged Beans

Substantial insect damage results in a loss of usable nib and even off-flavours. Insect fragments are more likely to be found.

Bean Size and Uniformity

The average weight of a cocoa bean should be at least 1.0 g because smaller beans have high shell and low fat percentages. Small beans can be used but require adjustment to factory processes which is inconvenient and costly, *e.g.* reduction in plant throughput. For this reason beans smaller than 1.0 g should be sold on the basis of a bean size classification, *e.g.* less than 110 beans per 100 g, 120 beans per 100 g *etc.*

Manufacturers also require beans to be reasonably uniform in size because it is difficult to achieve effective bean cleaning and uniform roasting in a parcel containing beans that are very variable in size. The traditional criterion is that no more than 12% of the beans should be outside the range ± one third of the average weight.

Most manufacturers calculate the value or yield of a consignment of cocoa beans in terms of shell percentage, moisture content and cocoa butter content.

For example:—

	Samples	
Analysis (%)	*A*	*B*
Shell	12.0	16.0
Moisture in nib	5.0	5.5
Fat in dry nib	57.5	56.0
Yield Calculation (by weight)		
Total bean	100.0	100.0
less Shell	12.0	16.0
Nib	88.0	84.0
less nib moisture	4.4	4.6

8

Dry nib	83.6	79.4
Fat %	57.5	56.0
∴ Fat yield	48.5	44.5
Fat yield B : A		92%

From the table it is seen that higher shell, and moisture contents and lower cocoa butter content will reduce the value to the manufacturer and hence the price which he is prepared to pay. In addition, manufacturers' experience with other factors such as foreign matter, uniformity of bean size and the actual weight of beans per bag *etc.* are also taken into account in assessing the price to be offered.

INTERNATIONAL AND CONTRACT STANDARDS

The aspects of quality that have been described cover the subject in its broadest sense and all have a bearing on the price paid for beans from a particular source compared with other sources. In a narrower sense 'quality' may refer solely to flavour and purity and it is these aspects that are covered − at least in part − by various cocoa standards. They cannot measure or ensure good flavour but they can, by means of the cut test, detect some of the defects which cause off-flavours. The standards can also help to ensure good keeping quality. There are various standards of which the most important are the International Cocoa Standards and the standards in commercial use defined in the contracts of the Cocoa Association of London (CAL), the Association Francaise du Commerce des Cacaos (AFCC), and, in the United States, the Cocoa Merchants Association (CMA).

International Cocoa Standards

The International Cocoa Standards were agreed at a meeting of producing and consuming countries held in Paris in 1969. These standards form the basis of the grading regulations of several cocoa producing countries. The grade standards are based on the cut test which allows some sources of off-flavours to be identified.

The full text of the International Cocoa Standards consists of two parts: a Model Ordinance giving the grade standards and definitions of terms used, followed by a Code of Practice indicating how the standards should be imposed.

The most important parts of the Model Ordinance are the definition of cocoa of merchantable quality and the grade standards laid down: Cocoa of merchantable quality must be:

● Fermented, thoroughly dry, free from smoky beans, free from abnormal or foreign odours and free from any evidence of adulteration.

● Reasonably uniform in size, reasonably free from broken beans, fragments and pieces of shell, and be virtually free from foreign matter.

9

The Grade Standards lay down the following maximum percentages:

Grade	Mouldy	Slaty	Insect damaged Germinated Flat
1	3	3	3
2	4	8	6

Contract Standards

Most of the world's cocoa is traded using the contracts of the CAL, AFCC or CMA, which historically have rather different and slightly lower standards. These standards do not imply acceptability for *all* chocolate manufacture, however, merely the levels above which allowances can become due under arbitration procedures.

Finally there are standards set down by the different terminal or futures markets as a basis for deciding whether a particular parcel is suitable for tendering on the market in question at the contract price, or at a premium or discount. Again these contract standards are not based on acceptability for all chocolate manufacture.

CONSISTENCY

It is important that the properties of cocoa beans from bag to bag and from consignment to consignment are consistent. Since manufacturers aim to produce chocolate of consistent quality, a mark or origin which can be relied upon to supply beans of constant quality will be more highly valued than one whose quality is variable.

To some extent consistency within a bulk cocoa can be achieved by mixing beans but all the cocoa being mixed should be of the same grade standard. It is not acceptable to mix or blend poor quality cocoa with good quality cocoa to obtain a cocoa that just meets minimum grade standards. Whilst the value of the poor cocoa can be increased in this way, the value of the good cocoa is correspondingly reduced. Sources of bulk cocoas whose quality is often very close to the prescribed Grade 1 standards tend to sell at a discount to bulk cocoas which are consistently well within the standards. Cocoa which is very near to the prescribed Grade 1 standards may contain as many as 8 or 9 per cent defective beans and this cocoa is unsuitable for use to make good quality milk chocolate.

QUALITY OF MALAYSIAN COCOA BEANS

To what extent do cocoa beans from trees grown in Malaysia meet the requirements of manufacturers of cocoa and chocolate? Work has reduced the acidity of the more acid beans, revealing sometimes a weakness in chocolate flavour. There are very few reports of objectionable impurities. Malaysian cocoa butters tend to be hard — a desirable characteristic. Malaysian cocoa production has made great strides forward in recent years and the introduction of appropriate grading standards is to be welcomed as they will further improve acceptability.

10

ACKNOWLEDGEMENT

REFERENCE

CCCA (1984) *Cocoa Beans. Chocolate Manufacturers Requirements.* London. pp 9–13

Some Differences in Cocoa Bean Quality Requirements Between Chocolate Manufacturers and Cocoa Powder and Cocoa Butter Manufacturers

J.L. TERINK

Cacaofabriek de zaan b.v., Koog aan de Zaan, Holland

In the past 10 to 15 years big shifts have occurred in the production between the various cocoa-producing countries.

As far as the selection of new cocoa varieties is concerned the chocolate industry has traditionally had a greater influence than the cocoa powder – cocoa butter industry (cocoa press industry). Possibly this is because the chocolate industry can less influence the taste than the cocoa press industry, which can use processes such as alkalizing and deodorizing.

The standards which the chocolate industry and the cocoa press industry apply to their raw materials are largely similar. A good survey can be found in the recently issued publication of the British Cocoa, Chocolate and Confectionery Alliance. On a number of points there are however differences, which are connected with some typical differences in processing. For example, differences in breakability of cocoa beans are more important in the cocoa press industry than in the chocolate industry. The problem of bean acidity is in the chocolate industry chiefly a question of taste, while in the cocoa press industry the emphasisi lies to a greater extent on the difference in alkalizing behaviour.

The physical behaviour of the cocoa butter is of eminent importance for the chocolate industry, hence also to their suppliers: the cocoa press industry. The physical quality which the cocoa press industry can attain is ultimately determined by the quality of the fat in the cocoa bean at the start of the secondary processing.

In the past 10 to 15 years being shifts in production have taken place between the various cocoa producing countries (Powell, 1983, *Table 1*). These shifts resulted mostly from internal political and social-economic factors and far less from external factors such as changed preferences of buyers in the traditional processing countries. The choice of the genetic variety plays an important part when starting to cultivate new production areas and re-planting existing areas. It takes some years before the cocoa tree bears fruit and, normally speaking, this should last a few decades.

Since the cocoa plant is sensitive to various diseases the resistance to a number of frequently occurring diseases is important in the selection of new varieties. Moreover, of course, of importance are the yield per hectare and the quality of the cocoa beans obtained. The research institutes in the various producing countries are important in selecting and making available sufficient new plant material. So it must be deemed of

TABLE 1. CHANGING PATTERN OF COCOA PRODUCTION

Country	Production ('000 tonnes)					
	1967/68		1974/75		1980/81	
Ghhana	422	(31)	377	(24)	258	(16)
Nigeria	239	(18)	214	(14)	155	(9)
	661	(49)	591	(38)	413	(25)
Ivory Coast	147	(11)	242	(15.5)	412	(25)
Brazil	144	(11)	273	(17.5)	354	(21)
Malaysia	1	(–)	13	(1)	40	(2)
	292	(22)	528	(34)	811	(48)
Others	401	(29)	429	(28)	449	(27)
Totals	1354	(1000)	1548	(100)	1673	(100)

Figures within brackets indicate percentage.   *Source:* Gill & Duffus Report Jan. 1982

importance that they know of the wishes of the buyers with respect to the desired quality. This is no simple matter since the flavour — one of the principal quality parameters — is difficult to define, and moreover taste preferences may differ. Also a problem is that a good taste evaluation can take place only in the various finished products. Fortunately, there is sufficient agreement about specific taste deviations such as smoky and mouldy. It becomes difficult with the so-called acidity. Should this be classified as a taste deviation, or as a type of taste? Of old with respect to questions of flavour, the chocolate industry has had most contacts with the research institutes in the cocoa producing countries. The cocoa press industry has been far less involved in this discussion, although it processes the greater part of the world crop of cocoa beans. At the moment the ratio is about 2 : 1 as shown in *Figure 1.*

It could be that the cocoa press industry outside the cocoa producing countries has no expectations of exerting actual influence. On the other hand, the cocoa press industry has more means at its disposal to adjust the taste of the finished products, cocoa powder and cocoa butter, by means of processes such as the alkalization of cocoa nibs, cocoa liquor or cocoa powder/cake and the deodorizing of cocoa butter. These possibilities however are restricted and also on other quality aspects the cocoa press industry sometimes faces problems. Therefore I appreciate the kind invitation of your organisation to deliver a paper which may hopefully contribute to a better understanding of some quality problems in the cocoa press industry. A great number of quality requirements, in particular in the field of off-flavours, purity and consistency apply to both the chocolate industry and the cocoa press industry.

In a recent publication of the British Cocoa, Chocolate and Confectionery Alliance (1984) a survey has been given of the quality requirements of the chocolate manufacturers. The various quality aspects are ranged under 5 chapters:

1. Flavour.
2. Purity or wholesomeness.
3. Consistency.

COCOA FLAVOURED PRODUCTS

Retail packages

COCOA POWDER

CHOCOLATE

Grinding

COCOA PRESS CAKE

Pressing

COCOA BUTTER

COCOA MASS

Blending
Refining
Conching
Moulding

SUGAR

MILK POWDER

Roasting
Alkalizing
Grinding

COCOA MASS

COCOA SHELL

Cleaning
Breaking
Deshelling
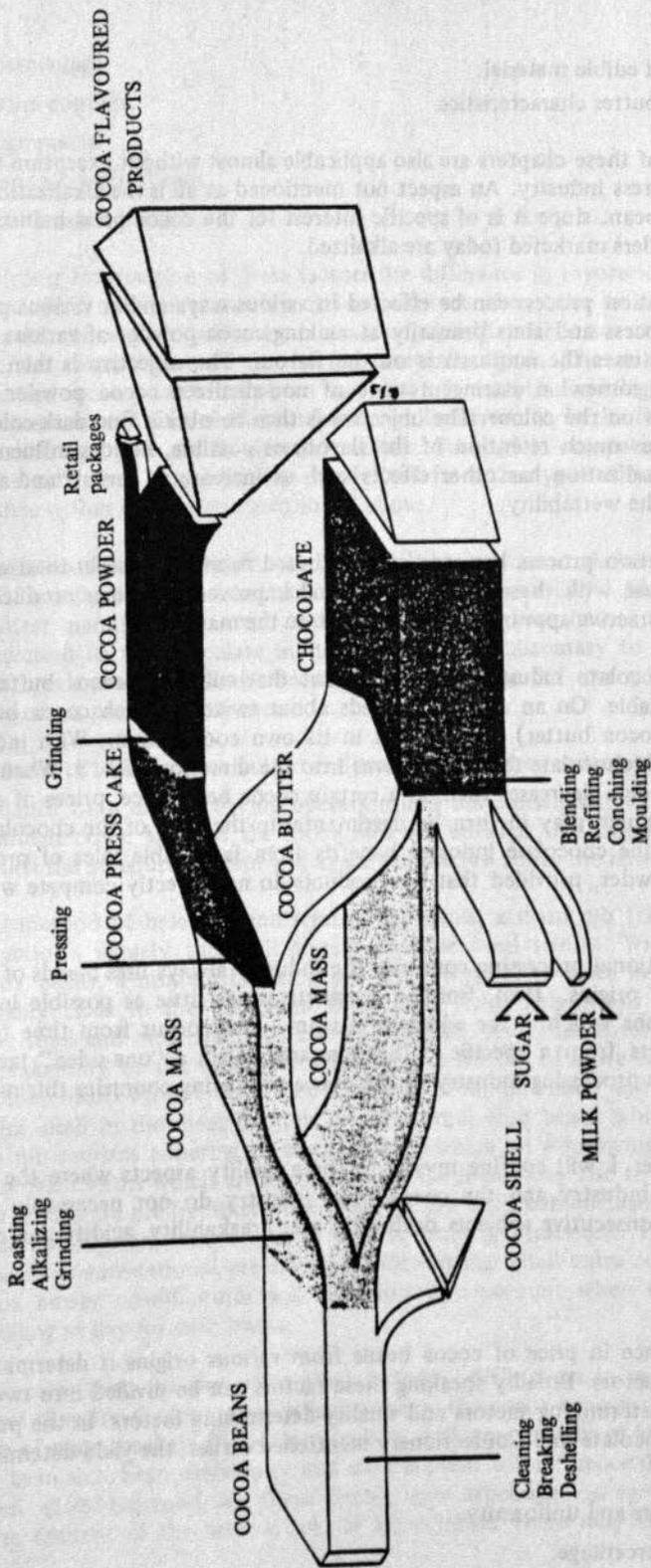
COCOA BEANS

Source: Cacaofabriek De Zaan B.V.

Figure 1. Worldwide use of cocoa beans.

4.   Yield of edible material.
5.   Cocoa butter characteristics.

The contents of these chapters are also applicable almost without exception to the cocoa to the cocoa press industry. An aspect not mentioned at all is the alkalization behaviour of the cocoa bean, since it is of specific interest for the cocoa press industry. Many of the cocoa powders marketed today are alkalized.

The alkalization process can be effected in various ways and at various points in the production process and aims primarily at making cocoa powder of various colours and flavours. Sometimes the emphasis is on the flavour. The objective is then the removal of the acidic, somewhat astringent taste of non-alkalized cocoa powder. Sometimes the emphasis is on the colour. The objective is then to obtain fine dark-coloured cocoa powders with as much retention of the flavour as possible. Besides influencing flavour and colour, alkalization has other effects such as increase of the pH and a (slight) improvement of the wettability.

The alkalization process has greatly contributed to an increase in total sale of cocoa powders, because with these powders new and improved consumer products of a good taste and an attractive appearance could be put on the market.

For the chocolate industry it is important that sufficient cocoa butter of a good quality is available. On an average it needs about twice as much cocoa butter (the so called added cocoa butter) than present in its own cocoa liquor. With increasing production of milk chocolate this ratio moves into the direction of 3 : 1. When the demand for cocoa powders decreases then, at a certain cocoa bean price, prices of cocoa butter will increase, which may in turn be detrimental to the sales of the chocolate industry. Consequently the chocolate industry benefits from favourable sales of products made with cocoa powder, provided that the products do not directly compete with real chocolate.

In the traditional processing countries the industry always uses blends of cocoa beans from different origins. Then, finished products are as little as possible influenced by quality variations which — for whatever reason — may occur from time to time with natural products from a specific cultivation area. Also, a "one-sided" taste profile is avoided. In the processing industry of the cocoa producing countries this method is not usual.

In this paper I will confine myself to three quality aspects where the interests of the chocolate industry and the cocoa press industry do not necessarily run entirely parallel. The consecutive subjects dealt with are: breakability, acidity and cocoa butter quality.

Breakability

The difference in price of cocoa beans from various origins is determined by quite a number of factors. Broadly speaking these factors can be divided into two categories, namely yield-determining factors and quality-determining factors. In the publication of the Cocoa, Chocolate and Confectionery mentioned earlier, the yield-determining factors are:

a)   Bean size and uniformity.
b)   Shell percentage.

4

c) Fat percentage.
d) Moisture content.
e) Foreign matter.
f) Flat and shrivelled beans.
g) Insect damaged beans.

With sufficient information of these factors the difference in theoretical yield in nib of a specified shell content with respect to a reference bean can be calculated. This difference in theoretical yield is based on the assumption that the losses of nib in the sub-fractions are the same. This need not be the case as is shown. The maximum allowed shell content for cocoa powder has been laid down in various food legislation. In the U.S.A. the maximum is 1.75% shell calculated on alkali free nib. In the E.E.C. the maximum is 5% shell and germ on fat free dry matter. For a yield comparison one should start from the same shell content in the nib derived from the types of beans being compared, of course within the maxima mentioned above.

A difference in theoretical yield calculated in this way must, however, sometimes be corrected for a factor which I indicate by the term "breakability". Most cocoa powder/cocoa butter manufacturers crush and clean the cocoa bean before roasting, which is in contradiction to the chocolate industry where it is customary to first roast and subsequently break and de-shell the beans. The reasons for the reversal of these operations by the cocoa press industry are:

- Avoidance of loss of cocoa butter to the shell during the roasting process.
- Avoidance of a double drying operation and the consequent extra energy and investment costs. Most of the cocoa nibs will undergo an alkalization treatment in which the moisture content will again be raised to above the natural level.

The usual method of breaking and winnowing yields, a main nib fraction and two other sub-fractions, namely the shell stream and the meal stream. With the current African cocoa beans, a modern breaking and winnowing plant gives in practice a nib yield reasonably close to the maximum theoretical yield. This means that the losses of nib in the shell and meal fractions are very limited. As a rule, these losses increase when the breakability of the beans decreases because the use of more energy results in a very fine nib, which cannot readily be separated from fine shell and ultimately will land with fine shell in the meal fraction. Furthermore, with beans which are hard to break, more nib remains adhering to shell particles which on winnowing end up in the shell fraction. With beans which are hard to break the losses may rise to such an extent that without a separate pre-treatment the specified low shell content cannot be attained without unacceptably large nib losses in one or both sub-fractions. The known pre-treatments such as conventional pre-drying or micronizing entail extra costs. The cocoa powder/cocoa butter manufacturer will take this into account when negotiating the price he is willing to pay for such beans.

It will be clear that, for the cocoa press industry, differences in breakability have greater impact than for the chocolate industry where the cocoa bean is directly roasted. The problem of poor breakability occurs regularly with cocoa beans of Malaysian origin. Factors like bean size, bean uniformity and shell content will influence the breakability. Chan and Lim (1983) showed that these factors were dependent on agronomic factors. The moisture content of the bean is also of importance. There may be other factors

5

which are not fully investigated yet such as fermentation reaction products and pulp residues which are left behind after drying. Further research to obtain a more uniform breakability, comparable with that of African cocoa beans, is recommended.

Acidity

Above all should be said that the problem of the acidic off-flavours has nothing to do with the occurrence of increased free fatty acids contents, usually abbreviated to percentage ffa. These apply to long-chained fatty acids resulting from (hydrolytic) fat splitting. In case of cocoa butter these mainly refer to C_{16} and C_{18} fatty acids, which have no acid taste. Acidic off-flavours are related to the presence of more than normal quantities of short-chained organic acids such as acetic acid and lactic acid.

These are formed during fermentation from sugars present in the pulp which surrounds the cocoa seeds in the cocoa pod. Carr *et al.* (1979) have shown that these acids, developing as reaction products, also gradually diffuse inwards and thus reach the cotyledons where they contribute to the "curing" process.

The concentration of the various organic acids ultimately remaining in the dried beans are dependent on a great many factors.

Carr *et al.* (1979) compared a number of fermentation methods and demonstrated that the pulp/bean ratio, the degree of aeration and the temperature history can be of influence. During the fermentation process the composition of the microbiological population changes considerably, where the fermentation products of the one microorganism form the substrate for the next.

The final result of such a complex of consecutive biochemical reactions vary considerably, depending on the course of the individual stages. Since the techniques used with fermentation are not exactly the same everywhere, it is not surprising that considerable differences are found in the pattern of these acids in beans of various origin. *Figure 2* gives an indication of these differences as they were found in our laboratory.

The acid taste can be favourably influenced by alkalization. However, a problem is that in food legislation of most countries maxima are stated for the amount of alkali which may be added.

In the U.S.A., for example, a maximum of 3 kg of sodium carbonate (or an equivalent quantity of another permitted alkalizing agent) per 100 kg nib. For the E.E.C. a maximum of 5 kg sodium carbonate (or an equivalent quantity of another permitted alkalizing agent) per 100 kg fat free dry matter. Because with acid cocoa beans more alkalizing agent must be used to attain the same pH, it is not always possible to attain (within the maximum additions allowed) the same colour results as with less acid cocoa beans. A further problem is that it is usual to specify quite restricted pH values for alkalized cocoa powders. Maintaining these by alternate use of more or less acid beans would result in unacceptable differences in the properties of the cocoa powders obtained. Because the cocoa powder manufacturer is obliged to supply a product as constant as possible, an acidity which fluctuates too strongly restricts his flexibility with respect to bean choice.

Summarizing, it can be said that the cocoa press industry has more means available than the chocolate industry to deal with the acid taste, but that the acid character of some bean types remains a restriction on the use of these beans for certain more inten-

6

C = Citric acid   A = Acetic acid   L = Lactic acid
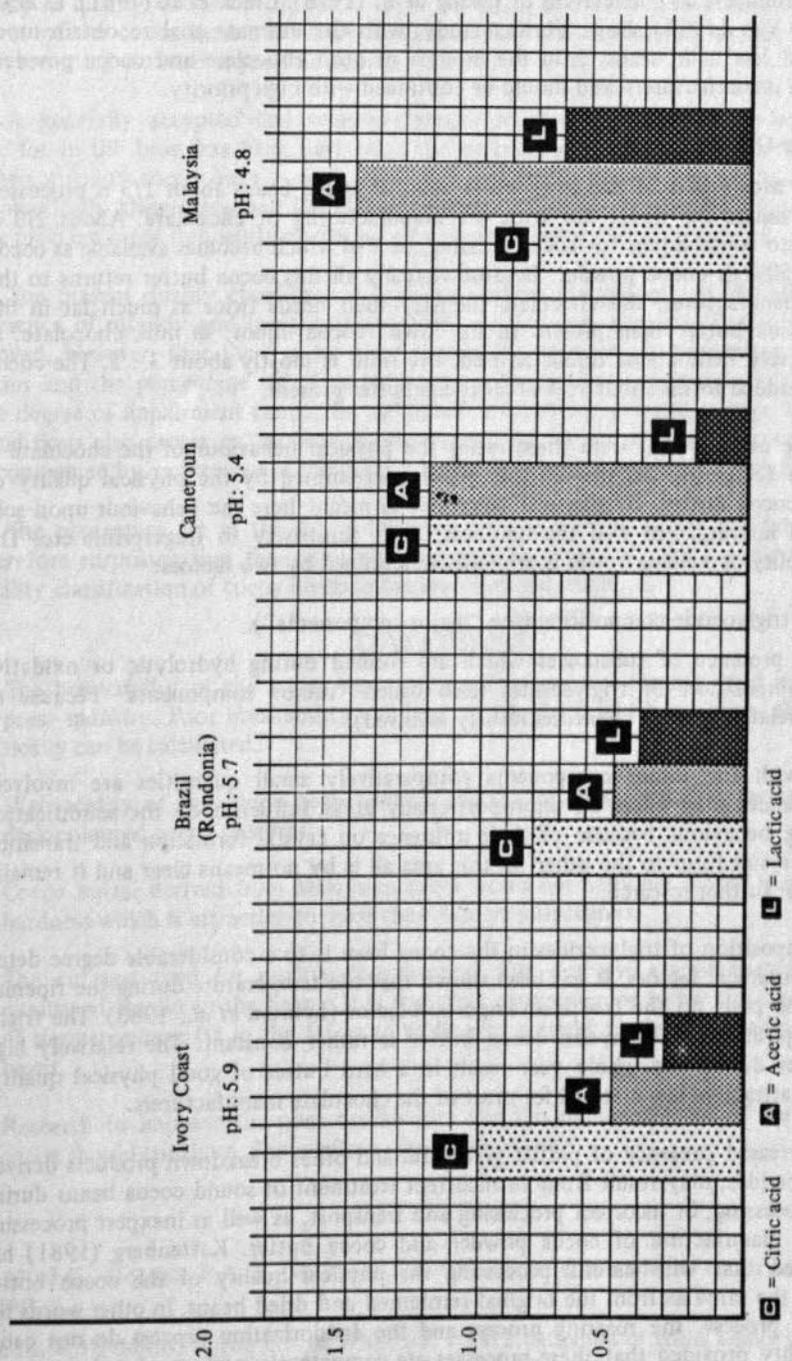
Figure 2. Acids present in nibs from dried, fermented cocoa beans (in g/100 g)

Source: Cacaofabriek De Zaan B.V.

sively coloured cocoa powder types. The acidity problem has the full attention of the Malaysian producers as publications of Chong *et al.* (1978), Chick *et al.* (1981), Li *et al.* (1983) and Yap (1983) show. Further study, with the ultimate goal to obtain more uniform and less acid beans, is in the interest of both chocolate and cocoa powder/cocoa butter manufacturers; and should be continued with high priority.

Cocoa Butter Quality

Figure 1 shows that of the total world crop of cocoa beans about 1/3 is processed into cocoa liquor for direct use with the manufacturing of chocolate. About 2/3 is processed into cocoa liquor for cocoa pressing, 50% of which becomes available as cocoa butter and 50% as cocoa powder. Because virtually all this cocoa butter returns to the chocolate manufacturer, the chocolate industry then needs twice as much fat in the form of cocoa butter than present in its "own" cocoa liquor. In milk chocolate, in which relatively little cocoa liquor is used, the ratio is mostly about 3 : 1. The cocoa butter then added forms about 75% of all cocoa butter present.

It will be obvious that with these ratios the physical behaviour of the chocolate — under given tempering conditions — is chiefly determined by the physical quality of the added cocoa butter. By physical behaviour is meant here the behaviour upon solidifying and melting, but also the hardness, snap, sensitivity to fingerprints etc. The physical quality of a cocoa butter is primarily determined by two factors:

- The triglyceride composition (the "major components").
- The presence of substances which are formed during hydrolytic or oxidative decomposition of triglycerides (also called "minor components" because of the relatively small quantities mostly involved).

Although with the minor components comparatively small quantities are involved, these substances may exert an unproportionally great influence on the solidification and melting behaviour because of their influence on crystal formation and transition from one crystal form to the other. In this area all is by no means clear and it remains attractive for further research.

The composition of triglycerides in the cocoa bean is to a considerable degree determined by botanical factors. It has been shown that the temperature during the ripening of the cocoa pods on the tree is an important factor (Lehrian *et al.*, 1980). The triglyceride composition of Malaysian cocoa butter is rather constant. The relatively high temperatures during the whole year result in a hard butter of good physical quality, which is an attractive raw material for most of the chocolate manufacturers.

The increased presence of partial glycerides and other breakdown products derived from triglycerides, may result from an incorrect treatment of sound cocoa beans during primary processing, or incorrect processing and transport, as well as inexpert processing during the manufacture of cocoa powder and cocoa butter. Kattenberg (1981) has demonstrated that with careful processing the physical quality of the cocoa butter obtained is the same as from the original fermented and dried beans. In other words the alkalization process, the roasting process and the deodorization process do not cause loss in quality provided that these processes are competently performed and the cocoa beans used are of good quality. The cocoa press industry has no processes available which could substantially improve the physical quality of the fat as present in the cocoa bean.

Consequently, since the quality of the fat in the bean determines the maximum physical quality of the cocoa butter to be obtained, it is of vital importance that treatment of the cocoa bean after harvesting until secondary processing should be directed to preventing as much as possible damage to the fat.

A generally accepted and relatively simple method to determine to what extent the fat in the bean has been harmed is the determination of free fatty acids (% ffa). When a sound cocoa bean is well fermented and dried, the ffa, calculated on the fat, is practically always less than 1%. Malaysian beans seldom show a problem in this respect; the problem more frequently occurs with beans from some African countries.

The present quality classification (cut test) misses the percentage ffa, although the presence of mouldy and insect-infested beans is taken into account. Kattenberg (1981) proved, however, that there is no good correlation between the percentage of mouldy beans and the percentage ffa. This is because with the visual evaluation in the cut test the degree of impairment cannot be estimated. Moreover prolonged storage under moist conditions also causes an increase in the percentage ffa without this necessarily being accompanied by an increase of the percentage mouldy and insect-infested beans.

The percentage ffa of the fat in the bean thus is a much better standard and it is therefore surprising that this relatively easy analysis does not play a direct part in the quality classification of cocoa beans in the international trade.

CONCLUSIONS

- The breakability of the cocoa bean influences in practice the nib yield in the cocoa press industry. Poor breakability will lead to nib yields which are lower than theoretically can be calculated.

- High acidity of the cocoa bean restricts the use of these beans for certain types of dark-coloured cocoa powders.

- Cocoa butter derived from Malaysian cocoa beans normally has a good quality with a hardness which is attractive to most chocolate manufacturers.

- The cut test used for quality classification does not give a good measure for the quality of the fat in the beans. It is therefore recommended to use the determination of the percentage ffa in the fat as an additional method for quality grading of cocoa beans.

- Research to improve the poor breakability and the acidity of most of the Malaysian cocoa should continue. The results so far are promising.

REFERENCES

CARR, J.G., DAVIES, P.A. & DOUGAN, J. (1979). Cocoa fermentation in Ghana and Malaysia, Report.

CHICK, W.H., MAINSTONE, B.J. & WAI, S.T. (1981). Mitigation of cocoa acidity in Peninsular Malaysia. In International Research Conference, 8a. Cartagena, Colombia.

CHAN, Y.H. & LIM, D.H.K. (1983). Some agronomic factors which would influence cocoa bean size, bean uniformity and shell content. Seminar on Primary Cocoa Processing & Quality Control, Tawau, Sabah, May, 1983.

CHONG, C.F. SHEPHERD, R. & POON, Y.C. (1978). Mitigation of cocoa bean acidity — fermentary investigations. *Proc. Int. Conf. on Cocoa and Coconuts, Kuala Lumpur, 1978.* Kuala Lumpur: Incorporated Society of Planters.

COCOA, CHOCOLATE AND CONFECTIONERY ALLIANCE (1984). *Cocoa Beans; Chocolate Manufacturers' Quality Requirements.* 3rd Ed.

KATTENBERG, H.R. (1981). The quality of cocoa butter. *The Manufacturing Confectioner.*

LEHRIAN, D.W., KEENEY, P.G., & BUTLER, D.R. (1980). Triglyceride characteristics of cocoa butter from cocoa fruit matured in a microclimate of elevated temperature. *J. Am. Oil Chem. Soc.* 57, 66–69.

LI, K., LIAU, H.T.L., & LEE, M.T. (1983). A brief account of the reduction of cocoa bean acidity and recent experience in two fermentaries in Sabah. *Seminar on Primary Cocoa Processing & Quality Control, Tawau, Sabah, May, 1983.*

POWELL, B.D. (1983). Changes in cocoa bean availability. *The Manufacturing Confectioner,* September 1983. 63–69.

YAP, T.N. (1983). Control of cocoa fermentation technique to enhance quality. *Seminar on Primary Cocoa Processing & Quality, Tawau, Sabah, May, 1983.*

Long Term Developments in World Cocoa
1985— 1990 — 2000

DAVID CROTTY

Gira S.A., 1239 Collex-Geneva, Switzerland

The purpose of the research, the key results of which are very briefly summarised here, is to forecast the very long-term developments taking place in cocoa through to 1990– 2000. The research was designed to determine the feasibility of investment in cocoa. As such, all aspects of the cocoa and chocolate industries were analysed, viz.

- *Price*
- *Demand*
- *Supply*
- *Semi-manufactured product processing*
- *Trade*

*Cocoa bean **prices**, declining since 1977, will continue to decline in real terms until 1985–87 and will then start to climb again to reach a peak in 1995 of some US dollars 4,500 per tonne (1981 constant terms). Prices follow a 23-year price cycle which is caused primarily by supply factors and only secondarily by demand. The introduction of high yielding, high technology cocoa on a significant scale in recent years will have a relatively small effect on this cycle although it will highlight the differences between efficient and inefficient producers of cocoa. Successful investment in cocoa planting depends to a large extent on a counter-cyclical calendar of establishment.*

*Despite relative stagnation of cocoa **consumption** in the 1970's, consumption is forecast to increase well through to 2000. **Consumption** increases in mature markets, caused by an assumed recovery of economies from 1985 on, will be accompanied by increased offtake in developing markets where demand for cocoa powder-containing products will be stronger than for butter-containing products – principally chocolate which is too expensive and difficult to distribute in many countries for climatic reasons. Dramatic increases since 1977 in **processing to semi-manufactured** products in countries of origin are expected to slow down considerably as the lessons of the African and Latin American experiences are digested. Processing in producing countries is expected to increase slowly from the present 30% of world total to around 40% in the year 2000.*

*On the **supply** side, there will continue to be important shifts away from Africa because of political and economic difficulties, and also because of the relatively slow introduction there of high yielding cocoas compared with other parts of the world. South-East Asia will be a prime cause of these shifts. Production costs (including all costs except transport to demand regions) of cocoa in this region are the lowest in the world, not only because of efficient growing, fermenting, drying, but also because of the effective, low cost distribution and marketing networks, minimum government intervention, the high costs of which are a major handicap in countries such as Brazil, certain African countries and Papua New Guinea.*

COCOA BEAN PRICE

Past Development

GIRA's aim has been to forecast the long-term movement of cocoa bean price *(Figure 1)*. Analysis of real* prices in the past shows that:

- The very long-term price trend has been *upwards*, unlike that of most other agricultural commodities.

- Prices have closely followed a 23-year cycle for the past sixty years.

- These cyclical movements of price will continue to be induced by supply/demand changes, but

- The arrival of hybrid cocoa will have the double effect of depressing the very long term trend line and shortening the periodicity of the price cycle.

Forecast 1990-2000

The resultant price forecasts are shown in *Figure 2*.

The solid line shows the cyclical regression for the past and the GIRA forecast to 2000. The broken line shows the mechanical projection before modification to allow for the effects of hybrid cocoa. The "+" line indicates the past movement of actual prices.

These forecasts correspond to:

(1981 Constant US$/tonne)

Year	Price
1985	1 900
1990	2 650
1995	3 500
2000	4 250

Effect of Hybrid

From detailed analysis of all supply countries, hybrid cocoa is forecast to represent half or more of the total supply in the major exporting countries between 1985 and 1990. As a result, in the forecast period:

- The cycle length will drop from 23 to 18 years (5 years gained by earlier maturity of tree);

- The average rate of price increase will drop from $39 to $16/tonne/year.

However, it should be emphasised that, in our analysis, hybrid cocoa will not essentially affect the cyclical nature of future price development.

CONSUMPTION – WORLD DEVELOPMENT 1950 – 2000

Overall Cocoa

In the thirty years 1950-1980, total world cocoa consumption very nearly doubled to reach 1,466,000 tonnes in 1980 *(Figure 3)*. Consumption rose particularly strongly

---

* deflated by U.S. wholesale price index.

2
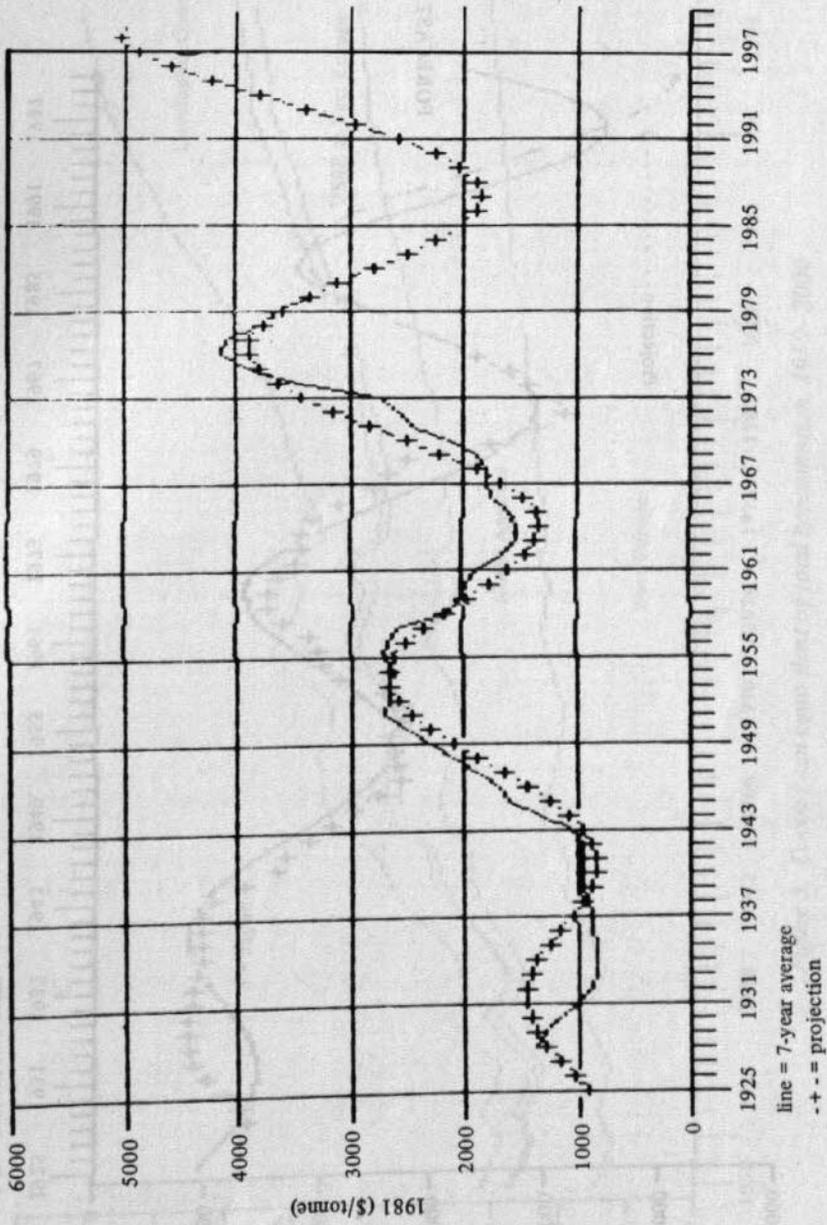
Figure 1. 1925–2000 Comparison of actual and simulated cocoa price

line = 7-year average

.-+-= projection

1981 ($/tonne)

3
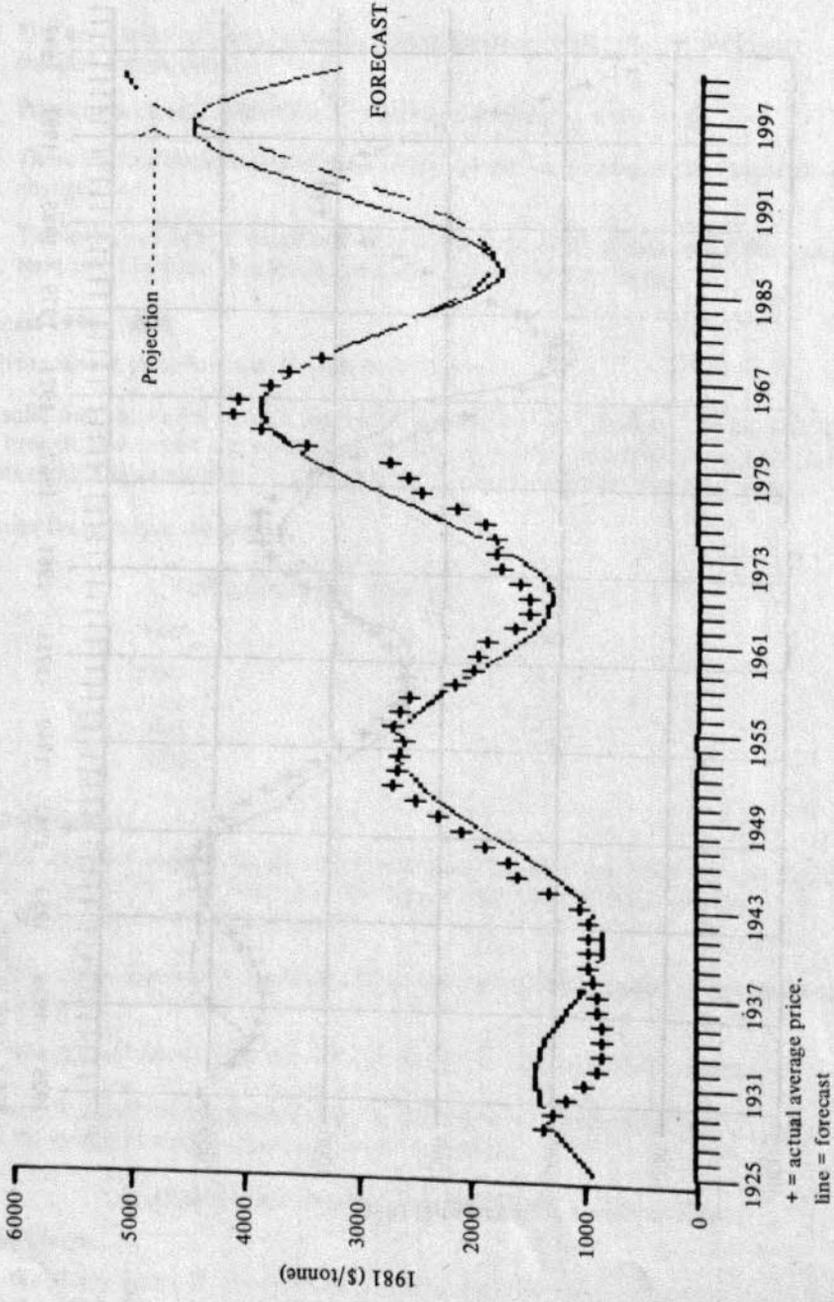
Figure 2. Cocoa bean price projection and forecast 1925–2000

+ = actual average price.
line = forecast

FORECAST

Projection - - - -

1981 ($/tonne)

1925 1931 1937 1943 1949 1955 1961 1967 1973 1979 1985 1991 1997

4
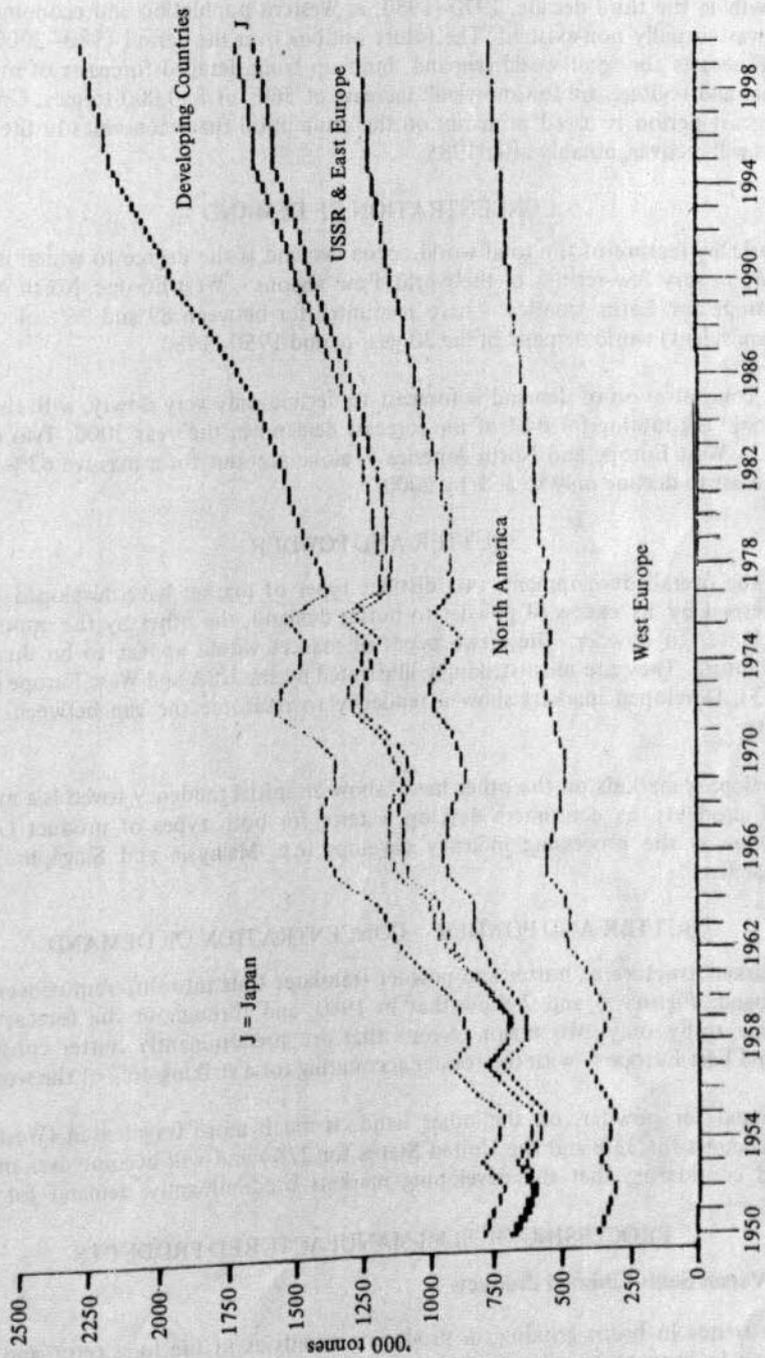
Figure 3. Cocoa bean equivalent of total consumption, 1950–2000

'000 tonnes

Developing Countries

J

USSR & East Europe

North America

West Europe

J = Japan

(+3.0–3.5% p.a.), under the influence of population and economic growth, in the first two decades.

Growth in the third decade, 1970–1980, as Western population and economies stagnated, was virtually non-existent. The future outlook over the period 1980–2000 is very good. Forecasts for total world demand, built up from detailed forecasts of individual countries and regions, are for an overall increase of 56%, or 830,000 tonnes. Growth in the forecast period is based primarily on the assumption that economies in the mature markets will recover, notably after 1985.

CONCENTRATION OF DEMAND

A remarkable feature of the total world cocoa demand is the degree to which it is concentrated in very few regions of the world. Four regions — West Europe, North America, East Europe and Latin America — have accounted for between 89 and 96% of the total (bean equivalent) world demand in the 30-year-period 1950–1980.

This concentration of demand is forecast to decline only very slowly, with these four regions still accounting for 84% of the forecast demand in the year 2000. Two of these regions — West Europe and North America — alone account for a massive 63% in 1980 and forecast to decline only to 55% by 2000.

BUTTER AND POWDER

Within the overall development, two distinct types of market have developed, the one characterised by its excess of powder to butter demand, the other by the opposite, *i.e.* excess butter to powder. These two types of market would appear to be the pattern for the future. They are most strikingly illustrated by the USA and West Europe *(Figures 4 and 5)*. Developed markets show a tendency to reinforce the gap between the two products.

Developing markets on the other hand, show an initial tendency towards a more even mix of products, as consumers develop a taste for both types of product (Asia and Africa) or as the processing industry develops (*e.g.* Malaysia and Singapore), which then stabilises.

BUTTER AND POWDER – CONCENTRATION OF DEMAND

The market structure of butter and powder translates thus into different concentrations of demand. *Figures 6* and *7* show that in 1980, and throughout the forecast period, there are really only two major regions that are predominantly butter consumers — West and East Europe — with the former accounting for a striking 46% of the world total.

Demand for powder, on the other hand, is much more fragmented (West Europe only accounts for 33% and the United States for 27%) and will become even more fragmented considering that the developing markets predominantly demand for powder.

PROCESSING OF SEMI-MANUFACTURED PRODUCTS

Beans Versus Semi-Finished Products

The trends in beans grinding in producing countries in the long term, and medium term can be seen to be related to the absolute level of cocoa price *(Figure 8)*. At the time of high bean prices, grindings increase because of the availability of subsidies for export of the semi-finished products. As prices decrease, the subsidies are removed

6
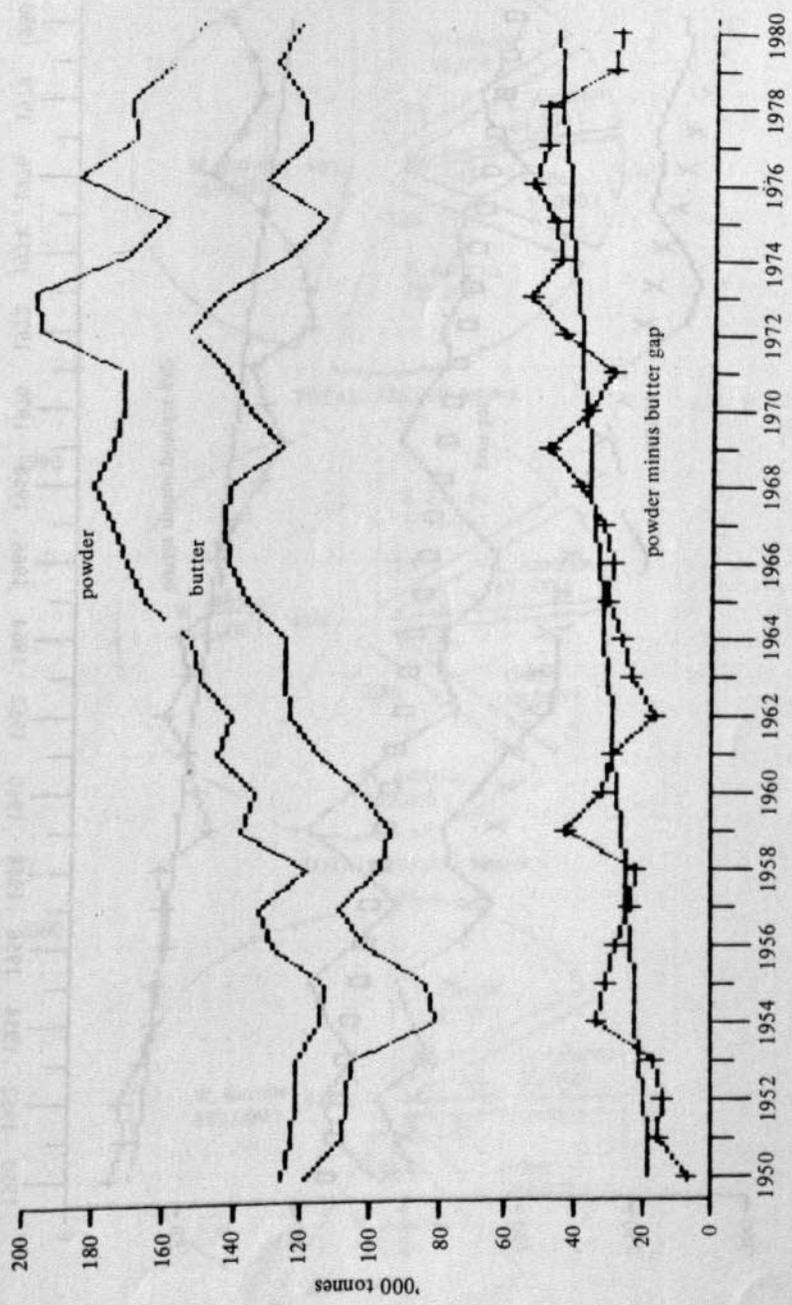
Figure 4. North America: powder and butter equivalent use, 1950–1980

'000 tonnes

powder

butter

powder minus butter gap

7
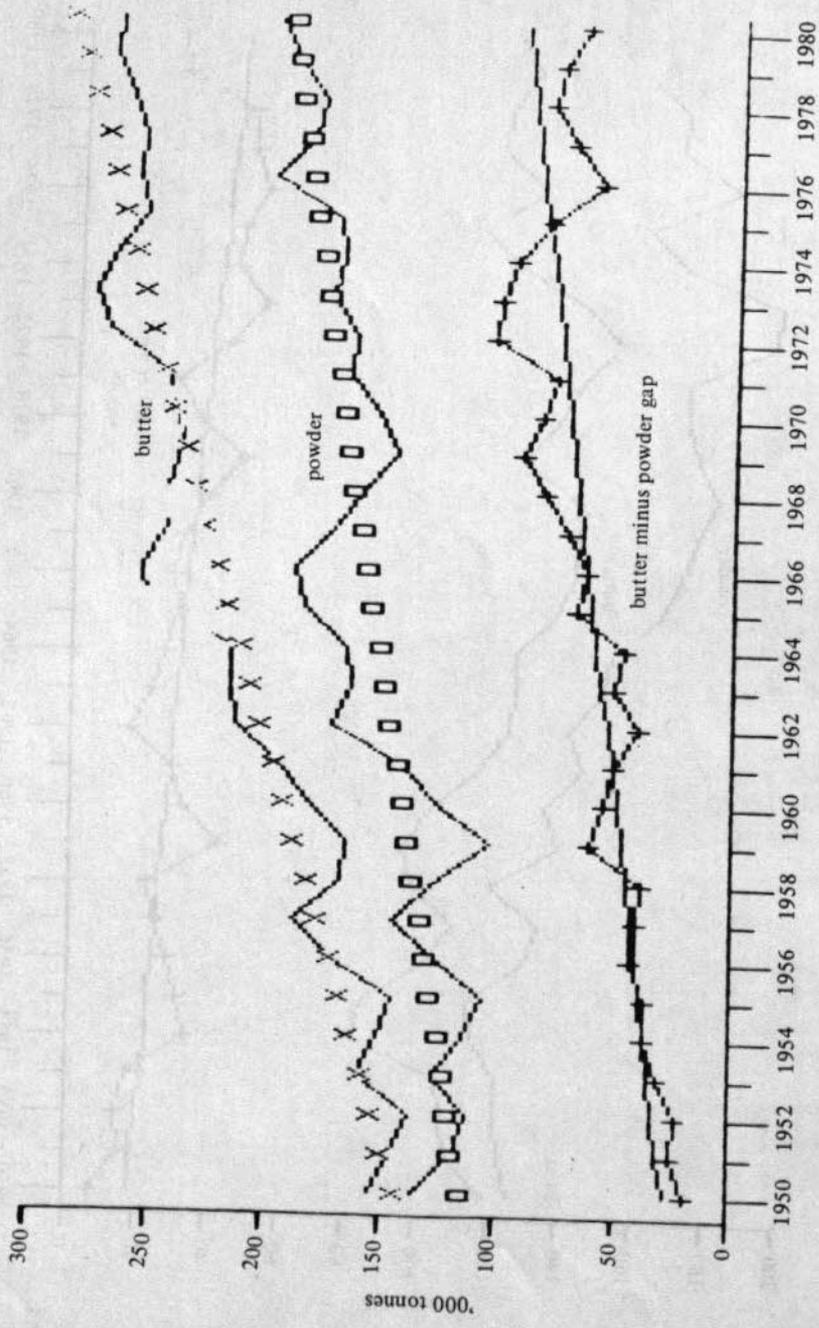
Figure 5. *West Europe: powder and butter equivalent use, 1950–1980*

8

1980

E. Europe
91,000 t

16%

L. America
44,000 t

W. Europe 46%
269,000t

9% Other
57,000 t

22%

N. America
125,000 t

TOTAL: 586,000 tonnes

1990

E. Europe
118,000 t

15%

L. America
9% 67,000 t

W. Europe
334,000 t 43%

13%

20% Other
98,000 t

N. America
160,000 t

TOTAL: 776,000 tonnes

2000

E. Europe
153,000 t

17%

L. America
9% 80,000 t

W. Europe 42%
382,000 t

13%

19% Other
126,000 t

N. America
177,000 t
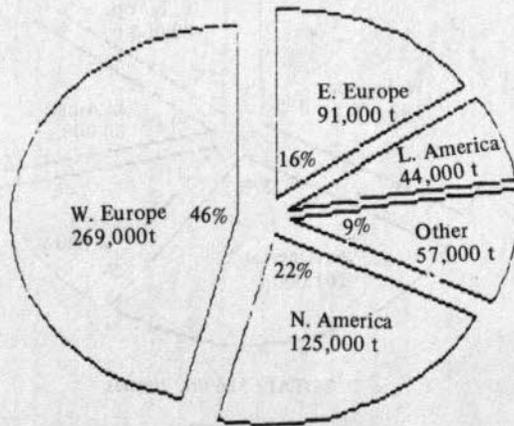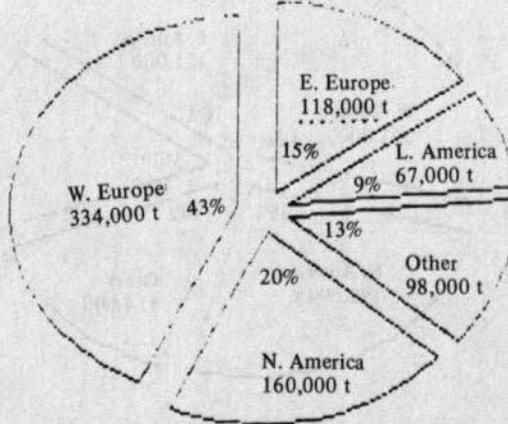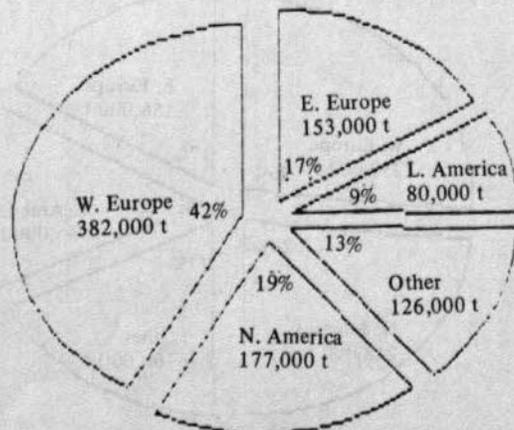
TOTAL: 918,000 tonnes

Figure 6. World butter demand

9

1980

W. Europe 192,000 t 33%

E. Europe 89,000 t 15%

L. America 14% 80,000 t

N. America 161,000 t 27%

11%

Other 64,000 t

TOTAL: 586,000 tonnes

1990

W. Europe 221,000 t 28%

E. Europe 121,000 t 16%

16%

N. America 199,000 t 26%

14%

Other 114,000 t

TOTAL: 776,000 tonnes

2000

W. Europe 239,000 t 26%

E. Europe 156,000 t 17%

16%

L. America 145,000 t

N. America 218,000 t 24%

17%

Other 160,000 t
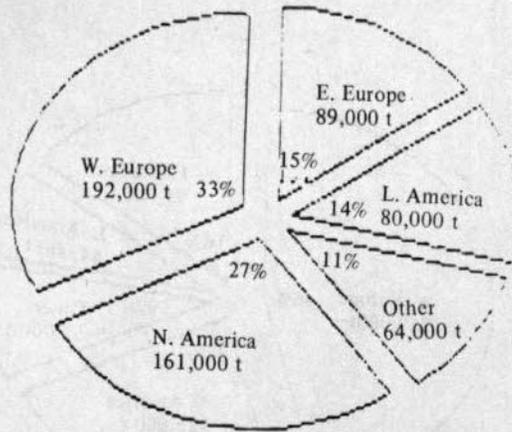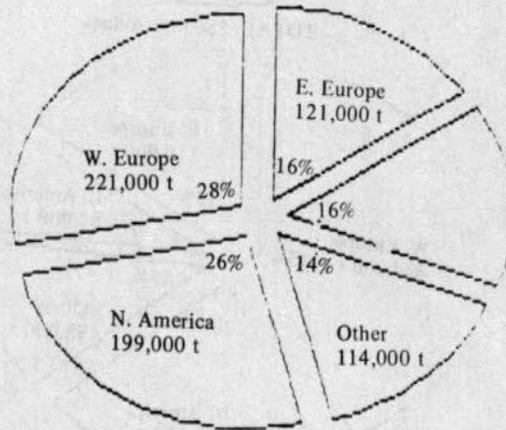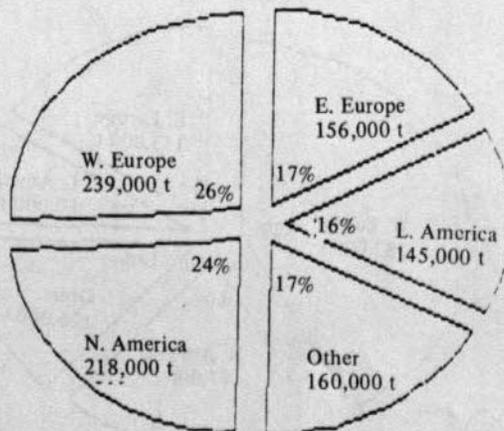
TOTAL: 918,000 tonnes

Figure 7. World powder demand

10
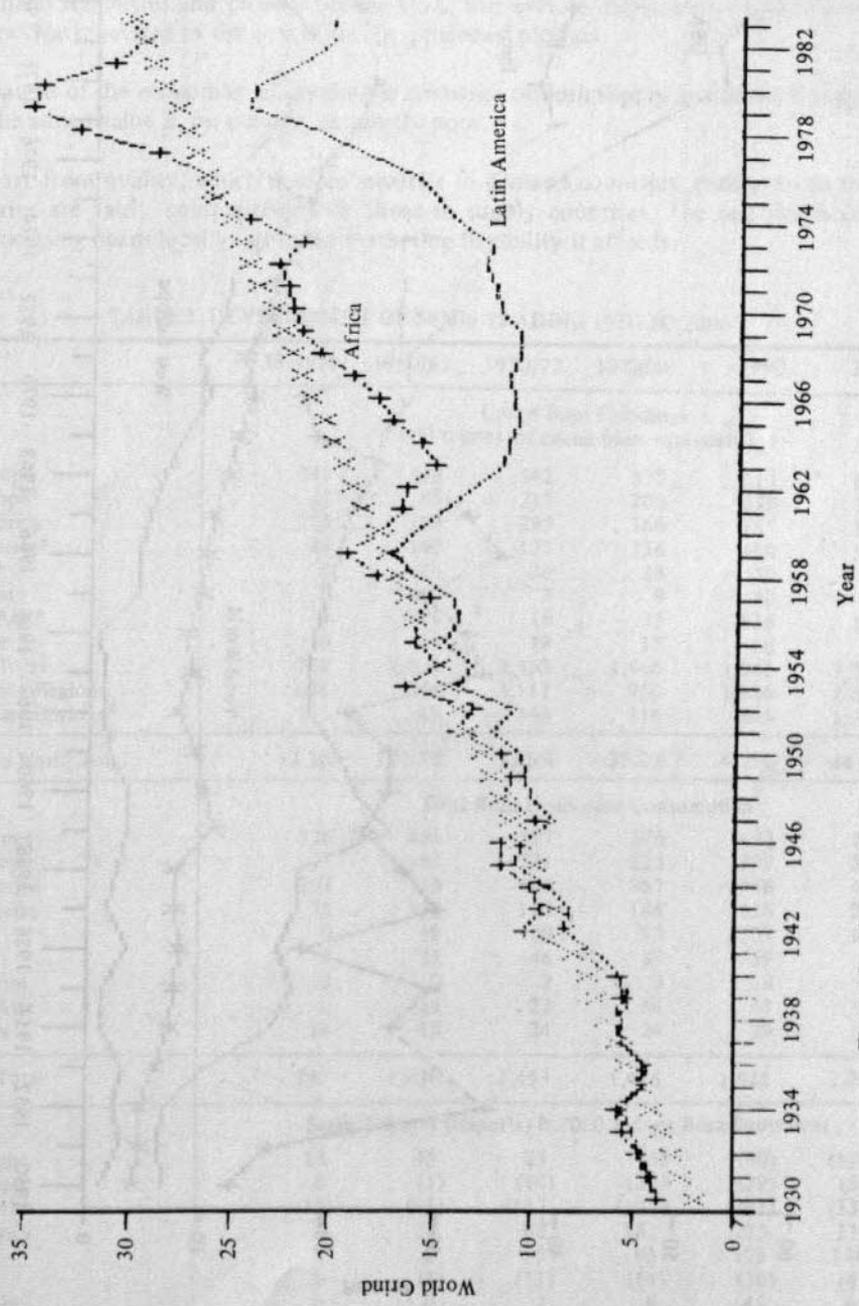
Figure 8. Share of cocoa processing in producing countries, 1930–1983
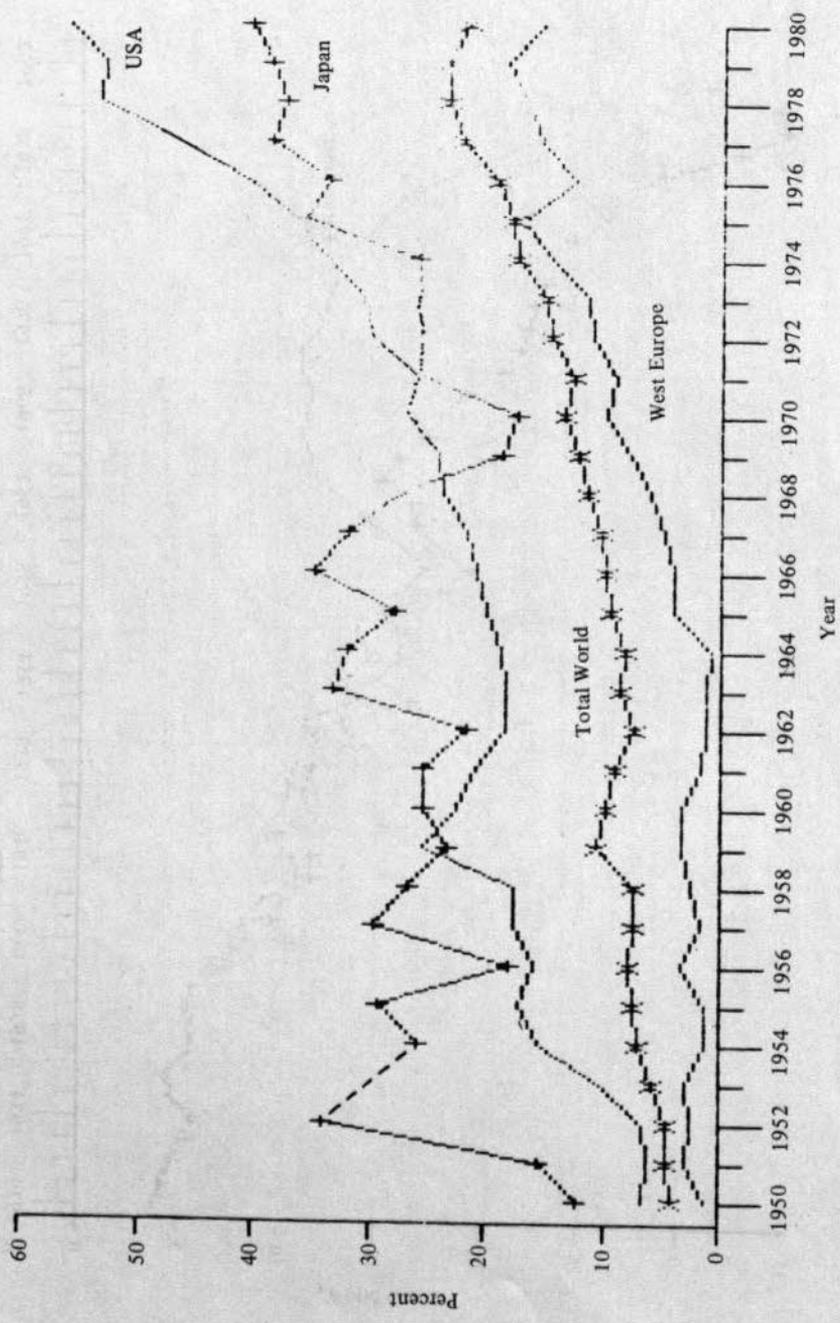
Figure 9. Share of semis imports in total cocoa consumption, 1950–1980

12

and grindings decline. Semi-finished imports from producing countries in world demand is now around 20% having declined slightly since the peak bean prices at end of the 1970's *(Figure 9)*. Imports into West Europe are principally to correct the imbalance in demand for butter and powder. In the USA, the level of imports from Latin America is more clearly related to the cost of locally processed product.

Analysis of the economies of grinding in countries of both supply and demand suggests that the added value is, on average, extremely poor.

Apart from quality, which is often superior in demand countries, converters in these countries are fairly competitive with those in supply countries. The real justification for processing beans locally lies in the marketing flexibility it affords.

TABLE 1. DEVELOPMENT OF SEMIS TRADING 1950 TO 2000

	1950/52	1960/62	1970/72	1978/80	1990	2000
	Cocoa Bean Grindings ('000 tonnes of cocoa bean equivalent)					
W. Europe	349	476	542	532	614	655
E. Europe	21	85	217	205	270	330
N. America	275	253	295	166	157	160
L. America*	84	147	177	336	460	550
Africa*	1	16	36	23	29	30
Singapore	0	0	3	9	50	80
Other Asia*	4	11	18	33	135	190
Oceania	10	14	18	15	16	20
World Total	757	1,026	1,453	1,466	1,941	2,295
Importing Regions	656	844	1,111	950	1,136	1.275
Exporting Regions*	101	182	343	516	805	1,020
– Share World Total	13.3%	17.7%	23.6%	35.2%	41.5%	44.4%
	Total Bean Equivalent Consumption					
W. Europe	336	431	517	576	693	777
E. Europe	21	86	231	225	299	385
N. America	293	319	408	357	448	493
L. America	75	118	115	155	235	280
Africa	9	19	89	53	107	142
Japan	2	21	46	37	59	73
Singapore	0	0	2	3	8	12
Other Asia	6	14	22	34	63	101
Oceania	14	18	24	24	29	32
World Total	757	1,026	1,453	1,466	1,941	2,295
	Semis Exports (Imports) in '000 tonnes Bean Equivalent					
W. Europe	13	45	25	(45)	(80)	(122)
E. Europe	0	(1)	(14)	(20)	(29)	(55)
N. America	(18)	(66)	(113)	(191)	(291)	(333)
L. America	9	29	62	181	225	270
Africa	3	6	59	93	103	138
Japan	0	(5)	(11)	(14)	(30)	(43)
Singapore	0	0	2	6	42	68
Other Asia	(2)	(3)	(4)	(1)	72	89
Oceania	(4)	(4)	(6)	(9)	(13)	(12)
World Total	0	0	0	0	0	0

Future Development

The share of grindings in the exporting countries is forecast to rise to over 40% of the world total in 2000 *(Table 1)*. A prime cause of this, relatively conservative, (forecast) is consumer resistance in demand countries. Grindings are expected to increase (but at a lower rate than consumption) in West and East Europe, but in the USA and Japan, it is expected to stagnate l or increase only slightly.

LONG-TERM DEVELOPMENT OF WORLD SUPPLY

Cocoa Supply Volume to 1990 and 2000

Past trends. Analysis of the past 60 years of production also highlights the main reason for the price cycle: high cocoa prices result in accelerated plantings over the following years and, because of the natural life cycle of cocoa, only increased production 5–10 years later ... by which time the world market price has slumped.

The past 30 years *(Figure 10)* are characterised by:

- Continued predominance of Africa as a whole.
- Shift of production from Ghana and Nigeria to the Ivory Coast.
- "Birth" of Asian cocoa production, mostly Malaysia.
- Little structural change in Latin America except for the shift of production from the West Indies to Brazil.

Forecasts

Two very different periods should be distinguished: *viz*

- 1980 to 1990: low cocoa prices depress Brazilian production (where production costs are high): Ghana continues its decline: all this market share is taken by Asian producers – still essentially Malaysia, but also Indonesia;
- 1990 to 2000: much more stable distribution typical of a rising/high price situation: Brazil regains market share at the expense of other Latin America and Africa: the Asian position is stabilised.

Cocoa Supply Costs

This comparison *(Figures 11 and 12)* highlights the close relationship between labour costs and bean growing cost: both are the lowest in the Ivory Coast and Indonesia and are the highest in Brazil.

Sabah has labour costs comparable with those of Brazil whereas the labour costs in Peninsular Malaysia are slightly lower. Malaysia's present competitive position in the market is purely the result of:

- High productivity: high yields, efficient organisation of large plantations, close control of pests, good upkeep;
- Very low farm-to-f.o.b. costs resulting in good inland roads, keen competition between exporters, minimal Government interference and expenditure.
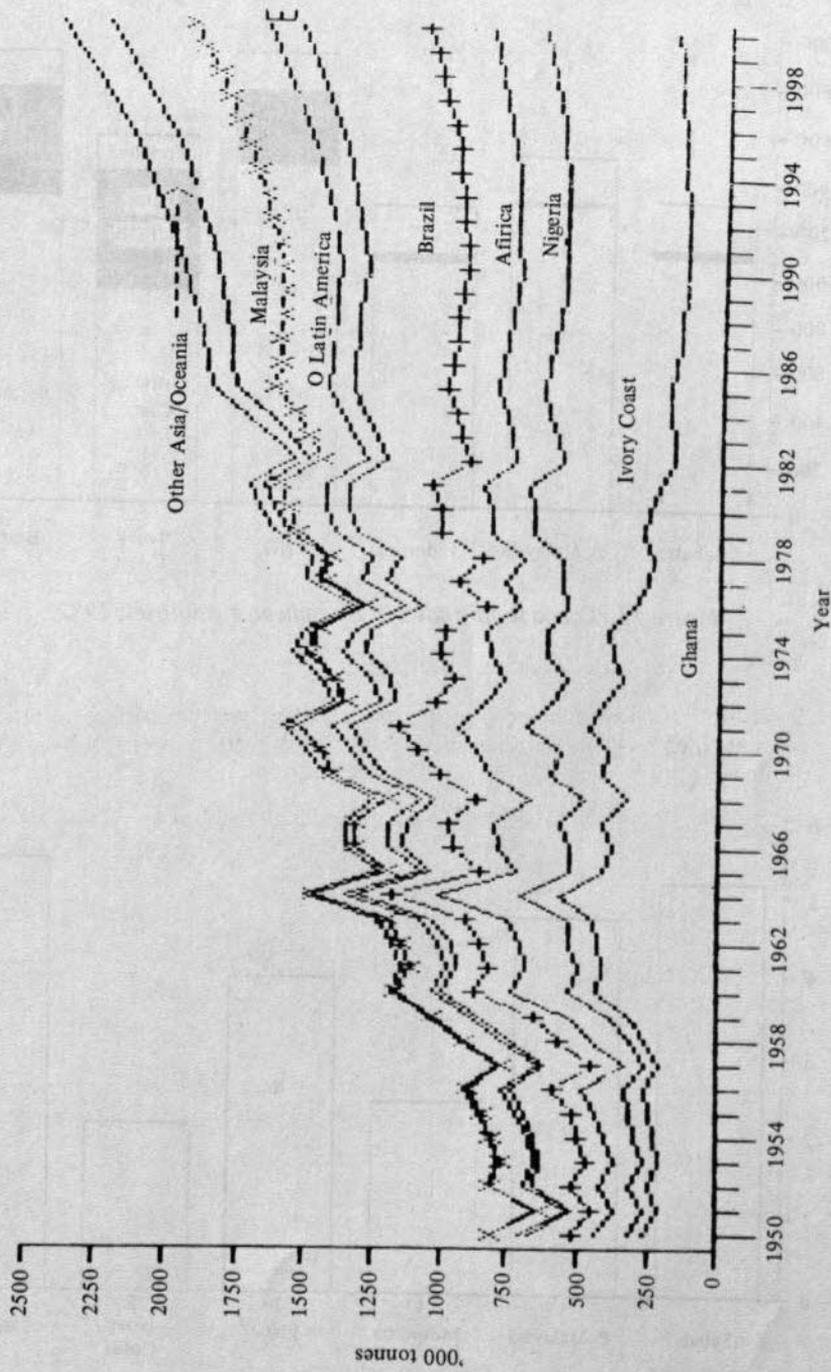
Figure 10. World cocoa bean production by major country, 1950 to 2000
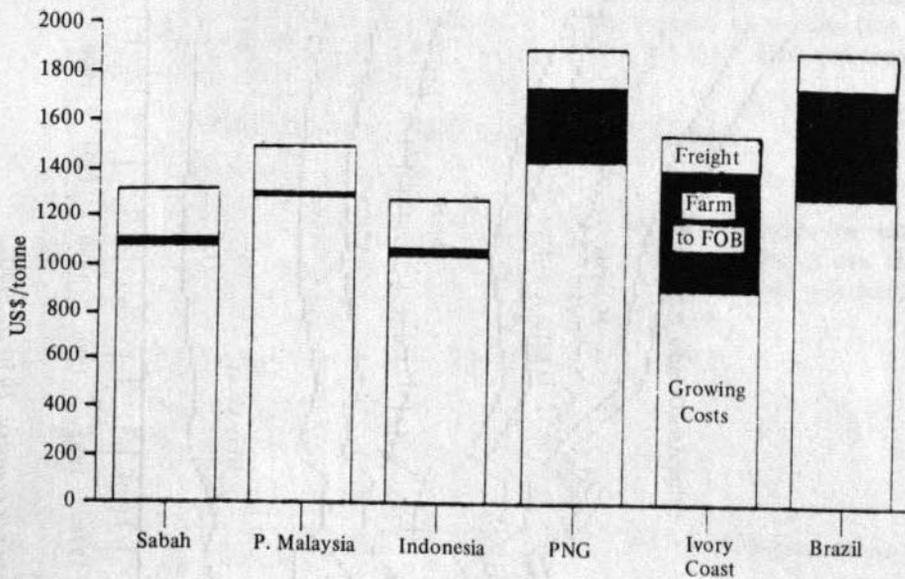
Figure 11. Cocoa supply costs in the indicator countries, 1982
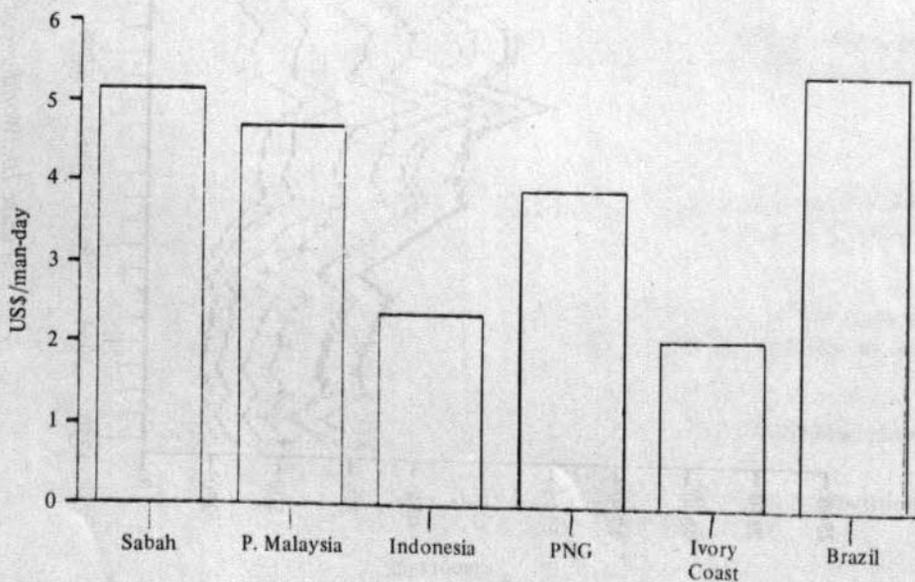
Figure 12. 1982 labour costs on cocoa plantations

16

THE MARKETING MECHANISM FOR SELLING COCOA POWDER AND
COCOA BUTTER IN THE MALAYSIA CONTEXT AND
ITS IMPLICATIONS ON THE INDUSTRY AS A WHOLE

PHILIP MEIJER
Cocoa Merchants Ltd, London, England

INTRODUCTION

For those of you unfamiliar with the cocoa business, let me start with a
quick resume of the path any cocoa bean must go before ending up in chocolate.

COCOA PROCESSING

The cocoa tree is found in most tropical climates. It produces a fruit with bea
inside. When harvested these cocoa beans are fermented and dried and then shipp
to chocolate makers all over the world. Here the cocoa beans are cleaned,
deshelled, roasted and ground into cocoa liquor. This liquor or mass is then
pressed to extract its fat, cocoa butter. The remaining defatted cake is ground
into cocoa powder.

Recombining cocoa liquor, cocoa butter, milk and sugar, will eventually produce
chocolate (fig.(1)). The proportions are roughly as follows: Out of 100 kilos
of beans, 80 kilos of liquor are produced, the remainder consisting of shell
and moisture. The 80 kilos of liquor will produce roughly 40 kilos butter and
40 kilos cake/powder of 10% fat.
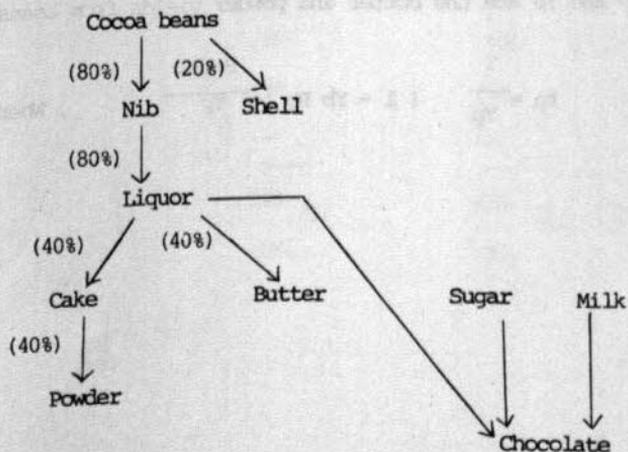
FIG. (1)

More and more, chocolate manufacturers decide not to process cocoa beans themselves but rather to leave this to a specialized converting industry which buys beans and sells semi-finished products; cocoa butter, liquor, cake and cocoa powder.

The main rationale for this specialization lies in the fact that most chocolates need rather more cocoa fats than solids, which leaves the chocolate manufacturer with stocks of cocoa cake they find hard to sell. Processing beans is also a capital intensive activity, making (seasonal) periods of idleness expensive to the individual manufacturer. Specialized/convertors will find ways to bridge these slack periods and will make use of economies of scale to cheapen processing costs further. As a last point, by offering their services, the converting industry allows most manufacturers to run down their raw material stocks substantially.

For any convertor to be profitable, it is clear that the cost of his inputs together with manufacturing costs and his profit margin should equal his revenues received from selling butter and powder.

For example, bearing in mind the yields mentioned earlier, if we bought beans at STG 1600/MT and achieved STG 3600/MT for the butter, then knowing production costs at say STG 100/MT of beans processed, then the powder should fetch at least

$$2 \ 1/2 \ X \ 1600 + 2 \ 1/2 \ X \ 100 - 3600 = 650.$$

In general, the following relationship should hold:

Bean price + costs + margin = Yb X butter price + Yp X powder price .

where, Yb and Yp are the butter and powder yields from beans respectively or

$$Pp = \frac{T}{Yp} \ (1 - Yb \ Rb)+ \frac{B+C+M}{Yp} \qquad , \text{ Where}$$

Pp = Powder price

T = Terminal market price

Rb = butter ratio

B = Bean premium

C = Processing cost/ton

M = Profit margin/Ton

(Fig. 2)

To develop the understanding of the industry further it is necessary to look at some of these variables in greater detail.

PROCESSING MARGIN

In reality the world is faced with an over capacity of grinding facilities . This means that in order to satisfy the formula, the margin M will be negative: i.e., total costs exceed revenues. The table below gives an idea of the size of this over capacity by setting out annual consumption, measured as grindings, versus our estimate of installed processing capacity, together with an estimate of how quickly this spare capcity could become operational.

	1983 Grind	Additional available within 6 mos.	over 12 mo.	Total Capacit
Western Europe	626	20	20	666
Eastern Europe	228	20	40	288
U.S.A.	194	50	50	294
Brazil	203	75	50	328
Other Americans	161	10	20	191
Africa	120	50	80	250
Asia	107	20	10	137
Oceania	12	–	–	12
	1651	245 (1)	270 (2)	2166
SOURCE:	G&D	CML	CML	CML

FIGURES IN THOUSANDS OF TONS

(Fig. (3)

1) Capacity estimated to be available through additional staffing (U.S.A., Europe, Brazil) or in process of starting up (Nigeria, Asia).

2) Capacity estimated to be currently retired and would require political decision (Eastern Europe) or financing for spare parts, working capital etc. (West Africa).

This vast potential extra capacity ensures that even in times of highest demand excess capacities are available. Margins are therefore rarely positive. The reasons for this over capacity are primarily political. Many governments of producing nations have and some still subsidise the development of converting industries aiming to create jobs and at the same time retain the theoretical added value derived from exporting semifinished products.

YIELDS

Yield is another important variable in the equation of fig.2. Not only is the fat yield different from one grade of cocoa beans to the next, but it can also change within a grade from season to season and even from month to month. Due to draught in Africa this past season, for instance, most manufacturers and processors have reported up to 1 percent reduction in the fat yields of certain African beans. It is also highly important how much a processor is able to extract from a particular bean: i.e., a question of technology.

RATIOS

Since the early 1970's it has become popular to trade and talk in ratios. The butter ratio is the butter price divided by the terminal market bean price. Similarly the cake ratio is defined by division of the cake price by the terminal price. The sum of the butter and the cake ratio is called the combined ratio.

In practice this combined ratio fluctuates as a result of any of the following factors:

A) Relative tightness in nearby processing capacity.

B) As a result of the bean price level.

C) Relative demand of butter versus cake.

A) In imperfect markets bottle neck situations develop in parts of the system, temporarily creating positive margins in an otherwise oversupplied environment. In such cases the combined revenues of butter and cake sales and therefore the combined ratio will be higher than usual.

B) The higher the price of beans, the lower the proportion of fixed costs in the values of the end product. In these cases the combined ratio is low.

C) This point needs more explanation. It is based on the empirical notion that the price elasticity of demand for cocoa powder and cake is substantially lower than cocoa butter; i.e. a doubling of the powder price has a lesser effect on powder consumption than a doubling of butter prices would have on butter consumption. As a result the combined ratio will be higher when relative demand for powder is high, all things being equal.

BEAN PREMIUMS

They are closely linked to bean yields, as chocolate manufacturers in buying beans, basically buy the amount of fat in those beans. Therefore Ghana beans trade at higher prices/differentials, than Ivory Coast beans. Certain grades, like Cameroon beans, trade at higher differentials than could be expected from their butter yield, as a result of the quality and special properties of its powder. In general it can be summarized as follows: As buyers hardly distinguish between the output from one convertor to the next and pay only one price to them, it is the convertor, who knowing his yields, who works backwards and determines what he can pay for the different bean grades. All in a perfect world though, as in the real world

relative tightness in a grade or position will drive the differential of
that grade up to uneconomical levels and will start affecting differentials
of replacement grades through increased demand also. Continued tightness
will eventually affect the ratios. For instance, if bean premiums rise
and the butter yield goes down because of tightness in high yielding beans,
then in a situation of unchanged powder demand, the butter ratio has to
increase (See fig 2). After this more or less theoretical background,let
us look at the following segmentation of the market.

MARKET SEGMENTATION

There are three ways in which the cocoa processing industry can develop/compete
in the world: through subsidy, technology or cost efficiency.

State subsidies no doubt can help an industry to gain an advantage over its
worldwide competitors. It should be remembered,however,that it can also lead
to inefficiency on a gradiose scale. Ecuador is a case in point, where through
subsidies, a massive industry was built up capable of processing the whole crop
and exporting its output below the cost of the beans that went into it.

Technology and investment are the tools used by the major processors in Europe
to stay ahead. Through it they achieve better yields than their competitors
from the same input, develop specialty powders for specific premium sectors of
the market, and find ways to increase factory throughput and cheaper bean mixes
without compromising on quality and specification of their end products.

Cost efficiency means much the same but also includes such geographical variables
as length of supply lines, labour costs, capital costs, distance to markets
and other special situations that could give a particular area an edge in
competition.

MALAYSIA

Turning now to Malaysia, it would seem that all three elements are combining here:

Firstly, a stable political climate and a government that supports the development of the industry. Secondly, the increasing knowledge locally and the continued participation of major international companies in the Malaysian industry has meant a constant improvement of quality, procedures and technology leading to better products and prices. Thirdly, Malaysia seems ideally placed for most "special effects": A cheap and abundant bean supply at its door step, relatively low labour and capital costs, hard butter, and best of all, a vast and captive, yet not fully developed powder market surrounding it. On the negative side, I should mention the distance from most final markets.

In all it is an enviable position, which can lead to a profitable and competitive industry worldwide. For that to be achieved, however, two things are needed: Quality and Reliability.

Quality always sells and in that respect I am very happy to see the new FAMA regulations on beans effectuated recently.

Reliability means performance on contracts on time and quality wise.

I am afraid that here, not unlike what happened in Brazil some 10 years ago a certain crowding out process will take place, leaving only those companies which are sound enough as a business and committed enough to their product and customers to make sure they retain the name of reliable suppliers of quality products.

To finish off, let me give the following answer to your chairman's question whether Malaysia could afford both exporters of beans and convertors in the long run. Keynes used to say "In the long run we are all dead" meaning do not attempt to plan too far ahead. More seriously, I think there is plenty of opportunity for both sides of the industry to co-exist, and as a dealer I feel that the element

of competitiveness it introduces ensures a continued drive for efficiency which can but benefit all.

Your chairman also asked me to contribute at least one brilliant idea for the further development of the Malaysian cocoa industry. To answer him on that point, if I were brilliant at all I would probably be too selfish to share such ideas! More mundane ideas are the following:

Set up a waste/subgrade processing facility amongst the processors.

Give up any ideas of setting up your own rules in the context of a local cocoa organization which run counter to normal international procedures: no-one can go it alone and it would kill your export business.

/rl

GENETIC ANALYSIS OF YIELD CHARACTERS IN SOME HYBRIDS OF COCONUT (COCOS NUCIFERA L.)

J. MEUNIER[1], A. SANGARE[2], J.P. LE SAINT[2]
AND F. BONNOT[3]

[1] Plant Breeding Department and [3] Statistics Department, I.R.H.O. GERDAT, B.P. 5035, 34032 Montpellier Cedex, France

[2] Marc Delorme Coconut Research Station, 07 B.P. 13, Abidjan 07, Ivory Coast

Running head : Genetic analysis of yield characters

Summary : Experiments PB-GC 3 and PB-GC-5, planted on the Marc Delorme Coconut Research Station (Ivory Coast), compared hybrids between Dwarf × Tall and Tall × Tall coconut ecotypes, respectively. These trials confirmed or revealed the high yield potential of some crosses, e.g., MYD × WAT (PB 121), MRD × PYT (PB 132) and WAT × RLT (PB 213). The factorial design of crosses in these experiments (NC II type) enabled us to make a genetic analysis of characters. In GC 5, the effect due to Dwarfs was generally greater than that due to Talls, because of major differences between Malayan Red and Yellow Dwarfs. For Talls, effects were mainly due to differences between West African and Malayan, and between Solomon and Rennell Talls. Heritability estimates were high for copra/nut and for oil weight/nut (correlated with copra), fairly high for number of nuts/ tree, medium for bunch number and very low to nil for copra yield/tree. Estimates for Dwarfs and for Talls were in good agreement.

GENETIC ANALYSIS OF YIELD CHARACTERS IN SOME
HYBRIDS OF COCONUT (COCOS NUCIFERA L.)

J. MEUNIER, A. SANGARE, J.P. LE SAINT AND F. BONNOT

INTRODUCTION

The genetic improvement of a complex character such as yield is always a difficult and costly task for a perennial plant. The length of time between two generations, and the surface area required for any trial make it essential to optimize methods and means. In practice, exploratory methodological trials must necessarily be limited, while any initial error of strategy could devalue the efforts of ten to twenty years.

In coconut, the low multiplication rate provides a further restriction; however, the improvement of this plant is vital for the numerous low-income zones where this crop is traditionally cultivated.

To improve his efficiency, the breeder relies on a good knowledge of the biology of the plant, and on certain "models" (maize, oil palm ...). The evaluation of genetic parameters remains the decisive tool in choosing a method of improvement. Because of the above-mentioned constraints, this type of information is rare for coconut. In this paper we shall present some data obtained from recent trials, which may help in the establishment of strategies for coco-
nut improvement.

MATERIAL AND METHODS

The coconut improvement scheme adopted by the I.R.H.O. includes trials for the evaluation of crosses between eco-types and hybrid improvement trials (Fremond & de Nucé de Lamothe, 1971; Gascon & de Nucé de Lamothe, 1976). Among these trials, we have used the data from three experiments run at the Marc Delorme Coconut Research Station in the Ivory Coast :

- trial PB-GC 5, planted in October 1971, comparing crosses between three Dwarf ecotypes : Malayan Yellow (MYD), Malayan Red (MRD), and Equatorial Guinea Green (EGD), and three Tall ecotypes : West African (WAT), Malayan (MLT), and Polynesian (PYT), with the WAT control. The incomplete block trial includes six replications, with 21 trees per elementary plot.

- Trial PB-GC 3.2, planted in April 1970, comparing crosses of two Tall ecotypes : Rennell (RLT) and Solomon (SNT) with three other Tall ecotypes : WAT, PYT and Mozambique (MZT), in a balanced block with five replications and 30 trees per plot.

- Trial PB-GC 2.1, studying the possibilities of improving a hybrid between two Talls : West African × Mozambique. The trial compares 24 lines with the WAT control using a balanced 5 × 5 lattice design with 9 trees per elementary plot.

Yield and nut composition were recorded using methods that have already been described (Meunier, Rognon & de Nucé de Lamothe, 1977; Wuidart & Rognon, 1978).

The crosses in trials PB-GC 3.2 and PB-GC 5 were made using a factorial model. Genetic variances and heritabilities were therefore estimated using model NC II of Comstock & Robinson (1952). To estimate additive variance (V_A) and dominance variance (V_D), we assumed that the Dwarf parents came from pure lines on account of their autogamy (inbreeding coefficient $F_D = 1$), whereas we assumed that the Talls were not inbred $(F_T = 0)$.

Sigma   Thus, variances due to Dwarfs σ^2_D and to Talls σ^2_T are estimated as $1/2 \, V_A$ and $1/4 \, V_A$, respectively, whereas interaction variances Dwarf $\times$ Tall and Tall $\times$ Tall are estimated as $1/2 \, V_D$ and $1/4 \, V_D$, respectively.

For trial PB-GC 2.1, heritability values were estimated using parent/offspring regressions (Falconer, 1960).

RESULTS

Means

Before studying the genetic parameters of these trials it is interesting to give a general idea of their main characteristics.

In trial PB-GC 3, (Table 1), the high copra/nut transmitted by the Rennell parent (292 g or more) should be noted. Since the WAT × RLT cross also has the advantage of bearing a large number of nuts, this hybrid appears supe-

rior for its total copra production. It is extended under the name of PB 213.

Table 2 gives results for Dwarf × Tall hybrids in trial PB-GC 5. Among these, crosses MYD × WAT (PB 121) and MRD × PYT (PB 132) are also used for seed production.

The WAT control common to both trials enabled environmental differences between the two trials to be accounted for, and the relatively poor performance of the Dwarf × Tall hybrids to be explained.

Variances and heritabilities

Analysis of variance shows that at maturity the effect due to Dwarfs is greater than that due to Talls for all characters except number of bunches, mainly on account of considerable differences between Malayan Red and Yellow Dwarfs (PB-GC 5).

For the Talls in trial PB-GC 3, there are few significant differences; effects are mainly due to the Rennells and Solomons, whose nuts are distinguished by their copra.

Table 3 shows the components of phenotypic variance for yield characters and heritabilities estimated from trials PB GC 3.2 and 5.

These estimates should be considered with caution, since they are subject to major errors, especially in trial PB GC 3.2, on account of the small number of crosses, and the evaluation by approximation of intra-cross variance, which is certainly exaggerated.

Certain indications become clear :

Additive effects are far greater than dominance effects for number of bunches, number of nuts and copra/nut. Only for copra production per tree is dominance significantly greater than additivity.

These results are reflected in the estimation of narrow-sense heritabilities. The heritability of copra/nut is always high (0.4 - 0.8), as is that of weight of oil/nut, which is closely correlated with the weight of copra. The number of nuts/tree (0.2 - 0.6) also appears to be governed by essentially additive factors.

For copra production per tree, the effects of environment appear very important, and heritability low or even nil in the case of Dwarf × Tall hybrids, but not negligible for Tall × Tall hybrids.

Table 4 shows estimated heritabilities in West African × Mozambique crosses (Tall × Tall intrahybrid crosses). It confirms the high heritability of copra/nut and the fairly high heritability of number of nuts and copra production.

DISCUSSION AND CONCLUSION

Genetic components of yield - heritabilities and correlations

The results given above confirm various aspects that were either known or suspected.

The amount of copra in one nut is a highly heritable character. The number of nuts produced per tree is also

heritable, although more or less so according to circumstances.

However, copra production per tree, resulting from the two above-mentioned components, appears slightly or not at all heritable in Dwarf × Tall hybrids : might this difference be linked to the types of planting mateial studied or to different expressions of similar phenomena?

It should be remembered that caution must be used when comparing heritability estimates, since these depend on the material used and on its environment.

A priori, it is not surprising that the product of two heritable components should not, itself, be heritable. For this, it suffices that there should be a negative correlation between the two components. For the Dwarf × Tall hybrids in trial PB-GC 5, there is a correlation of -0.87** between the number of nuts and the copra/nut : these components are inherited in progenies, but the copra yield is the result of the interaction of these components, resulting in its low heritability.

Regarding Talls, the results of trial PB-GC 3 need to be moderated. It is true that the inadequate number of parents and the discrepancy between the nut composition of Rennell and Solomon parents (307 g and 206 g of copra, respectively) are enough to explain difference in yield in the progenies, resulting in apparently high heritability.

For the West African × Mozambique hybrid (PB-GC 2), the medium heritability of copra/tree is due to a strong correlation of this character with the number of nuts per

tree, whose variability in the parents is greater than that of nut composition.

Consequences for improvement - Number of nuts or copra/nut?

Because of their high heritability, the number of nuts and especially the copra/nut will be easy to improve individually by simple mass selection.

However, the interactions of these two components will not enable the yield of hybrids between various ecotypes to be predicted, especially for Dwarf × Tall hybrids. The search for the best hybrids will be performed by producing these hybrids, and evaluating them in comparative trials.

It is nevertheless true that copra yield is often preferentially linked to one component (the most variable) rather than the other. Selection according to this component will lead to improvement of yield. This method will certainly be effective for improving the hybrid once a good cross between two ecotypes has been found. In this case, it will be sufficient to apply a more intensive selection to the variable character in the parents.

It appears that the number of nuts is often the most variable character. In trial PB-GC 2, a simple path coefficient analysis shows that the number of nuts has three times as much influence as copra/nut in determining yield. In other words, this means that it will be easier to improve yield by increasing the number of nuts than by increasing the copra/nut.

This may also be true for the search for high-yielding hybrids between different ecotypes when the variability of two components is not the same. Thus, in trial PB GC 8, which compares crosses between ecotypes with a low or high number of nuts (N^- or N^+), and a low or a high copra content (C^- or C^+), the best copra production is obtained by crossing two ecotypes with many small nuts (Table 5).

We shall not spend any more time on this trial (which will be the subject of other studies), which shows the vital importance of the number of nuts for obtaining a high yield. The size of nut compatible with the planters' local habits, the market conditions and suitable technology would fix the limits of a development of this kind.

REFERENCES

COMSTOCK, R.E. & ROBINSON, H.F. (1952) Estimation of average dominance of genes. In Heterosis, pp. 494-516. Ames : Iowa State College Press.

FALCONER, D.S. (1960) Introduction to Quantitative Genetics, pp. 165-185. New York : The Ronald Press Company.

FREMOND, Y. & NUCE DE LAMOTHE (DE), M. (1971) The coconut improvement block at Port-Bouët. Oléagineux, 26, No. 2, 71-82.

GASCON, J.P. & NUCE DE LAMOTHE (DE), M. (1976) Coconut improvement method and suggestions for international cooperation. Oléagineux, 31, No. 11, 479-482.

MEUNIER, J., ROGNON, F. & NUCE DE LAMOTHE (DE), M. (1977) Analysis of nut components in the coconut. Study of sampling. Oléagineux, 32, No. 1, 9-14.

WUIDART, W. & ROGNON, F. (1978) Analysis of nut components of the coconut. Method of copra determination. Oléagineux, 33, No. 5, 225-233.

TABLE 1 : PB-GC 3.2. TALL x TALL HYBRIDS
ANNUAL RESULTS (MEAN 9 - 11 YEARS)

========================

CROSS	Nº BUNCHES	Nº NUTS/ TREE	COPRA/NUT (a) (g)	COPRA/TREE (kg)
WAT CONTROL	12,7	91	221	20.0
RLT x WAT	13,9	122	313	37.9
RLT x MZT	13.0	104	292	30.4
RLT x PYT	13.6	105	328	34.2
SNT x WAT	13.8	125	238	29.7
SNT x MZT	13.6	123	217	26.4
SNT x PYT	13.5	113	258	29.1

(a) Mean 7 - 11 years for copra/nut

WAT = WEST AFRICAN TALL   RLT = RENNELL   SNT = SOLOMON

MZT = MOZAMBIQUE   PYT = POLYNESIAN

TABLE 2 : PB - GC 5 - DWARF x TALL HYBRIDS

ANNUAL RESULTS (MEAN 9 - 11 YEARS)

============================

CROSS	N° BUNCHES	N° OF NUTS/ TREE	COPRA/NUT(a) (g)	COPRA/TREE (kg)
WAT CONTROL	11.5	55	234	13.0
MYD x PYT	13.4	99	253	25.2
MYD x MLT	13.7	95	260	24.5
MYD x WAT	14.3	104	248	25.6
MRD x PYT	13.7	93	282	26.2
MRD x MLT	13.3	77	291	22.4
MRD x WAT	14.1	86	265	22.7
EGD x PYT	12.6	87	262	22.7
EGD x MLT	13.5	80	288	23.0
EGD x WAT	13.8	88	266	23.5

(a) Mean 6 - 10 years for copra/nut

DWARFS : MYD = MALAYAN YELLOW   MRD = MALAYAN RED
         EGD = EQUATORIAL GUINEA

TALLS : WAT = WEST AFRICAN   MLT = MALAYAN
        PYT = POLYNESIAN

TABLE 3 : ESTIMATED VARIANCES AND HERITABILITIES

IN TRIALS PB - GC 5 AND PB - GC 3

=========================

CHARACTER	AGE OBSERVED	ESTIMATED VARIANCES (GC - 5) (% of V_P)		HERITABILITIES ESTIMATED ON		
		V_A	V_D	DWARF (GC5)	TALL (GC5)	TALL (GC3)
NUMBER OF BUNCHES	5 - 8 yrs 9 - 11 yrs	52 36	5 15	0.12 0.08	0.91 0.65	- 0.11
NUMBER OF NUTS/ TREE	5 - 8 yrs 9 - 11 yrs	40 43	8 1	0.25 0.49	0.56 0.37	0.31 0.14
COPRA/NUT	6 - 10 yrs	74	16	0.70	0.78	0.40
COPRA/TREE	5 - 8 yrs 9 - 11 yrs	9 4	18 17	0.02 0.09	0.17 0	0.36 0.35

VARIATIONS : V_A = additive V_D = dominance V_P = phenotypic

TABLE 4 : ESTIMATED HERITABILITIES IN THE WAT x MZT
IMPROVEMENT TRIAL (PB - GC 2.1, MEAN 9-11 YEARS)

===========================

CHARACTER	HERITABILITY H^2
NUMBER OF BUNCHES	0.13 ∓ 0.12
NUMBER OF NUTS	0.30 ∓ 0.22
COPRA/NUT	0.57 ∓ 0.07
COPRA/TREE	0.27 ∓ 0.23

TABLE 5 = PB - GC 8 - COMBINATION OF CHARACTERS :
NUMBER OF NUTS AND COPRA/NUT

============================

| TYPE OF CROSS | | VALUE OF PROGENIES (9-10 YEARS) | | |
CARACTERISTICS	PARENTS (TALLS)	NUMBER OF NUTS	COPRA/NUT (G)	COPRA/TREE (KG)
N^+C^- x N^+C^-	WAT x NHT	106	211	22.3
N^+C^- x N^-C^+	WAT x PYT	57	275	15.5
	WAT x MLT	53	300	15.8
	NHT x PYT	66	225	14.9
	NHT x MLT	53	246	13.0
N^-C^+ x N^-C^+	PYT x MLT	25	328	8.2
CONTROL	WAT	42	232	9.7

NUMBER OF NUTS : N^+ = HIGH ; N^- = LOW

COPRA/NUT : C^+ = HIGH ; C^- = LOW

(WAT = WEST AFRICAN ; NHT = VANUATU ; MLT = MALAYAN ; PYT = POLYNESIAN).

Recent Advances in Genetic Improvement of Coconut Yield

J. MEUNIER
IRHO Gerdat, France

J. P. LE SAINT
Marc Delorme Coconut Research Station, Abidjan, Ivory Coast.

J. P. GASCON
IRHO Gerdat, France

AND

M. DE NUCE DE LAMOTHE
IRHO Petrarque, Paris, France

The general method for genetic improvement of yield in coconut as adopted by the Institut de Recherches pour les Huiles et Oleagineux (IRHO) has been already described in several articles. It comprises a stage in which genetic variability is accumulated by prospecting and collection, followed by comparative tests of hybrids between different ecotypes to select the best ones, and improvement of these superior hybrids. Multisite performance trials allow an assessment of environmental effects and disease incidence.

As a result of recent advances in modern plant breeding, new methods can now be used for many species. They are particularly attractive when it comes to surmounting the biological constraints limiting coconut improvement. This paper outlines the new strategies developed and the programmes set up in order to produce above-average clones through vegetative propagation by in vitro culture, as well as to obtain new varieties from gamete cell culture through androgenesis and gynogenesis.

Although coconut is a fundamental ingredient of human activity in many intertropical countries, coconut-growing was neglected by research until the beginning of the 20th century, and it was only after the Second World War that rising prices, a mounting fats and oils deficit, and the social and economic importance of the coconut grove really gave rise to proper research programmes, for genetic improvement in particular (Kunhi-krishnan, 1976; Ninan, 1976).

This has been a big handicap for a perennial plant like coconut which requires at least 12–15 years performance evaluation per generation. Nevertheless, 40 years later, expanding research and the application of standard breeding methods have brought about a rich harvest of knowledge and sometimes spectacular results.

The Institut de Recherches pour les Huiles et Oleagineux (IRHO), itself has put a considerable effort into the selection and breeding of varieties capable of raising the "all-purpose tree" to the status of a commercial crop culture.

The methods used by the IRHO have been explained earlier. We feel that this is the time to outline them and bring them up to date, at a moment when the application of new techniques opens up new horizons.

GENERAL

From the **biological** standpoint, the characteristics which concern breeding directly are: the species itself, a bulky, long-cycle perennial monocotyledon; its mode of reproduction, purely sexual, self or cross-pollinated according to variety; the low multiplication rate of this monoecious species; the absence of seed dormancy; the chief product, albumen, of triploid nature.

There have been attempts at varietal classification, but only the distinction between Dwarfs and Talls has remained of practical value. The study of the above characters and of qualitative and quantitative variations in the stem, foliage, inflorescences and fruit has allowed the definition of numerous local or introduced **ecotypes** (Liyanage, 1965; de Nuce de Lamothe & Rognon, 1977; de Nuce de Lamothe & Wuidart, 1979; de Nuce de Lamothe & Wuidart, 1981). The characteristics of these ecotypes can be either very different or similar, without necessarily having any phylogenetic relationships among them.

The first attempts at selection were naturally biased towards improving the copra yield of local populations. The adoption of breeding criteria concerning the appearance of the tree, the number of nuts, copra/nut (Pieris, 1934) led to populations which were much improved for certain characters. However, as Child (1974) wrote, mass selection has proved to be of very limited value in improving yield; a programme of progeny trials is indispensable if any further progress is to be made (Chan, 1982; Liyanage, 1956).

The creation and study of hybrids between ecotypes revolutionised coconut improvement. The earliest Dwarf x Tall crosses made by Patel did not have the practical impact which might have been hoped for, but gradually increasing research led to the unanimous conclusion of the existence of hybrids which gave performances very superior to those of the parental ecotypes (Arasu, *et al.*, 1977; Fremond & de Nuce de Lamothe, 1971; Liyanage, 1956; Liyanage & Azis, 1979; Santos *et al.*, 1982). The Dwarf x Tall hybrids which have been studied most extensively show hybrid vigour in their vegetative characters, precocity and yield. This superiority is also found in some Tall x Tall crosses. The comparison made in *Table 1* between the West African Tall ecotype, considered a good yielder, and four hybrids created by the IRHO, shows the amplitude of the progress made.

From the very beginning the IRHO orientated its coconut improvement programme towards production of high-yielding hybrids by crossing different ecotypes (Fremond & de Nuce de Lamothe, 1971; de Nuce *et al.*, 1980). We will discuss the main lines in the pages which follow.

THE COCONUT IMPROVEMENT PLAN

As described elsewhere (de Nuce de Lamothe *et al.*, 1980; Gascon & de Nuce de Lamothe, 1976); this includes several phases.

TABLE 1.   YIELD OF FOUR SELECTED HYBRIDS COMPARED TO WEST AFRICAN TALL
(MARC DELORME STATION, IVORY COAST)

Hybrid	Yield (t/copra/ha/yr)		Hybrid/WAT (%)	Age observed (years)
	Hybrid	WAT		
PB 121 : MYD x WAT	3.3	1.2	275	5–9
	5.5	2.9	190	11–17
PB 132 : MRD x PYT	3.3	1.2	275	5–9
	3.5	1.8	201	9–11
PB 111 : CRD x WAT	3.9	1.4	279	5–8
PB 213 : WAT x RLT	4.3	2.1	205	5–9
	4.6	2.5	187	9–12

The making-up of collections' contributes to the preservation of germplasm and provides the breeders with the genetic variability indispensable to their work. The 60 ecotypes introduced from the whole intertropical zone of the world to the Marc Delorme Station i form the biggest coconut collection in the world. 28 origins are gathered together in Vanuatu in a collection of great interest to the Pacific. The importance of these gene banks is universally recognised, and for some years national and international bodies have been making an effort to set up basic collections: Brazil, India, Malaysia and the Philippines.

The making of as many hybrids as possible between these ecotypes and their appraisal in comparative trials bring to light the best ones (*Figure 1*). Depending on the means available, priority is given to the making of crosses whose parents seem the most different but with complementary phenotypic characteristics. **94 types of hybrid** between coconuts of diverse origin are being studied at the Marc Delorme and Saraoutou Stations.

At present four best hybrids are tested and extended by the IRHO (*Table 1*) to which should be added the Vanuatu Tall x Rennel Tall, a hybrid reasonably tolerant to the leaf wilt transmitted by *Myndus taffini*. Great interest has also been aroused by the Equatorial Guinea Green Dwarf x Rennell Tall, and Malayan Yellow Dwarf x Rennell Tall, of which the per-hectare yield approaches that of PB 121 and 111, with a better copra/nut, as well as by West African Tall x Vanuatu Tall which, although the nuts are small (210 g copra), produced 230% of the WAT control at nine and 10 years.

The parents which gave the best hybrids are crossed with one another and their progenies are tested again to carry out a second selection cycle (*Figure 2*). The Marc Delorme Station is in this phase of the programme.

At all stages, this selection based on breeding value is combined with a phenotypic choice of parents for heritable characters.

Each of these crosses being a hybrid between two populations of which at least one is variable, we can proceed to improvement of the hybrid itself by selecting within each parent population the individuals giving the best progenies (*Figure 3*). This improvement is all the easier in that the hybrid chosen has a Dwarf parent, and all the more effective in that it has wide variability.

3

Varieties
A   D   F   B   C   H

Choice

Choice c

Hybrid test

Seed garden
A x B
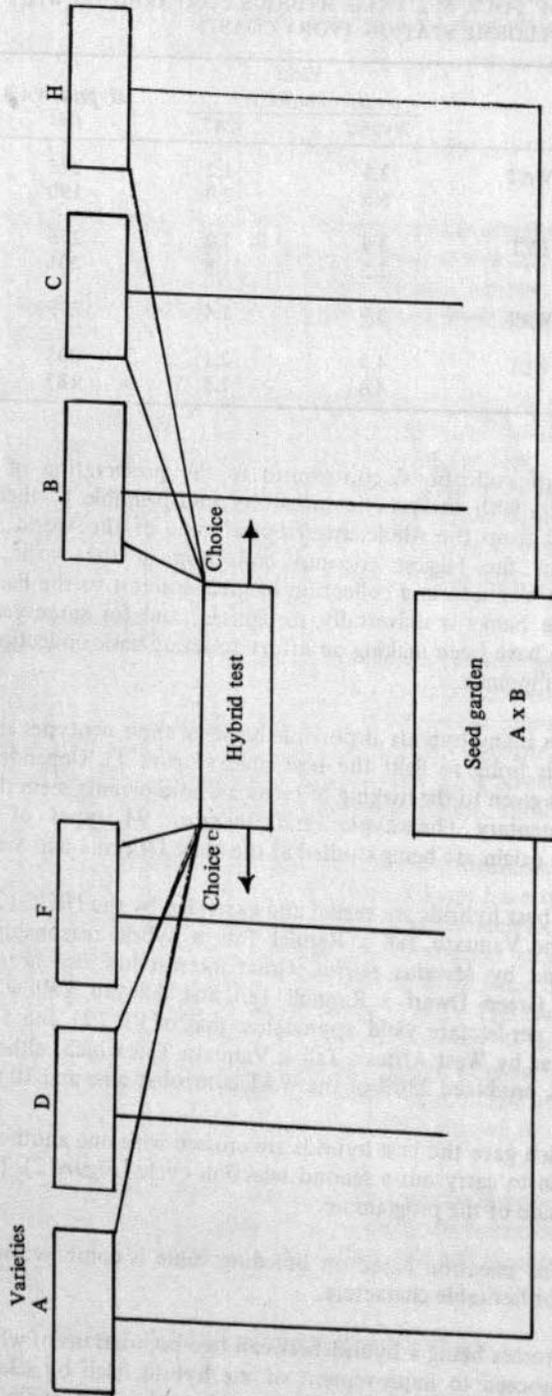
Figure 1. Combining ability between varieties

4
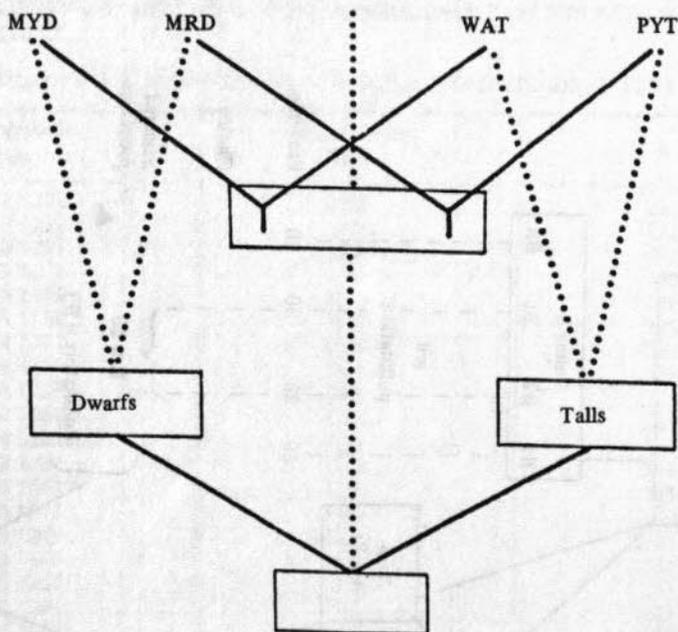
Figure 2. Example of selection recombining the parents of two good hybrids (MYD x WAT and MRD x PYT).

Ten types of hybrid are in stages of improvement at Port Bouet. The first trial leads to a cumulative yield increase at 12 years of 27% through the selection of 17% of the male parents on their combining ability (*Table 2*).

The approaching application of techniques for *in vitro* culture to vegetative propagation of coconut makes it necessary to find exceptional individuals to serve as ortets.

To begin with, such individuals are chosen amongst the best hybrids now in the comparative trials. Later they will be selected in the second cycle trials from crosses issuing from recombinations between the best trees of the first cycle:

(MYD x CRD) x (WAT x RLT)

(MYD x MRD) x (WAT x PYT)

Another possibility is to try and recombine interesting characters by making wide crosses (F_2 in the broad sense) between individuals whose performances are complementary. Amongst the combinations retained are:

(MYD x WAT) x (EGD x RLT), (MRD x RLT) x (WAT x PYT),
(NHT x WAT) x (EDG x RLT)...............

PROGRESS IN KNOWLEDGE AND TECHNIQUES

A certain number of recent advances help to increase the breeder's effectiveness:

TALL x TALL
RECIPROCAL SELECTION

Population A

Palms A
A1   A2   Ai   An

self pollination

20   20   20   20

K x 20
A'i = pollinators

Test B x Ai

Seed garden B x A'i

Progenies
Choice
Selected progenies

Population B

Palms B
B1   B2   Bi   Bn

self pollination

20   20   20   20

K x 20
Pollinators = B'i

Test A x Bi

Seed garden A x B'i

Progenies
Choice
Selected progenies
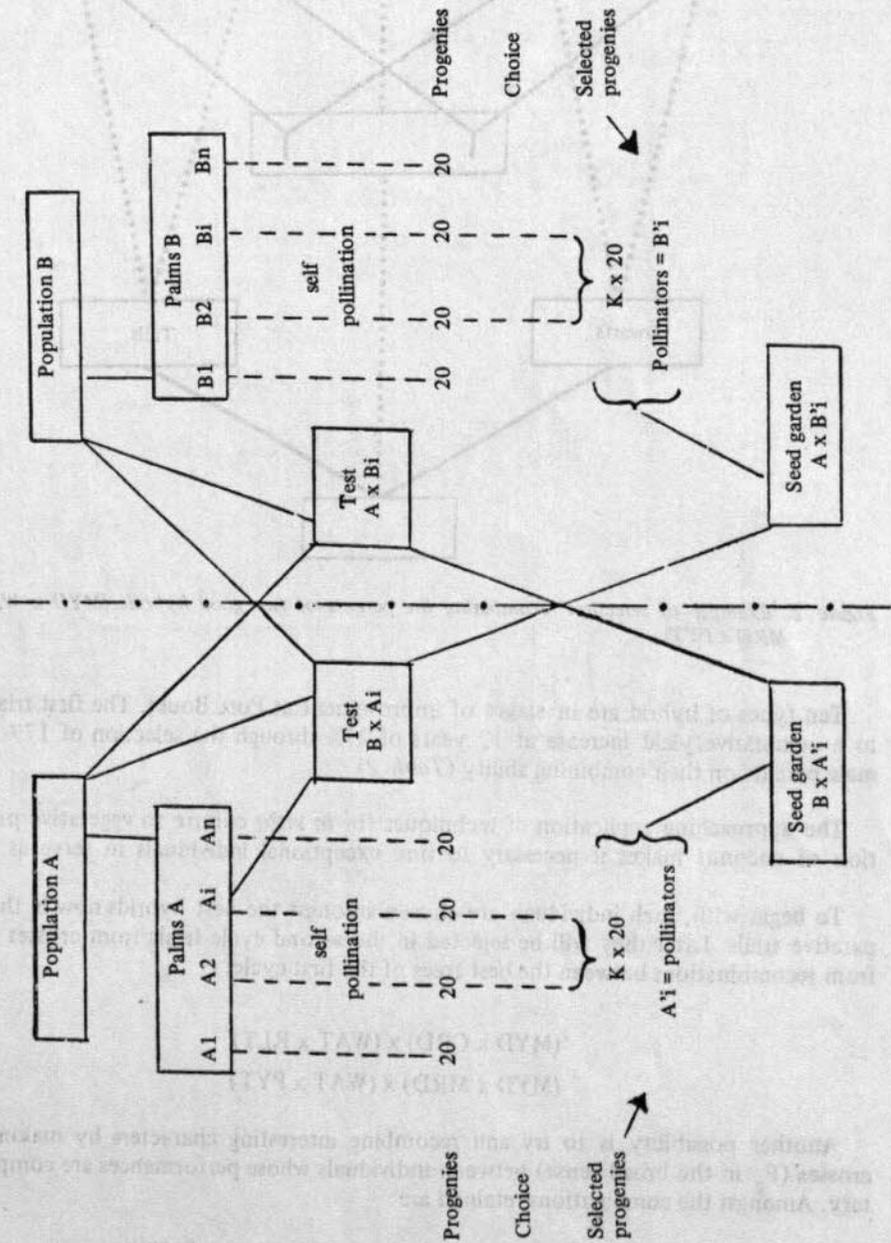
Figure 3: Combining ability of individual palms

TABLE 2. COMBINING APTITUDE OF POLYNESIA TALL PARENTS WITH WEST AFRICAN TALL.

PORT BOUET, IVORY COAST – PB-GC 2.2, MEAN YIELDS, 9–12 YEARS.

Polynesia Parent No.	Copra/tree/year (kg)	%
PB 1251	18.8	232
PB 1252	13.9	172
PB 1253	15.5	192
PB 1254	18.5	228
PB 1255	19.1	235
PB 1256	16.6	205
PB 1257	18.8	232
PB 1258	18.7	230
PB 1259	22.6	279
PB 1260	23.1	285
PB 1261	15.9	196
PB 1262	19.7	243
PB 1263	23.3	288
PB 1264	14.1	173
PB 1265	18.0	221
PB 1266	16.8	206
PB 1267	16.5	203
PB 1268	22.2	274
PB 1269	19.0	234
PB 1270	18.2	224
PB 1271	16.9	209
PB 1272	15.0	181
PB 1273	20.1	249
PB 1274	8.8	109

	kg copra/tree	Theoretical equivalent (t/ha)	%
Overall mean	17.90	2.56	100
Mean of four best[a]	22.83	3.26	127

[a]The difference in yield between the four best parents and the 17 least good is significant at 5%

1. Selection criteria have been narrowed down to fit more precise and diverse aims:

- Increased income per hectare is naturally the final goal, so that copra yield per hectare remains the chief preoccupation, but great importance is also attached to such components as number of nuts and copra/nut, depending on what use is to be made of the products.

- Fruit composition must take account of the effect of the quantity of copra/nut on copra processing costs, and of the proportion of shell and fibre on uptake and immobilisation of mineral elements.

7

- Oil content.

- The number of leaves and their length as well as vertical growth influence the choice of planting densities and associated crops.

- Adaptation to environmental conditions and disease resistance, a factor which is often limiting.

2. Data concerning character inheritance, in particular estimates of heritability and of genetic parameters, are more available (Arasu, 1972; Liyanage & Sakai, 1961; Meunier *et al.*, 1984), making it possible to define selection criteria. The use of planting layouts and crossing plans adapted to perennial plants leads to practical genetic analysis of coconut. Factorial-type crossing plans (NCM II) and particularly of incomplete factorials, seem to us very well suited to coconut.

3. New techniques have expanded the range of tools at the disposal of research workers:

- The genetic determinism of enzyme systems by electrophoresis and its application to the study of genetic variability in coconut populations can offer a guideline for improvement work.

The research of Benoit & Ghesquiere (1984) into 11 enzyme systems, although carried out on a small sample, has shown that there is little enzymatic polymorphism in the coconut. This does not mean that there is no variability, but reflects the waning of the initial variability in certain ecotypes under the action of phenomena such as successive foundation effects or a changeover to self-pollination (genetic drifts). This confirms that priority should be given to inter — rather than intra-ecotype variability. This research is to be pursued in order to analyse as many ecotypes as possible.

Biochemical analyses are used more and more for understanding biological processes. In the oil palm, a yield test to allow early selection, using certain mitochondrial characteristics, has been worked out (Kouame, 1978). Its application to coconut is contemplated.

Of all the new techniques, those concerned with *in vitro* tissue culture promise the greatest number of applications in the short term.

IN VITRO METHODS

Vegetative Multiplication *'In vitro'*

The progress made by several research teams' means that vegetative propagation of coconut can be visualised in the near future (Branton & Blake, 1983; Guzman & Rosario, 1972; Pannetier & Buffard-Morel, 1982). The practical consequences will be important.

The production for plantations of homogeneous, high-yielding material. In fact, the present plantations are populations of trees from crosses between heterozygous parents. Even in selected hybrids of which one parent is a dwarf, there is still far from negligible variability between trees. *Figure 4* represents the distribution of copra/tree for 100 trees of the hybrid PB 121, considered as one of the most homogeneous materials.

8
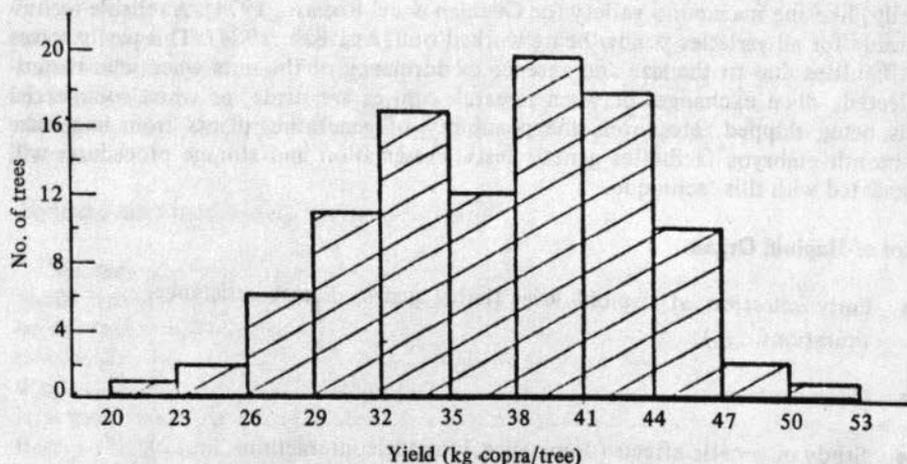
Figure 4: Distribution of copra/tree in a PB 121 population.

This simple example shows that cloning of the 13 best trees would lead, theoretically, to an increase of 24% in individual copra yield (more than 7 t/copra/ha). The improvement would be even more marked in certain Tall x Tall crosses, where the heterogeneity of the two parent populations gives considerable variability to the progeny. Thus, the hybrid WAT x RLT could be expected to yield 30–40% more through cloning of the 10% best trees.

The apparent simplicity of application of this promising technique should not be allowed to mask the difficulties involved in carrying it out.

We think that the working-out of a reliable process of *in vitro* propagation is not the major problem; it is just a question of time and means. On the other hand, the choice of trees to be cloned will always be delicate and require reflection and study. How probable is it that the best tree observed will give the best clone when yield is so greatly influenced by environment? An ortet selection policy should define the number and length of observations in experimental designs assuring the best possible control of the environment and analysis of genetic effects.

Easy vegetative propagation could do away with seed gardens, a relatively cumbersome system, or lead to the creation of seed gardens composed of a few well-defined genotypes.

In plant improvement, new prospects are opened up by the creation of genotype collections *in vitro*, the multiplication of parent plants, the estimate of the effect of environment in the trials, the possibility of distributing a genotype quickly. We have already seen some of the implications at the level of the improvement plan (recombining).

Agronomic research in general benefits from the elimination of genetic differences between individuals in nutrition, density and other trials.

Culture of Zygotic Embryos

Several researchers have succeeded in excising coconut embryos and culturing them *in*

9

vitro. This method allows the raising of plants of which the seed does not germinate naturally, like the macapuno variety (de Guzman & del Rosario, 1974). A reliable technique usable for all varieties is now being worked out (Assi Bah, 1984). This partly solves the difficulties due to the size and absence of dormancy of the nuts when wild material is collected, when exchanges between research centres are made, or when commercial seed is being shipped. Moreover, the possibility of generating plants from immature seven-month embryos facilitates genetic tests. Preservation and storage procedures will be associated with this technique.

Culture of Haploid Organs

- Early selection at haploid level (lethal genes, disease resistance, mutations.......).

- Gene fixation.

- Study of genetic effects (dominance, interallele interactions...........).

- Rapid production of pure lines.

Research into haploid production by gynogenesis and androgenesis has made possible the definition of a certain number of parameters necessary to the development of the male gametophyte; anther culture appears to be a promising way of producing haploids (Montfort, 1984).

Genetic Engineering

Recent advances in research have forged a panoply of more or less sophisticated techniques opening limitless prospects, even if practical applications are still rare. The fallout will not benefit coconut for some while, but the future must be prepared straight away.

Protoplast culture is already being researched (Kovoor, 1981) and genetic engineering in the broad sense should make an important contribution in future; manipulation, transfer and cloning of genes, insertion of agronomically desirable genes, the introduction of foreign genes of disease resistance, all these could play an important part in improving yield. In particular, various coconut diseases are blamed on viroid or mycoplasma-like organisms; their exact identification and the discovery of inactive forms would allow them to be used as **gene vectors**, transforming these scourges into powerful tools of genetic transformation.

DISCUSSION

The expansion of our knowledge of coconut biology, the value and variability of ecotypes, character genetics, leads to effective use of standard improvement methods. By the choice of an appropriate strategy, it has been possible in one generation to create crosses with a copra yield more than double that of the best selected local varieties.

An enormous amount of work remains to be done, since we are far from having exploited all the natural variability of the species or found out the breeding value of different ecotypes.

The ever more complete range of new techniques gives promise of further progress in many fields. Methodologies have been worked out, and advances depend mainly on the means put to work. On the other hand, we think that the definition of the aims of improvement should be the subject of permanent reflection so that the wishes of the growers may be met. Without dealing with all of them, we would like to refer to some of the points which may have caused misunderstandings, and all of which concern the breeder.

Hybrid Coconut or Local Coconut?

We have no doubts about this; the superiority of some hybrids in terms of precocity, yield, performance, in all the environments in which they have been compared and even in the face of certain diseases, is such that it would be condemning the planters to under-production and under-development to deprive them of the fruits of research by dissuading them from planting hybrids (de Nuce de Lamothe, Pomier, & de Taffin, 1983). It is true that at the same time we must be careful to parry any disadvantages resulting from a change of habits (local ecotypes must be safeguarded, for example). Furthermore, homogeneity does not mean uniformity. We have always advised research for the best-adapted hybrids, and even now the IRHO recommends at least four, and others are still to be discovered. Homogeneity does not mean homozygosis, either, and our hybrids are certainly more heterozygotic than many local populations which have undergone strong genetic drifts.

Tall x Tall or Dwarf x Tall hybrids?

Our experience has shown that Tall x Tall crosses as interesting as the best Dwarf x Tall can be found. The first will be better adapted to associated cropping, the second more homogeneous as a pure crop. The choice will depend on socio-economic factors.

Number of nuts or copra/nut?

Both characters correlate negatively, and for the same yield one or other can be privileged. It is certain that copra producers often prefer big nuts, but in some countries such as Brazil, where a large quantity of the nuts is to be used for drinking or home consumption, a large number of medium-sized fruits is preferred. It is also possible that it is easier to improve copra yield by increasing the number of nuts; here again, a choice has to be made, taking account of development and technology.

These few examples show that the breeder can set himself a variety of goals, some of them leading in opposite directions; his choice will have to be made in conjunction with local authorities in charge of development and in function of social and environmental conditions.

REFERENCES

ARASU, N.T. (1972) Coconut improvement in West Malaysia. In *Cocoa and Coconuts in Malaysia* (ed. Wastie & Earp), pp. 302–307. Kuala Lumpur: Incorporated Society of Planters.

ARASU, N.T., VANIALINGAM, T. & CHAN, E. (1977) Interpopulation crosses in coconut improvement. *Malaysian Applied Biology*, 6(2), 181–184.

ASSI BAH, B. (1984) Culture d'embryons zygotiques de *Cocos nucifera*. Internal report, 8 pp.

BENOIT, H. & GHESQUIERE, M. (1984) Electrophorese. Comte rendu cocotier. IV. Determinisme genetique. Internal report, 11 pp.

11

BRANTON, R.L. & BLAKE, J. (1983) Development of organised structures in calluses derived from explants of *Cocos nucifera* L. *Annals of Botany*, 52, 673–678.

CHAN, E. (1982) Progress in coconut breeding in United Plantations Berhad. *Proc. Int. Coconut Conf., Kuala Lumpur, 1982.*

CHILD, R. (1974) *Coconuts.* London: Longmans, 2nd. edtn.

FREMOND, Y. & DE NUCE DE LAMOTHE, M. (1971). The coconut improvement block at Port Bouet. *Oleagineux*, 26(2), 71–82.

FREMOND, Y. & DE NUCE DE LAMOTHE, M. (1971) Caracteristiques et productions du cocotier hybride Nain jaune Malaisie x Grand Ouest Africain. *Oleagineux.* 26(7), 459–464.

GASCON, J.P. & DE NUCE DE LAMOTHE, M. (1976) Amelioration du cocotier. Methodes et suggestions pour une co-operation internationale. *Oleagineux*, 31(11), 479–482.

GUZMAN, DE, E.V. & ROSARIO, DE L., A.G. (1972) Tissue culture, a tool in coconut propagation and varietal improvement. *NIST Wk. Symp., Manila*, 1972.

GUZMAN, DE, E.V. & ROSARIO, DE L., A.G. (1974). The growth and development in soil of Makapuno seedlings cultured *in vitro. NRCP Res. Bull*, 29, (1), 1–16.

KOUAME, B. (1978) Measurement of mitochondrial activity in the oil palm (*E. guineensis* Jacq.). Demonstration of mitochondrial heterosis and comparison of the mitochondrial activity of several hybrids. *Oleagineux*, 33(6), 267–275.

KOVOOR, A. (1981) Palm tissue culture. State of the art and its application to coconut. *FAO Plant Production and Protection*, paper No. 30, 69 pp.

KUNHIKRISHNAN, K. (1976) Sixty-years of coconut research : A resume. *Coconut Bull.*, (Oct/Nov), 9–10.

LE SAINT, J.P., NUCE DE LAMOTHE, M. DE & SANGARE, A. (1983) The dwarf coconuts at Port Bouet, Ivory Coast. II. Sri Lanka Green Dwarf. *Oleagineux*, 38(11), 595–606.

LIYANAGE, D.V. (1956) Intra-specific hybrids in coconuts. I. Preliminary report on crosses between typica and nana varities. *Coconut Res. Inst. (Ceylon) Bull.*, No. 7, 16.

LIYANAGE, D.V. & SAKAI, K.I. (1961) Heritabilities of certain yield characters of coconut palm. *J. Genetics*, 57, 245–252.

LIYANAGE, D.V. & AZIS, H. (1979) Programme underway to develop high-yielding strains of coconut hybrid seed. *Indonesian Agric. Res. Dev. J.*, No. 1/2, 18–20, 25.

NINAN, C.A. (1976) Coconut breeding in India: Achievements, lapses, problems and promises. *Coconut Bull.*, (Oct/Nov), 7–8.

NUCE DE LAMOTHE, M. DE & ROGNON, F. (1977) Les cocotiers nains a Port Bouet. I. Nain jaune Ghana, Nain rouge Malais, Nain vert Guinee Equatoriale, Nain rouge Cameroun. *Oleagineux*, 32 (8–9), 367–375.

NUCE DE LAMOTHE, M. DE & WUIDART, W. (1979) The tall coconuts at Port Bouet (Ivory Coast). I. West African, Mozambique, Polynesia, Malayan. *Oleagineux*, 34(7), 338–349.

NUCE DE LAMOTHE, M. DE, & WUIDART, W. (1981) The tall coconuts at Port Bouet. II. Rennell, Solomon, Thailand, New Hebrides. *Oleagineux*, 36(7), 353–365.

NUCE DE LAMOTHE, M. DE. WUIDART, W. & ROGNON, F. (1980) Review of 12 years of genetic research on coconut in the Ivory Coast. *Oleagineux*, 35(3), 131–144.

NUCE DE LAMOTHE, M. DE, POMIER, M. & DE TAFFIN, G. (1983) Local coconut or hybrid coconut in the village environment. *Oleagineux*, 38(3), 183–191.

PANNETIER, C. & BUFFARD-MOREL, J. (1982) Production of somatic embryos from leaf tissues of coconut, *Cocos nucifera* L. *Proc. 5th. Intl. Cong. Plant tissue and cell culture, Tokyo.*

PIERIS, W.V. (1934) Studies on the coconut palm. I. Morphological characters and standards of selection. *Trop. Agriculturalist, Ceylon,* **82,** 75–97.

SANTOS, G.A., CARPIO, C.B., ILAGAN, M.C., CANO, S.B. & CRUZ, B.V. DE LA (1982) Flowering and early yield performance of four IRHO coconut hybrids in the Philippines. *Oleagineux,* **37(12),** 571–582.

THE EFFECT OF CLIMATIC FACTORS UPON NUT CHARACTERISTICS
OF THE COCONUT PALM (COCOS NUCIFERA, L.)

BY

E.E.J. AKPAN AND I.O. OBISESAN
Nigerian Institute for Oil Palm Research, Benin City, Nigeria.

ABSTRACT

Using stepwise multiple regression and path analyses
individual as well as combined effects of annual rainfall
(RA) annual sunshine hours (SH) annual mean temperature (T)
number of dry days per annum (DD) and annual relative humidity
(RH) were examined on each of eleven traits in the coconut
palm. The traits considered were length, circumference and
weight of nuts (before and after dehusking) percentage shell
and percentage copra to-nut (before and after dehusking) and
percentage oil-to-copra.

Out of the five climatic factors not more than three
contributed substantially to the year to year fluctuations in
any given trait. T, RH and DD were the most important climatic
factors affecting length of nut with direct path coefficients
of 0.6596, 0.6853 and 0.2120 respectively. Only DD and SH
accounted adequately for the variation in the observed
percentage copra - to - nut and oil - to - copra. DD and T
were largely responsible for annual variation in percent shell -
to - nut whereas weight of nut was influenced by RA and SH.

Correlation coefficients and direct path coefficients
bore direct correspondence to each other for majority of the
traits investigated except for the effect of RH on weight of
dehusked nut with correlation coefficience of -0.1812.
The result showed that subtle indirect effects of RH through
other climatic factors were more important upon weight of
dehusked nut than direct effect of RH itself. When possible,
path coefficient analysis should be conducted in addition to
single correlation analysis.

INTRODUCTION

Climatic factors are known to exert a profound influence on the performance of many crop plants. Van, (1974) stated that temperature, relative humidity, solar radiation and water could have a considerable effect on the performance of crops both at the vegetative and reproductive phases. Influence of climatic factors on the yield of some palms of economic importance have been reported by a number of workers. In the oil palm, for instance, Broekmans(1957), Bredas and Scuvie (1960) and Sparnaaij (1963) indicated that rainfall and solar radiation could be implicated for major year to year fluctuations in yield. In recent and more detailed studies, Obisesan (1981) showed that rainfall, sunshine hours, relative humidity, temperature, number of dry days as well as number of thermal units accounted for a substantial year to year fluctuations in yield and its components.

In the coconut palm, Patel (1938) stated that inherent characters, management practices and seasonal effects were the factors which affect yield. Tammes (1937) mentioned that yield was not controlled by flower production or pollination but extensively by nutritional factors especially water supply, and, according to Marar and Pandalai (1957), abortion of spedices was influenced by high temperatures which ultimately led to reduced yield.

Although information is available on the effect of climatic factors on the yield of the coconut palm, there is no information so far on the effect of climatic factors upon the nut character- istics of the crop. This investigation was carried out with the objective of providing such information.

MATERIALS AND METHODS

Ten palms were selected at random from each of the unreplicated progeny rows of Nigerian Tall, Nigerian Dwarf, Cameroon Dwarf, Malayan Dwarf and Tall x Dwarf Coconut palms planted in 1968 at the Main Station of the Nigerian Institute for Oil Palm Research (NIFOR) near Benin City. An average of five nuts harvested at different times of the year, was selected at random for the study and the following data were obtained namely, length, circumference and weight of nuts before and after de-husking. Percentage copra, percentage shell and percentage oil were estimated. Data were collected for a period of five years (1976 - 1980).

Data on annual rainfall (RA), annual sunshine hours (SH), annual relative humidity (RH), annual temperature (T) and annual number of dry days (DD) were obtained from the meteorological station at NIFOR for the period covered by this investigation.

Stepwise multiple regression analysis of each of the eleven nut characteristics on each of the five climatic factors were performed for the pooled data of all the cultivars using the model (Draper and Smith, 1966);

$$Y_{jk} = \mu + \sum_{i=1}^{4} B_{ijk} X_{ijk} + \Sigma_{jk}$$

Y_{jk} = predicted value for trait k ($k = 1-11$) due to the climatic factor j ($j = 1-5$)

μ = predicted overall mean (intercept)

i = values of the climatic factor under consideration for the year of analysis (XO) and the three preceeding years (X-1, X-2, X-3) = 0, -----, 3.

j = total number of climatic factors; $j = 1$, ----, 5

k = number of nut characteristics, $k = 1, 2$---- 11

B_j and X_j = appropriate regression coefficients and means of the climatic factor j, respectively.

In another series of stepwise multiple regression analyses, each of the eleven characteristics (traits) was regressed on all the five climatic factors for the pooled data of all the cultivars using the model:

$$Yk = \mu + \sum_{j=1}^{5} Bjk \, Xjk + \Sigma k$$

Yk = predicted value for trait k due to all climatic factors

K = γ number of traits; k = 1, 2 ......, 11

μ = predicted overall mean

j = total number of climatic factors; j = 1 ......, 5

β and X = appropriate regression coefficients and means of the five climatic factors respectively.

Path coefficient analysis was carried out as outlined by Li, 1981. The eleven traits were considered as resultant variables while climatic factors were regarded as causal variables. The analysis, which is simply a standardized partial regression analysis, was used to decompose phenotypic correlations between each of the eleven traits and a given climatic factor into a direct effect component through that climatic factor and indirect effects through the other climatic factors. Effect coefficient (C) is the sum of direct effect (P) and total indirect effects (I). Residual or non-causal correlation (E) is the coefficient of total correlation (r) minus the effect coefficient (C).

The individual influence (D) of a climatic factor towards the determination of a trait was estimated as (Li, 1981):

$$D = riy \times pyi$$

While the cumulative influence (D^1) of all climatic factor was obtained by summing individual D values:

$$D^1 = \sum_{i=1}^{5} D$$

where

r = correlation coefficient between trait y and climatic factor i (y = 1....11, i = 1...5)

P = direct path coefficient between trait y and climatic factor i.

RESULTS AND DISCUSSION

Rainfall

Annual rainfall recorded one year proceeding harvest was positively and significantly associated with circumference of dehusked nut (Table 1). When the four levels of annual rainfall was considered on each trait, they explained more than 80% of annual variation in circumference of nut, length of dehusked nut, circumference of dehusked nut, percent copra/nut and % oil/copra (Table 1). However, when the combined effects of all five climatic factors were examined on each trait, rainfall alone explained 37% of annual fluctuations in circumference of nut (Table 2). Correlation and path coefficient analyses (Tables 3 - 13) indicated that rainfall had an inverse relationship with traits where it exerted substantial effects. The direct effect of rainfall was greatest on circumference of nuts $P_{xy} = -0.6616$. Its indirect effect through RH and DD were neglible (-0.0292 and 0.0527 respectively).

Sunshine hours

Sunshine hours recorded three years before harvest had a significant positive effect on circumference of dehusked nut (Table 1). The four levels of SH accounted for above 80% of annual fluctuations in circumference of nut, length of dehusked nut, circumference of dehusked nut, percentage copra-to-nut and shell to nut (Table 1). Results of stepwise multiple regression of all climatic factors on a given trait (Table 2) and path analysis (Table 7) showed that SH was the most important determinant of circumference of dehusked nut ($R^2 = 0.89$; $P_{xy} = -0.9923$). The direct effect of SH on copra-to-dehusked nut through DD (0.4614) was greater than its own direct effect (0.2560). Therefore the greater SH, the higher the copra-to-nut percentage.

Temperature

Temperature of the year of harvest was positively and significantly associated with weight of dehusked nut. T explained between 66% and 87% of annual fluctuations in length of nut and weight of dehusked nut respectively (Table 2). Path analysis showed that for these two traits, direct effects of T were 0.6596 and 0.9617 respectively Tables 3 and 8). The direct path coefficient of T on weight of nut (Table 5), length of nut (Table 6), percent copra-to-nut (Table 9), shell to nut (Table 11)) and shell-to-dehusked nut (Table 12) were negative viz -0.6664, -0.0851, -0.3677, -0.8621, -0.7246 respectively. However, the indirect effect of T through the other climatic factor (DD) on shell-to-nut was positive (0.2849).

Number of dry days

The number of dry days three and two years proceeding harvest had significant but opposite effects on percent copra-to-nut (Table 1). That climatic factor, recorded three years before harvest, was positively associated with percent copra-to-nut. However, when the four levels of DD were examined for all traits, DD had substantial effects on each of the

traits with R^2 of between 73% and 99% except length of nut (R^2 = 37%).
Path coefficient analysis showed that the greatest direct effect of DD on
all traits was exoerted on shell-to-nut (P_{xy} = 0.8546; Table 12). Its
direct effect on shell-to-nut was also positive (P_{xy} = 0.6947; Table 11).
The direct path-coefficient of DD on percent copra-to-nut and percent oil
to copra were -0.7984 and -0.7980 respectively. Thus while higher number
of dry days increase shell-to-nut components (Before and after dehusking)
extremely dry years have detrimental effects on copra and oil yields of
the nut.

Relative humidity

This climatic factor, determined three and two years before harvest,
had significant effects on length of dehusked nut (Table 1). Similarly
when the effects of all the five climatic factors were examined on each of
the eleven traits, RH was ranked as the most important climatic factor in
the determination of length of dehusked nut (R^2 = 0.96; Table 1) and circum-
ference of nut (R^2 = 0.61; Table 1). Path coefficient analysis showed that
the direct effects of RH on length of dehusked nut (Table 6), circumference
of nut (Table 4) and length of nut (Table 3) were 0.9672, 0.8659 and 0.6853
respectively. However, the direct effect of RH on percent copra-to-nut was
negative (-0.4577) while its indirect effects through SH and T were also
negative resulting in an effective coefficient of -0.7132 (Table 9).

With the type of measurement taken, the eleven traits could be
classified into four categories:

1. traits relating to size of nut namely length and circumference of
    nuts before and after dehusking.

2. traits relating to nut-weight determination i.e. weight of nuts
    before and after dehusking.

3. percentage copra/nut - before and after dehusking, and percentage
    oil/copra.

4. traits concerned with shell content determination, e.g. % shell/nut -
    before and after dehusking.

The major climatic factors considered important in the first category were
T, HH and SH. In the second group T, RA and SH were critical climatic
factors. The traits in the second category have direct bearing on the nut
yield since nut yield is a product of number of nuts and weight of nuts.
T, RA and SH could account for the year to year fluctuations in yield in
coconut. Such an observation had been made in the oil palm (Sparnaaij, 1963).
DD and SH were very important in the determination of traits classified
under the third category while DD and T played significant roles in
shell-to-nut components. In an earlier work on oil palm, Obisesan (1981)
observed that T was an important climatic factor affecting shell component
and the present trend in the coconut with regard to shell content seemed
to be in agreement with the observation in oil palm

Out of the five climatic factors not more than three contributed substantially to the determination of any given trait. For example, T, RH and DD were the three most important climatic factors which affected length of nut while RH, RA and DD were the three climatic factors that modified the circumference of nut (Tables 3 and 4). In the two climatic factors situation, using direct path coefficients as criteria, DD and SH were the two climatic factors of importance in percent copra-to-nut and percent oil-to-copra determination (Tables 10 and 13) while T and DD were critical in percent shell-to-nut determinations (Tables 11 and 12). For the two traits, the direct effect of DD was positive while that of T was negative.

The study indicates that the results of stepwise multiple regression and path analyses for most of the trait/climatic factor associations corroborated one another. However the advantage of path analysis over simple correlation coefficients and stepwise multiple regression analysis is that path analysis allows the researcher to quantify the cause effect relationships of climatic factors with each of the traits studied. For example correlation analysis alone showed that correlation coefficient between RH (cause) and length of dehusked nut (effect) was 0.9988 (Table 6) and the R^2 obtained from multiple regression analysis (Table 2) was shown to be 0.96. The corresponding D- value of RH on this trait was also 0.96 (Table 6). The correlation coefficient between D and R^2 values for all traits were highly significant (P<0.01). Path analysis showed that the magnitude of the direct effect was 0.9672, while indirect effects through SH and T were 0.0110 and 0.0502 respectively both of which were negligible. In order situations, there may be a wide disparity between correlation coefficients and direct path coefficients. The correlation coefficient between RH and weight of dehusked nut was 0.8365 while the direct path coefficient of RH on weight of dehusked nut was -0.1812. Simple correlation analysis thus indicated RH as an important climatic factor influencing weight of dehusked nut. However, path coefficient analysis suggested that RH had no direct influence on weight of dehusked but had indirect influence through T (0.8704) and through RA (0.1473). These indirect effects, although subtle, are quite substantial. Bhatt (1972) reported a similar situation among yield components in wheat. The apparent contradiction in this instance is due to the fact that correlation coefficients simply measure mutual associations without regard to causation, whereas the path coefficient analysis specifies causes and measures their relative importance.

REFERENCES

Bhatt, G.M. 1973. Significance of path coefficient analysis in determining the nature of character association. Euphytica 22: 338-343

Bredas, J. and Scuvie, L. 1960. Apercu de influences climatiques sui les cycles du production du palmier a huile. Oleagineux 15: 211-222

Broekmans, A.F.M. 1957. Growth, flowering and yield of the oil palm in Nigeria. J.W. Afr. Inst. Oil Palm Res. 4: 109-111

Li, C.C. 1981 Path analysis - a primer. The Boxwood Press, California. pp 100-134

Marar, M.M.K. and Pandalai, K.M. 1957. Influence of weather factors on coconut crop. Indian J. Geophys. 8: 60

Obisesan, I.O. 1981. Evaluation of yield and associated traits in some hybrids of oil palm. Ph.D. Thesis Unife (unpublished) pp 220.

Patel, J.S. 1938. The coconut - a monograph - Madras Govt. Press pp. 124.

Tammes, P.M.L. 1937. Factors determining yield of coconut palms. Landbouw 13: 260-269.

Van, T.K. 1974. The effect of climate on rice yields in Malaysia. Malay. Agric. J. 49: 296-301.

Drapper, N.R. and H. Smith 1966. Applied Regression Analysis. John Wiley and Sons Inc. New York, London, Sydney.

Table 1:   Correlation coefficients (r-values) between eleven traits and climatic factors for each of 4 years.

Traits	CLIMATIC					FACTORS									
	Rainfall					Sunshine hours					Temperature				
	X-3	X-2	X-1	XO	R^2	X-3	X-2	X-1	XO	R^2	X-3	X-2	X-1	XO	R^2
1	-0.2106	-0.08	0.19	0.30	0.12	0.08	-0.35	0.67	-0.30	0.96	0.81	0.37	-0.63	-0.47	0.98
2	-0.64	0.18	0.28	0.55	0.80	0.08	-0.08	0.48	0.12	0.81	0.56	0.46	0.11	-0.27	0.74
3	0.35	-0.58	-0.07	0.33	0.36	0.07	-0.70	0.66	-0.15	0.99	0.44	0.48	-0.82	-0.35	0.99
4	0.62	-0.70	-0.04	-0.06	0.98	-0.30	-0.35	0.28	-0.24	0.62	-0.10	0.13	-0.62	0.24	0.99
5	-0.42	-0.39	0.87	0.18	0.99	0.94**	0.33	0.73	-0.56	0.98	0.50	0.31	-0.26	0.71	0.99
6	-0.15	0.52	0.47		0.70	-0.80	0.12	0.45	0.12	0.95	-0.25	0.52	0.31	0.93**	0.98
7	0.37	-0.65	0.52	0.47	0.70	0.14	0.33	-0.89*	0.13	0.99	-0.73	-0.65	0.40	0.18	0.99
8	-0.82	0.27	-0.37	-0.60	0.46	-0.06	0.72	0.13	-0.37	0.97	0.52	-0.38	0.29	-0.08	0.96
9	0.62	0.85	0.45	-0.27	0.99	-0.48	0.08	-0.86	-0.09	0.96	-0.47	-0.82	-0.12	-0.32	0.94
10	-0.24	0.36	-0.62	-0.82	0.96	0.28	0.01	0.19	-0.55	0.88	0.83	-0.23	-0.61	-0.67	0.99
11	0.81	0.46	0.09	-0.26	0.22	0.39	-0.59	-0.03	-0.19	0.96	0.02	-0.15	-0.84	-0.52	0.99
	-0.31	-0.53	-0.29	0.74											

*,** = significant at .05 and 0.01 levels of probability respectively.

XO, X-1, X-2, X-3 = climatic factor during the current and the three preeding years respectively.

*,** = significantly at 0.05 and 0.01 levels of probability respectively.

Data were collected for only 5 years n.". = 5 for table 1.

Table 1 cont.

Traits	CLIMATIC					FACTORS				
	Dry days					Relative Humidity				
	X-3	X-2	X-1	X0	R²	X-3	X-2	X-1	X0	R²
1	00.05	-0.20	-0.12	-0.22	0.58	-0.07	0.14	-0.43	0.67	0.50
2	0.36	-0.48	-0.12	-0.69	0.93	0.68	0.70	-0.54	0.79	0.89
3	-0.51	0.41	-0.03	0.06	0.92	0.52	-0.16	0.49		0.85
4	-0.81	0.79	-0.20	0.40	0.99	0.99**	-0.98**	0.56	-0.36	0.99
5	-0.42	0.27	0.96	-0.01	0.98	0.46	-0.55	0.78	-0.34	0.76
6	-0.69	0.65	-0.71	-0.33	0.93	0.43	-0.53	0.84	0.035	0.90
7	0.12	0.05	0.34	0.52	0.37	0.10	-0.13	0.26	-0.71	0.69
8	0.89**	-0.95	-0.18	-0.02	0.99	-0.80	0.74	-0.25	0.01	0.76
9	0.21	-0.05	0.62	0.80	0.99	0.21	-0.17	-0.06	-0.53	0.90
10	0.53	-0.63	0.10	0.22	0.87	-0.27	0.33	-0.55	0.38	0.31
11	-0.36	0.39	0.42	0.54	0.73	0.67	-0.57	-0.15	0.03	0.98

** = significant at 0.01 level of probability.

1 = Length of nut (cm); 2 = Circumference of nut (cm); 3 = Wt. of nut (g); 4 = Length of dehusked nut (cm); 5.= Circumference of dehusked nut (cm); 6 = Wt. of dehusked nut (g); 7 = % copra/nut (unhusked); 8 = % copra/nut (dehusked); 9 = % shell/nut (unhusked); 10 = % shell/nut (dehusked);

11 = % oil/copra.

Table 2: Order of selection of climatic factors in stepwise multiple regression of different traits on climatic factors.

Trait	CLIMATIC		FACTORS			
	RA	SH	T	DD	RH	R^2
1	–	–	1 (0.66)	3 (0.02)	2 (0.27)	0.99
2	2 (0.37)	–	–	3 (0.01)	1 (0.61)	0.99
3	–	3 (0.04)	2 (0.19)	1 (0.67)	–	0.91
4	–	2 (0.02)	3 (0.01)	–	1 (0.96)	0.99
5	3 (0.02)	1 (0.89)	–	2 (0.08)	–	0.99
6	2 (0.12)	–	1 (0.87)	–	3 (0.01)	0.99
7	–	1 (0.73)	3 (0.09)	–	2 (0.17)	0.99
8	3 (0.04)	2 (0.05)	–	1 (0.89)	–	0.98
9	–	3 (0.24)	1 (0.33)	2 (0.40)	–	0.97
10	–	3 (0.25)	2 (0.35)	1 (0.36)	–	0.96
11	3 (0.02)	2 (0.08)	–	1 (0.82)	–	0.92

1.....3 = order in which climatic factors enter the stepwise multiple regression equation. Additional R^2 value contributed by a climatic factor is shown in parenthesis.

Table 3: Summary of direct (diagonal), total indirect (I), residual effects (E), D – and R² values of climatic factors on Length of Nut.

	T	RH	DD	I	C	E	D	R²
T	0.6596 (0.8137)+	0.1410	0.0131	0.1541	0.8137	0.0000	0.5367	0.6621
RH	0.1357	0.6853 (0.6733)	-0.1478	-0.0121	0.6732	0.0000	0.4614	0.2672
DD	0.0408	-0.4777	0.2120 (-0.2248)	0.4369	-0.2249	0.0001	0.0477	0.0211

Table 4: Summary of direct (diagonal), total indirect (I) residual effects (E), D – and R² values of climatic factors on Circumference of Nut.

	RH	RA	DD	I	C	E	D	R²
RH	0.8659 (0.7853)+	0.0223	0.1029	-0.0896	0.7853	0.0000	0.6800	0.6166
RA	-0.0292	-0.6616 (-0.6381)	0.0527	0.0235	-0.6381	0.0000	0.4222	0.3746
DD	-0.6035	-0.2361	0.1476 (-0.6919)	-0.8396	-0.6920	0.0001	-0.1021	0.0088

R² = coefficient of determination values obtained from stepwise multiple regression equation.

+ = figures in parenthesis are correlation coefficients between a climatic factor and a given trait.

Table 5: Summary of direct (diagonal), total indirect (I) residual effects (E), D – and R² values of climatic factors on Weight of Nut.

	T	SH	RA	I	C	E	D	R²
T	-0.6664 (-0.8242)+	0.1098	-0.1381	-0.2479	-0.9143	0.0901	0.5492	0.6794
SH	-0.2258	-0.3240 (-0.6992)	-0.1494	-0.3752	-0.6992	0.0000	0.2265	0.1991
RA	-0.1381	-0.2089	-0.2316 (-0.5786)	-0.3470	-0.5786	0.0000	0.1340 / 0.9097	0.0313 / 0.9099

Table 6: Summary of direct (diagonal), total indirect (I) residual effects (E), D – and R² values of climatic factors on Length of dehusked nut.

	RH	SH	T	I	C	E	D	R²
RH	0.9672 (0.9988)+	0.0110	0.0502	0.0612	1.0284	-0.0296	0.9660	0.9976
SH	-0.2993	-0.0354 (-0.3465)	-0.0284	-0.3277	-0.3631	0.0166	0.0123	0.0016
T	-0.5702	-0.0118	-0.0851 (-0.6172)	-0.5820	-0.6671	0.0500	0.0525 / 1.0303	0.0008 / 0.9999

Table 7: Summary of direct (diagonal), total indirect (I) residual effects (E), D - and R² values of climatic factors on Circumference of dehusked nut

	SH	I	C	E	D	R²
SH	$\underline{-0.9923}$ (-0.9816)+	0	-0.9923	0.0107	0.9740	0.89691

Table 8: Summary of direct (diagonal), total indirect (I) residual effects (E), D - and R² values of climatic factors on Weight of dehusked nut

	RA	RH	I	C	E	D	R²
T	$\underline{0.9617}$ (0.9319)+	0.1342	-0.1640	-0.0298	0.9319	0.0000	0.8962	0.8685
RA	-0.3306	$\underline{-0.3903}$ (-0.6526)	0.0684	-0.2622	-0.6525	0.0001	0.2547	0.1252
RH	0.8704	0.1473	$\underline{-0.1812}$ (0.8365)	1.0177	0.8365	0.0000	$\underline{-0.1516}$ 0.9993	$\underline{0.0058}$ 0.9995

Table 9: Summary of direct (diagonal), total indirect (I) residual effects (E), D - and R² values of climatic factors on % copra - to fruit.

	SH	RH	T	I	C	E	D	R²
SH	$\underline{-0.4707}$ (-0.8578)+	-0.1749	-0.2122	-0.3871	-0.8578	0.0000	0.4038	0.7358
RH	-0.1799	$\underline{-0.4577}$ (-0.7132)	-0.0756	-0.2555	-0.7132	0.0001	0.3264	0.1739
T	-0.2716	-0.0941	$\underline{-0.3677}$ -0.7335	-0.3652	-0.7334	-0.0001	$\underline{0.2697}$ 0.9999	$\underline{0.0901}$ 0.9999

Table 10: Summary of direct (diagonal), total indirect (I) residual effects (E), D - and R² values of climatic factors on % copra - to nut.

	SH	I	C	E	D	R²
DD	$\underline{-0.7984}$ (-0.9463)+	-0.1479	-0.1479	-0.9463	0.0000	0.7555	0.8955
SH	0.4614	$\underline{0.2560}$ (0.7174)	0.4614	0.7174	0.0000	$\underline{0.1837}$ 0.9392	$\underline{0.0437}$ 0.9392

Table 11: Summary of direct (diagonal), total indirect (I) residual effects (E), D - and R² values of climatic factors on shell/fruit.

	DD	I	C	E	D	R²
T	$\underline{-0.8621}$ (-0.5772)+	0.2849	0.2849	-0.5772	0.0000	0.4976	0.3331
DD	-0.3535	$\underline{0.6947}$ (0.3412)	-0.3535	0.3412	9.0000	$\underline{0.2370}$ 0.7346	$\underline{0.4011}$ 0.7342

Table 12: Summary of direct (diagonal), total indirect (I) residual effects (E), D - and R^2 values of climate factors on shell to nut.

S_n	DD	T	I	C	E	D	R^2
DD	0.8546 (0.5661)+	−0.2885	−0.2885	0.5661	0.0000	0.4838	0.3604
T	0.3390	−0.7246 (−0.3856)	0.3390	−0.3856	0.0000	0.2794 0.7632	0.3521 0.7125

Table 13: Summary of direct (diagonal), total indirect (I) residual effects (E), D - and R^2 values of climate factors on % oil to copra.

	DD	SH	I	C	E	D	R^2
DD	−0.7980 (−0.9460)+	−0.1480	−0.1480	−0.9460	0.0000	0.7550	0.8194
SH	0.4618	0.2562 (0.7174)	0.4618	0.7180	0.0006	0.1838 0.9388	0.0799 0.8993

Comparison of Precocity and Yield of Hybrid Coconut Varieties in Thailand

MALIWAN RATTANAPRUK, J.C. HOWL, ANUPAP THIRAKUL,
CHULAPHAN PETCHPIROON AND J. DOOTSON
Horticultural Research Institute, Bangkok, Thailand

A trial comparing hybrid coconut varieties with local Thai Tall palms was established at Sawi Horticultural Research Centre in 1975, with the aim of finding a higher yielding variety, with greater precocity than the Thai Tall, for use in enhancing national coconut production. Four hybrids were imported from I.R.H.O. in the Ivory Coast in 1974 and planted in the field with selected Thai Tall as control.

Preliminary results suggest that MYD x WAT is the most precocious and has the highest early yield, with the Thai Tall x WAT hybrid ranking second for yield. The local Tall yielded the least, principally through the absence of any marked precocity.

Coconut is a major economic crop in Thailand, playing an important role in the Thai diet. Unlike most other countries in the region Thailand has no history of plantation agri-culture, and coconuts are grown mainly by smallholders. The area under coconuts is estimated at 390,880 ha (Office of Agricultural Economics, 1983).

The Thai Tall (THT) is characterized by palms bearing a small number of large nuts, with thin husk, high water content and a relatively low percentage of albumen in the nut. The average yield from the THT palm is low at 20–25 nuts per palm (Office of Agri-cultural Economics, 1983), although individual palms may give from 60–90 nuts. The yield at maturity rarely exceeds 1.5–2.0 tonnes copra per hectare. The THT palms on average do not start bearing before the sixth year after planting, and in poorly maintained plantations may not reach full bearing for 9–15 years.

Despite the highly heterogeneous nature of the local THT population, it has not proved practical to improve the THT by mass selection, and it is hoped to increase coconut yields by the wide-scale planting of high-yielding hybrids, such as the P.B. 121, Malaysian Yellow Dwarf x West African Tall. Frémond and de Nuce de Lamothe (1971) reported that in the Ivory Coast this hybrid yielded 4 tonnes copra per hectare seven to eight years after planting, rising to 6 tonnes per hectare at full maturity (de Nuce de Lamothe & Rognon, 1975).

Many of the Dwarf x Tall hybrids tested by IRHO in the Ivory Coast and elsewhere, have given high yields out-performing most local tall varieties (Sangare *et al.*, 1983). As the success of individual hybrids varied with the soil and climatic conditions, a hybrid variety trial was established at Sawi Horticultural Research Centre to compare a selection of exotic hybrids with the local THT.

MATERIALS AND METHODS

Seednuts of four hybrid varieties were imported from IRHO in 1974, and the seedlings were planted in June 1975 together with selected Thai Tall seedlings of a similar age. The trial was conducted at Sawi Horticultural Research Centre in Chumphon Province, Thailand. The soil is of the Chumphon Series; a sandy loam with low organic matter and available nutrient content, capability sub-class for upland crops UVIe in an eight-group classification, where UVIII denotes a soil which does not produce economic returns in agriculture or forestry (Soil Survey Division, 1972).

The design is a Youden Square (Incomplete Latin Square) with four replicates and five treatments. Net plots were of 20 palms with inter-block guards of mixed varieties. Spacing was 9 m triangular (142.5 points/ha). Fertilizer was applied in May and October as 2 equal splits, at the rates given in *Table 1*. A mixed cover-crop was established.

TABLE 1. ANNUAL FERTILIZER APPLICATION RATES

Fertilizer	Fertilizer application (kg/palm/year)				Final rate of nutrient (kg)	
	Year 1	Year 2	Year 3	Year 4+		
Ammonium sulphate	0.2	0.8	1.2	1.5	0.32	(as N)
Triple superphosphate	0.2	0.8	1.0	1.0	0.44	(as P_2O_5)
Potassium chloride	0.5	1.5	2.0	2.5	1.5	(as K_2O)
Kieserite	0.3	0.9	1.2	1.5	0.39	(as MgO)

Treatments were as follows:—

1. Thai Tall (THT)
2. Tahiti Tall x West African Tall (TAT x WAT)
3. Thai Tall x West African Tall (THT x WAT)
4. Malaysian Red Dwarf x Tahiti Tall (MRD x TAT)
5. Malaysian Yellow Dwarf x West African Tall (MYD x WAT)

RESULTS AND DISCUSSION

Precocity

All four hybrids were observed to flower considerably earlier than the local THT, as shown in *Table 2*. The inherited precocity of the Dwarf parent was anticipated and consistent, with both the Dwarf x Tall hybrids, MYD x WAT and MRD x TAT attaining 50% flowering in 44—45 months from planting, intermediate between their respective parents. The two Tall x Tall hybrids reached 50% flowering in 57 months, earlier than the parents of either. THT reached 50% flowering in 70 months (*Table 2*) and under IRHO conditions WAT and TAT reached 50% flowering in 64—66 and 66—70 months after planting, respectively (de Nuce de Lamothe & Wuidart, 1979).

TABLE 2. AGE AT 50% FLOWERING

Variety	Months from planting
THT	70
TAT x WAT	57
THT x WAT	57
MRD x TAT	45
MYD x WAT	44

Yield

As expected, the hybrids all outyielded the local Tall, although the early yield data may be misleading as it is influenced by the precocity of flowering. This is reflected in *Table 3*, which gives the early yields of the five varieties, and shows both Dwarf x Tall hybrids outyielding the other varieties in the first two years of bearing. By the seventh year the less precocious THT x WAT ranked second, outyielding the earlier bearing MRD x TAT, and the other Tall x Tall hybrid, TAT x WAT. The data on nuts per palm and nuts per bearing palm (*Table 4*) further illustrate the effect of precocity on early yield, and demonstrate more clearly the potential yield of the hybrids and the limitations of the local THT.

TABLE 3. YIELDS OF COPRA PER HECTARE IN YEARS FIVE TO EIGHT FROM PLANTING

Variety	Yield (kg copra/ha/year)			
	Year 5	Year 6	Year 7	Year 8
THT	10.62^a	92.16^c	266.79	859.61
TAT x WAT	0^a	164.58^{bc}	793.96^a	1744.03^b
THT x WAT	49.40^a	410.49^{ab}	1198.04^a	2131.63^{ab}
MRD x TAT	172.63	566.59^a	996.18^a	1860.99^{ab}
MYD x WAT	289.74	1105.80	1608.60	2533.36^a
S.E.	31.01	86.03	126.30	206.14

a, b, c Denote significance; varieties with the same letter do not differ significantly at the 5% level using Duncan's Multiple Range Test.

The anticipated vigour of the hybrids involving TAT was not realized with MRD x TAT yielding over 35% less than the corresponding Dwarf x Tall, MYD x WAT, and the TAT x WAT yielding over 30% less than the corresponding Tall x Tall, THT x WAT, in the seventh year. The differences within these hybrid pairs had narrowed by the eight year and may be reduced further when the palms are fully mature. The lack of vigour of these hybrids was unexpected, particularly for the MRD x TAT which is one of IRHO's most promising hybrids, outyielded only by the MYD x WAT, at Port Bouet (Anon, 1977). It may be due to the unsuitable soil and climatic conditions for this hybrid at the Sawi Horticultural Research Centre (S.H.R.C.), but this could only be confirmed by

3

TABLE 4. COMPONENTS OF YIELD FIVE TO EIGHT YEARS FROM PLANTING

Variety	No. nuts/palm	No. nuts/bearing palm	Mean wt. copra/nut (g)	Mean wt. copra/palm (kg)
		YEAR 5		
THT	0.19^a	4.21^{cd}		0.07^a
TAT x WAT	0^a	0^d		0^a
THT x WAT	1.70^a	18.04^a		0.35^a
MRD x TAT	5.26	9.43^{bc}		1.21
MYD x WAT	10.21	16.75^{ab}		2.03
S.E.	1.04	2.49		0.22
		YEAR 6		
THT	2.03^c	8.96^c	337	0.65^c
THT x WAT	4.56^{bc}	11.34^{bc}	249	1.15^{bc}
MRD x TAT	10.55^{ab}	16.96^{ab}	268	2.88^{ab}
MRD x TAT	16.30^a	20.36^a	248	3.97^a
MYD x WAT	36.42	39.23	214	7.76
S.E.	2.14	2.16		0.60
		YEAR 7		
THT	5.89	15.11	323	1.87
TAT x WAT	22.70^a	31.68^a	244	5.57^a
THT x WAT	32.08^a	38.58^a	267	8.40^a
MRD x TAT	27.92^a	30.74^a	249	6.99^a
MYD x WAT	51.68	63.43	198	11.28
S.E.	3.53	2.77		0.89
		YEAR 8		
THT	18.68	26.16	317	6.03
TAT x WAT	50.76^a	55.94^a	243	12.23^b
THT x WAT	53.70^a	54.23^a	284	14.95^{ab}
MRD x TAT	51.79^a	52.84^a	251	13.05^{ab}
MYD x WAT	77.08	78.04	232	17.77^a
S.E.	4.99	4.90		1.45

a, b, c Denote significance; varieties with the same letter do not differ significantly at the 5% level using Duncan's Multiple Range Test.

replicating the trial at other sites in Thailand. Unfortunately there are no TAT palms in the Thai varietal collection; hence observation of the vigour of the TAT parent under local conditions is not possible.

· As widely observed elsewhere, the MYD x WAT out-performed the other hybrids, giving a consistently high yield, although by the eighth year the yield of copra/palm was no longer significantly higher than that of THT x WAT and MRD x WAT. This lack of significance is partly due to the highly variable nature of the soil which gives a high level of error variation. The superiority of the MYD x WAT may be due to its uniformity and the consistency of its yield, as both parents are derived from relatively homogeneous populations.

4

The high yield of the MYD x WAT is due to its very high nut production as the actual copra/nut is the lowest of the varieties tested (*Table 4*). The components of yield differ markedly between varieties, with the MYD x WAT at one extreme with its high yield of very small nuts (c. 215 g copra/nut) compared with the low yield of very large nut (c. 325 g copra/nut) of the Thai Tall variety at the other extreme. The other varieties are intermediate for nuts/palm, copra/nut and copra/palm. The THT x WAT appears to give the highest number of nuts/palm, the highest weight of copra/nut and consequently the highest weight of copra/palm as compared to the other three hybrids; although at this stage the differences are not statistically significant.

Fruit Component Analysis

Table 5 gives the fruit weight and the fruit component percentages of the five varieties. It can be seen that the MYD x WAT fruit is almost half the size of the THT fruit, and as the Thai consumer is accustomed to the larger fruit of the THT, there has been considerable resistance when the hybrid is sold on the fresh market (Hensey, 1984). The small fruit size of the MYD x WAT hybrid is at a further disadvantage when considering handling and dehusking operations.

TABLE 5. FRUIT COMPONENT CHARACTERISTICS

Variety	Sample size	Whole fruit weight (g)	Husk (%)	Nut component percentage			
				Water	Shell	Meat	Copra
THT	55	2173.48	32.65	40.6	17.76	41.64	22.02
TAT x WAT	77	1448.69	39.91	30.33	21.74	47.93	29.8
THT x WAT	238	1596.26	39.61	33.32	20.38	46.3	27.14
MRD x TAT	197	1485.73	32.71	35.7	17.17	47.13	25.32
MYD x WAT	297	1133.28	42.21	29.1	20.1	50.8	29.82

The THT x WAT hybrid has the largest fruit of the four hybrids as well as the highest weight of copra/nut. As the fruit is visually similar to a medium size THT, this hybrid is likely to be more acceptable than MYD x WAT, as an alternative to THT.

The made-up of the individual fruits is illustrated by the fruit component analyses in *Table 5*. Besides having the smallest fruit size, MYD x WAT also has the highest percentage of husk/fruit, but this is compensated for by the highest percentage of copra/nut. Conversely, THT has the lowest percentage of husk and the lowest percentage of copra, although this is also the greatest actual weight of copra/nut. Interestingly the ranking for percentage of husk is the same as the ranking for percentage of copra in each case.

CONCLUSION

The MYD x WAT hybrid has proved to be the most precocious and high-yielding of the varieties tested, although the yield of 2.5 tonnes copra per hectare is low compared with the 4 tonnes copra per hectare reported by I.R.H.O. for MYD x WAT at 8 years (de Nuce de Lamothe & Rognon, 1975). This can probably be attributed to the very poor soil conditions at Sawi Horticultural Research Centre, and it seems unlikely that the potential

of this hybrid can be maximised on poor soils. The small fruit size of MYD x WAT will act against its promotion for the Thai fresh nut market, but as the copra yield is so much greater than that of any of the other varieties tested, it would appear the most suitable planting material for the larger farms and industrial plantations, where coconut for copra alone is grown.

Most smallholder coconut farmers only sell coconuts for copra during seasonal peaks in production when the price falls on the fresh nut market, so that a suitable smallholder variety must retain flexibility for both end-uses, making the precocious, high-yielding and relatively large fruited THT x WAT an attractive choice. It is intended to start planting a WAT seed-garden during 1984, for mass-controlled-pollination by Thai Tall pollen, despite the difficulties inherent in pollinating Tall varieties and the absence of an easy technique for off-type identification in the nursery, as exists for the MYD x WAT hybrid (Rognon, 1972).

Ideally the variety trial would be replicated at other sites in Thailand to compare the yield of the four hybrids under different soil and climatic conditions, but planting material and suitable sites are not available. However 15 small on-farm demonstrations comparing the THT with MYD x WAT and THT x WAT have been established in the three principal coconut-growing provinces of southern Thailand.

Due to the success of the THT x WAT hybrid, other trials involving Thai varieties have been established, with the aim of producing high-yielding hybrids with a large nut size, well adapted to local conditions. However, as the emphasis of these trials has been towards the use of local and regional varieties which are more closely related, some of the yield heterosis may have been sacrificed for the sake of enhanced adaptability.

With the rapid expansion of the oil-palm industry in the region, the emphasis of the Thai coconut breeding programme should now be towards the production of nuts for domestic consumption, rather than copra production.

REFERENCES

ANON (1977) Cocotier — sélection. Rapport d' activités. Institut de Recherches pour les Huiles et Oleagineux, 1976—77.

FREMOND, Y. & DE NUCE DE LAMOTHE, M. (1971) Characteristics and production of the hybrid coconut palm, Malayan Dwarf x West African Tall. Proc. Int. Conf. on Cocoa and Coconuts, Kuala Lumpur: Incorporated Society of Planters.

DE NUCE DE LAMOTHE, M. & ROGNON, F. (9175) The hybrid Port-Bouet 121. New Results. Oleagineux, 30 (11), 457—465.

DE NUCE DE LAMOTHE, M. & WUIDART, W. (1979) The Tall coconuts at Port Bouet (Ivory Coast) West African Tall, Mozambique Tall, Polynesian Tall, Malayan Tall. *Oléagineux*, 34 (7), 339–349.

HENSEY, F.J. (1984) Personal Communication. Horticultural Research Centre, Amphoe Sawi, Chumphon 86 130, Thailand.

OFFICE OF AGRICULTURAL ECONOMICS (1983) Oil Crop Statistics of Thailand 1982/83.

ROGNON, F. (1972) Production of coconut planting material. Selection of hybrids during the germination period. *Oléagineux*, 27 (4), 203–204.

SANGARE, A., DE NUCE DE LAMOTHE, M. & LE SAINT, J.-P. (1983) Promising hybrid coconuts: PB 111 and PB 213. *Oléagineux*, 38 (8–9), 481–491.

SOIL SURVEY DIVISION (1982) Detailed reconnaissance soil map of Chumphon Province. Province series: No. 7; Bangkok, 1972. Produced by the Department of Land Development, Ministry of National Development, Kingdom of Thailand and the F.A.O.

Distribution and Morphology of Roots of the Nigerian Tall Coconut in Relation to Nutrient Absorption and Fertilizer Placement

U. OMOTI, U. C. AMALU AND D. O. ATAGA

Nigerian Institute for Oil Palm Research, Benin City, Nigeria.

The distribution and morphology of the roots of five, 11 and 13-year-old Nigerian Tall coconuts in fields at the Nigerian Institute for Oil Palm Research (NIFOR) Main Station and Badagry on a sandy and clay-loam soils respectively were studied by direct excavation.

Quantitative estimate of the distribution of the roots laterally and vertically showed that the mass of the primary roots were significantly higher than the roots of the other orders. The primary roots had zones of concentration laterally and vertically which were significantly different, while the distribution of the secondaries and combined tertiaries and higher order roots showed no significant differences either laterally or vertically between the 12 distance and 4-depth intervals studied except at the 0–30cm depth in the 13-year-old palms in which the tertiaries and higher order roots combined had significantly higher concentration than at other depths.

Root production in the five-year-old palms showed that significantly more roots were produced under Pueraria phaseoloides and Centrosema pubescens mixture than under the bare soil surface condition.

In the mature palms, the results suggest that upto the distance of 3.6m investigated, the zone of fertilizer placement may not be critical. For the younger palms, however, application should be restricted to about 0.6m radius for efficient utilization by the palms. In both young and adult palms, surface application by broadcasting or incorporation to a depth not exceeding 60cm, particularly, in slopy areas is recommended to enhance efficient utilization.

The coconut palm grows on a wide variety of soils — coastal soils as well as inland soils. Various methods of fertilizer placement have been recommended in the literature for the manuring of this crop. Some of these recommendations according to Nethsinghe (1966) and De-Geus (1967) include the traditional applications in circular trenches 0.9m wide 0.15m deep, cut at a distance of about 0.9m from the palm; fertilizer application in combination with the ploughing–in of green manures or with the burying of husks in "long-line" trenches between rows of palms, on the basis that the roots of the coconut tree are more vigorous towards the extremeties of the primaries; broadcasting over the whole area of the plantation and harrowing or ploughing–in, in the belief that this practice promotes extensive development of feeding rootlets over the whole area; and by spreading fertilizers in circular basins and forking-in at a radius of 1.2 to 1.8m round the base of the palm, a recommendation based on the visual observations by

Menon and Pandalai (1958) that the main feeding roots are concentrated around the stem.

These recommendations generally lacked any firm basis and Salgado (1957) found that on a light, sandy loam soil in Sri Lanka, broadcasting proved to be as efficient as circular trench manuring. More recent studies by Nethsinghe (1966) with radioactive ^{32}P on light well drained soils in Sri Lanka have led to the recommendation that fertilizer be applied in the entire area around the palm to a distance of 1.68m from the bole as the density of the absorbing roots is highest in the area immediately surrounding the base of adult palms upto a radius of 1.68m from the bole.

At the Nigerian Institute for Oil Palm Research (NIFOR) fertilizer placement in coconut, currently, is by broadcasting in a ring-weeded circle around the base of the palm to a distance of 1–1.5m radius, a practice which is based primarily on the experience with the oil palm and on the assumption that the two crops have similar root systems.

To ensure maximum efficiency of fertilizer utilization in our coconut plantations, quantitative information on the root system of the crop under Nigerian conditions is necessary as according to Child (1964) the distribution of coconut roots in soil is a dynamic process controlled by factors such as the variety of palm, the nature and drainage conditions of the soil. This paper describes the distribution and morphology of the root system of the Nigerian Tall coconut growing at the NIFOR Main Station and Badagry coconut Sub-station in relation to nutrient absorption and fertilizer placement.

MATERIALS AND METHODS

Study Sites and Palms

Details of the study sites and palms have been given previously (Omoti et al., 1984). Two palms each of the 13, 11 and five-year-old NIFOR Talls (NFT) and two palms of the five-year-old Badagry Tall (BDGT) were used for this study.

Total amount of roots

The total amount of roots to a depth of 200cm was determined by direct excavation from four rectangular trenches as described by Omoti et al. (1984).

Lateral and Vertical Distribution of Roots

For a systematic examination of the types of roots, their lateral and vertical distributions, soil cores 30 x 30 x 15cm were cut from two depths (0–15, 15–30cm) and further down the profile 30 x 30 x 30cm cubic samples were taken at three depths (30–60, 60–90 & 90–120cm) parallel to the open trenches. Laterally, cores were taken to a distance of 3.6m from the base of the palm giving altogether 60 cubic samples per trench. Each cubic sample was shaken in a sieve to remove soil particles and then weighed and bagged. In the laboratory, the roots were washed with a jet of water on a sieve. They were then separated into three major categories—primaries, secondaries, and combined tertiaries quarternaries and quinternaries. The samples were then oven-dried at 80°C to constant weight.

2

To obtain a clear picture of the root system in its natural state in the field, a jet of water was used to wash away soil particles at the sides of some trenches so that the roots were clearly exposed. The roots and the pneumathodes were described in their natural positions.

Dimensions of Root Orders

After separation into the size classes, approximate lengths and diameters of the different orders were measured both in the field and in the laboratory. The extent of rooting was estimated by tagging some primary roots and tracing them to their limits.

Number of Primary Roots

To determine the number of primary roots, the bole was dug up and divided into four quadrants to enable counting of the roots at their points of origin. Each point was stained with a marker pen after being counted.

Distribution and Development of Roots under
Leguminous Covers and Bare Soil Conditions

With the five-year-old palms growing at Badagry, it was possible not only to study the distribution of the roots but also to compare their production under a mixed leguminous cover of *Pueraria phaseoloides* and *Centrosema pubescens* and bare soil conditions from the same palms in which one-half of the surrounding area had been under legumes and the other half bare and used as harvesters path. As in the mature palms, the total amount of roots were determined and cubic samples from the base of the palm to a distance of 2.4m within the 0–30cm depth were taken.

RESULTS

Root Orders

Observations of the exposed roots in the field showed that the palms were characterized by a dense mat of interlocking roots of various sizes. Based on thickness, length and points of origin, five orders namely, primary, secondary, tertiary, quarternary and quinternary roots were identified. In the older literature the primary roots are usually described as main roots while the secondaries to the quinternaries are collectively described as root-lets. In this presentation, the terms primary, secondary, tertiary, quarternary and quinternary will be used for the root orders.

The primaries originate from the bole spreading in all directions and give rise to the secondaries, the secondaries give rise to the tertiaries, which inturn, give rise to the quarternaries. Little projections from the quarternaries form the fifth order quinternaries.

In addition to these root orders, pneumathophores which are regarded as breathing organs (Davis, 1966) were identified. The pneumathophores were uniformly distributed among the primaries, secondaries and tertiaries but there were little or none in the fourth and fifth order roots. Further study of this root type was not undertaken as the primary interest was in the nutrient and water-absorbing roots.

Root Population

The total dry mass of roots produced by the palms in the upper 200cm of soil and the dry mass of the various root orders are shown in *Table 1*. The results obtained from root population counts of the primaries at their points of origin on the bole in the three age groups of palms are given in *Table 2*. The primaries were observed to radiate horizontally, diagonally and vertically from the bole. *Table 2* shows that the horizontal and diagonal primaries were in the majority. *Tables 1* and *2* show that both root weight and root number increased with age. The five-year-old Badagry Tall had a higher dry mass of root than the NIFOR Tall.

TABLE 1. TOTAL AMOUNT OF VARIOUS ROOT ORDERS IN UPPER 200 CM OF SOIL
SUPPORTING NIGERIAN TALL COCONUT PALMS OF DIFFERENT AGES

| Age of Palms (year) | Cultivar | Location | Amount of various root orders (kg) | | | |
			Primaries	Secondaries	Tertiaries & higher orders	Total
5	BDGT	Badagry	16.7	3.8	5.2	25.7
5	NFT	Badagry	7.4	2.1	2.0	11.5
11	NFT	NIFOR	100.6	36.8	46.8	184.2
13	NFT	NIFOR	109.7	47.3	49.1	206.1

TABLE 2: TOTAL NUMBER OF PRIMARY ROOTS RADIATING FROM THE BOLE OF
NIGERIAN TALL COCONUT PALMS OF DIFFERENT AGES

| Age of Palms (Year) | Cultivar | Location | Number of Primary roots* | Directly descending roots | |
				Number	Percent
5	BDGT	Badagry	521	–	–
5	NFT	Badagry	548	101	18
11	NFT	NIFOR	4032	968	24
13	NFT	NIFOR	5200	1213	23

– not determined.
* horizontal and diagonal

Dimensions of Roots

The length and diameter of the root orders are given in *Table 3*. For the horizontal primaries, the furthest distances recorded were 10.1m for the 13-year-old and 9.3m for the 11-year-old palms. At these points the roots had descended to about 27cm. For the five-year-old palms the furthest distances to which the primaries were traced were 3.4m for the Badagry Tall and 2.9m for the NIFOR Tall at a depth of 18cm.

TABLE 3: DIMENSIONS OF VARIOUS ROOT ORDERS UNDER STANDS OF NIGERIAN TALL COCONUT PALMS OF DIFFERENT AGES

Age of Palm (year) and Cultivar	Primaries			Secondaries				Tertiaries				Quarternaries			
	Mean Length	Mean Diameter	Range (cm)	Mean Length	Range (cm)	Mean Diameter	Range (cm)	Mean Length	Range (cm)	Mean Diameter	Range (cm)	Mean Length	Range (cm)	Mean Diameter	Range (cm)
5(NFT)	330	0.8	0.6-0.9	41	39-47	0.3	0.1-0.4	2.1	2.0-2.5	0.06	0.05-0.08	0.10	0.05-0.13	0.02	0.01-0.03
11(NFT)	602	0.9	0.6-1.3	65	41-69	0.4	0.1-0.5	2.7	2.0-3.5	0.07	0.05-0.08	0.15	0.05-0.18	0.03	0.01-0.04
13(NFT)	830	1.0	0.5-1.5	58	48-77	0.4	0.2-0.5	2.6	2.0-4.0	0.08	0.05-0.1	0.19	0.05-0.2	0.03	0.01-0.05

Lateral and Vertical Distribution of Roots

The lateral distribution of the roots with depth is shown in *Figures 1a-c* for the 13-year-old, *Figures 2a-c* for the 11-year old and *Figures 3a-c* and *4a-c* for the five-year-old NIFOR and Badagry Talls respectively. The mean weights of roots produced per $30cm^3$ soil core at the various distances and depths for the different root orders are shown in *Tables 4* and *5* for the 13-year-old palms, *Tables 6* and *7* for the 11-year-old and *Tables 8a* and *b* for the five-year-old palms of the Badagry and NIFOR Tall cultivars respectively.

TABLE 4. LATERAL DISTRIBUTION OF VARIOUS ROOT ORDERS UNDER STANDS OF 13-YEAR-OLD NIFOR TALL COCONUT PALMS

Distance from base of Palm (cm)	Mean weight[a] of root orders per $30cm^3$ of Soil (g)			
	Primaries	Secondaries	Tertiaries & higher orders	Mean
30	575.0	97.3	121.9	264.7
60	322.7	95.4	108.0	175.4
90	259.1	84.7	109.0	150.9
120	176.1	84.4	95.0	118.5
150	142.7	91.4	86.7	107.6
180	112.4	75.4	92.0	93.3
210	132.7	77.3	87.8	99.3
240	109.2	72.5	81.3	87.7
270	93.6	69.0	73.8	78.8
300	106.8	66.5	77.9	83.7
330	93.2	72.9	67.0	77.7
360	110.7	75.2	70.5	85.5
Mean	186.2	80.2	83.4	

	P	0.05	0.01	0.001
LSD between any two means within the table		81.0	104.9	140.7
LSD between any two root order means on the border of the table		23.4	30.3	40.6
LSD between any two distance mean on the border of the table		47.2	63.4	83.6

[a] Each value is the mean of 4 cores taken over four-depth intervals.

TABLE 5. VERTICAL DISTRIBUTION OF VARIOUS ROOT ORDERS UNDER STANDS OF 13-YEAR-OLD NIFOR TALL COCONUT PALMS

Depth of Soil (cm)	Mean weight[a] of root orders per $30cm^3$ of Soil (g)			
	Primaries	Secondaries	Tertiaries & higher orders	Mean
0–30	222.5	119.7	137.8	159.9
30–60	234.6	75.2	84.0	131.3
60–90	159.4	65.3	73.1	99.3
90–120	128.2	60.4	62.6	83.7
Mean	186.2	80.2	83.4	

	P	0.05	0.01	0.001
LSD between any two means within the table		46.8	60.6	81.2
LSD between any two root order mean at border of the table		23.4	30.3	40.6
LSD between any two depth means at border of the table		27.2	36.6	48.3

[a] Each value is the mean of 12 cores taken over twelve–distance intervals.

6
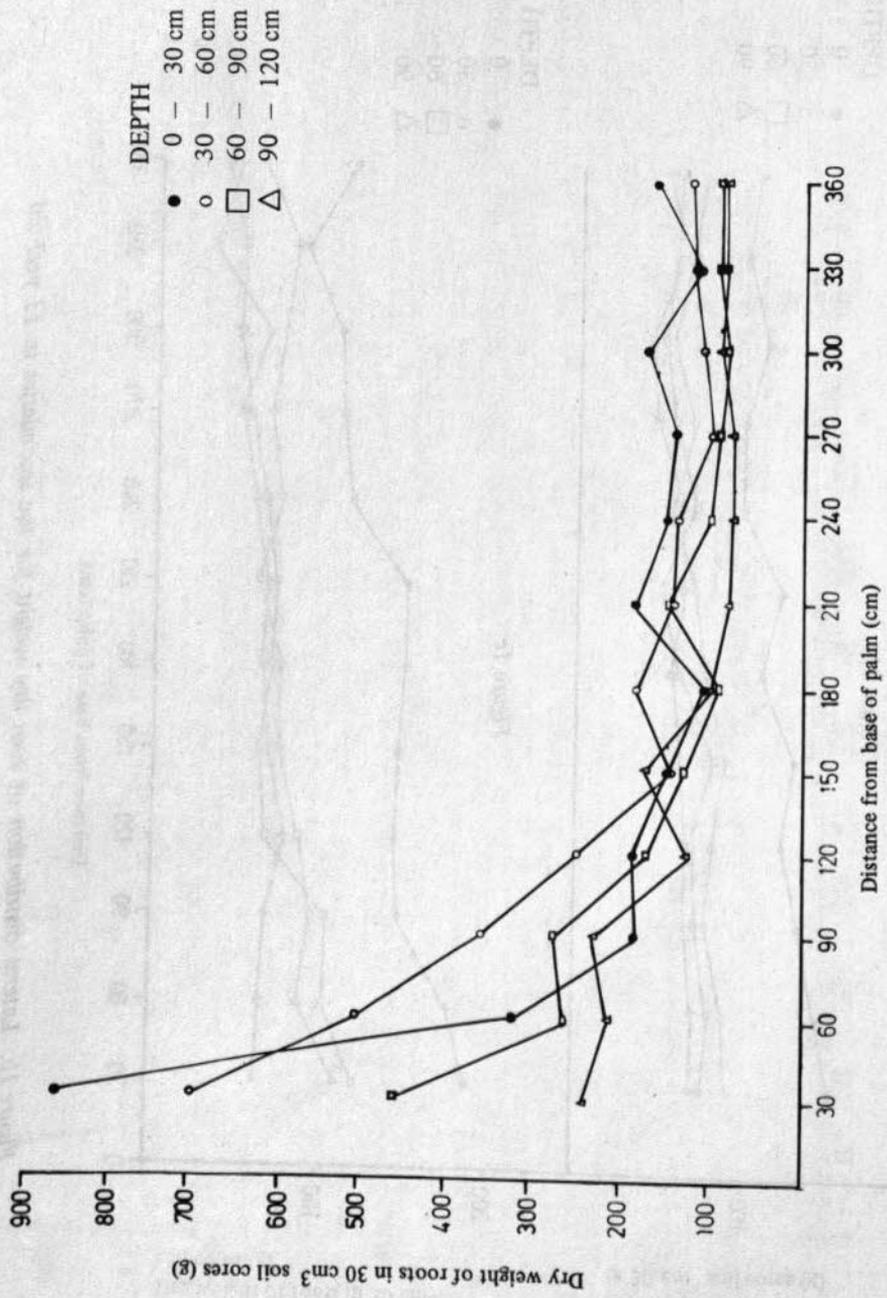
Figure 1a.   Lateral distribution of root dry weight for the primaries in 13 year-old palms.

DEPTH

- ●   0 — 30 cm
- ○   30 — 60 cm
- □   60 — 90 cm
- △   90 — 120 cm

Distance from base of palm (cm)

Dry weight of roots in 30 cm³ soil cores (g)

7
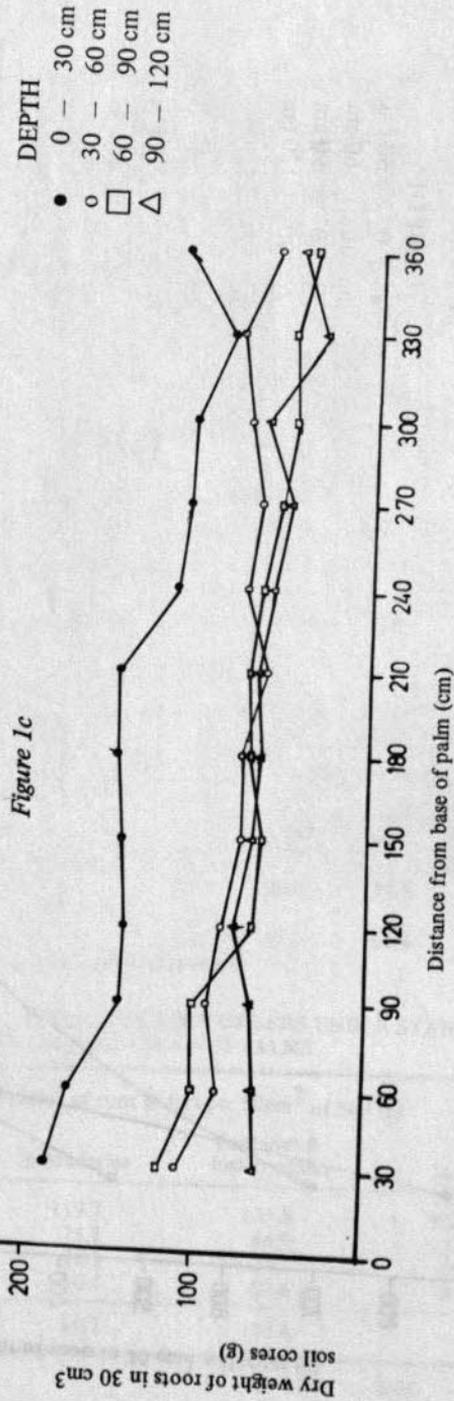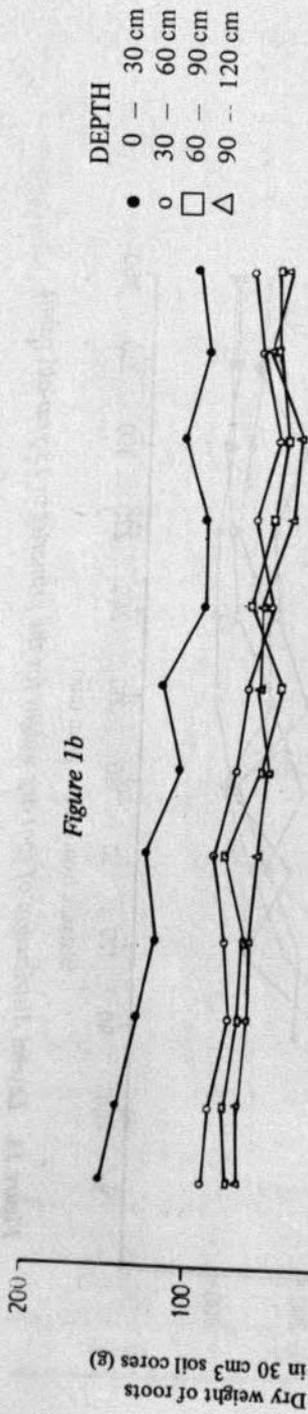
Figure 1b. Lateral distribution of root dry weight for the secondaries in 13 year-old palms

Figure 1c. Lateral distribution of root dry weight for the tertiaries/quarternaries in 13 year-old palms

8
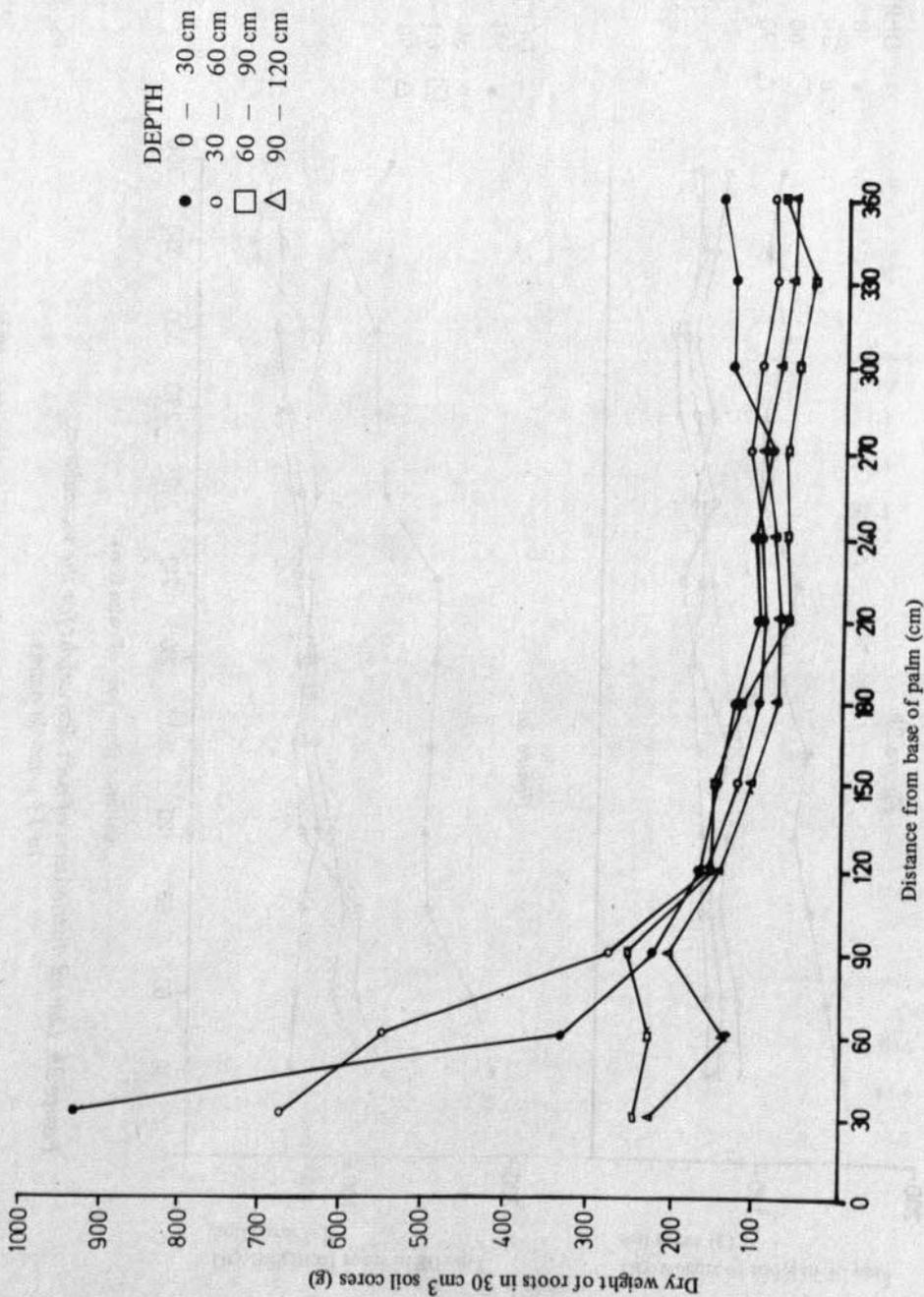
Figure 2a.Lateral distribution of root dry weight for the primaries in 11 year-old palms
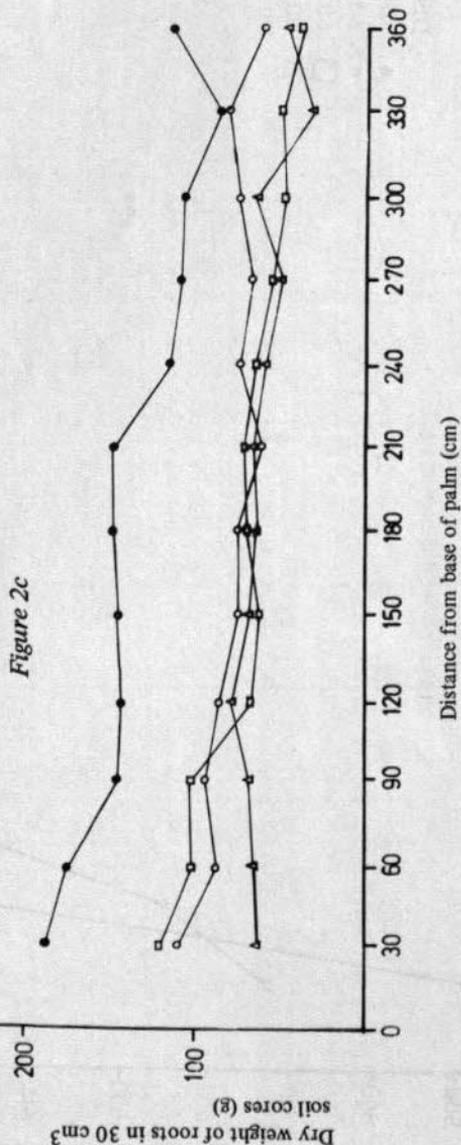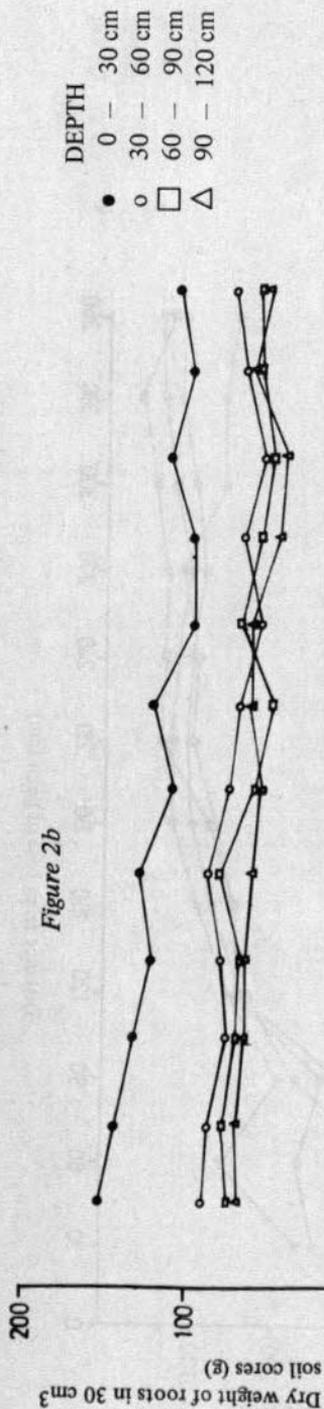
Figure 2b. Lateral distribution of root dry weight for the secondaries in 13 year-old palms

Figure 2c. Lateral distribution of root dry weight for the tertiaries/quartemaries in 13 year-old palms

10

TABLE 6. LATERAL DISTRIBUTION OF VARIOUS ROOT ORDERS UNDER STANDS OF 11-YEAR-OLD NIFOR TALL COCONUT PALMS

Distance from base of palm (cm)	Mean weight[a] of root orders per 30cm^3 of soil (g)			
	Primaries	Secondaries	Tertiaries & higher orders	Mean
30	518.2	90.3	131.9	246.8
60	309.5	61.9	101.1	257.5
90	239.7	64.9	94.1	132.9
120	155.2	53.9	73.3	94.1
150	130.9	64.2	68.4	87.8
180	101.7	54.7	66.4	74.2
210	79.0	52.3	58.3	63.2
240	86.6	61.7	57.0	68.4
270	90.9	48.1	67.2	68.7
300	92.7	62.0	69.9	74.9
330	79.4	50.6	59.4	63.1
360	93.2	58.7	71.9	74.6
Mean	164.7	60.3	76.6	

	P	0.05	0.01	0.001
LSD between any two means within the table		90.6	117.4	157.3
LSD between any two root order means on the border of the table		26.1	33.9	45.4
LSD between any two distance means on border of the table		52.7	70.9	93.5

[a] Each value is the mean of 4 cores taken at four-depth intervals.

TABLE 7. VERTICAL DISTRIBUTION OF VARIOUS ROOT ORDERS UNDER STANDS OF 11-YEAR-OLD NIFOR TALL COCONUT PALMS

Depth of Soil (cm)	Mean weight[a] of root orders per 30cm^3 of Soil (g)			
	Primaries	Secondaries	Tertiaries & higher orders	Mean
0–30	218.6	84.8	205.8	136.4
30–60	203.6	54.9	85.5	114.7
60–90	125.5	49.5	64.9	80.0
90–120	111.4	51.8	49.9	71.0
Mean	164.8	60.3	76.6	

	P	0.05	0.01	0.001
LSD between any two means within the table		52.3	67.8	90.8
LSD between any two root order means on the border of the table		26.1	33.9	45.4
LSD between any two depth means on the border of the table		36.4	40.9	54.0

[a] Each value is the mean of 12 cores taken over twelve-distance intervals.

11

TABLE 8. LATERAL DISTRIBUTION OF THE VARIOUS ROOT ORDERS WITHIN 0–30CM
DEPTH IN FIVE-YEAR-OLD COCONUT PALMS

a. BADAGRY TALL

| Distance from base of palm (cm) | Mean weight[a] of the root orders (g) | | | |
	Primaries	Secondaries	Tertiaries & higher orders	Mean
30	385.3	46.9	83.9	172.1
60	101.8	31.2	52.0	61.7
90	84.7	31.5	24.1	46.7
120	67.7	23.1	19.0	36.6
150	46.9	13.0	18.2	26.0
180	27.0	8.1	16.5	17.2
210	14.1	6.0	10.1	10.1
240	3.7	6.1	3.7	4.5
Mean	91.4	20.7	28.4	

	P	0.05	0.01	0.001
LSD between any two means within the table		31.1	42.2	56.7
LSD between any two root order means on the border of the table		18.0	24.4	32.7
LSD between any two distance means on the border of the table		11.0	14.9	20.0

[a]Values under each root order are averages of the amounts under
legume cover and bare soil surface.

b. NIFOR TALL

| Distance from base of palm (cm) | Mean weight[a] of the root orders (g) | | | |
	Primaries	Secondaries	Tertiaries & higher orders	Mean
30	242.3	38.4	19.8	100.1
60	112.9	30.9	31.1	58.3
90	57.6	23.5	22.2	34.4
120	46.6	20.6	18.1	28.4
150	31.3	14.3	19.3	21.6
180	22.0	6.6	9.6	12.7
210	10.7	8.2	10.1	9.7
240	3.6	5.5	8.4	5.8
Mean	65.8	18.5	17.3	17.3

	P	0.05	0.01	0.001
LSD between any two means within the table		27.7	37.6	50.5
LSD between any two root order means at border of the table		9.8	13.3	17.9
LSD between any two distance means at border of the table		16.00	21.7	29.2

[a]Values under each root order are averages of the
amounts under legume cover and bare soil surface.

In all the three age groups of palms, the mean weight of primary roots produced at
all the distances and depths was significantly higher (P = 0.001) than the weights of
secondaries or combined tertiaries and roots of higher orders.

12
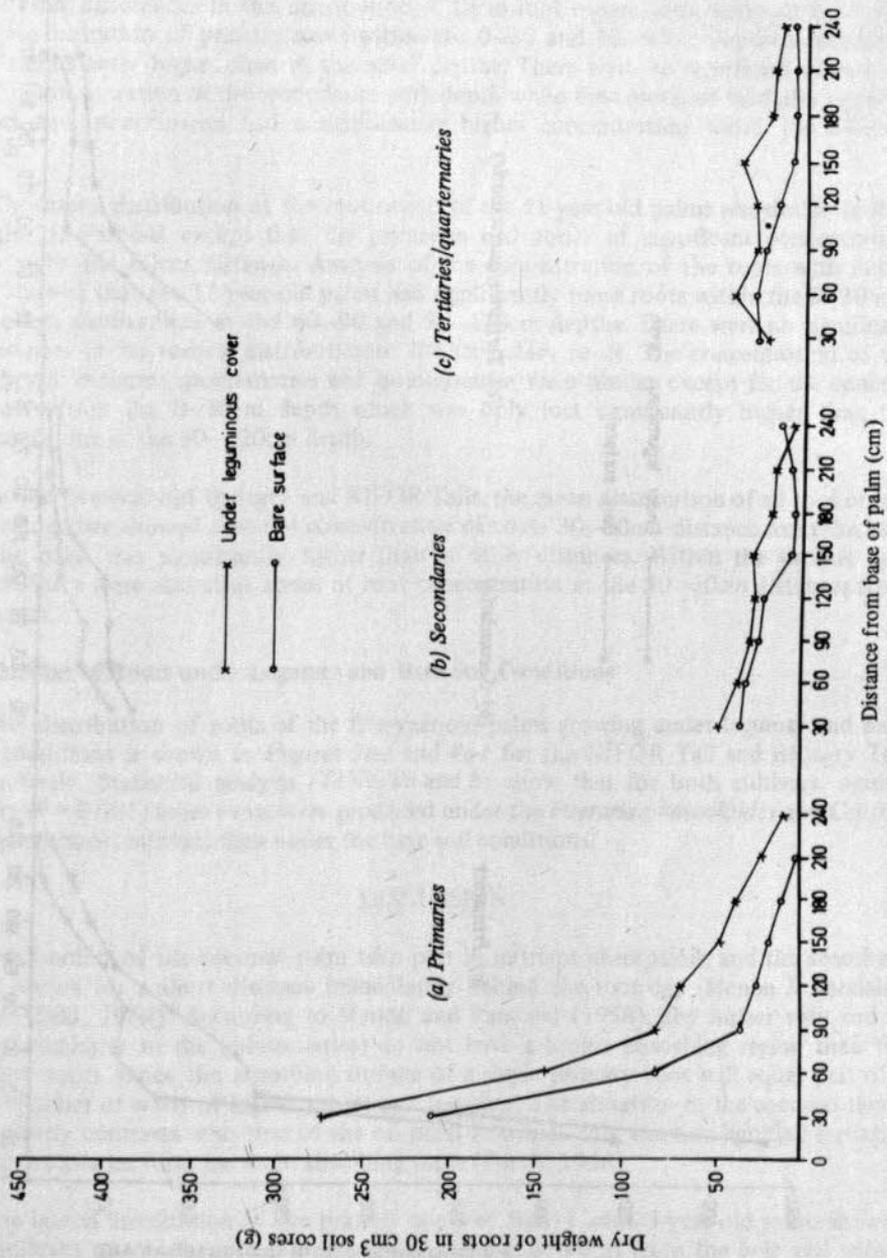
Figures 3a–c. Lateral distribution of root dry weight for the primary, secondary and tertiary/quarternary categories in 5 year-old NIFOR talls.

Legend: Under leguminous cover · Bare surface

(a) Primaries (b) Secondaries (c) Tertiaries/quarternaries

Dry weight of roots in 30 cm³ soil cores (g)

Distance from base of palm (cm)
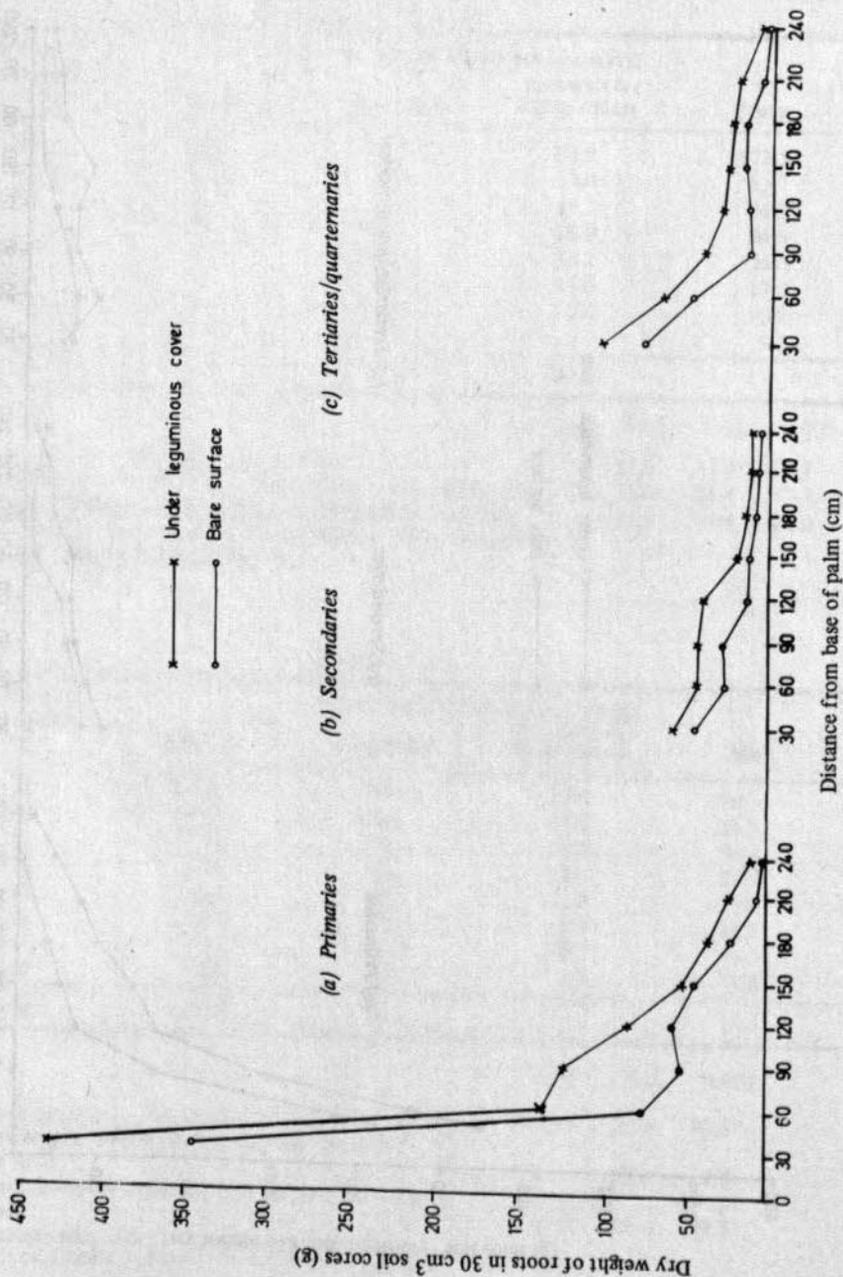
Figures 4a–c. Lateral distribution of root dry weight for the primary, secondary & tertiary/quarternary categories in 5 year-old BADAGRY talls.

(a) Primaries (b) Secondaries (c) Tertiaries/quarternaries

Distance from base of palm (cm)

Dry weight of roots in 30 cm³ soil cores (g)

×——× Under leguminous cover

o——o Bare surface

In the 13-year-old palms, statistical analysis showed that over the 360cm distance, the concentrations of primary roots at the 30—90cm distances from the bole of the palm were significantly higher than at the other distance intervals. Analysis of the secondaries, and the combined tertiaries, quarternaries and quinternaries showed that there were no significant differences in the distribution of these root orders with distance. Vertically, the concentration of primary roots within the 0—30 and 30—60cm depths were similar and significantly higher than at the other depths. There were no significant differences in the concentration of the secondaries with depth while the combined tertiaries, quarternaries and quinternaries had a significantly higher concentration within the 0—30cm depth.

The lateral distribution of the root orders of the 11-year-old palms was similar to that of the 13-year-old except that the primaries had zones of significant concentration only upto the 60cm distance. Analysis of the concentration of the roots with depth also showed that the 11-year-old palms had significantly more roots within the 0—30 and 30—60cm depths than at the 60—90 and 90—120cm depths. There were no significant differences in the vertical distribution of the secondary roots. The concentration of the combined tertiaries quarternaries and quinternaries were similar except for the concentration within the 0—30cm depth which was only just significantly higher than the concentration at the 90—120cm depth.

In the five-year-old Badagry and NIFOR Talls, the mean distribution of all root orders taken together showed that the concentration of roots 30—60cm distance from the bole of the palm was significantly higher than at other distances. Within the various root orders there were also clear zones of root concentration at the 30—60cm distances from the palm.

Production of Roots under Legumes and Bare Soil Conditions

The distribution of roots of the five-year-old palms growing under legumes and bare soil conditions is shown in *Figures 3a-c* and *4a-c* for the NIFOR Tall and Badagry Tall respectively. Statistical analysis *(Tables 9a* and *b)* show that for both cultivars, significantly (P = 0.001) more roots were produced under the *Pueraria phaseoloides* and *Centrosema pubescens* mixture than under the bare soil conditions.

DISCUSSION

All root orders of the coconut palm take part in nutrient absorption, and the absorbing zone occurs for a short distance immediately behind the root cap (Menon & Pandalai, 1958; Child, 1964). According to Menon and Pandalai (1958), the higher root orders (*i.e.* secondaries to the quinternaries) do not have a longer absorbing region than the primary roots hence the absorbing surface of a single primary root will equal that of a large number of roots of higher others put together. The situation in the coconut therefore clearly contrasts with that of the oil palm in which only the non-lignified tertiaries and quarternaries form the main absorbing roots (Purvis, 1956).

The lateral distribution of the primary roots of the 11 and 13-year-old palms showed a significant concentration of roots upto a distance of 90cm from the bole and within 0—60cm depths. In these palms the mean lengths of the horizontal primaries extended well beyond 3.6m (see *Table 3*). Therefore, since, the absorbing zone is just behind the root tip, it is unlikely that the primary roots will play an important role in the nutrient absorption in the immediate vicinity of the adult palms, despite the significant concentration observed close to the base of the palm. Thus, in terms of nutrient absorption

TABLE 9. COMPARISON OF THE DEVELOPMENT OF ROOTS UNDER LEGUME COVER AND BARE SOIL CONDITIONS WITHIN 0–30CM DEPTH IN FIVE-YEAR-OLD PALMS

a. BADAGRY TALL

Distance from base of palm (cm)	Mean weight[a] of roots under covers (g)	Mean weight[a] of roots under bare surface (g)
30	193.0	151.1
60	76.4	46.9
90	65.1	28.4
120	47.1	26.0
150	29.1	22.9
180	21.6	21.8
210	16.0	4.1
240	7.4	1.6
Mean	57.0	36.7

LSD between the treatment means

P (0.001) = 16.4

[a]Values represent means of amount of primary, secondary and combined tertiaty and roots of higher orders.

b. NIFOR TALL

Distance from base of palm (cm)	Mean weight[a] roots under covers (g)	Mean weight[a] of roots under bare surface (g)
30	112.3	87.9
60	71.8	44.8
90	43.0	25.8
120	38.0	18.7
150	34.9	8.3
180	20.4	5.0
210	16.4	2.9
240	7.1	4.5
Mean	43.0	24.7

LSD between the treatment means

P (0.001) = 14.6

[a]Values represent means of amount of primary, secondary and combined tertiary and roots of higher orders.

and fertilizer placement in the vicinity of the palms, we have to look upon the short length secondaries and roots of higher orders.

For these bearing palms, although the concentration of the secondaries and the combined higher root orders were slightly higher close to the palm (30—60cm from the base), the distributions over the 12 distance intervals from the base up to 3.60cm were not significantly different.

This would suggest that nutrient absorption over this distance intervals would be similar and that the zone of fertilizer placement would not be critical. This probably explains why Salgado (1957) found no difference in yields over a ten-year period between

16

the traditional circular trench system and broadcast applications of fertilizers in the entire area on a light sandy soil in Sri Lanka. In the studies carried out in the Philippines on 15 and 60-year-old palms on a silt loam, clay loam, and sandy loam, there were no significant differences between the uptake of ^{32}P at 1, 2, 3 and 4m distances from the palm. In the silt loam soil, highest activity was at the 4m distance within 30—60cm depth while in the clay loam and sandy loam, root activity was highest at the 1—2m distances within the 15—30cm depths. Our results are in agreement with these findings.

In the ^{32}P studies (International Atomic Energy Agency, 1975) conducted in Sri Lanka, however, on sandy loam and lateritic clay loam over four distances (0.5, 1, 2 and 3m) and four depths (10, 30, 45 and 60cm) significantly higher root activity was obtained at the 0.5—1m distances within the 10cm depth zone for the sandy loam and 12—24cm depth for the lateritic clay loam. In the same studies in Sri Lanka, it was found that placement of ^{32}P labelled fertilizer in the entire area within a radius of 0.5m (area $0.78m^2$) from the palm gave significantly higher activity than placement in a rectangular strip 20cm x 200cm running lengthwise parallel to the rows of palms at 1m distance from the tree (area $0.4m^2$) or placement in a strip 20cm x 200cm but at a distance midway between adjacent palms (area $0.4m^2$). Nethsinghe (1966) working on the same sandy loam in Sri Lanka had found that using the same areas and depths, the ^{32}P uptake in a basin 1.65 radius was about 100 percent higher than the uptake in centres of squares mid-way (3.9m) between palms or in the traditional manure treches 0.9m wide and 0.9m away from the palm. The Sri Lanka studies with ^{32}P clearly establish the existence of significantly high root activity within 0.5—1.65m from the palm in that environment. In terms of the long term uptake of nutrients, however, and the effect on yield, these zonal differences in activity may not be significant as the results of Salgado (1957) suggest.

In our studies the young palms showed a clear zone of significant high root density at a distance of 30—60cm from the palm for all the root orders. Owing to the shorter lengths of the primaries at this age, their contribution to the total nutrient uptake in the vicinity of the palms would be very significant. Therefore, at about the age of five years, maximum fertilizer uptake should occur if placed round the palm up to about the 0.6m limit from the bole.

The results of the five-year-old palms also showed that significantly more roots of all orders were produced under the legume covers than under bare soil conditions. This greater root production under legumes should enhance further, the efficiency of fertilizer utilization apart from the improved soil structure and nutritional benefits which the legumes confer on the palms.

For the adult Nigerian Tall coconut on sandy soils, our results suggest that fertilizer can be applied to as wide a zone as possible up to the limit of 3.6m tested. The results also suggest that surface application or working in the fertilizer within the 0—60cm depth would be equally efficient as the concentrations of roots of the secondaries and higher orders of root within the 0—120cm depths were similar. The practice of working in the fertilizer would be especially beneficial in slopy areas where fertilizers would be most susceptible to loss by surface wash-off.

ACKNOWLEDGEMENT

REFERENCES

CHILD, R. (1964) *Coconuts*, pp 34—35. London: Longmans.

DAVIS, T. A. (1966) Contribution to the physiology of the coconut palm. *Proc. FAO Technical Working Party on Coconut Production, Protecting and Processing. Colombo Ceylon 1964*, 150.

DE GEUS, J. G. (1967) *Fertilizer Guide for Tropical and Subtropical Farming*, pp 304. Zurich: Centre d'Etude de l'Azote.

INTERNATIONAL ATOMIC ENERGY AGENCY (1975) Root Activity Patterns of some Tree Crops. *Technical Report Series No. 170*. IAEA Vienna 1975. 65.

MENON, K. P. V. & PANDALAI, K. M. (1958) *The Coconut Palm* — a monograph, pp 15—30. Ernakulam: India Central Coconut Committee.

NETHSINGHE, D. A. (1966) A study on root activity (in soil) of coconut palms using radioactive phosphorus. *Proc. FAO Technical Working Party on Coconut Production Protecting and Processing, Colombo Ceylon 1964*, 108.

OMOTI, U., ATAGA, D. O. & AMALU, U. C. (1984) Dry matter production and macronutrient content of the Nigerian Tall Coconut. *Proc. Int. Conf. on Cocoa and Coconuts — Progress and Outlook, Kuala Lumpur, 1984*.

PURVIS, C. (1956) The root system of the oil palm, its distribution morphology and anatomy. *J.W. Afric. Inst. Oil Palm Res.*, 4, 60—82.

SALGADO, M. L. M. (1957) *Annual Report of the Coconut Research Institute of Ceylon for 1957*, 16—17.

Clonal Propagation of Coconut Palm

R.L. BRANTON AND JENNET BLAKE

Wye College (University of London), Ashford, Kent, United Kingdom.

The coconut palm is, at present, propagated entirely by seed. Since this palm is generally cross-pollinated and heterozygous the resulting variation between seedlings is a serious problem. Clonal propagation from proven, high-yielding, disease-resistant hybrids would provide uniform material for replacement planting and high quality parental stocks for breeding programmes.

Clonal propagation was attempted using tissue culture techniques. Explants were obtained from mature palms of Cocos nucifera *c.v. 'Malayan Dwarf' grown in Jamaica. Calloid initiated from rachillae of young inflorescences was maintained on a semi-solid medium containing 2,4-D at $10^{-4}M$. This calloid was nodular in appearance and histological investigations showed small, densely cytoplasmic cells with little differentiation of cell types. Reduction of the 2,4-D concentration to about $10^{-8}M$ over several subcultures resulted in the calloid producing white embryoid-like structures. Sections through this calloid showed meristematic tissue similar to embryogenic areas in oil palm and date palm callus. In many cases these white embryoid-like structures developed into abnormal shoot or leaf-like structures often with a good primary root. However, two normal plantlets have been obtained and we are now developing a more reliable system.*

The only method at present available to both breeders and planters for propagation of the coconut palm (*Cocos nucifera* L.) is by the use of seed. However, since this palm is generally cross-pollinated and heterozygous (Davis, 1969) the resulting variation between seedlings presents a serious problem, particularly as the coconut is a long-term plantation crop. Variation in such characters as yield and resistance to disease may have serious consequences. A method of vegetative propagation is therefore vital for any future growth of the coconut industry.

Various centres around the world have been applying the techniques of tissue culture in an attempt to develop a clonal propagation system (Blake, 1983). Once such a system is successfully developed, rare individual palms with yields in excess of 200 nuts per year (approx. 50 kg copra, depending on copra content) would be ideal candidates for clonal propagation which would provide uniform material for replacement planting and aid breeding programmes. Work at Wye College has been in progress from 1970 and since the last Conference in Kuala Lumpur on Cocoa and Coconuts (Blake & Eeuwens, 1980) there has been considerable progress towards the development of a clonal propagation system for the coconut palm using immature inflorescences as a source of explant tissue.

MATERIALS AND METHODS

Immature inflorescence tissue from *C. nucifera* L. cv. 'Malayan Dwarf' was obtained through the Coconut Industry Board, Jamaica. Whole palms were harvested and the

cabbage and inflorescences were cooled (to about 5°C) and flown directly to London. On receipt, which was about four days after harvest, the outer and inner spathes were swabbed in 85% ethanol and removed under aseptic conditions. The rachillae (8–50 mm in length depending on the age of the inflorescence) were sliced transversely (0.25–1 mm thick) discarding the basal portion bearing female flowers (*Figure 1*). The rachillae slices were carefully positioned on the surface of the callus-induction medium, and incubated in the dark at 30 ± 1°C. Detailed descriptions of the culture methods, nutrient media and culture conditions have been fully reported by Eeuwens (1976, 1978), Blake and Eeuwens (1982) and Branton and Blake (1983b). *Table 1* gives the composition of the callus initiation medium.
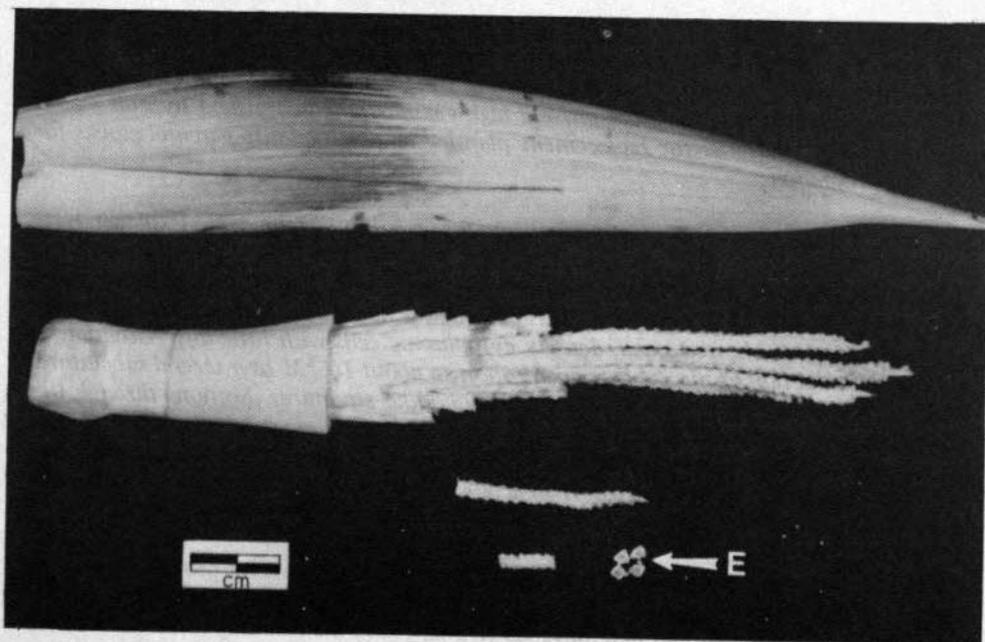
Figure 1. Immature inflorescences of C. nucifera L. with prepared explants (E).

RESULTS AND DISCUSSION

After four to 16 weeks on the callus initiation medium, with sub-culture onto the same medium at four to six-week intervals, callus was initiated on over 95% of the explants (*Figure 2*). (Details on the rate of callus growth will be given in a subsequent publication.) It appears that this callus is derived from existing floral meristems (male) and probably represents a proliferation of the meristem rather than a true callus such as that obtained on, for example, tobacco pith. A suitable term for this type of callus may be 'calloid', since this has already been used by Nyman *et al.*, (1983) in describing a similar type of callus observed on *Taro*. Coconut calloid is characterised by small cells with densely staining nuclei (*Figure 3*) and can be maintained and multiplied on the same medium. This semi-disorganised meristematic state is maintained by a high concentration of 2,4-D $(10^{-4} M)$ in the medium, but if this auxin is omitted, the calloid expands and produces a white, spongy mass of tissue, often with associated roots (*Figure 4*). This may represent the haustorium associated with the normal zygotic development (Branton & Blake 1983b). If, however, the auxin concentration is gradually reduced over several sub-cultures to $10^{-8} M$, the nodular areas of the calloid develop into embryoid-like structures (*Figure 5*),

TABLE 1. COMPOSITION OF CALLUS INITIATION MEDIUM FOR IMMATURE INFLORESCENCE EXPLANTS FROM *COCOS NUCIFERA* L. cv. 'MALAYAN DWARF'

Constituents	Concentration	
	$mg\ l^{-1}$	mM
Oxoid purified agar	5000.0	–
Activated charcoal (neutralized)	2500.0	–
Sucrose	50000.0	146.07
Casein (enzymatic hydrolysate)	300.0	–
Myo-inositol	100.0	0.555
NH_4NO_3	1655.0	20.677
KNO_3	1900.0	18.793
KH_2PO_4	170.0	1.249
NaH_2PO_4	80.0	0.513
$MgSO_4.7H_2O$	370.0	1.501
$CaCl_2.2H_2O$	440.0	2.992
FeNaEDTA	37.5	0.102
H_3BO_3	3.1	0.05
$MnSO_4.4H_2O$	11.2	0.05
KI	8.3	0.05
$ZnSO_4.7H_2O$	7.2	0.025
$CuSO_4.5H_2O$	0.25	0.001
$CoCl_2.6H_2O$	0.24	0.001
$NaMoO_4.2H_2O$	0.24	0.001
$NiCl.6H_2O$	0.024	0.0001
Thiamin HCl	2.0	0.0059
Nicotinic acid	0.5	0.004
Ca Panthothenate	0.5	0.001
Pyridoxin HCl	0.5	0.0024
Biotin	0.5	0.002
Choline Chloride	0.5	0.0035
L-ascorbic acid	0.5	0.0028
Adenine sulphate	0.5	0.0027
6-benzylaminopurine (6-BAP)	1.113	0.005
N^6-isopentenyladenine (2-iP)	1.015	0.005
2,4-dichlorophenoxyacetic acid (2,4-D)	22.1	0.100

which, upon further sub-culture, may develop or 'germinate' into normal plantlets with root, shoot and haustorium (*Figures 5, 6* and *7*). Since reporting the production of the first coconut platlet through tissue culture (Branton & Blake, 1983a), a further planlet has been obtained (*Figure 8*). However, using a standard compost (Levingtons) and maintaining a high humidity, these plantlets, due to root infection, were not successfully established.
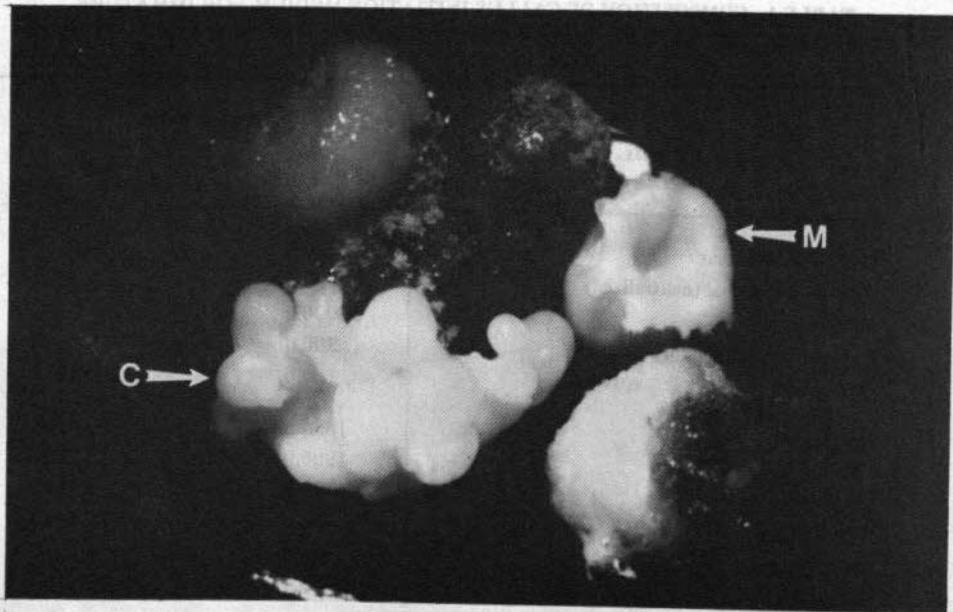
Figure 2. Callus (calloid) initiation on (C) inflorescence explants. Note abnormal male flower (M).
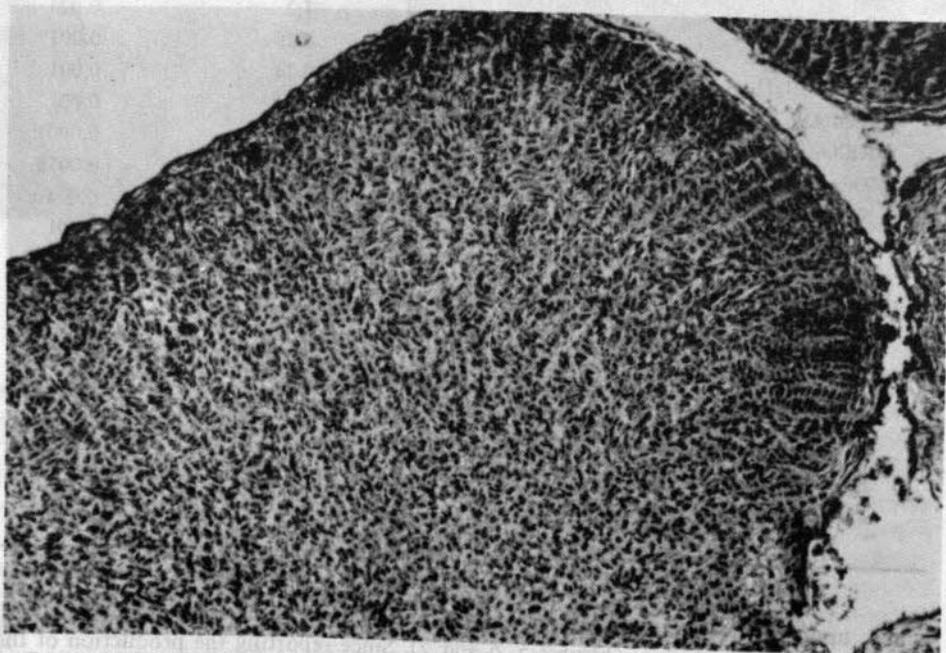
Figure 3. Section through coconut calloid showing small densely staining cells x 200.
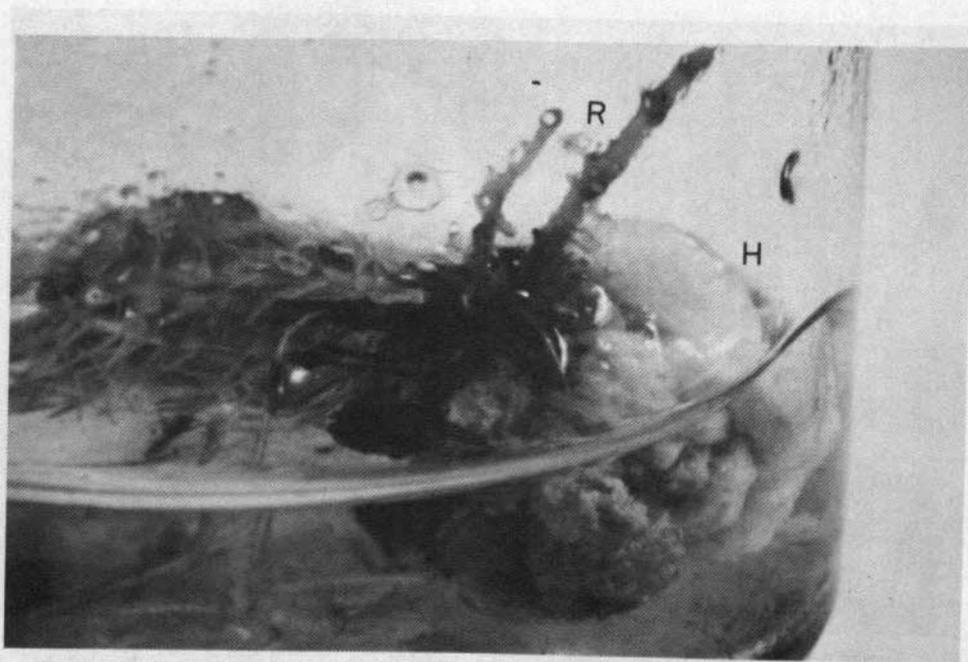
Figure 4. Expansion of calloid following omission of 2,4-D showing haustorium-like structure (H) with associated root system (R).
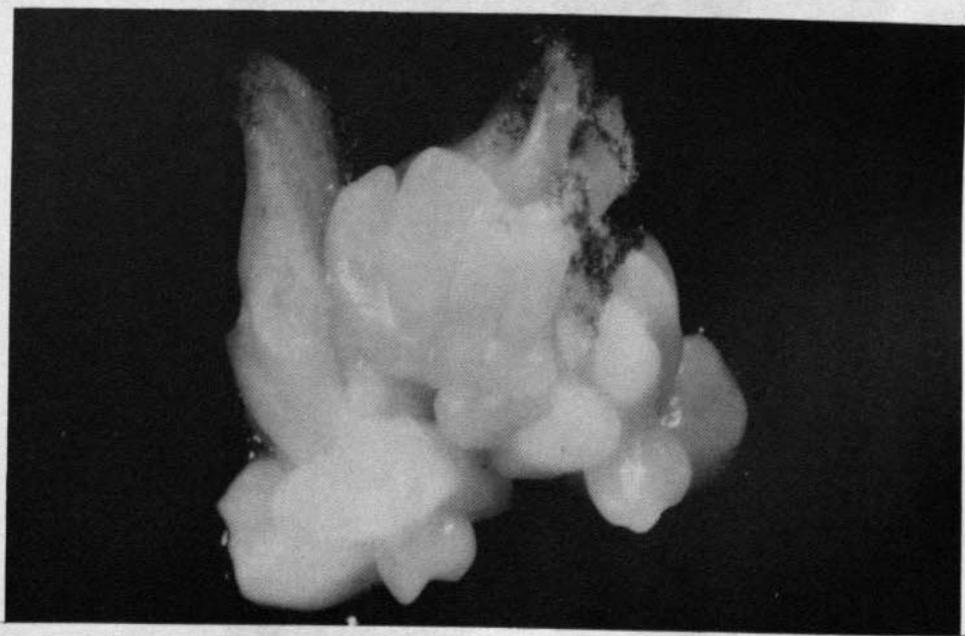
Figure 5. Development of embryoid-like structures on coconut calloid.
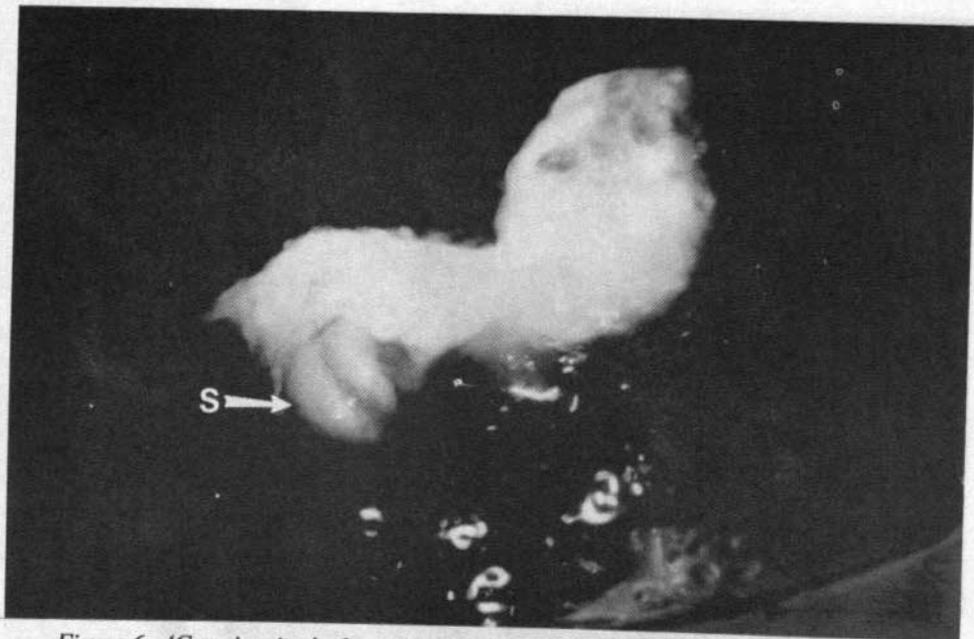
Figure 6. 'Germination' of coconut embryoid, showing emergence of shoot (S).

Figure 7. Development of shoot from embryoid.

6
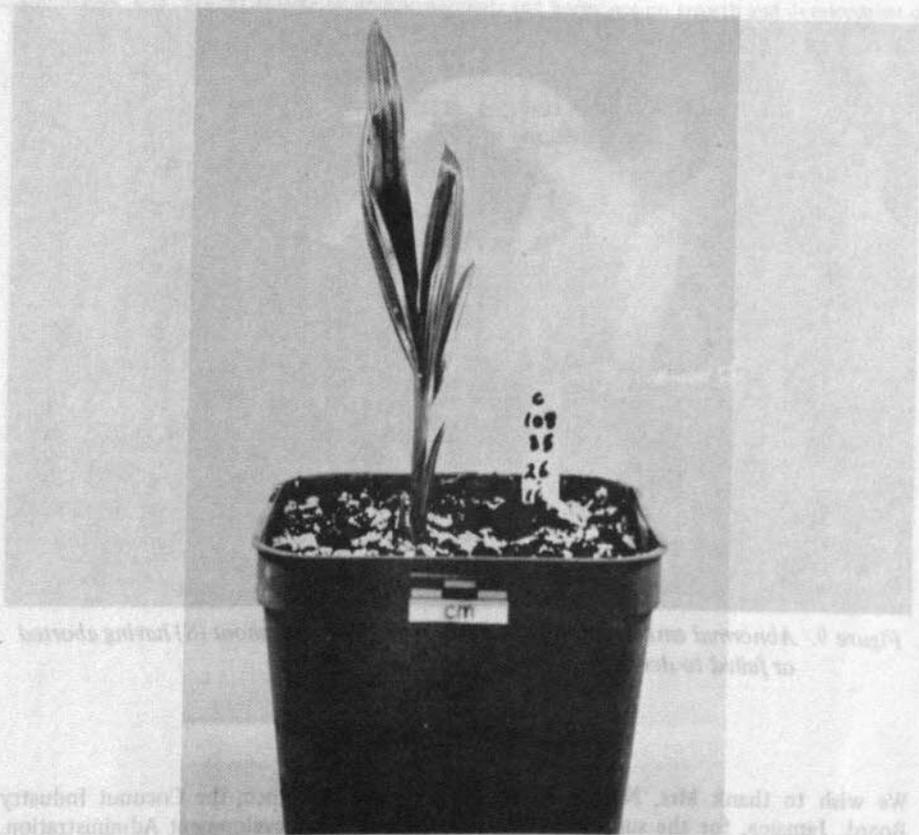
*Figure 8. Normal plantlet developed from embryoid
and transferred to compost.*

Although it is clear that normal embryoids can be produced by the calloid, there is a much higher frequency of development of abnormal structures, approx. 90% at present, with aborted shoot-like structures (*Figure 9*), as well as roots and haustorial-type structures. It seems probable that the auxin concentration is critical for the normal development of the embryoid with a balance being maintained between the developing shoot, root and haustorial meristems. Work is continuing in this area to develop a more reliable and reproducible system.

Until recently and inflorescences used as explant sources were immature and required a destructive harvest of the palm. However, we are now working with older inflorescence tissue which can be harvested without destructing the palm, since it is vitally important to maintain elite stocks in the field. As an inflorescence is produced approximately every month, it is a 'renewable' explant source which can provide several hundred explants at regular intervals.

Once a tissue culture system is developed, many years of field trials will be required to assess the variation within and between the clones. It is therefore unlikely that clonal propagation will be of any practical benefit to coconut growers until the early part of next century, but the future is promising.

7
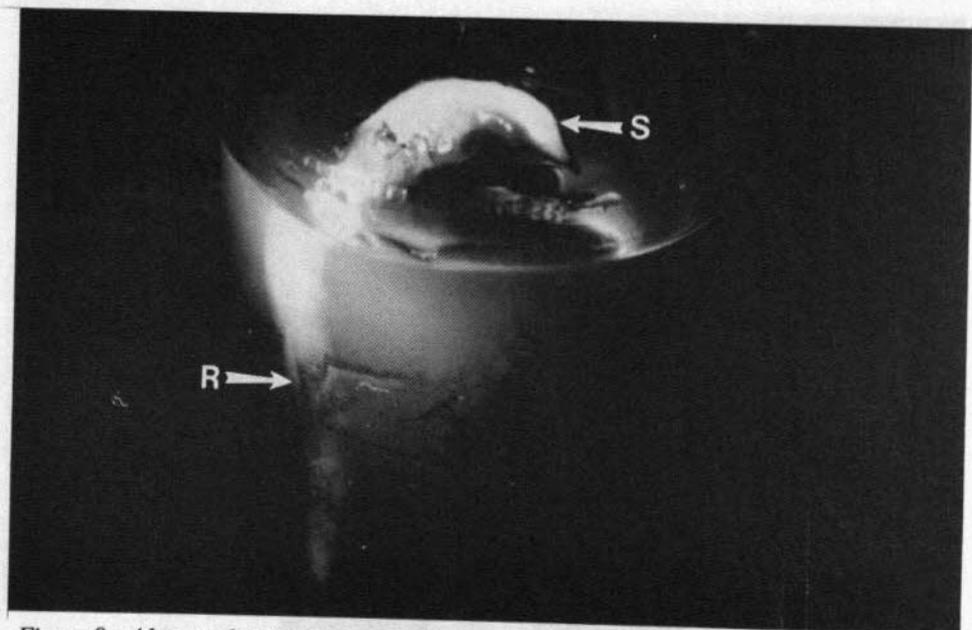
Figure 9. Abnormal embryoid producing a root (R), but with shoot (S) having aborted or failed to develop.

ACKNOWLEDGEMENT

REFERENCES

BLAKE, JENNET (1983) Tissue culture propagation of coconut, date and oil palm. In *Tissue Culture of Trees* (ed. J.H. Dodds), pp. 29–50. London: Croom Helm.

BLAKE, JENNET & EEUWENS, C.J. (1980) Inflorescence tissue as source material for vegetative propagation of the coconut palm. *Proc. Int. Conf. on Cocoa and Coconut, 1978*, pp. 549–556.

BLAKE, JENNET & EEUWENS, C.J. (1982) Culture of coconut palm tissues with a view to vegetative propagation. *Proc. Int. Symp. on Tissue Culture of Economically Important Plants* (ed. A.N. Rao), 1981, pp. 145–148. Singapore: COSTED/ANBS.

BRANTON, R.L. & BLAKE, JENNET (1983a) A lovely clone of coconuts. *New Scientist*, 98 (1359), 554–557.

BRANTON, R.L. & BLAKE, JENNET (1983b) Development of organised structures in callus derived from explants of *Cocos nucifera* L. *Ann. Bot.*, 52 (5), 673–678.

DAVIS, T.A. (1969) Clonal propagation of the coconut. *Wld. Crops* Sept./Oct., 253–255.

EEUWENS, C.J. (1976) Mineral requirements for growth and callus initiation of tissue explants excised from mature coconut palms (*Cocos nucifera*) and cultured *in vitro*. *Physiol. Pl.*, 36, 23–28.

8

EEUWENS, C.J. (1978) Effects of organic nutrients and hormones on growth and development of tissue explants from coconut (*Cocos nucifera*) and Date (*Phoenix dactylifera*) palms cultured *in vitro*. *Physiol. Pl.*, **42**, 173–178.

NYMAN, L.P., GONZALES, C.J. & ARDITTI, J. (1983) Reversible structural changes associated with callus formation and plantlet development from aseptically cultured shoots of Taro (*Colocasia esculenta var antiquorum*). *Ann. Bot.*, **51** (3), 279–286.

Optimum Density for Mawa Hybrid

TAN YAP PAU AND EDWARD CHAN*

United Plantations Berhad, Teluk Intan, Perak

A density trial, testing four equilateral triangular spacings was established in 1975 on a coastal alluvial soil in Lower Perak. Vegetative measurements showed that frond length, frond production and relative leaf area were similar between treatments. By the 7th year after field planting, palm height and petiole length showed clear indications of etiolation, although the differences between treatments were not statistically significant. The adverse effect of high density planting was more clearly demonstrated on nut production per palm, the effect being observed from the second year of production (five years after field planting) onwards but copra per nut was not affected. The low nut production per palm was however more than compensated for by the high palm population, resulting in the highest density planting producing the highest number of nuts per hectare except for the fifth year of production when the 185-palms-per-hectare-treatment gave the best yield.

Mathematical calculation projects a stable optimum density of 180 palms per hectare (equilateral triangular planting). The trial has to be continued to confirm the projection.

The excellent yield of the MAWA, hybrid between the Malayan Dwarf and the West African Tall coconuts in Ivory Coast (Fremond & de Nuce de Lamothe, 1971) convinced United Plantations Berhad (UPB) to introduce this material into Malaysia and to establish seedgardens to produce seednuts for commercial plantings. Both the Malayan Red Dwarf (MRD) and Malayan Yellow Dwarf (MYD) are used as mother palms, while the pollen is obtained from the West African Tall (WAT).

Appreciating that there may be interest in planting this high-yielding hybrid as a mono-crop, and that optimum density for a crop varies with edaphic and climatic conditions, a density trial was identified as a priority project especially when experimental evidence for optimum density of the Malayan Tall and Malayan Dwarf is also lacking in Malaysia. Using the planting density adopted by IRHO (*i.e.* 160 palms/ha) as a guide (de Nuce & Rognon, 1975), the experiment was drawn up and implemented in 1975.

MATERIALS AND METHODS

The trial was established on a coastal alluvium (typic tropaquapt) in Lower Perak, Malaysia. Eight-month old seedlings raised in polybags were field-planted in July 1975, in an ex-coconut field. Leguminous cover was not established and palm circles were maintained weed-free at all times.

Four densities, spaced at equilateral triangular spacing were compared. A randomized complete block design with three replicates was adopted. The plots are separated from each other by individual guard palms, and the size of each plot is approximately 0.4 ha. Spacing between palms is given in *Table 1*.

---

*Presently in Australia.

TABLE 1. PLANTING DENSITY AND RESPECTIVE DISTANCE BETWEEN PALMS OF EQUILATERAL TRIANGULAR PLANTING SYSTEM

Treatment	Palms/ha	Distance between palms (m)	No. of palms per plot
A	136	9.19	34
B	160	8.48	40
C	185	7.85	46
D	211	7.39	52

Cocoa was underplanted when the MAWA was two years old (since field planting). Although early growth of the cocoa was satisfactory, it became apparent that the MAWA, even at 136 palms per hectare, was providing too much shade. The cocoa was subsequently removed.

RESULTS AND DISCUSSION

Frond Length

The length of Frond 14 increased with increasing density but differences between treatment were small and statistically non-significant.

Figure 1 shows that the increase in rachis length after the fourth-year was small and would likely stabilize by the time the palms reach 10 years old. On the other hand, petiole length had continued to increase though gradually. The trend, as shown in *Figure 1*, suggests that petiole length is likely to show greater etiolation effect than rachis length.

It would be of interest to note that at the 136 palms per hectare, petiole to rachis ratio of three-year-old MAWA palms was 1 : 2 and for the next three years, the ratio was 1 : 3.

Frond Production

Frond production of the MAWA hybrid was not statistically different between treatments, although a small reduction was observed at higher densities (see *Table 2*).

The result shows that the MAWA hybrid produce 18 fronds per year, under normal weather conditions of Lower Perak. The lower production in 1981 (seventh year) could be due to the effect of adverse weather condition.

Relative Leaf Area

In July 1983, the number of pinnae per frond and length and width of the middle pinnae of Frond 14 were measured, and found to be similar in all four densities. Mean relative leaf area was 20.1 m^2 (see below). Since the palms were retaining 30 green fronds per palm at that time, the relative area per palm was therefore 603 m^2.
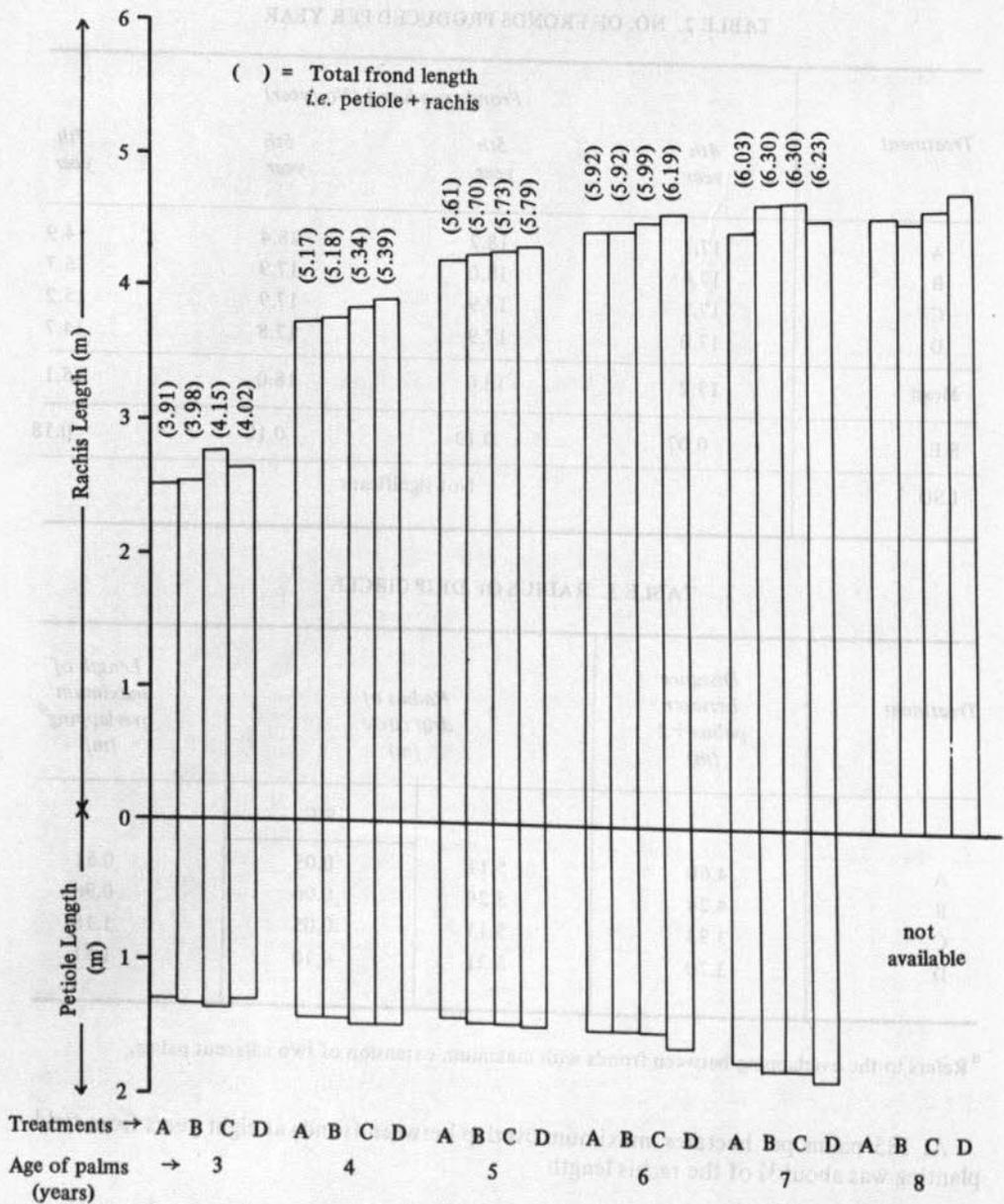
Relative Leaf Area (RLA)

No. of pinnae/frond = 240

Figure 1. Frond Length

Mean pinnae length	=	135.7 cm
Mean pinnae width	=	6.18 cm
RLA	=	20.1 m²

Canopy Spread

Canopy spread is also referred to as drip circle. Generally the radius of the drip circle is measured, and this is done by taking the perpendicular distance from the centre of the palm to the tip of the fronds with the furthest extension. Measurements carried out in December 1983 on only 10 palms per treatment are shown in *Table 3*.

TABLE 2. NO. OF FRONDS PRODUCED PER YEAR

Treatment	Fronds produced (No./year)			
	4th year	5th year	6th year	7th year
A	17.1	18.2	18.4	14.9
B	17.4	18.0	17.9	15.7
C	17.1	17.9	17.9	15.2
D	17.0	17.9	17.8	14.7
Mean	17.2	18.0	18.0	15.1
S.E.	0.07	0.13	0.10	0.18
LSD		Not significant		

TABLE 3. RADIUS OF DRIP CIRCLE

Treatment	Distance between palms ÷ 2 (m)	Radius of drip circle (m)		Length of maximum overlapping[a] (m)
			S.E.	
A	4.60	5.11	0.05	0.51
B	4.24	5.20	0.06	0.96
C	3.93	5.11	0.05	1.18
D	3.70	5.21	0.10	1.51

[a] Refers to the overlapping between fronds with maximum extension of two adjacent palms.

At 185 palms per hectares, maximum overlap between fronds at eight years from field planting was about ¼ of the rachis length.

Since frond length during the last two years of recording had increased only marginally, it is assumed that the canopy of the MAWA at later years would not extend significantly beyond the drip circle of 5.11 m, in the absence of interpalm competition.

Trunk Height

As an indication of palm height, the distance from ground level to the base of Frond 24 was measured annually. Although a clear trend of increasing height with higher planting densities was observed, the differences were not statistically significant up to eight years from field planting. Indications are that the increments in later years might be significant. (*Table 4*)

4

TABLE 4. HEIGHT OF PALMS

Treatment	Height Dec. 1979 (m)	Height increment (m)				Height July 1983 (m)	Mean increase per 12 months
		Dec 79 – Dec 80	Dec 80 – Dec 81	Dec 81 – July 82	Jul 82 – Jul 83		
A	1.62	0.91	0.85	0.48	0.84	4.70	0.88
B	1.74	0.84	0.87	0.52	0.87	4.84	0.89
C	1.72	0.91	0.89	0.54	0.94	5.00	0.94
D	1.78	0.98	0.88	0.62	1.06	5.32	1.01
Mean	1.72	0.91	0.87	0.54	0.93	4.97	0.93

Yield

First flowering. Census for the first flowering of the palms commenced two years after field planting when spikes were observed on three palms. Six months later 45% of the palms had commenced flowering and by the thirty-third month more than 90% of the palms had produced at least one inflorescence.

Although harvesting of mature nuts had begun towards the end of 1978, yield recording commenced only from January 1979 (three and half years after field planting).

Age of palms at first spiking was not affected by the four densities tested in the experiment.

Nut production per palm. Within individual treatments, the number of nuts produced per palm per year increased with increasing age, but the rate of increase was lower with increasing densities. By the fifth year of production, nut yield per palm per year of Treatment A was 88% higher than that of the first year of production. For the same period, nut production in Treatment D had increased by 62% only.

Comparisons between treatments clearly demonstrated the adverse effect of high density plantings on nut production per palm. The difference in nut production between Treatment A and Treatment D was 22 nuts per palm per year during the second year of production, and 26–27 nuts per palm per year during the following years (*Table 5*).

Cumulative production per palm during the first five years of yield recording was the highest in Treatment A, outyielding Treatments B, C and D by 4%, 7% and 15% respectively.

In an attempt to assess fruit set efficiency of the MAWA, the number of buttons produced in 1982 was compared with the number of nuts harvested in 1983. (*Table 6*).

It was observed that only 37% of the buttons developed successfully into mature nuts, and planting densities had no influence on fruit set. The significant differences in nut production between treatments was therefore due to differences in the total number of buttons produced per year, which was influenced by the number of inflorescences produced and not by the number of buttons per inflorescence.

5

TABLE 5. NUMBER OF NUTS PRODUCED PER PALM PER YEAR

Treatment	Nut production (No./palm/year)					Total
	1st year	2nd year	3rd year	4th year	5th year	
A	86	122	153	139	162	662
B	92	115	142	132	156	637
C	93	112	137	122	148	614
D	84	100	127	112	136	560
Mean	89	112	140	126	151	618
LSD (P=0.05)	ns	8.8	10.3	10.7	9.5	37.7
(P=0.01)	ns	13.4	15.6	16.3	14.5	57.1

TABLE 6. BUTTON vs. NUT PRODUCTION IN EIGHT-YEAR OLD MAWA

Treatment	No. of buttons per inflorescence[a]	No. of inflorescences per year	Total no. of nuts per year		Fruit set (%)
			Potential	Actual harvest	
A	26.9	16.4	441	162	37
B	26.5	16.1	427	156	37
C	25.1	15.6	392	148	38
D	24.4	15.4	376	136	36
Mean	25.7	15.9	409	151	37
LSD					
P=0.05	ns	0.37	45.0	9.5	–
P=0.01	ns	0.56	ns	14.5	–

[a] buttons = Female florets.

Nut production per hectare. The superior nut production per palm in Treatments A and B could not compensate for the low palm population per hectare. (*Table 7*) As a result, the cumulative number of nuts per hectare of the two treatments was 21% and 10% lower than that of Treatment C. The cumulative nut yield in Treatment D was the highest, but its superiority over Treatment C was not statistically significant. It is interesting to note the change in rating during the fifth year of harvest, when Treatment C had a small (though non significant) edge over Treatment D for the first time.

Copra production. Results of the laboratory analysis for albumin and oil content were similar between treatments and as such do not effect the interpretation of this trial.

6

TABLE 7. NUMBER OF NUTS PRODUCED PER HECTARE PER YEAR

Treatment	Nut production (No./ha/year)					Total
	1st year	2nd year	3rd year	4th year	5th year	
A	11,688	16,637	20,748	18,904	21,971	89,948
B	14,722	18,515	22,859	21,252	25,054	102,402
C	17,295	20,782	25,448	22,632	27,486	113,643
D	17,710	21,070	26,740	23,590	27,200	116,310
Mean	15,354	19,251	23,949	21,594	25,428	105,576
LSD (P=0.05)	1,661	1,473	1,902	2,000	1,710	6,939
(P=0.01)	2,515	2,230	2,880	3,028	2,590	10,205

Assuming a conversion rate of 5,000 nuts per tonne of copra, the copra yield per hectare in 1983 was as follows:—

Treatment Identity	Palms (No./ha)	Yield (tonnes/ha)
A	136	4.4
B	160	5.0
C	185	5.5
D	211	5.4

Optimum Density

From the production data given in *Table 7*, the optimum density for different ages was determined using a quadratic equation. The results are as follows:—

Third year of harvest 297 palms/ha.
Fourth year of harvest 228 palms/ha.
Fifth year of harvest 198 palms/ha.

On the basis of the above, the modified exponential curve, with yield Y as a function of age t : $Y = K + ab^c$ (where K, a and b are estimated parameters) was used to project the stable optimum density K. It was found to be 180 palms per hectare (*Figure 2*).

DISCUSSION

Amongst the various vegetative parameters, palm height appeared to be the best indicator of inter-palm competition. Recent measurements also suggest that petiole length could be an indicator of etiolation effect, but further measurements are necessary to confirm this observation.
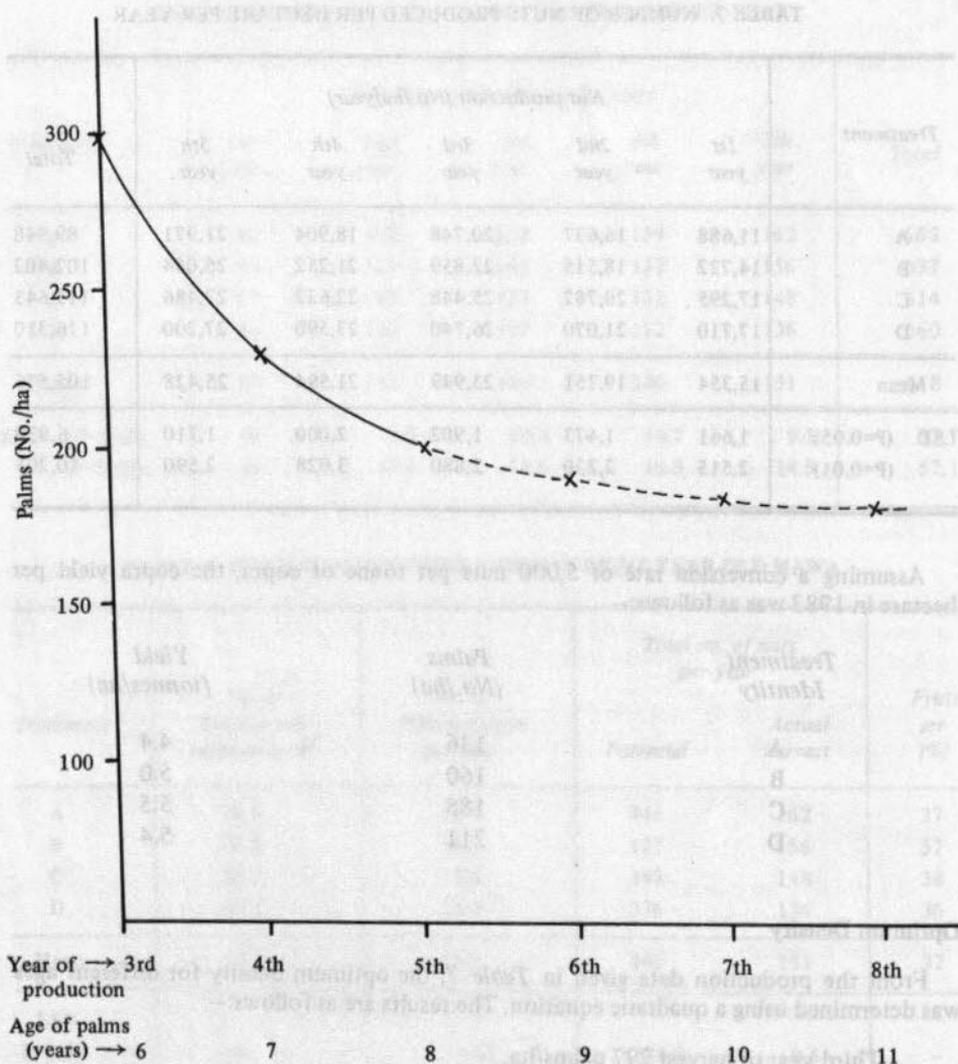
7

| Year of → production | 3rd | 4th | 5th | 6th | 7th | 8th |
| Age of palms (years) → | 6 | 7 | 8 | 9 | 10 | 11 |

Figure 2. Optimum density per hectare.

However, nut yield was more sensitive and the adverse effect of dense planting on yield per palm was expressed as early as the second year of production, but the higher palm population per hectare more than compensates for the lower yield per palm.

Based on the mathematical calculation, the optimum density for MAWA at eight-years was close to 200 palms per hectare and the stable optimum density is projected to be 180 palms per hectare. Given similar growth conditions and environment, MAWA hybrids planted at this density should yield in excess of 5.5 tonnes of copra by the tenth year after planting.

It is as yet too early to conclude this experiment, and further recording is necessary to confirm the stable optimum density for the MAWA hybrid.

8

At a later stage, it should be possible to extrapolate for optimum densities in other environments, from the results of this experiment.

ACKNOWLEDGEMENT

REFERENCES

FREMOND, Y. & DE NUCE DE LAMOTHE, M. (1971). Characteristics and Production of the Hybrid Coconut Palm, Malayan Dwarf x West African Tall. *Cocoa and Coconuts in Malaysia* (ed. R.L. Wastie & D.A. Earp) pp. 309–319. Kuala Lumpur: Incorporated Society of Planters, 1971

DE NUCE DE LAMOTHE, M. & ROGNON, F. (1975). The Hybrid Port-Bouet 121. New Results. *Oleagineux,* 30 (11), 457–465.

Dry Matter Production and Macro-Nutrient Content of the Nigerian Tall Coconut

U. OMOTI, D. O. ATAGA AND U. C. AMALU

Nigerian Institute for Oil Palm Research, Benin City, Nigeria

Growth quantities, accumulated and annual dry matter production, macro-nutrient composition and removal with respect to two Nigerian coconut cultivars, the Badagry Tall and NIFOR Tall, were studied by total harvesting and analysis of all the component parts of palms ranging in age from five to 32 years.

Data on accumulated dry matter production showed that the two cultivars at maturity produced at harvest between 528–804 kg dry matter per palm. The Nigerian NIFOR (Institute for Oil Palm Research) Talls generally had lower dry matter but were superior in nut production. Records of nuts and copra production of the palms, however, show them to be predominantly low to medium yielders (340–1680 kg copra per hectare per annum).

Chemical analysis of the various organs of the palms showed the predominance of potassium, followed by nitrogen, calcium, magnesium and phosphorus among the macro-nutrients. From the roots and above ground accumulated biomass, annual dry-matter production and percentage nutrient content, the amounts of nutrients immobilized and amounts removed annually were calculated. For the bearing palms, average annual nutrient removal was 142 kg N, 17kg P, 202kg K, 82kg Ca and 28kg Mg per hectare of 200 palms. The results suggest an imbalance in current fertilizer use and emphasize the need for increasing fertilizer input particularly K and N in order to improve growth and boost present yields.

Research on the coconut palm in Nigeria is comparatively recent and much of the work done over the last fifteen years has been on the introduction and evaluation of exotic and indigenous coconut genotypes with a view to identifying the best materials for planting and for the coconut breeding programme (Nigerian Institute for Oil Palm Research, 1976–1981).

With the initiation of agronomic experiments, the need has arisen for the rationalizing of fertilizer trials first, by ascertaining the nutrients which are in highest demand by the coconut palm and secondly, determining approximate amounts removed/or immobilized over a growing period. This information can be obtained rapidly from data on dry-matter production and nutrient analysis of the component parts of the palm. Studies of this kind have been carried out for coconut palms by several workers in Asia (Pillai, 1919, Sampson, 1923; Georgi & Teik, 1932, Patel, 1938, Carvalho, 1947; Davis, 1966) and more recently in the Ivory Coast by Ouvrier and Ochs (1978) for nuts of hybrid palms. Although information now abound from these studies, there is need for evaluating the nutrient removal under Nigerian conditions because as pointed out by Davis (1966) there is great variation in the values reported by the various workers probably due to

varietal differences, geographical and ecological situations, the experimental methods employed and the component parts of the palm used in the estimations.

Apart from enabling computation of nutrient removal, dry-matter production data *per se* is important in estimating the net photosynthetic production in relation to the photosynthetic apparatus of the crown and the supporting land area.

This paper reports on the dry matter production and macro-nutrient content of all the component parts of palms of two indigenous cultivars, the Badagry Tall and the NIFOR (Nigerian Institute for Oil Palm Research) Tall coconuts. The study was conceived as part of a broad programme to determine the dry-matter production, macronutrients and micronutrients content of the Tall, Dwarf, and Hybrid materials which are available to-date at the Main Station of the NIFOR and the Badagry coconut sub-station.

MATERIALS AND METHODS

Locations

The study was conducted in fields located at the NIFOR Main Station (06° 33'N, 05° 37'E, 149.2m alt.) and the Badagry coconut substation (06° 24'N, 02° 53'E, 7m alt.). Both locations are on the coastal plain sand. General information on the topography, climate and soil can be found in Vine (1956) and Ogunkunle *et al.* (1980) for NIFOR and in the FDA (1979) for Badagry.

Study Sites

At the NIFOR Main Station, palms from the coconut gene pools in Field 51 were used for the study. Field 51 lies at the northern and of the station characterized by very deep and very sandy soils of the Ahiara Series (Typic Dystropep, USDA Soil Taxonomy). The field has 1–2% slope and was first planted with coconuts between 1967 and 1968.

At Badagry Substation, palms from a 200 ha field located at Abia were used. The soils here are more clayey than the Main Station soils and belong to the Iju series classified as Typic Paleudult (FDA, 1979). The site is slightly depressed and drainage is fair-good. The land had been used for arable crops mostly maize before the establishment of coconuts in 1978.

At both sites, planting is at a spacing of 7.5 x 7.50m triangular giving a density of about 200 palms per hectare. At the Badagry Sub-Station, NPK Mg compound fertilizer is routinely applied at the rate of 2.5kg per palm per year. Field 51 on the other hand has not been fertilized for some years now. The palms at the NIFOR Main Station are under natural cover while at Badagry there is a mixed leguminous cover of *Pueraria phaseoloides* and *Centroscema pubescens* in the interrows leaving bare strips along the harvesters' paths.

Some soil properties of the sites are given in *Table 1.*

Palms

Two cultivars, the NIFOR Tall (NFT) and the Badagry Tall (BDGT) were used for the investigation. These cultivars were selected because they have been best studied among the numerous cultivars of the Nigerian Tall. A total of twelve palms representing different

2

TABLE 1. SOME PHYSICAL AND CHEMICAL PROPERTIES OF NIFOR AND BADAGRY SOILS SUPPORTING THE PALMS

Soil	Depth (cm)	pH H$_2$O 1:1	Exchangeable Cations (me/100g)				Exchange Acidity (me/100)	ECEC (me/100g)	C (%)	N (%)	Avail. P (ppm)	Particle size Analysis			Bulk density (g/cm^3)
			Ca	Mg	K	Na						Clay (%)	Silt (%)	Sand (%)	
NIFOR (Field 51)	0–15	4.40	0.50	0.10	0.13	0.01	0.90	1.64	1.40	0.15	5.97	12.8	1.9	85.3	1.51
	15–30	4.40	0.60	0.20	0.19	0.02	1.00	2.01	0.78	0.12	2.81	13.8	1.9	84.3	1.53
	30–60	4.40	0.50	0.20	0.19	0.02	0.80	1.89	0.60	0.13	1.76	13.8	1.9	84.3	1.56
	60–90	4.45	0.40	0.20	0.26	0.01	1.00	1.87	0.52	0.085	2.11	14.8	1.9	83.3	1.59
	90–120	4.60	0.40	0.10	0.13	0.01	1.00	1.64	0.44	0.12	1.76	15.8	1.9	82.3	1.68
	120–150	4.70	0.35	0.15	0.06	0.01	0.80	1.37	0.40	0.075	1.27	15.8	1.9	82.3	1.66
Badagry (Abia)	0–15	5.40	2.65	1.55	0.29	0.01	0.10	4.50	1.6	0.16	5.27	21.8	4.9	73.3	
	15–30	5.60	2.10	1.00	0.064	0.01	0.10	3.27	1.00	0.13	3.51	27.8	2.9	69.3	
	30–45	5.35	1.80	1.20	0.064	0.01	0.40	3.47	0.96	0.18	1.40	38.8	1.9	59.3	
	45–60	5.20	1.60	1.00	0.19	0.02	0.40	3.21	0.88	0.11	0.35	41.8	1.9	56.3	
	60–75	5.50	1.60	1.00	0.13	0.01	0.40	3.14	0.82	0.11	0.35	41.8	1.9	56.3	

3

age groups were selected for study. The intention was to select palms from each cultivar, representing the important physiological growth stages in the economic life of the coconut palm. However, owing to the limitations posed by the availability of materials and the age ranges available, only two palms of each in the age group five, 11, 13 and 32-year-old trees of the NIFOR Tall and five and 13-year old of the Badagry Tall cultivar could be worked upon. These age groups represent pre-flowering initiation stage, early maturity and maturity stages. The five-year olds were located at the Badagry Substation while the 11, 13 and 32-year olds were located at the NIFOR Main Station. The selected palms did not show any specific symptoms of possible nutritional deficiencies and no abnormalities were observed. It is to be noted however, that some palms in Field 51 quite often exhibit symptoms suggesting K/or Mg deficiency. The two 32-year-old palms were from Field 61 (The NIFOR Palmetum), located on a more clayey soil, west of the Main Station.

Field Operations

To determine the total dry-matter production, individual palms were harvested and sampled according to the main morphological units of the palms. Harvesting of the palms in the NIFOR Main Station was done between February and April, 1981 while the five-year-old palms at the Badagry Substation were harvested in August, 1982.

Leaflets. First, a climber went up the palm and tagged the fronds from the last fully-opened frond counted as No. 1 to the oldest non-desiccated frond. Then the fronds were cut down. The leaflets from each frond were stripped off the rachises and weighed in the field in previously tarred sacks. For the young five-year-old palms tagging and harvesting of the fronds were done at ground level.

Rachises. The rachises including the petiole were cut into short lengths and weighed. After weighing they were further quartered down and chopped into small pieces which were bagged.

Spear leaves. The unopened spear leaves were cut down after the fronds and after the palm had been felled. The spear leaves were cut up into sections, weighed and further quartered down and taken to the laboratory.

Growing point. The growing point or cabbage was taken as that soft succulent portion of the stem and was cut off from the trunk after felling the palm. It was cut into sections and weighed. The various sections were further quartered, chopped, bagged and taken to the laboratory.

Bunches and inflorescences. The inflorescences, the mature and immature fruit bunches including the stalks were harvested and weighed. Each bunch was tagged and the fruits labelled and weighed individually.

The trunk. The trunk was cut down at the beginning of the root system with a Dolmar motor-saw. The total length of the trunk was measured and then cut into regular one meter long sections which were furthered sectioned and weighed. The saw dust from each cut was collected with a polythene sheet placed underneath the trunk. This dust was weighed and the weight added to the weight of the corresponding section. Measurements of the diameter and circumference of the regular 1m cylinderical sections were made with a view to determine the volume and bulk density of the trunk. Each section of the trunk was quartered down, cut into small pieces which were bagged and taken to the labora-

4

tory. The small trunk of the five-year-old palms was only exposed after removing the fronds.

Roots. The total amount of roots produced by the palms was estimated from the roots excavated from four rectangular trenches 3.5 x 0.8 x 2.0m radiating from the bole in an E.W and N.S directions and representing about 22.4% the ground area allocated to each palm. At the depth of 2.0m nearly all the roots were removed. The excavated roots were shaken in a builder's sieve to remove soil particles, weighed then washed with a jet of water and then sub-sampled. The cone-shaped bole of the palm and associated roots were dug up and added to the total root weight.

Pre-treatment of Samples

In the laboratory, the leaflets, rachises, spear leaves, cabbage, stem roots and inflorescences were furthered quartered, chopped into small pieces and from these triplicate 1.0kg weighed out into labelled paper bags and oven-dried in a forced draft oven to constant weight at 80°C for two to three days.

The leaflets samples intended for chemical analysis were taken separately from the base, middle and tip sections of the frond on both sides of the rachises and composited. The leaflets were cleaned with cotton wool moistened in 0.2% 'Teepol' detergent solution to remove dust. The mid-ribs were then removed and the lamina chopped into pieces of about 2–3cm and oven-dried.

The fruits were dehusked and the nuts weighed. Husk weight was then determined by difference. The nuts were cracked and drained and then weighed. The weight of nut water was determined by difference. The shell was separated from the copra and weighed and the copra fresh weight determined by difference. The husk, shell and copra components from each fruit were oven-dried to constant weight while the coconut water was stored in plastic bottles in a deep freezer.

After over-drying, all the samples with the exception of the shell and copra were milled to pass a 1mm sieve using a micro-hammer mill. The milled samples were stored in sealed polythene bags.

Dry-matter Production of 13-year-old Badagry Tall and 32-year-old NIFOR Tall

The 13-year-old Badagry Tall and the 32-year-old NIFOR Tall could not be destructively harvested as they are limited in number and are an important source of material for the coconut breeding programme – the 32-year-old NIFOR Tall for instance being regarded as very good mother palms. Their dry-matter production, therefore, had to be estimated as follows:

Fronds. The total number of fronds were counted and a frond was sampled from each whorl in the phyllotaxy. These fronds were separated into leaflets and rachises oven dried and weighed and the mean dry matter per frond for the leaflets and rachis obtained. These figures were multiplied by the total number of fronds to get the total dry-matter produced by the leaflets and rachises.

The trunk. The trunk dry-matter was estimated from measurements of the trunk height, circumference and a mean stem dry bulk density of $0.27g/cm^3$ (range 0.64–$0.10g/cm^3$) obtained from the 11 and 13-year-old NIFOR Talls.

5

Fruit bunches and inflorescences. These were estimated from yield records of nuts and inflorescence production and then converted to dry-matter from dry-matter to fresh weight ratios obtained from the 11 and 13-year-old NIFOR Tall palms.

Roots. An estimate of the total above ground dry biomass having been obtained, the roots dry-matter production was obtained using an above ground to root dry-matter ratio of about 2 obtained for all the other palms including the five-year-olds.

Chemical Analysis

For the component parts except the shell, copra, and coconut water, 1g of the finely ground sub-sample was re-dried at 105°C for 2 h and ashed at 550°C for 3 h in a muffle furnace. The ash was digested in a hot water bath for 30 min with 25ml of 20% HNO_3 filtered and made up to 250ml with distilled water. Aliquots from these were used for the estimation of P, K, Ca, Mg, and Na. For nitrogen, a separate 0.120g of dried sample was digested by the micro-Kjeldahl digestion method and the digest made up to 100ml. Potassium, Calcium and Sodium were determined by flame photometry using an EEL flame photometer. Magnesium was determined colorimetrically by the Titan Yellow method. Nitrogen and phosphorus were determined on the Technicon (AA2) auto-analyser, the former by the indophenol blue method and the latter by the molybdenum blue method.

The shell, copra and coconut water were ashed by the wet oxidation method using 20ml of perchloric and nitric acid mixture (ratio 1:2). The shell was crushed with a hammer and 1g of it ashed. The copra was cut into small pieces and 1g taken for ashing. For the coconut water, 5—10ml was weighed out and evaporated to dryness in a beaker and the residue taken up in the oxidation mixture. The samples were all made up to volume in a 100ml volumetric flask and the elements analysed as for the other components.

RESULTS

Total Dry-matter Production

The total dry-matter produced by the palms is shown in *Table 2.* In the five-year-old palms, the crown which includes the spear leaves, cabbage, leaflets, rachises and inflorescences accounted for about 52% of the total dry matter produced with the photosynthetic leaflets accounting for 17% in the BDGT and 22% in the NFT.

The two cultivars had about the same proportion (about 37%) of dry matter in the roots. The BDGT had about 15% dry matter in the trunk and the NFT 8%. On the older palms the bulk of the dry-matter was in the trunk (37—49%), followed by the roots which were similar and averaged about 34% and the crown with a percentage dry matter varying from 10% in the 32-year-old NFT to about 24% in the 11 and 13-year-old NFTS. The percentage of dry matter by the photosynthetic leaflets was further reduced in these older palms to between 5% and 9%. Generally, the Badagry Talls had more dry-matter than the NIFOR Talls.

The fruits or nuts dry matter was very low and ranged from 1—7% of the total dry matter. The distribution of the dry matter in this organ into husk, shell, copra and coconut water is shown in *Table 3.*

TABLE 2: AVERAGE DRY-MATTER (DM) PRODUCTION OF STANDS OF NIGERIAN TALL COCONUTS OF VARIOUS AGES

Palm age (years)	Cultivar	Location	Dry weights (kg/palm)							Total D.M. production (kg)	D.M. production per ha. (kg)
			Spear Leaves and Cabbage (kg)	Leaflets (kg)	Rachises and Petiole (kg)	Trunk[a] (kg)	Inflorescences (kg)	Fruit Bunches (kg)	Roots in upper 200cm of soil (kg)		
5	Badagry Tall	Badagry	2.1	12.1	21.3	10.4	-	-	25.7	71.6	14320
5	NIFOR Tall	Badagry	1.0	6.7	9.1	2.4	-	-	11.5	30.7	6140
11	NIFOR Tall	NIFOR	9.2	48.1	79.2	193.7	6.9	6.7	184.2	528.0	105600
13	NIFOR Tall	NIFOR	11.8	49.9	81.7	230.3	7.9	28.4	206.1	616.1	123220
13	Badagry Tall	NIFOR	13.7	55.7	94.8	355.1	9.0	7.7	268.0	804.0	160800
32	NIFOR Tall	NIFOR	5.8	32.0	23.6	295.9	6.0	39.4	198.2	600.9	120180

a Trunk heights were: 5 yr. BDGT 0.7m, 5 yr. NFT 0.8m, 11 yr, NFT 7.7m, 13 yr. BDGT 10.1m, 13 yr. BDGT 9.1m and 32 yr. NFT 11.8m.

– No inflorescences and no bunches.

TABLE 3: AVERAGE DRY MATTER COMPOSITION OF FRUITS FROM PALMS OF DIFFERENT AGES

Fruit Components	11-Year NFT DM (kg)	13-Year NFT DM (kg)	13-Year BDGT DM (kg)	32-Year NFT DM (kg)	Average Composition (%)
Husk	4.6	17.4	4.2	23.0	60.7
Shell	1.0	5.4	1.8	7.9	19.3
Copra	1.03	5.5	1.7	8.4	19.6
Water	0.03	0.09	0.04	0.12	0.4
Total DM	6.7	28.4	7.7	39.4	100.0

Percentage Macronutrient Composition

The average percentage content of N, P, K, Ca, Mg and Na in the various organs is given in *Tables 4* and *5*. Except for nitrogen in the leaflets and copra, irrespective of cultivar, age and location, the potassium percentage concentration was the highest in the various plant parts followed by nitrogen, calcium, magnesium, phosphorus and sodium in decreasing order. The levels of all the elements but particularly potassium were very high in the growing portions of cabbage and spear leaves, in the inflorescences, husk and in the coconut water where the K content reached about 10% on dry matter basis or about 1g/litre (*i.e.* 1000 ppm K).

The five-year-old palms had higher levels of Ca and Mg in the cabbage, spear leaves and trunk than the older palms. In the five and 11-year-old palms for which complete sodium determination was performed, this element was at a lower level than the other cations.

Nutrients Stored per Hectare of Land

The nutrients stored per hectare of palms in the various component parts are given in *Table 6*. The results follow the trend in *Tables 4* and *5* and show that very large amounts of potassium, nitrogen and calcium are immobilized by a hectare of palms. In the five-year-olds, the bulk of the nutrients is stored in the crown components while in the older palms, the largest proportion is immobilized in the trunk, followed by the crown and roots. The amount removed in the nuts is relatively small. In the nuts, however, the nutrient immobilization shows that the K demand is on a very high level roughly doubling the N removed in all the palms.

Annual Growth and Dry-matter Production

Annual growth quantities and dry-matter production per palm are given in *Table 7*. The annual growth quantities of the roots and cabbage are not presented as these could not be estimated.

For the frond and nut production, annual yield records for the palms studied or mean values of several palms of the same age and cultivar taken over a number of years, where available, were used to increase reliability. The trunk annual increment was not determined but a value of 30cm per annum based on work done on tall palms in India (Davis, 1966) was assumed for the 11–32-year-old palms. In the five-year-old palms because of the small weight of the trunk which was not apparent at this age and because measurements of its circumference and even height were not as clearcut as in the older palms, its annual increment could not be estimated. In proportion to the fronds, the error involved in neglecting this component must be very small. For the older palms the annual stem increment was converted to annual dry matter using the previously determined dry bulk density and volume of the sections.

Annual Nutrient Removal

The relative amounts of the nutrients removed per palm per annum followed the pattern observed earlier except that in the components of the bearing palms, the proportion of nutrients removed in the various organs changed. The amounts in the nuts increased such that in the 13 and 32-year-old NFTS, the total amount of the various nutrients removed per annum in the nuts was higher than in the other components.

8

TABLE 4: AVERAGE PERCENTAGE MACRO-NUTRIENT CONCENTRATION IN VARIOUS PARTS OF PALMS

Nutrient element (%)	Plant parts	Cultivar and age of palm in years						Mean
		5 BDGT	5 NFT	11 NFT[a]	13 NFT[a]	13 BDGT	32 NFT	
N	Cabbage	1.46	2.42	1.88	1.14	–	–	1.6 ± 0.320[b]
	Spear Leaves	1.79	1.05					
	Leaflets	2.10	1.77	1.95	1.89	1.84	1.85	1.91 ± 0.125
	Rachises	0.59	0.42	0.49	0.66	0.56	0.53	0.54 ± 0.092
	Trunk	1.28	1.28	1.05	1.06	–	–	1.17 ± 0.130
	Roots	0.44	0.22	0.77	0.73	–	–	0.54 ± 0.259
	Inflorescence	–	–	1.24	1.06	–	–	1.15
P	Cabbage	0.48	0.55	0.21	0.10	–	–	0.26 ± 0.134[b]
	Spear Leaves	0.19	0.24					
	Leaflets	0.15	0.14	0.15	0.12	0.11	0.11	0.13 ± 0.019
	Rachises	0.08	0.06	0.23	0.11	0.06	0.07	0.10 ± 0.066
	Trunk	0.11	0.11	0.22	0.12	–	–	0.14 ± 0.054
	Roots	0.05	0.04	0.12	0.05	–	–	0.07 ± 0.037
	Inflorescence	–	–	0.31	0.21	–	–	0.26
K	Cabbage	3.62	3.88	4.08	2.39	–	–	3.02 ± 0.73[b]
	Spear Leaves	1.91	1.77					
	Leaflets	0.78	0.64	1.35	1.44	1.16	0.63	1.00 ± 0.362
	Rachises	0.88	0.94	1.28	1.15	1.08	0.39	0.95 ± 0.311
	Trunk	1.31	1.31	1.78	0.93	–	–	1.33 ± 0.348
	Roots	0.34	0.53	0.62	1.22	–	–	0.68 ± 0.380
	Inflorescence	–	–	2.83	3.01	–	–	2.92
Ca	Cabbage	1.54	2.73	0.74	0.71	–	–	1.08 ± 0.497[b]
	Spear Leaves	0.61	0.83					
	Leaflets	0.49	0.48	0.59	0.47	0.69	0.62	0.56 ± 0.090
	Rachises	0.48	0.75	0.45	0.58	0.66	0.67	0.60 ± 0.117
	Trunk	0.75	0.75	0.43	0.48	–	–	0.60 ± 0.172
	Roots	0.19	0.31	0.15	0.24	–	–	0.22 ± 0.069
	Inflorescence	–	–	0.72	0.86	–	–	0.79
Mg	Cabbage	1.62	1.44	0.35	0.16	–	–	0.70 ± 0.583[b]
	Spear leaves	1.00	0.47					
	Leaflets	0.18	0.51	0.16	0.17	0.29	0.33	0.38 ± 0.247
	Rachises	0.37	0.37	0.12	0.14	0.25	0.24	0.25 ± 0.108
	Trunk	0.46	0.46	0.08	0.10	–	–	0.25 ± 0.241
	Roots	0.09	0.07	0.11	0.05	–	–	0.08 ± 0.026
	Inflorescence	–	–	0.27	0.57	–	–	0.42
Na	Cabbage	0.38	0.23	0.09	–	–	–	0.20 ± 0.106[b]
	Spear leaves	0.22	0.20					
	Leaflets	0.17	0.19	0.06	–	0.12	0.17	0.14 ± 0.053
	Rachises	0.42	0.37	0.10	–	0.16	0.28	0.25 ± 0.149
	Trunk	0.45	0.45	0.8	–	–	–	0.33 ± 0.214
	Roots	0.22	0.18	0.06	–	–	–	0.15 ± 0.083
	Inflorescence	–	–	0.07	–	–	–	

–Not determined.
[a]The cabbage and spear leaves were combined and analysed for the various elements.
[b]Means of cabbage and spear leaves.

TABLE 5. AVERAGE PERCENTAGE MACRO-NUTRIENT CONCENTRATION IN COMPONENTS OF NUTS OF THE 11 AND 13-YEAR—OLD NFT PALMS

Nut Components	Nutrient element (% DM.)					
	N	P	K	Ca	Mg	Na
Husk	0.62	0.05	1.77	0.61	0.08	–
Shell	0.03	0.03	0.44	0.19	0.01	–
Copra	1.30	0.11	0.80	0.19	0.07	–
Water	0.84	0.50	18.64	5.47	0.64	–

TABLE 6. AVERAGE AMOUNT OF MCRO-NUTRIENT STORED PER HECTARE IN VARIOUS PARTS OF NIGERIAN TALL COCONUT PALMS OF DIFFERENT AGES

Palm age (Years)	Cultivar	Plant Part	Nutrient element immobilized (kg/ha)					
			N	P	K	C	Mg	Na
5	BDGT	Crown	82.8	8.2	67.8	36.8	41.0	23.2
		Trunk	26.6	2.2	27.2	15.6	9.6	9.4
		Roots	22.6	2.6	17.4	9.8	4.6	11.4
		Total	132.0	13.0	112.4	62.2	55.2	44.0
5	NFT	Crown	34.8	3.6	31.4	23.6	15.5	9.8
		Trunk	6.2	0.6	6.2	3.6	2.2	2.2
		Roots	5.0	0.8	12.2	7.2	1.6	4.2
		Total	46.0	5.0	49.8	34.4	19.3	16.2
11	NFT	Crown	317.0	59.0	446.6	151.6	44.6	23.8
		Trunk	406.8	85.2	689.8	166.6	31.8	31.0
		Roots	283.6	44.2	228.4	55.2	40.6	20.6
		Nuts	8.6	0.8	20.0	7.0	1.0	–
		Total	1016.0	189.2	1384.8	380.4	118.0	75.4
13	NFT	Crown	393.0	37.6	432.4	172.4	52.6	
		Trunk	491.2	56.8	427.0	222.2	44.4	
		Roots	306.8	20.4	513.8	99.8	20.2	
		Nuts	41.2	4.8	86.0	26.6	5.0	
		Total	1232.2	119.6	1459.2	521.0	122.2	
13	BDGT	Crown	361.4	32.2	453.6	236.8	94.4	43.8
		Trunk	752.8	85.2	660.4	340.8	67.4	
		Roots	391.2	26.2	654.0	128.6	25.8	
		Nuts	11.6	1.4	24.2	7.6	1.4	
		Total	1517.0	145.0	1792.2	713.8	189.0	43.8
32	NFT	Crown	169.4	15.0	122.8	89.8	40.4	24.0
		Trunk	627.4	71.0	550.4	284.0	56.2	
		Roots	289.4	19.4	483.2	95.2	19.0	
		Nuts	51.0	4.6	106.2	35.6	5.4	
		Total	1137.2	110.0	1263.0	504.6	121.0	24.0

TABLE 7. ANNUAL GROWTH AND DRY-MATTER PRODUCTION RATES OF COCONUT PALM PARTS OF VARIOUS AGES (200 PALMS/HECTARE)

Palm age (Years)	Cultivar	Annual growth		Nut Production Fresh (No./Wt. (kg))	Annual dry-matter production per palm					
		Stem increment[a] (cm)	Frond Production (No.)		Leaflets (kg)	Rachises (kg)	Inflores- cences (kg)	Nuts (kg)	Trunk (kg)	Total (kg)
5	Badagry Tall	–	4.3 ± 1.06[b]	–	3.7	6.5	–	–	–	10.2
5	NIFOR Tall	–	3.7 ± 0.76[b]	–	2.2	2.9	–	–	–	5.1
11	NIFOR Tall	30	6.6 ± 1.74[c]	17.0/24.6[d]	12.1	19.9	6.9	8.5	4.9	52.3
13	NIFOR Tall	30	8.2 ± 2.49[c]	24.5/81.2[e]	15.7	25.7	7.9	28.4	7.1	84.8
13	Badagry Tall	30	9.5[c]	19.8 ± 2.23/22.9 + 2.60[f]	19.2	32.8	9.0	7.7	11.7	80.4
32	NIFOR Tall	30	11.6[d]	73.3 ± 36.28/98.6 + 48.8[g]	12.0	8.9	6.0	39.4	7.5	73.8

a – Assumed from Davis (1966)

b & c – Figures for the five- year old palms are means of 42 palms for the Badagry Tall and 33 palms for the NIFOR Tall taken over four years while the figures for the 11 & 13 year-old are actual values for the palms harvested recorded over five years (Akpan, 1983).

d – From NIFOR Progress Report on 1979/1980 Annual Research programme.

e – Actual values for the palm harvested.

f – Mean of 28 palms (NIFOR Progress Report on 1981 Annual Research Programme).

g – Calculated from two years yield data on the two palms reported in NIFOR 1978/79 Annual Report.

– – Not determined.

11

The annual nutrient removal expressed per hectare is presented in *Table 8*. The table shows that the amount of all nutrient removed per hectare per annum in the nuts increases in direct proportion to the copra yield per annum. At the highest yield attained in the 32-year-old NFT, the K removed annually in the nuts exceeds that in all the other components combined. Although the copra yield varied, the total amount of nutrient removal per annum for both nut production and growth of the entire plant are similar for the 11–32-year-old palms. The means together with their standard errors have therefore been given for these four groups of palms.

DISCUSSION

Vegetatively, the Badagry Tall cultivars are more vigorous and more robust than the NIFOR Talls and the results of dry matter production per palm at the two locations confirm this. This higher total dry matter production has not, however, been reflected in the yields at the NIFOR Main Station where the NIFOR Talls have been found to out-yield the Badagry Talls. This superiority in yield has been attributed to the fact that the NIFOR Talls have undergone two cycles of purposive selection for higher yield (Nigerian Institure for Oil Palm Research, 1979; 1981). Comparison of the total dry-matter production figures obtained in this study with those of Tall coconuts elsewhere is difficult as such data are not reported in the literature available to us. However, the dry-matter yield of 528–804kg/palm from these 11 to 32-year old palms is quite appreciable and is of the same order of magnitude as the figures obtained by Rees and Tinker (1963) for oil palms of equivalent ages planted at a density of 148 palms per hectare under Nigerian conditions. For the five-year-old coconuts, however, the disparity in dry-matter yield compared with similar ages of oil palm is very great; at this age the coconuts dry-matter yield is very much smaller. The root dry-matter production in these coconuts is substantial and this merits attention. For the old coconut palms it averaged about 34% of total dry-matter yield. This figure is much higher than the value of about 17% obtained for the oil palm from the work of Rees and Tinker. Considering the natural habitat of coconuts which is the coastal areas, high root density is obviously needed to ensure a good achorage.

Turning to the annual growth quantities, yield and dry-matter production, both the Badagry and NIFOR Talls have very low rate of leaf production (3.7–4.4 per annum for the five-year-olds) and low yields of nuts and copra (340–1100kg copra/ha for the 11 and 13-year-olds) compared with the Malaysian Talls which at five-year produce 13.9 leaves per annum and at seven years up to 1542kg/ha per annum of copra (Vanialingam *et al.*, 1978). Even at the age of 32 years, at which stable yield should be expected, the 32-years-old reported in this study which are among the best mother palms in the NIFOR collection, only yield 1680kg copra per hectare per annum. It is likely that the climatic conditions — particularly the unfavourable rainfall distribution in Nigeria in which there is a dry season that lasts upto four months, the genetic quality of the palms themselves and inadequate fertilizer and other management inputs are responsible for the poor performance of these Nigerian Talls.

The nutrient content and nutrient removal estimates of these palms show the predominance of potassium, followed by nitrogen and calcium and the relatively very low removal of magnesium and phosphorus among the macro-nutrients. In many previous reports summarized by Menon and Pandalai (1958) the order of importance of the nutrients is often given as K, N, P, Mg and Ca. The order of K, N, Ca, Mg and P obtained in this study is in agreement with the results of Davis (1966). The amounts of these elements immobilized (*Table 6*) are large and although the annual nut and copra yields are low —

12

TABLE 8. AVERAGE ANNUAL MACRO-NUTRIENT REMOVAL PER HECTARE BY COCONUT PALMS OF DIFFERENT AGES FOR GROWTH AND NUT PRODUCTION (200 PALMS/HA)

Palm age (Years)	Cultivar	Plant part	Copra yield (kg/ha)	Nutrient element removed (kg/ha)					
				N	P	K	Ca	Mg	Na
5	BDGT	Above ground	–	23.2	2.2	17.2	9.8	10.0	6.6
		Nuts		–	–	–	–	–	–
		Total		23.2	2.2	17.2	9.8	10.0	6.6
5	NFT	Above ground	–	10.2	1.0	8.2	6.6	4.4	3.0
		Nuts		–	–	–	–	–	–
		Total		10.2	1.0	8.2	6.6	4.4	3.0
11	NFT	Above ground		94.4	19.2	140.0	46.4	13.2	7.2
		Nuts	366	11.2	1.0	23.0	7.8	1.2	–
		Total		105.6	20.2	163.0	54.2	14.4	7.2
13	NFT	Above ground		125.2	14.6	165.2	65.0	23.0	–
		Nuts	1100	41.2	4.8	86.0	26.6	5.0	–
		Total		166.4	19.4	251.2	91.6	28.0	–
13	BDGT	Above ground		151.4	15.0	191.4	96.2	40.2	15.0
		Nuts	340	11.6	1.4	24.2	7.6	1.4	–
		Total		163.0	16.4	215.6	103.8	41.6	15.0
32	MFT	Above ground		82.6	8.2	72.2	44.4	20.4	9.0
		Nuts	1680	51.0	4.6	106.2	35.6	5.4	–
		Total		133.6	12.8	178.4	80.0	25.8	9.0
		Mean Nutrient removal per ha. for the 11–32 years-old palms		142.2 ± 28.47	17.2 ± 3.36	202.1 ± 39.51	82.4 ± 21.16	27.5 ± 11.16	

13

medium, the annual removal of potassium, nitrogen and calcium in general growth and nut production is equally considerable (*Table 8*). The average annual amounts of 142kg N, 17.2kg P and 202.1kg K removed per hectare of 200 palms in this study are similar to the 126kg N, 19.6kg P and 120kg K removed by 156 palms per hectare reported by Carvalho (1947). The calcium annual removal in this study is much higher than those reported by earlier workers (*e.g.* Georgi & Teik, 1932; Cooke, 1950; Davis, 1966).

Per tree, the average nutrient removal for the bearing palms was 0.71kg N, 0.09kg P, 1.0kg K, 0.4kg Ca and 0.14kg Mg.. This removal when related to the current annual routine dressing rate of 2.5kg per palm of an 12:12:17:2 NPK Mg compound fertilizer, calculations show that the supply of N, K and Mg in this formulation just make good the amount of these elements removed annually. P on the other hand is over supplied while Ca has been found to rank third in importance is not given at all except perhaps from the phosphate fertilizer. To correct for this imbalance in the fertilizer application the use of single fertilizers mixed in the proportion obtained in this study and tested by further field experimentation is desirable.

The West African Talls according to Ouvrier and Ochs (1978) are capable of yielding up to 3.5 tonnes of copra per hectare per annum. Inspection of *Table 8* shows that for the yielding palms, the amount of nutrients removed in the nuts is directly proportional to the copra yield and per kilogram of copra, the amount of nutrient removed is approximately the same irrespective of age and cultivar. On the average this is about 0.033kg N, 0.0035 kg K, 0.022kg Ca and 0.0038kg Mg. Based on this, to produce 3.5 tonnes of copra about 115.5kg N, 12.3kg P, 241.5kg K, 77.0kg Ca and 13.3kg Mg would be removed in the nuts per hectare per annum and about 229.4kg N, 26.5kg P, 383.2kg K, 140.0kg Ca and 37.5kg Mg for both nut production and the growth of the entire plant. The removal of N, K and Ca are enormous and to achieve this yield or even improve on present yields under Nigerian conditions, more selection and a much higher fertilizer input would be necessary.

The annual nutrient removal of the young palms up to the age of five years is very low when compared to the bearing palms. The data suggests that a plantation under legumes and which is not deficient in K, Ca and Mg should be able to provide the necessary plant nutrients. In less than these ideal conditions, however, as in Field 51 at the NIFOR Main Station, moderate applications of about 0.5kg each of N and K which appear to be required in about equal amounts at this age and about 0.1–0.2kg of each of Ca and Mg the latter which according to Cooke, (1953) is most essential for the development of the wood tissue in young coconut palms would seem adequate.

ACKNOWLEDGEMENT

REFERENCES

AKPAN, E. E. J. (1983). Private communication. Nigerian Institute for Oil Palm Research, Benin City.

CARVALHO, R. F. DE. (1947). The fertilising of coconut palms. *Bol. Sec. Agric. Perambuco*, **14**, 275–278. Cited by MENON, K.P.V. & PANDALAI, K.M. (1958).

COOKE, F. C. (1950). The tapering disease of coconuts. *Ceylon Coconut Quart.*, **1**, 17–21.

DAVIS, T. A. (1966). Contribution to the physiology of the coconut palm. *Proc. FAO Technical Working Party on Coconut Production, Protection and Processing. Colombo, Ceylon 1964*, 150.

FEDERAL DEPARTMENT OF AGRICULTURE (FDA) (1979). Report on the 2nd Southwest zone soil correlation committee meeting. Badagry 1979, 17.

GEORGI, C. D. V. & TEIK, G.L. (1932). The removal of plant nutrients in coconut cultivation. *Malay. agric. J.*, **20**, 358–364. Cited by MENON, K. P. V. & PANDALAI, K.M. (1958).

MENON, K. P. V. & PANDALAI, K. M. (1958). *The Coconut Palm – A Monograph*, pp. 155–183. Ernakulam: Indian Central Coconut Committee.

NIGERIAN INSTITUTE FOR OIL PALM RESEARCH (1976). Twelfth Annual Report, NIFOR, 1975–76, pp. 40–46.

NIGERIAN INSTITUTE FOR OIL PALM RESEARCH (1977). Thirteenth Annual Report, NIFOR, 1976–77, pp. 34–36.

NIGERIAN INSTITUTE FOR OIL PALM RESEARCH (1978). Fourteenth Annual Report, NIFOR, 1977–78, pp. 56–58.

NIGERIAN INSTITUTE FOR OIL PALM RESEARCH (1979). Fifteenth Annual Report, NIFOR, 1978–79, pp. 56–63.

NIGERIAN INSTITUTE FOR OIL PALM RESEARCH (1980). Progress Report on the 1979/1980 Annual Research Programme, pp. 89–92.

NIGERIAN INSTITUTE FOR OIL PALM RESEARCH (1981). Progress Report on the 1981 Annual Research Programme, pp. 156–157.

OGUNKUNLE, A. O., OMOTI, U., ATAGA, D. O. & ESEICHE, A. (1980). Field Tour Rept. 8th Joint Ann. Conf. Nat. Soil Corr. Comm. and the Soil Science Society of Nigeria, Benin City, 1980.

OUVRIER, M. & OCHS, R. (1978). Nutrient removal by hybrid coconut Port-Bouet 121 (MAWA). *Proc. Int. Conf. on Cocoa and Coconut Kuala Lumpur 1978*, 595.

PATEL, J. S. (1938). *The Coconut – A monograph*. Cited by MENON, K. P. V. & PANDALAI, K. M. (1958).

PILLAI, N. K. (1919). Coconut – the wealth of Travancore. *Agri. J. India*. Cited by MENON, K. P. V. & PANDALAI, K. M. (1958).

REES, A. R. & TINKER, P. B. H. (1963). Dry-matter production and nutrient content of plantation oil palms in Nigeria. *Pl. Soil*, **19**, 19–32.

SAMPSON, H. C. (1923). *The Coconut Palm*, pp. 170–211. London: John Bale, Sons & Danielson Ltd.

VANIALINGAM, T., KHOO, K. T., & CHEW, P. S. (1978). Performance of Malayan Dwarf x Tall Coconut Hybrids in Peninsular Malaysia. *Proc. Int. Conf. on Cocoa and Coconuts, Kuala Lumpur, 1978*, 532.

VINE, H. (1956). Studies of Soil profiles at the W.A.I.F.O.R. Main Station and at some other sites of oil palm experiments. *J. West Afri. Inst. Oil Palm Res.*, **1**, 8–59.

Dry Matter and Nutrient Composition in Hybrid Coconuts (MAWA) and Cocoa on Coastal Clay Soils

K.C. TEOH, K.S. CHAN AND P.S. CHEW

Highlands Research Unit Sdn. Bhd., Kelang, Selangor

Information on the dry matter and nutrient composition of MAWA hybrid coconuts and cocoa on coastal clay soil has not been available in Malaysia. As hybrid coconuts will in the future be mainly planted as shade trees with cocoa, a study involving the destructive sampling of MAWA coconuts was supplemented by another involving cocoa planted under coconuts.

The coconuts were sampled at seven months in the nursery and at 1½, 2½, 3½, 4½, 5½ and 6½ years after field planting. The dry matter and nutrient content of the MAWA palm showed most rapid growth between 2½ and 5½ years after which a lower growth rate was maintained. The fronds contributed the major proportion of dry matter production followed by the trunk in the early years.

The pinnae and the trunk accumulated the most N whereas K was found mainly in the trunk and rachis. The amount of nutrients accumulated was in the order of K>N >Ca≏Mg>P. For the nuts the highest amount of nutrient removed was K and N followed by smaller amounts of P, Mg and Ca. N was highest in the kernel and K was highest in the husk.

The total nutrients removed in a yield of 4 tonnes copra was 47 kg N, 7 kg P, 106 kg K, 4 kg Ca and 9 kg Mg.

The cocoa was sampled at 6, 8, 11 and 15 years after field planting. Growth and accumulation of nutrients was fairly steady at this stage. The branches and main stem contributed to most of the dry matter production followed by the roots, leaves and fruits.

The highest amount of nutrients accumulated in situ was K and N, followed by lower amounts of Mg, Ca and P. The stem and branches appeared to be the main area where the major nutrients were accumulated. The leaves and roots were the next important organs. The main nutrients removed in the cocoa pods were K and N. K was highest in the husks and N in the beans.

The total nutrients removed by a yield of 1000 kg dry cocoa beans amounted to 31 kg N, 5 kg P, 56 kg K, 5 kg Ca and 8 kg Mg.

Root sampling indicated that about 85% of the coconut roots and 90% of the cocoa lateral roots were within 30 cm of the soil surface, and that very few roots were found below 60 cm. Horizontally most of the coconut roots were found within 2 m of the palm base and that of cocoa within 114 cm of the plant base.

The study showed that the main nutrients immobilised in both coconuts and cocoa was K followed by N. These same nutrients were removed in highest quantities in the

cocoa pods as well as in the coconut. The high amounts of K and N found in both the cocoa and coconut husks should be recycled to reduce nutrient requirement in the inter-cropped areas.

If this is carried out, the total net nutrient removal in the cocoa-coconut system (yielding 3 tonnes copra and 1250 kg cocoa dry bean or 4 tonnes copra and 850 kg cocoa dry bean per hectare per year) can be reduced to about 85 kg N, 14 kg P, 97 kg K, 17 kg Ca and 15 kg Mg per hectare per year.

In Peninsular Malaysia a large section of the cocoa areas is planted under coconuts on coastal clay soils (Tropaquepts) in the Bagan Datuk/Sabak Bernam areas. Economic studies on crop profitabilities have shown this cropping combination to be the most pro-fitable when compared with rubber and oil palm (Lim & Chai, 1978).

Large areas of the coconuts in plantations are old. New plantings on the coastal clay soils are generally with MAWA hybrids which are the best proven planting materials (Vanialingam *et al.*, 1978; Chan, 1978; Fremond *et al.*, 1972) and interplanted with cocoa.

Little data on the nutritional requirements of the MAWA hybrids is available in Malaysia. This was initially reported by Chew (1978) and more complete information is presented here. Studies on the nutrients removed in the yield have been reported by Ouvrier and Ochs (1978) on the coastal sands of the Ivory Coast.

No data on the nutritional requirements of cocoa underplanted under coconuts on coastal clays are available. The nutrient requirement for monoculture cocoa on inland soils has been reported by Thong & Ng (1978). As the edaphic conditions under which cocoa is grown differ greatly in the cocoa-coconut system, a separate study on the cocoa is required.

MAWA hybrid coconuts were planted in this country only since 1970 and as no signi-ficant areas of cocoa planted with MAWA coconuts are available for sampling, the samples for this study were taken separately from mono-coconut hybrid areas and areas of cocoa underplanted under Tall coconuts.

METHODS AND MATERIALS

Coconut

Two representative coconut (MAWA) palms were selected from two fields at various times to obtain the required palm ages for this study. The details of the sampling are shown in *Table 1*.

The whole palm was sampled and divided into their separate components of fronds, trunk, fruits and inflorescences to obtain their fresh weights. Representative samples were taken for dry weight estimation and chemical analysis. In the 4½ and 6½-year-old palms, one palm from each age was selected for root sampling. Three trenches (at right angles to one another) were dug per palm and the details of one trench are shown in *Figure 1*. Dry weights for all root samples were taken.

TABLE 1. DETAILS OF MAWA COCONUT PALM SAMPLING

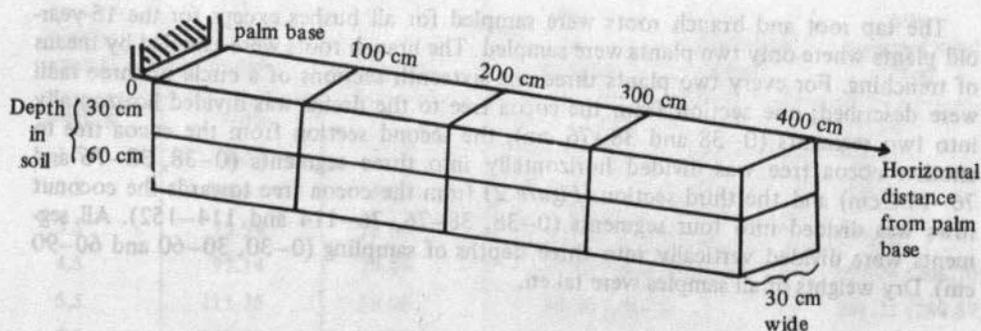| Date of planting	Date of sampling	Age of plant	Stand/ha	No. of plants sampled
Nursery	Apr. '76	7 months	–	2
1974	Apr. '76	1.5 years	138	2
1974	Apr. '77	2.5 years	138	2
1976	May '80	3.5 years	121	2
1976	Apr. '81	4.5 years	121	2
1974	May '80	5.5 years	138	2
1974	Apr. '81	6.5 years	138	2

Figure 1. Details of MAWA root sampling

Ripe coconuts were taken from the normal harvesting round from coconut trees. The samples were selected to reflect the distribution of nut size in the populations which were harvested.

Twenty-five nuts were individually analysed for the following:—

- Distribution of fresh weight in husk, shell, kernel and juice.

- Distribution of dry weight in husk, shell and kernel by oven drying at 100°C overnight.

- Nutrient analysis of the oven dried husk, shell and kernel. The fresh juice was analysed directly.

Cocoa

Four representative cocoa bushes were selected from each age group from the various fields for the study. The details are tabulated in *Table 2*.

The cocoa plants were sampled and divided into main stem, branches, leaves and fruits. The flowers and buds were very few and were not sampled separately. Fresh

TABLE 2. DETAILS OF COCOA PLANT SAMPLING

Date of planting	Date of sampling	Age of plant (years)	Stand/g ha	No. of plants sampled	Age of coconuts (years)	Stand/ha of coconuts
1975	Aug. '81	6	976	4	31	119
1973	Jul. '81	8	842	4	31	119
1970	Aug. '81	11	919	4	53	119
1966	Aug. '81	15	711	4	53	119

weights of all plant samples were obtained. About one-eighth of the samples was cut into smaller pieces and oven dried at 100°C for at least 18 h for dry weight estimation. Representative sub-samples were taken for chemical analysis.

The tap root and branch roots were sampled for all bushes except for the 15-year-old plants where only two plants were sampled. The branch roots were sampled by means of trenching. For every two plants three one-sixteenth sections of a circle of three radii were described; one section from the cocoa tree to the drains was divided horizontally into two segments (0–38 and 38–76 cm), the second section from the cocoa tree to another cocoa tree was divided horizontally into three segments (0–38, 38–76 and 76–114 cm) and the third section (*Figure 2*) from the cocoa tree towards the coconut rows was divided into four segments (0–38, 38–76, 76–114 and 114–152). All segments were divided vertically into three depths of sampling (0–30, 30–60 and 60–90 cm). Dry weights of all samples were taken.
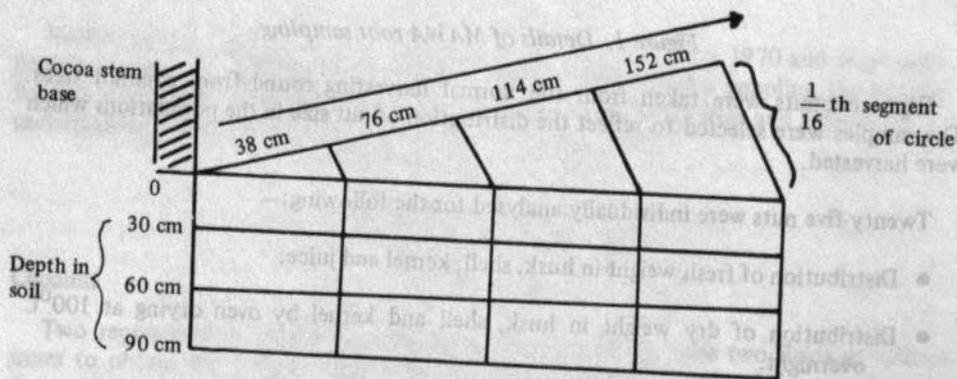

Figure 2. Details of cocoa root sampling (section from cocoa plant towards coconut rows)

Twenty ripe cocoa pods were taken from each of the four areas and sampled for chemical analysis. Two additional samples were taken from the 11-year-old area. These were separated into their components of (i) beans and mucilage and (ii) husks and residue.

The ratio of the bean to the husk components was estimated from the 11-year-old planting by sampling 30 pods per plot x 90 plots quarterly in 1982 (Ooi, 1984). Weights

of fresh husks, wet beans, dry beans were obtained. Dry weights of the husks were calculated based on a mean 20% moisture content.

RESULTS

Coconut (MAWA)

Dry matter content. The dry matter content of MAWA increased rapidly from 2½ years after field planting up to about 5½ years when growth appeared to have reached a steady state (*Table 3*). Accumulation of dry matter in the fronds and fruits, spikelets and inflorescences was most rapid between 2½ and 5½ years. After this period the increase in dry matter of these components were slower. After an initial lag period of 2½ years the growth of the trunk reached a fairly steady rate.

TABLE 3. DRY MATTER CONTENT OF MAWA PALMS (KG/PALM)

Age after planting (year)	Fronds	Trunk	Fruits & spikelets	(harvested nuts)[a]	(plus harvested nuts) Total
Seedling	0.13	–	–		0.13
1.5	8.82	1.73	–		10.55
2.5	26.91	6.90	–		33.81
3.5	73.94	26.90	40.14		140.98
4.5	92.14	39.20	65.90 (9.46)		197.24 (206.70)
5.5	111.35	53.60	66.30 (38.62)		231.25 (269.87)
6.5	114.80	71.60	65.80 (49.54)		252.20 (301.74)

[a] estimated from average field yield.

Initially (<3½ years) most of the dry matter was accumulated in the fronds but this was reduced when the palms started to fruit after 3½ years (*Table 4*). Between 4½ to 6½ years the fronds contributed about 29–36% of dry matter followed by the roots (20–23%), fruits (29–30%) and trunk (15-18%).

The dry weight distribution of the root system is shown in *Table 5*. About 85% of the roots were confined to the top 30 cm with only 15% of the roots in the 30–60 cm region. Horizontally most of the roots were found within 200 cm of the palm base. In the 6½-year-old palms moderate amounts of roots were still found after 300 cm.

Nutrient composition of MAWA palms. The nutrient content of MAWA palms is shown in *Table 6*. K was taken up in the highest amount from 1½ years after field planting and reached 3447 g K per palm at 6½ years. N was next in quantity at about 1600 g N per palm (mean of 5½ and 6½ years) followed by Ca, Mg and lastly P. The average ratio of the nutrients taken up at 5½ and 6½ years when the growth was fairly steady was:

N	P	K	Ca	Mg
6	1	11	3	2

5

TABLE 4. DISTRIBUTION OF DRY MATTER CONTENT OF MAWA COCONUTS BY COMPONENTS (INCLUDING HARVESTED NUTS)

Field age (year)	Mean % of component to total D.M. (of tops only)			
	Fronds	Trunk	Inflorescence & fruits	Roots
Seedling	100	—	—	—
1.5	83.5	16.5	—	—
2.5	79.6	20.4	—	—
3.5	52.4	19.1	28.5	—
4.5	44.6	19.0	36.4	—
5.5	41.3	19.9	38.8	—
6.5	38.0	23.7	21.8	—
4.5[a]	35.9	15.3	29.3	19.3
6.5[a]	29.4	18.4	29.6	22.6

[a] tops and roots

TABLE 5. DISTRIBUTION OF ROOTS IN 4½ AND 6½-YEAR-OLD MAWA PALMS DRY WEIGHT (KG/PALM)

Field age (years)	Depth (cm)	Dry weight distribution (kg/palm)				
		Distance from palm base				
		0–100 cm	100–200 cm	200–300 cm	300[a] cm	Total
4.5	0–30	26.58	10.40	5.54	0.41	42.93
	30–60	4.52	1.37	0.93	0.32	7.14
	Total	31.10	11.77	6.47	0.73	50.07
6.5	0–30	30.19	19.92	14.87	9.14	74.12
	30–60	7.18	3.09	2.07	1.90	14.24
	Total	37.37	23.01	16.94	11.04	88.36

[a] estimated for remainder of area per palm

The distribution of the nutrient in the various palm components at 1½, 4½ and 6½ years are given in *Figures 3* to *5*. In the 6½-year-old palms most of the K is in the fruits and spikelets (34%) with substantial amounts in the rachis (27%) and trunk (24%). N is accumulated mainly in the pinnae (37%) followed by the fruits and spikelets (26%) and trunk (24%). Ca, Mg and P were found mainly in the rachis followed by the trunk, pinnae and fruits and spikelets.

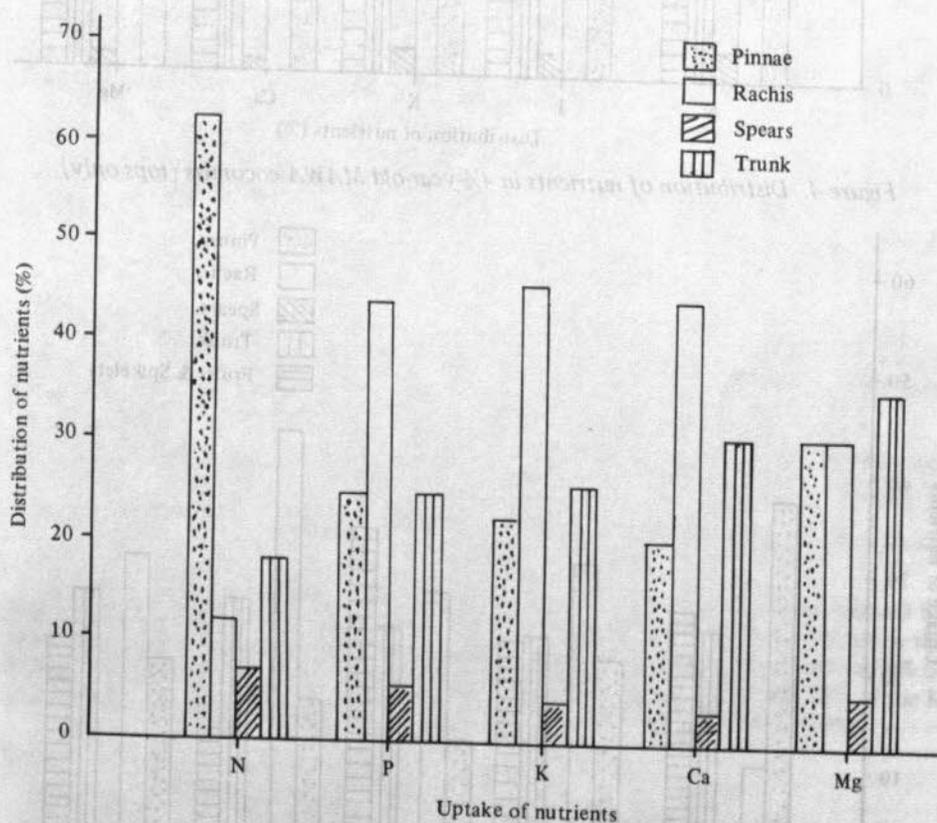| Field age (years)	Nutrient composition of palm (g/palm)				
	N	P	K	Ca	Mg
Seedling	2.4	0.2	1.5	0.3	0.3
1.5	69	14	118	28	29
2.5	220	56	608	106	100
3.5	1000	194	2430	289	474
4.5	1513	232	3363	532	645
5.5	1712	341	3312	913	481
6.5	1608	265	3447	654	608

[a] Estimated from average field yield

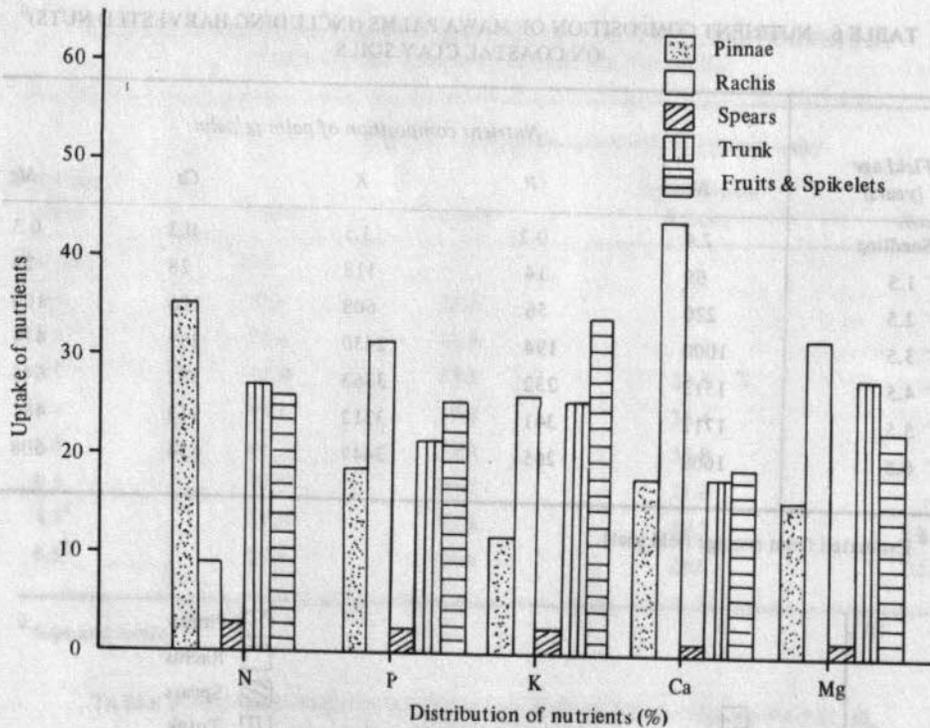Figure 3. Distribution of nutrients in 2½-year-old MAWA coconuts (tops only)

7

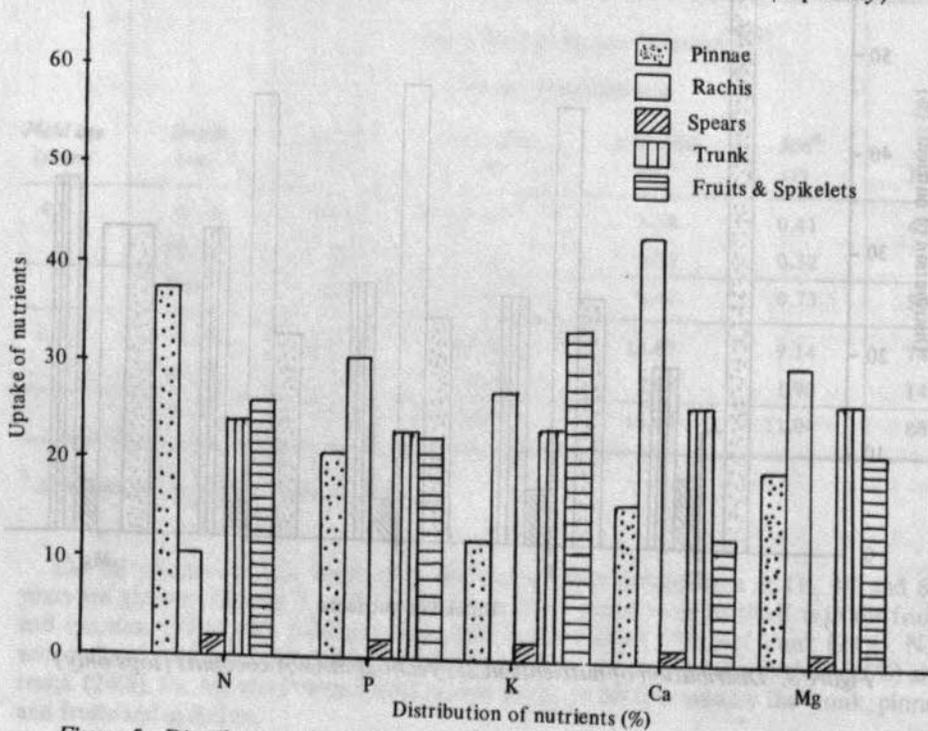*Figure 4. Distribution of nutrients in 4½-year-old MAWA coconuts (tops only)*

Figure 5. Distribution of nutrients in 6½-year-old MAWA coconuts (tops only)

8

Dry matter content of nuts. The distribution of dry weights is summarised in *Table 7.*

TABLE 7. DISTRIBUTION OF DRY WEIGHT OF VARIOUS NUT COMPONENTS
OF MAWA COCONUTS (MEAN AND s.d. OF 25 ANALYSIS)

Nut component	Dry weight (g/nut)	%
Husk	203.7 ± 18.1	39.9
Shell	117.5 ± 9.4	23.0
Kernel	189.6 ± 14.4	37.1
Total	511 ± 94	(100)

The husk formed the biggest component of the nut (39.9%) followed by the kernel (37.1%). The shell contributed 23% of the dry weight.

Nutrient composition of nuts. The mineral concentration varied considerably between the various nut components (*Table 8*). K was highest in the husk (1.55%) and N highest in the kernels (0.99%). In the nutwater the dominant mineral was K at about 2300 ppm.

TABLE 8. DISTRIBUTION OF NUTRIENT CONTENT OF THE VARIOUS NUT COMPONENTS
IN MAWA COCONUTS (MEAN AND s.d. OF 25 ANALYSIS)

Nut component	Nutrient content				
	N	P	K	Ca	Mg
Husk (% DM)	0.215 ± 0.035	0.027 ± 0.008	1.55 ± 0.340	0.07 ± 0.010	0.09 ± 0.033
Shell (% DM)	0.089 ± 0.010	0.008 ± 0.003	0.28 ± 0.048	0.015 ± 0.005	0.01
Kernel (% DM)	0.986 ± 0.102	0.189 ± 0.015	0.79 ± 0.057	0.022 ± 0.004	0.12 ± 0.010
Juice (ppm)	na	80 ± 34	2326 ± 244	150 ± 20	149 ± 31

Estimation of nutrients removed by the crop. An estimate of the nutrients removed by MAWA at a yield of 4 tonnes copra per hectare is given in *Table 9.* K was exported in the largest amount (106 kg/ha) followed by N at 47 kg/ha. The husks contributed to 59% of K and 18% of the N exported. The kernels contributed to 78% of the N and 28% of the K exported. Mg and P are exported in smaller amounts (8–9%) followed by Ca (4%).

Cocoa

Dry matter content. Dry matter of leaves, stems, branches and roots generally increased with plant age (*Table 10*). At the ages sampled the dry matter accumulation was in a fairly steady stage. In older cocoa it appears that increments in dry matter were mainly in the branches and stems followed by the roots. The branches and fruits however are subject to removal by purning and harvesting, periodically.

TABLE 9. NUTRIENTS REMOVED IN VARIOUS YIELD COMPONENTS OF COCONUT (MAWA) AT 4 TONNES PER HECTARE

Nut component	Nutrient removed				
	N	P	K	Ca	Mg
Husk	8.62	1.18	61.96	2.75	3.53
Shell	1.96	0.20	6.47	0.20	0.20
Kernel	36.67	7.06	29.41	0.78	4.51
Juice	n.a.	0.20	7.84	0.59	0.59
Total	47.25	8.64	105.68	4.32	8.83

TABLE 10. DRY MATTER CONTENT OF COCOA PLANT COMPONENTS

Age (years)	Mean dry matter content of plant components (kg/plant)					
	Leaves	Branches	Stem	Fruits	Roots	Total
6	3.82	6.27	3.38	.33	3.00	16.79
8	2.99	6.62	3.60	.67	6.42	20.20
11	3.72	16.97	5.17	1.98	5.97	33.82
15	4.63	20.92	4.82	1.79	12.66	44.82

The branches and stem together contributed to about 50—65% of the total dry matter. The roots contributed on an average about 24% of the total dry matter. The leaf components decreased slightly with age as the other parts increased their contributions.

The dry weight distribution of the root system is shown in *Table 11*. Almost 90% of the branch roots were confined to the top 30 cm and very little roots were found below 60 cm (<1%). Horizontally most of the lateral roots were within 76 mm of the palm base. Eighteen to 34% of the branch roots were found in the 76—114 cm segment. Beyond 114 cm, there were few roots (<5%) as there was only one direction where the roots were sampled up to 152 cm (*i.e.* towards the coconut rows). The root system of cocoa on coastal soil appeared to be affected by the height of the water-table. The 15-year-old plants were from a better drained area and more roots were found. The tap roots were generally fairly short and stout and ranged from 60 cm in the six-year-old plants to about 100 cm in the 11 and 15-year-old plants. They contributed between 15 to 30% of the total root dry weight.

Nutrient composition of the cocoa plants. The nutrient composition of the cocoa plants are presented in *Table 12*. K was taken up in the greatest amount followed by N for all plant ages. Mg and Ca were taken up in small amounts, followed by P.

TABLE 11. ESTIMATED ROOT WEIGHT DISTRIBUTION OF COCOA AT VARIOUS AGES

Age (years)	Depth (cm)	Root weight-distribution (g) Distance from plant base 0–38 cm	38–76 cm	76–114 cm	114–152 cm	Sub total	Mean D.W. of tap root (g)	Total of root system (g)
6	0–30	780.8	517.6	470.0	80.8	1849.2		
	30–60	122.5	35.1	18.1	4.6	180.3		
	60–90	15.2	5.5	1.4	1.0	23.1		
	Total	918.5	558.2	489.5	86.4	2052.6	944	2997
8	0–30	1466.5	1340.4	1165.3	186.4	4158.6		
	30–60	539.9	266.2	290.7	125.2	1222.0		
	60–90	86.9	5.6	7.0	2.6	102.1		
	Total	2093.3	1612.2	1463.0	314.2	5482.7	940	6423
11	0–30	1869.3	825.0	630.9	259.9	3585.1		
	30–60	289.2	97.5	84.9	5.8	477.4		
	60–90	2.1	3.8	7.2	–	13.1		
	Total	2160.6	926.3	723.0	265.7	4075.6	1897	5973
15	0–30	3712.7	2481.5	3366.5	137.1	9697.8		
	30–60	156.1	86.8	63.5	78.8	385.2		
	60–90	10.1	5.0	0.8	–	15.9		
	Total	3878.9	2573.3	3430.8	215.9	10098.9	2565	12664

TABLE 12. NUTRIENT COMPOSITION OF COCOA PLANTS GROWN ON
COASTAL CLAY SOILS

Field age (years)	Nutrient composition of plant (g/plant) N	P	K	Ca	Mg
6	132.3	16.9	173.3	77.4	99.3
8	162.4	16.4	180.9	90.0	138.5
11	208.4	22.4	302.5	131.0	184.5
15	350.6	30.8	556.9	199.5	158.6
Mean	213.4	21.6	303.4	124.5	145.2

The average ratio of the nutrients accumulated in the plants was:

N	P	K	Ca	Mg
10	1	14	6	7

11

The average distribution of the nutrient content in the various components of the mature cocoa plants is shown in *Figure 6*.
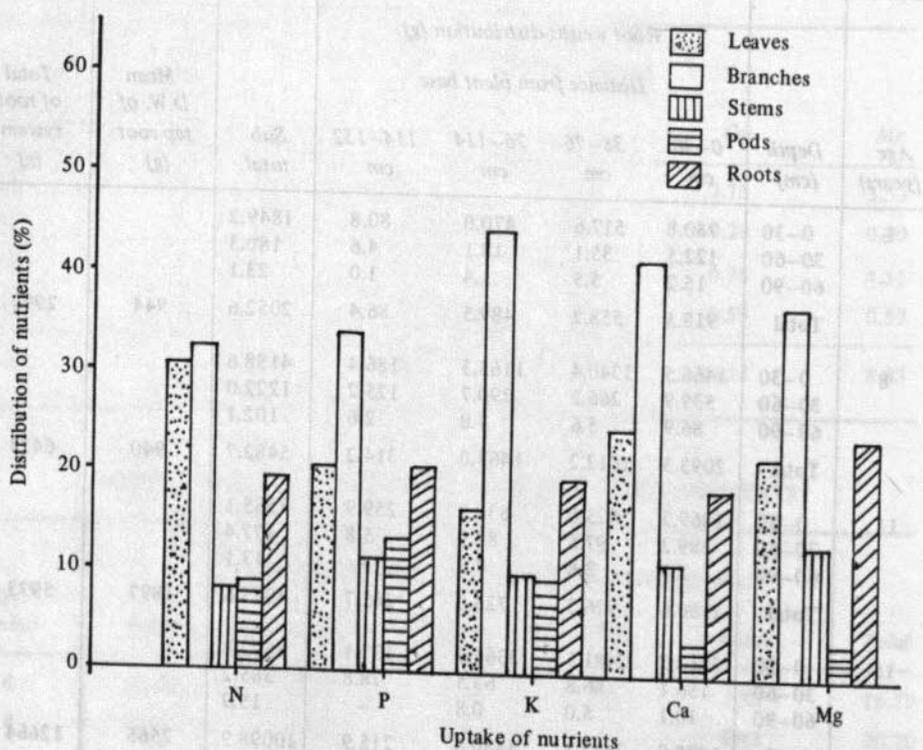

Figure 6. *Mean distribution of nutrients in mature cocoa (6 to 15 years)*

The trend of nutrient accumulation followed that of the dry weight. The branches accumulated most of the nutrients. The leaves accumulated N and Ca more than the remaining components. P, K and Mg were accumulated in comparable amounts by the roots and leaves. The exact amount accumulated by the pods at the time of sampling was relatively variable due to the small number of pods present (due to harvesting).

Dry matter content of ripe pods. The average ratio of the dry bean : pod for the 11-year-old plants during one year was 0.488 (*Table 13*). The mean number of beans per pod was 41 and the average bean dry weight was 1.05 g. A mean pod value (number of pods per kg dry beans) of 23.6 was obtained.

TABLE 13. ANALYSIS OF RIPE COCOA PODS (MEAN AND s.e. FOR 1982)

Dry bean wt. Dry pod wt.	Bean no. p. pod	Dry bean wt. (g)	Pod value
0.488 ± .036	41.1 ± 3.5	1.05 ± .12	23.6 ± 2.7

Nutrient composition of pods. Chemical analysis showed high concentrations of K in the husks (4.30%) and moderate amounts in the beans (1.06%) (*Table 14*). N concen-

TABLE 14. MEAN CONCENTRATION OF NUTRIENTS IN RIPE COCOA PODS
(MEAN AND s.e. OF SIX ANALYSIS)

Component	Nutrient concentration (% on D.M.)				
	N	P	K	Ca	Mg
Beans + mucilage	2.14 ± .24	0.42 ± .08	1.06 ± .13	0.14 ± .03	0.33 ± .04
Husk + residue	0.93 ± .27	0.09 ± .02	4.30 ± .36	0.34 ± .07	0.44 ± .04

tration was high in the bean fraction (2.14%) and moderate in the husk (0.93%). Relatively high concentration of P was found in the bean and mucilage fraction (0.42%) as compared to the husk fraction (0.09%).

Estimation of nutrient removal by the crop. An estimate of the nutrients removed by a cocoa crop of 1000 kg dry beans is shown in *Table 15*. The main nutrient removed was K followed by N. The ratio of the nutrients removed was

N   P   K   Ca   Mg
6 : 1 : 11 : 1 : 2

K was removed mainly by the husks (81%) whereas N was mainly from the bean and mucilage fraction (68%).

TABLE 15. NUTRIENTS REMOVED IN 1000 KG DRY BEANS PER HECTARE

Component	Nutrient content (kg)				
	N	P	K	Ca	Mg
Beans and mucilage	21.40	4.15	10.60	1.35	3.25
Husk and residue	9.88	0.96	45.67	3.61	4.67
Total	31.28	5.11	56.27	4.96	7.92

DISCUSSION

The nutrient uptake results of MAWA coconuts indicate that the increase in demand for nutrients was most rapid between 2½ and 5½ years after field planting. At this stage the requirement was mainly for potassium and nitrogen. After this initial exponential phase of growth, the demand for nutrients for vegetative growth is mainly in the production of new fronds as the old ones senescent and also in the gradual growth of the trunk. Compared with oil palms, MAWA coconuts have a much lower dry matter content in its trunk (*Table 16*). Although the frond weights are comparable, the turnover of fronds and hence the dry matter production of oil palms are higher (24 fronds per year) compared to MAWA (16 fronds per year). However, the nutrients in these fronds will eventually be released into the system when they fall to the ground.

13

TABLE 16. DRY MATTER CONTENT OF OIL PALM AND MAWA COCONUTS

Parts	Dry matter (kg/palm)	
	Oil Palm[a] (76 months)	MAWA (78 months)
Trunks	145	72
Fronds	106	115
Roots	70	88
Total	321	275

[a] Ng et al. (1968)

The highest amount of nutrients removed from a mature MAWA coconut planting (> six years) is in the yield. Potassium is the main nutrient removed followed by nitrogen. The other nutrients form only a small fraction of the nutrients removed in the yield. As most of the potassium is found in the husk, the coconuts should preferably be dehusked in the field and the husk recycled as much. For a yield of 4 tonne copra per hectare, as much as 62 kg K and 8.6 kg N per hectare can be returned to the field and the net amount of nutrients removed from the coconut system is greatly reduced. By comparison all the nutrients in the oil palm bunch are at present removed from the field and the total removal in oil palm is much higher. A yield of 25 tonnes FFB per hectare per year will remove 73 kg N and 93 kg K (Ng, 1972). This is much higher than the 39 kg N and 36 kg K removed in the shells and kernels of MAWA coconuts yielding 4 tonnes copra per hectare per year.

The dry matter accumulation and nutrient content of cocoa on coastal clay soils appear to be lower than that on inland soils in Peninsular Malaysia. Total dry matter content of six to eight year-old plants in situ on coastal clays was between 16 to 20 kg compared with 40 to 56 kg for inland soil as reported by Thong and Ng, (1978). This may be due to poorer growing conditions due to high water-table and poor soil structure of coastal clay soils and also competition by the coconut palms.

As with coconuts the main nutrients removed by cocoa are potassium followed by nitrogen and these are mainly in the yield. However, if the husks (containing 46 kg K and 10 kg N for a yield of 1000 kg db per hectare) are returned to the field, the nutrients removed will be only those in the beans and the mucilage fraction.

Cocoa can be intercropped with MAWA coconuts in several planting patterns depending on weightage of the soil, climate, economics and management factors. The three main approaches allow for:—

- Equal emphasis on both cocoa and coconuts (with lower than normal density cocoa and coconuts).

- Emphasis on the coconuts with the cocoa infilled between the coconut rows (with normal density coconuts and low density cocoa).

- Emphasis on cocoa with coconuts planted sparsely as permanent shade (with normal density cocoa and low density coconuts).

14 -

The growing conditions of the cocoa sampled in our exercise were in areas following the first two approaches. Estimates of yields from cocoa and coconuts intercropped and the nutrients removed from these two types of planting are given in *Table 17.*

Where 111 MAWA coconuts/ha (yielding 3 tonnes copra) is intercropped with 833 cocoa bushes/ha (yielding 1250 kg db), the net nutrient removal of the two crops is quite similar. K and N were the main nutrients removed. Ca, Mg and P were only required in small amounts by both crops.

Where more emphasis is placed on the MAWA coconuts (138 palms/ha yielding 4 tonnes copra/ha) than cocoa (556 bushes/ha yielding 850 kg db/ha), the coconuts removed about twice the amount of K and N as that of cocoa. The total requirement of both the crops in the two planting systems were comparable. Thus the nutrient removal from these two systems were basically the same, except that the relative quantities removed by each crop differ. The ratio of the nutrients required by cocoa and coconuts were surprisingly similar. This requirement may enhance the competition for nutrients by the two crops.

Results here and elsewhere (FAO IAEA, 1975; Mohd Noh Abdul Jalil, 1982) have shown that the distribution of roots of the two crops to be concentrated in discrete regions near the plant stem base. This characteristic can to a certain extent help in discriminating fertilizer inputs for the two crops.

CONCLUSION

Dry matter and nutrient uptake by MAWA palms was most rapid between 2½ and 5½ years after field planting, after which a lower rate was maintained. The main nutrients required for both immature and mature MAWA coconuts were K and N in that order. The requirements for these nutrients were lower than for oil palms.

The main nutrients required for mature cocoa were N and K.

The removal of K from the cocoa-coconut planting system can be substantially reduced by returning their respective husks back into the field as much. This should minimise the requirement for fertilizer K.

The total net nutrients removed from the two cocoa-coconut systems described were comparable but the relative quantity for each crop is different. The ratio of the nutrients removed by both crops were similar.

The separate and discrete areas of root concentration of the two crops may help in discriminating fertilizer inputs for the two crops.

ACKNOWLEDGEMENT

TABLE 17. NET NUTRIENT REMOVAL IN TWO SYSTEMS OF COCOA-COCONUT INTERCROPPING

Crop Component	System 1: Equal emphasis on cocoa and cocoa Nutrient (kg/ha)					System 2: More emphasis on coconut Nutrient (kg/ha)				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
MAWA Coconut										
Nutrients accumulated in trunk	12.7	2.2	24.1	4.6	3.1	15.8	2.7	30.0	5.8	3.9
Nutrients in shells and kernels	29.1	5.5	27.1	0.7	3.5	38.6	7.3	35.9	1.0	4.7
Sub-total	41.8	7.7	51.2	5.3	6.6	54.4	10.0	65.9	6.8	8.6
Cocoa										
Nutrients accumulated in vegetative tissues	17.7	1.0	32.9	11.1	4.9	11.8	0.7	22.0	7.4	3.3
Nutrients in beans and mucilage	26.8	5.2	13.3	1.7	4.1	18.2	3.5	9.0	1.1	2.8
Sub-total	44.5	6.2	46.2	12.8	9.0	30.0	4.2	31.0	8.5	6.1
Total	86.3	13.9	97.4	18.1	15.6	84.4	14.2	96.9	15.3	14.7

Note: System 1. Coconuts @ 111/ha (7.5 m x 12 m rows)
Yield expected = 3 t copra/ha
Cocoa @ 833/ha (3 m x 3 m in triple rows)
Yield expected = 1250 d b/ha

System 2. Coconuts @ 138/ha (9 m x 9 m △)
Yield expected = 4 t copra/ha
Cocoa @ 556/ha (3 m x 3 m in twin rows)
Yield expected = 850 kg d b/ha

The co-operation and assistance of the managers of Chersonese, Torkington and Kuala Bernam Estates are gratefully appreciated.

Thanks are also due to Mr. L.H. Ooi of HRU for helpful discussions.

REFERENCES

CHAN, E. (1978). Growth and early yield performance of Malayan Dwarf x Tall coconut Hybrids on the coastal clays of Pen. Malaysia. *Proc. Int. Conf. Cocoa and Coconut. Kuala Lumpur*, 522–531.

CHEW, P.S. (1978). Nutrition of coconuts — a review for formulating guidelines on fertilizer recommendations in Malaysia. *Planter, Kuala Lumpur*, 54, 115–141.

FAO/IAEA (1975). Root activity patterns of some tree crops. Tech. Rep. Series No. 170 Int. Atomic En. Ag. Vienna, pp 65–70.

FREMOND, Y.L. & DE NUCE, D.L.M. (1972). Characteristics and production of the hybrid coconut palm, Malayan Dwarf x West African Tall. *Proc. Conf. Cocoa and Coconuts in Malaysia. Kuala Lumpur:* 309–319.

LIM, K.P. & CHAI, W. (1978). Cocoa-coconuts and oil palm as possible alternatives in replacing old rubber — An economic appraisal. *Proc. Int. Conf. Cocoa and Coconuts, Kuala Lumpur*, 368–381.

MOHD NOH ABDUL JALIL (1982). Studies on root distribution in coconuts. Pre-print National Coconut Conf. Kuala Lumpur.

NG, S.K. (1972). *The Oil Palm, its Culture, Manuring and Utilization.* Berne (Switzerland) Int. Potash Inst.

NG, S.K. THAMBOO, S. & DE SOUZA, P. (1968). Nutrient contents of oil palms in Malaya. II Nutrients in vegetative tissues. *Malay. Agric. J.*, 46, 421–434.

OOI, L.H. (1984). Per Comm.

OUVRIER, M. & OCHS, R. (1978). Nutrient removal by Hybrid coconut Port Bouet 12 (MAWA). *Proc. Int. Conf. Cocoa and Coconuts., Kuala Lumpur*, 595–605.

THONG, K.C. & NG, W.L. (1978). Growth and Nutrients composition of monocrop cocoa plants on inland Malaysian soils. *Proc. Int. Conf. Cocoa and Coconuts, Kuala Lumpur*, 262–286.

VANIALINGAM T., KHOO, K.T. & CHEW, P.S. (1978). Performance of Malayan Dwarf x Tall coconut hybrids in Pen. Malaysia. *Proc. Int. Conf. Cocoa and Coconuts, Kuala Lumpur*, 532–542.

Foliar Decay by *Myndus taffini* (FDMT):
New Results

J.F. JULIA

I.R.H.O., Saraoutou Station, Santo, Vanuatu

M. DOLLET

I.R.H.O. Gerdat, France

AND

C. CALVEZ

I.R.H.O., Saraouton Station, Santo, Vanuatu

This paper reviews the research that has led to the identification of the Homoptera *Cixiidae,* Myndus taffini *as the vector of FDMT, a wilt known only in Vanuatu, where it only affects the introduced varieties, but not the Vanuatu Tall (NHT). Experiments on the number of adult* M. taffini *required for transmission of FDMT have shown that the symptoms could easily be obtained on young Malayan Red Dwarf (MRD) plantlets, even after very short exposure, or with very limited numbers of insects. These results seem more favourable to the hypothesis of a causal agent of the viral type than to that of a mycoplasma-like organism or a toxin.*

Two trials using oxytetracycline chloride treatments of adult trees and plantlets showed no effect of the antibiotic and showed indirectly that FDMT (unlike American and African Lethal Yellowings) is not caused by a mycoplasma-like organism.

Studies on the sensitivity to FDMT of coconut crosses and cultivars, performed directly in the field or after exposure to M. taffini *in insect cages, are reported and the practical difficulties encountered are described. A classification of different types of coconut according to sensitivity to FDMT is proposed, subject to certain verifications. The results established before 1981 on the resistance of the Vanuatu Tall (NHT) and the tolerance of the cross with the Rennell Tall (NHT x RLT) are confirmed.*

This paper follows an earlier article concerning *Myndus taffini (Homoptera Cixiidae),* a vector of foliar decay of coconut in Vanuatu (Julia, 1982).

Recapitulation of Research leading to Discovery of *Myndus taffini* in 1981–82

In 1981, insect introduction experiments in cages were performed, and at the same time an inventory was taken of insects likely to transmit the wilt that, in Vanuatu, affects varieties of coconut introduced into the country, but spares the local Tall variety (NHT).

Using this inventory, it was possible to suspect only the new species *Myndus taffini (Homoptera Cixiidae),* which was always found in disease foci, with gradients superimposable on those of the disease. Cage trials then confirmed that *M. taffini* alone transmitted the disease on more than 90% of the sensitive coconuts exposed in cages, after an incubation period of 6–13 months.

The adults of this species frequent the leaves of the coconut, whereas the larvae develop underground on the roots of the "bourao" *(Hibiscus tiliaseus)*, which is the only laying site observed up to now.

METHODS AND RESULTS

Studies of Transmission of FDMT in Cages

The object of these studies was to define *M. taffini* infestation, and the length of exposure sufficient to obtain 100% transmission of FDMT on the sensitive Malayan Red Dwarf (MRD) variety. These studies may enable precious information to be obtained concerning the nature of the pathogen, and, naturally, for the conduct of cage tests of the sensitivity of coconut cultivars and crosses to FDMT.

Trial 51 : Number of *M. Taffini* Required for Transmission of Disease to Young MRD Plantlets in Individual Cages 20 cm in Diameter.

The MRD was, of course, chosen on account of its great sensitivity to FDMT and because it showed the most typical symptoms of this wilt. It is important to prove that the disease can be transmitted to a 20 cm high plantlet, since this is very easily manipulated material that can be sent to virology laboratories. Ten replications were performed between September 1982 and September 1983 to compare, initially, 1,500 – 2,500 insects brought to each plant over a three to seven week period (10 – 150 insects/plantlet/working day), and then, under the same conditions, 100 – 1,500 insects/plant. The insects survived four days on average.

Table 1 shows that up to 15 April, 1984, all plants subjected to *M. taffini*, except one (100 insects, introduced in June 1983), were affected by FDMT. The controls without *Myndus* remained unaffected.

Transmission to young MRD plantlets can thus be easily obtained, and, in individual cages, the minimum number of insects required to obtain 100% transmission of the disease is less than 500 *M. taffini* introduced over a 20 – 45 day period.

Trial 53 : Exposure Time Necessary for Transmission of FDMT to MRD Seedlings in Large Cages

Exposure times were chosen at random, and therefore independently of the mean number of insects applied per plant and per day; in fact, this number was remarkably consistent: 24 ± 1.6. Each batch of MRD used consisted of 10 plants.

All the plants in the trial, for each of the exposure times compared, contracted FDMT. Under the conditions of this experiment in large cages, the shortest exposure to the insect (five days), corresponding to a mean infestation of 120 *M. taffini* per plant, proved sufficient to obtain 100% transmission of FDMT on MRD.

This result confirms that the number of insects chosen for trials in large cages designed to test the sensitivity of coconut cultivars and crosses compared to the MRD (1500 insects/plant during 10 – 20 weeks' exposure) corresponds to a very high epidemicity. It also justifies the study of exposures to 24 or fewer *M. taffini.*

Total number of insects introduced progressively									Replication number dates – duration
0	100	250	500	750	1000	1500	2000	2500	
0	•	•	+	•	+	•	+	+	1: 27/9–12/11/82.47 d
0	•	•	+	•	+	•	+	+	2: 17/10–10/11/82.25 d
0	•	•	+	•	+	•	+	+	3: 15/11–09/12/82.25 d
0	•	•	+	•	+	•	+	+	4: 17/12/82–18/01/83.33 d
0	•	•	+	•	+	•	+	+	5: 01/03–25/03/83.25 d
0	•	•	+	+	+	+	•	•	6: 01/04–27/04/83.27 d
0	+	+	+	+	•	+	•	•	7: 05/05–26/05/83.22 d
0	0	+	+	+	•	+	•	•	8: 03/05–23/06/83.21 d
0	+	+	+	+	•	+	•	•	9: 20/07–24/08/83.36 d
0	+	+	+	+	•	+	•	•	10: 01/09–21/09/83.21 d
0/10	3/4	4/4	10/10	5/5	6/6	5/5	5/5	5/6	Number of transmissions/Number of plants

* = untested dose in current replication
0 = tested dose, no transmission
+ = tested dose, transmission of FDMT

TABLE 2. TRANSMISSION OF FDMT ACCORDING TO EXPOSURE
TIME IN LARGE CAGES (TRIAL 53)

Treatment	Exposure		Cumulative Infestation mean/plant	FDMT Transmission (%) 10 Plants/Treatment
	Period 1983	Duration in days		
A	20/07 – 04/08	15	360	100
B	5/08 – 10/08	5	120	100
C	5/08 – 16/08	10	240	100
D	10/08 – 11/09	31	744	100
E	16/08 – 06/09	20	480	100
F	6/09 – 30/09	25	600	100
G	12/09 – 30/09	20	480	100

Trial 54 : Study of probability of FDMT Transmission according to Number of Insects Introduced at one time and Maintained for 24 h only in small Individual Cages.

This trial was set up before obtaining the results of trial No. 53. The results of trial No. 51 were taken into account, and the same cages were used, with 20 cm high MRD plantlets. On Professor Randles' suggestion, exposure was restricted to 24 h, and the

quantities of insects studied constituted a logarithmic progression. The numbers chosen were 0, 25, 50, 100, 200, 400 and 800 *M. taffini*/plant/24 h, and 12 replications were performed. The trial took place at the end of September 1982.

On 15 April 1984, the results of trial No. 54 appear to show that the probability of transmission is proportional to the logarithm of the number of insects introduced and maintained for 24 h (*Figure 1*). No FDMT was observed in the "insectless" control.
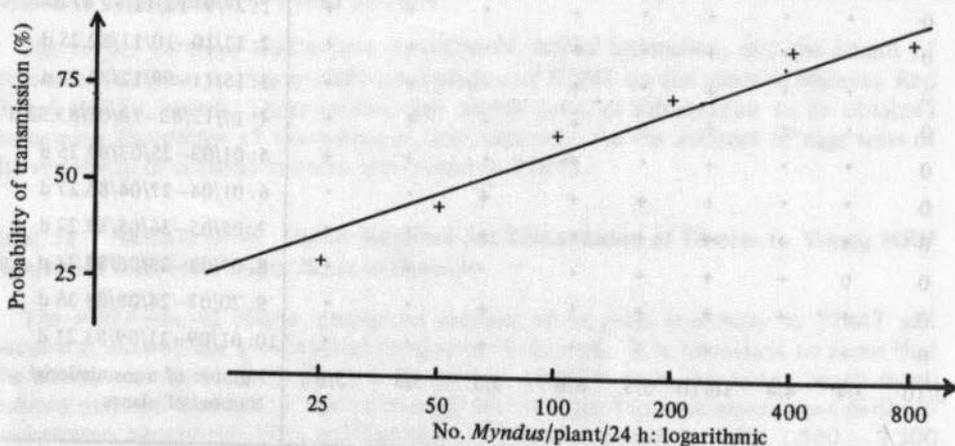
Figure 1. ES 54 – *Probability of transmission of FDMT according to number of* M. taffini *introduced in one day's exposure (provisional result)*

It appears that 2400 "*Myndus* hours" (100 insects maintained for 24 h) are sufficient to obtain a minimum of 50% transmission in small individual cages.

Trial 55 : Definition of Minimum Insect-plant Contact Time Required for FDMT Transmission:

The object of this trial was to see whether limiting the feeding time required for inoculation had any influence on the probability of FDMT transmission.

This trial was performed at the end of September and beginning of October 1983 (at the same time as Trial 54) but using six-month-old MRD seedlings (the only ones available), whose first four leaves had been pruned so as to fit into individual cages 20 cm in diameter and 60 cm high. (The older leaves were cut.) On Professor Randles' suggestion, we compared exposures of 1, 6, 12 and 24 h. In all cases, 400 insects/cage were introduced.

Each experimental exposure was performed on 11 plants divided into two batches, tested at two or three days' interval. There was one 11-plant insectless control.

In this trial as well, results are provisional; new cases of FDMT may occur. However, it is certain that more than 45% transmission was obtained in each case, and differences will not necessarily be noticeable at the end of the trial (*Table 3*). The insectless control remained healthy.

From a qualitative point of view, a contaminating feeding period limited to 1 h may be enough to obtain almost 50% transmission of FDMT under the conditions of Trial 55.

4

TABLE 3. DEFINITION OF MINIMUM TIME OF CONTACT
INSECT/PLANT TO OBTAIN FDMT (TRIAL 55)

Treatments	Exposure (Hours–Dates)	Cases Transmission/ Total Plants Tested
1 h	4 pm – 5 pm 30/09/83	3/5
	4.30 pm – 5.30 pm 04/10/83	5/11
		2/6
6 h	11.10 am – 5.10 pm 30/09/83	4/5
	11.00 am – 5.00 pm 04/10/83	6/11
		2/6
12 h	4.10 pm – 11.10 pm 03/10/83	4/6
	4.10 pm – 23/10 pm 06/10/83	5/11
		1/5
24 h	4.10 pm – 4.10 pm 03/10 – 4/10/83	3/6
	4.10 pm – 4.10 pm 6/10 – 7/10/83	6/11
		3/5

It is thought that the minimum feeding period required for transmission of disease is shorter for viral diseases than for mycoplasma diseases. The result of the trial therefore seems to point to the hypothesis of a virus.

Also, the very short "dose-length" of 400 *"Myndus* hours" that proved effective on six-month-old nursery plants (70 cm high) seems to exclude the hypothesis of an insect toxin, although this point should be checked.

Trials for Indirect Revelation of a Mycoplasma-like Pathogen

In America, and in some West African countries (Ghana, Togo, Cameroon) several diseases of the "Lethal Yellowing" type exist, all of which are caused by mycoplasma, probably of different strains (Ollagnier & Weststeyn, 1961; Dollet & Gianotti, 1976; Dollet et al., 1977; McCoy et al., 1983).

Mycoplasma-like organisms are very sensitive to tetracycline but insensitive to penicillin. Also, remission of symptoms has been obtained by tetracycline treatment in Florida (Lethal Yellowing) and Togo (Kainkope disease) (McCoy et al., 1983).

The discovery of a *Cixiidae* insect vector of the genus *Myndus* both for Jamaica L.Y. *(M. crudus)* and for leaf wilt in coconuts introduced into Vanuatu *(M. taffini)* suggested a possible similarly between the pathogens involved in these diseases.

For FDMT, whose symptoms and sensitivity spectrum are characteristic, and different from those of Lethal Yellowing-like diseases (Renard, 1980; Calvez et al., 1980), it has not been possible to reveal the presence of mycoplasma (Dollet & Taffin, 1979). This

negative result obviously had to be checked by tetracycline treatment trials. Reduction of epidemicity and remission of FDMT symptoms after tetracycline treatment would have enabled either a hardly detectable mycoplasma-like pathogen or a bacterium to be suspected, and further studies with penicillin would have confirmed either the bacterial hypothesis if the treatments had worked, or, if not, the hypothesis of a possible similarity between FDMT and mycoplasma diseases of the Lethal Yellowing type.

Trial 44 : Tetracycline Injection in Adult Coconuts

After several inconclusive guidance trials, this trial was set up in August 1981 on five rows of 40 coconuts severely exposed to attacks of FDMT (31 trees already destroyed by this disease). Trees in even numbered rows (88 in all) were treated every three months, from August '81 — February '83 (seven treatments), each time using 20 g Terramycin Tree Injection Formula (T.T.F.), at a concentration of 21.6% oxytetracycline hydrochloride (this is greater than the dose recommended for Florida L.Y. (McCoy *et al.*, 1983). Trees in odd-numbered rows were used as an untreated control (81 trees).

Table 4 shows the lack of any preventive of curative effect of the treatments; there was a slightly greater incidence of the disease in the treated section (20.5% as opposed to 18.5%). No remission was recorded, in complete contradiction to results obtained in Florida, Jamaica and some African countries (Dollet & Gianotti, 1976; Dollet *et al.*, 1977; McCoy *et al.*, 1983).

Trial 50 : Tetracycline Treatments of MRD Seedlings Raised in Hydroponic Culture, in a Large Cage, Exposed to Numerous *M. taffini* Introductions

This trial began at the end of October 1982, on 20 plantlets 40 cm high, placed in hydroponic culture one month previously. Ten plants received tetracycline treatment (300 mg T.T.F. in 3 litres of culture water, mixture renewed every 10 days) from 13 October 1982 to 15 September 1983. This technique has proved very effective in Africa to prevent Blast damage to young seedlings. The insect introductions took place from 22 October 1982 to 15 June 1983 more than 3000 *M. taffini* per plant were introduced. The first symptoms appeared at the end of April 1983 and by July 1983 all plants were affected. Since the disease developed in the same way in all treatments, the trial was terminated at the end of September 1983.

It was concluded that tetracycline treatments were without any effect under the experimental conditions used. The results of Trials 44 and 50 did not enable the hypothesis of a mycoplasma-like pathogen, similar to those responsible for American and African Lethal Yellowings, to be considered valid. This conclusion had long been suspected, since electron microscopic studies failed to reveal any MLOs, despite repeated observations.

Results of Studies on Sensitivity of Coconut Crosses and Cultivars to FDMT

Up to the end of 1981, an attempt was made to establish the sensitivity of the types of coconuts present according to the severity of the damage recorded in different collection or genetic experiment plots. Some of these plots, although this could not have been foreseen before planting, proved very little affected by FDMT, to such an extend that, since varieties known to be sensitive were practically unaffected, it was not possible to evaluate the sensitivity of the other types of coconut being studied.

The incidence of FDMT attacks in plantations is not often rapidly visible. The MRDs are usually the first to be attacked, and almost all plants affected die within 12 — 36

TABLE 4. INJECTION OF TETRACYCLINE INTO ADULT MRD (TRIAL 44)

Period when symptoms appeared	Expected effects of treatments	Treated (88 trees) Aug, Nov 81 – Feb, May, Aug, Nov 82 – Feb 83.		Untreated (81 trees)	
		No. trees diseased	Death by FDMT	No. trees diseased	Death by FDMT
Before 1st treatment					
5/81 – 8/81	Curative only	12	12	12 (14,8%)	12
9/81 – 8/82	Preventive + curative	10	10	8	8
9/82 – 12/82	Mainly preventive	1	1	1	1
1/83 – 7/83	Preventive only	7	7	6	6
Period covered by treatment 9/81 – 7/83	Preventive and/or curative	18 (20,5%)	18	15 (18,5%)	15

months after appearance of the symptoms. For the Rennell Tall (RLT), the propagation of FDMT and the development of the disease in affected plants are much slower. Many cures occur, but the yield of the cured plants is often reduced, and their sensitivity to wind is greater.

At least four years' exposure to FDMT in the field are necessary to judge whether an unaffected type of coconut (when the sensitive control is affected) is likely to prove highly tolerant.

Up to now, nearly 50 varieties and crosses have been observed in plantations, and nearly 40 can be classified (*Table 5*: Observation in the field, and *Table 6*: Variety code). The results already published in 1980 are confirmed: Resistance of the NHT, high tolerance of the NHT x RLT, and high sensitivity of NHT hybrids.

Slightly sensitive or tolerant coconuts have been revealed (RHD, BGD x NHT, RHD x TGT, RHD x RTT) and one highly tolerant hybrid (RHD x NHT). This represents most encouraging progress.

The discovery of FDMT transmission to nursery plants exposed to *M. taffini* has justified the setting up of cage tests for establishing the sensitivity of the different types of coconut to this wilt, thus enabling the most tolerant varieties or crosses to be selected. In this test, a cage 6 m x 5 m x 2 m was used, and the MRD was taken as a control for the crosses or cultivars under study (two to six types as well as the MRD, each represented by 20 – 30 plants, according to trials). Introductions of adult *M. taffini* were performed each working day, until a total of 1500 insects/plant was reached. This required 10 – 20 weeks.

It is now known that a total of 1500 *Myndus*/plant is far greater than the minimum number necessary to obtain 100% FDMT symptoms in MRD. We have now decided to include a second control, the BGD x NHT, which has proved only slightly sensitive in the field up to now, and a total of 1500 *Myndus*/plant would be more suitable for this cross.

In all tests, 100% FDMT was obtained on the MRD control within 11 months of the first insect introductions into the cage. A minimum of two years is required to obtain the same result in the field, or more frequently, over five years.

To date, 21 types of coconuts have been tested in cages, including a certain number of cultivars introduced into Vanuatu. It was originally intended to keep these plants under observation in the nursery for 13 months after the end of the cage test, and they show a much greater tendency towards remission than in the plantation. This tendency can be seen despite particularly poor vegetative development of diseased trees from particularly sensitive varieties such as MRD and MYD. This unexpected performance makes interpretation of the first tests difficult, and for this reason, the results are expressed with certain reservations (*Table 5*: Observations after tests in cages, and *Table 6*: Variety code). However, there is good agreement between the results of field observations and those obtained in cages for all the cultivars and crosses that have been examined in both situations.

The cage tests established the high sensitivity of new varieties: PGD2, NBD, CRD, TNT, and seemed to confirm the low sensitivity or tolerance of NHT, BGD x NHT, MYD x NHT, and the good performance of NHT x RLT and NHT. The Bay-Bay Tall, tested in cages only, appeared as little sensitive as the NHT (late or incomplete symptoms,

TABLE 5. PRESENT CLASSIFICATION OF COCONUT CULTIVARS AND CROSSES ON THE SANTO STATION (VANUATU) ACCORDING TO THEIR SUSCEPTIBILITY TO FDMT

Categories	Field Observations	Observations after tests in cages with M. Taffini
Very susceptible	MRD, MGD, BGD MLT, MVT, SNT, RLT MRD x RLT, MRD x SNT, MLT, MRD x PYT2, MRD x WAT, MRD x RTT, MRD x TGT MGD x WAT, MGD x RTT, MGD x TGT, MGD x RLT EGD x WAT, CRD x WAT RLT x SNT	MRD, MGD, BGD, PGD2, NBD, CRD, TNT
Susceptible	PYT2, WAT AYD x SNT, AYD x RTT, AYD x RLT, AYD x MLT, TGT x AYD RHD x RLT, RHD x CRD	AYD
Low susceptibility or tolerance	BGD x NHT, MGD x NHT, RHD x TGT, RHD x RTT RHD	BBT BGD x NHT, MGD x NHT
Very tolerant	NHT x RLT, RHD x NHT	NHT x RLT – RHD x NHT NHT
Resistant	NHT	
Not yet classed; observations going on or programmed for near future	TGT, RTT, NLD, BGD x RHD, MRD x NHT, NLD x NHT, AYD x NHT, NHT x PGD 2, NHT x CRD	

9

TABLE 6. VARIETY CODE

Dwarf types		Tall types	
• MRD =	Malayan Red	• NHT =	Vanuatu Tall
• MGD =	Malayan Green	• RLT =	Rennell Tall
• BGD =	Brazil Green	• WAT =	West African Tall
• EGD =	Equatorial Guinea Green	• MVT =	Markham Valley Tall
• AYD =	Samoa Yellow	• SNT =	Salomon Tall
• CRD =	Cameroon Red	• MLT =	Malayan Tall
• RHD =	Vanuatu Red	• PYT2 =	Rangiroa Tall
• NBD =	Papua Brown	• TNT =	Tagnanan Tall
• PGD2 =	Catigan Green	• BBT =	Bay Bay Tall
• NLD =	Niu Leka	• TGT =	Tonga Tall
		• RTT =	Rotuma Tall

rapid regression). This good performance of the NHT and BBT should be checked but it may be considered that these cultivars are likely to transmit tolerance characters in crosses. This was the case with the NHT x RHD cross, since the 70 plants tested in cages have not yet shown any symptoms of FDMT (the NHT and NHT x RLT were also unaffected after cage tests).

From now onwards, the trees tested are planted in the field as soon as possible after exposure in cages. The growing conditions in the nursery (watering, phytosanitary protection) may be responsible for slowing down the development of the disease in cases of FDMT.

Observations made to date confirm that it is possible to reveal crosses and cultivars tolerant to FDMT. This possibility has been greatly improved by the discovery of the vector, and justifies the extensive programme of introduction of planting material presently under way at the Vanuatu Research Station.

CONCLUSION

The studies on foliar decay by *M. taffini* (FDMT) conducted at the IRHO's Santo Station in' Vanuatu have confirmed the role of this insect in the transmission of the disease. It has been found that transmission to young MRD plantlets can be easily obtained, even after a short exposure of about one hour, or with insect introductions limited to 25 per plantlet.

The lack of effect of tetracycline treatments of trees and seedlings exposed to FDMT means that it is unlikely that FDMT is similar to American and African Lethal Yellowings, which are caused by mycoplasma-like organisms.

The study of varietal sensitivity in the field was completed and accelerated by the setting up of FDMT sensitivity tests using nursery plants raised in cages with introductions of *M. taffini.* Important results have emerged, especially the high tolerance display-

ed up to now by the hybrids between the "local" Red Dwarf and the local Tall : RHD x NHT.

The revelation of one or several high-yielding hybrids that are very tolerant to FDMT remains, of course, the main aim of this research. The studies undertaken for the identification of the causal agent are not dealth with in this paper; they are conducted in collaboration with the Waite Agricultural Research Institute Adelaide (Professor Randles). This collaboration has already enabled it to be proved that the pathogenic agent of FDMT is different from the viroid responsible for Guam and Cadang-Cadang diseases, but the hypothesis of a virus remains the most likely (Dollet & Randles, unpublished).

REFERENCES

CALVEZ, C., RENARD, J.L. & MARTY, G. (1980) Tolerance of the hybrid coconut Local x Rennell to the New Hebrides disease. *Oleagineux*, 35 (10), 443–451.

DOLLET, M. & DE TAFFIN, G. (1979) Progress report on the virological study of the New Hebrides coconut disease. I.R.H.O. Document No. 1437–1437 b.

DOLLET, M. & GIANOTTI, J. (1976) Kaincope disease: Presence of mycoplasma in the phloem of diseased coconuts. *Oleagineux*, 31 (4), 169–171.

DOLLET, M., GIANOTTI, J. RENARD, J.L. & GHOSH, S.K. (1977) Study of a Lethal Yellowing of coconuts in Cameroon: Kribi Disease. Observation of mycoplasma-like organisms. *Oleagineux*, 32 (7), 317–322.

JULIA, J.F. (1982) *Myndus taffini (Homoptera Cixiidae)*, vector of foliar decay of coconuts in Vanuatu. *Oleagineux*, 37 (8.9), 409–414.

McCOY, R.E., HOWARD, F.W., TSAI, S.H., DONSELMAN, H.M., THOMAS, D.L., BASHAM, H., ATILAND, R.A., ESKAFI, F.M., BRITT, L. & COLLINS, M.E. (1983) Lethal Yellowing of Palm. Bulletin 834, Institute of Food Sciences, University of Florida, Gainesville.

OLLAGNIER, M. & WESTSTEYN, G. (1961) Les maladies du cocotier aux iles Caraibes. Comparaison avec la maladie de Kaincope au Togo. *Oleagineux*, 16 (12), 729–736.

RENARD, J.L. (1980) Note de synthese sur la maladie du cocotier au Vanuatu. I.R.H.O. Document No. 1565.

Severe Stem Bleeding and Frond Fracture of MAWA Hybrid Coconuts in North Sumatra

D. KARTIKA AND F.X. SOEBAGYO

Bah Lias Research Station, PTPP London Sumatra Omdpmesoa.
Medan, Sumatra, Indonesia.

P.D. TURNER AND C.J. BREURE

Harrisons Fleming Advisory Services, Ltd., London, UK

In a NPK Mg fertiliser trial in Sumatra on Malayan Dwarf x West African Tall (MAWA) hybrid coconuts, applications of both potassic and nitrogenous fertilisers were found to influence significantly the stem bleeding disease. From leaf analysis over several years, it was evident that the chlorine component of applied potassium chloride was the most important since no significant differences occurred in potassium levels in the different treatments. Disease incidence in the K0 plots exceeded 50% within nine years after field planting, with the lowest incidence in K2 plots. Vegetative development and yield were also greatly reduced in affected palms. Both Ceratocystis paradoxa *and* Phoma leveillei *were isolated from lesions deep inside stems but pathogenicity could not be demonstrated. Frond fracture is clearly related to chlorine deficiency but may not be directly associated with stem bleeding. Results are discussed.*

The disease of coconuts (*Cocos nucifera*) known under the general name of stem bleeding was first described by Petch in 1903 from Sri Lanka (Child, 1974). Since then it has been reported in so many countries that it can be described as pan-tropical, occurring wherever conditions are favourable for its development (*e.g.* Bain, 1940; Chona & Adansi, 1970; Dash, 1922; Eaton, 1922; Schieber, 1970). Stem bleeding has long been known from the South-east Asia and South Pacific regions (Anon., 1927; Dadant, 1954; Dwyer, 1937; Lee, 1922; Mitra, 1929). Whilst stem bleeding is not usually considered to be a disease of major economic importance, significant losses have periodically occurred.

In one Philippines survey, symptoms of stem bleeding were found on 29,407 palms (Anon., 1927); in St. Lucia 12.3% of all coconuts surveyed were affected (Walters, 1930); and it has long been held that severe infection reduces crown size and yield whilst rarely killing the palm (Sundararaman, 1922; Venkatarayanan, 1929). Most severe effects are found when young palms are attacked, and one finding from Sri Lanka was that only young plants with immature wood were attacked (De Mel, 1927; Sundararaman, 1922). Symptoms similar to stem bleeding have also been noted on *Borassus flabellifer* and *Areca catechu* (Sundararaman, 1928; Sundararaman, *et al.*, 1928).

The variety of causes ascribed to stem bleeding is a good indication of the complex nature of the disease, which is further borne out by the various types of stem bleeding which have been described. There has frequently been a close association reported between the disease and the presence of *Ceratocystis paradoxa*, often linked with mechanical injury to the outer stem tissues (Anon., 1924; Butler, 1972; Fulton, 1922; Goberdhan, 1961; McPaul, 1962; Sundararaman, 1922; 1928; Sundararaman *et al.*, 1928). In Malay-

sia, *C. paradoxa* could be isolated but pathogenicity could not be demonstrated (Sharples, 1923). In general it would seem that direct pathogenic attack by the fungus in the absence of predisposition is unlikely. This could well account for the distinctions sometimes made between different types of stem bleeding, including some ascribed to physiological causes, environmental effects or pest attack (Martyn, 1945; Mathews & Ramanandan, 1980; Salgado, 1942; Sulladmath *et al.*, 1980; Thompson, 1924).

In this paper the occurrence of stem bleeding in a fertiliser trial on Malayan Dwarf x West Africa Tall (MAWA) hybrids is described, together with a widespread frond fracture. Nutrition was clearly a primary factor in disease incidence, particularly that of chlorine, with fungal attack also occurring. In addition, symptomology is detailed where it differed from that previously described.

MATERIALS AND METHODS

The fertiliser trial was on MAWA hybrids imported as nuts from the Ivory Coast in 1973 and planted on podsolic soil in 1974. A 3 x 3 x 3 factorial experiment was laid out in 1977 for N, P, K, with each plot split for Mg. Full details have been given by Rosenquist (1980) and for this paper it is sufficient to state the amounts of fertiliser applied annually (*Table 1*). Leaf analysis was carried out annually with sampling according to normal estate practice, using frond 14, together with records of growth and yield components. The experimental plots adjoined plantings of more MAWA hybrids and plots of local material, *i.e.* Nias Dwarf and Local Tall (Pantai Labu). These received routine applications of fertiliser at estate rates of (per palm) 500 g NPK Mg 15.15.6.4, 1 kg muriate of potash and 30 g fertiliser borate (46% B_2O_3). Disease incidence in these plantings was recorded for comparative purposes.

TABLE 1. AMOUNTS OF FERTILISER APPLIED TO EXPERIMENTAL BLOCKS

Fertiliser	Treatment (kg/palm/year)		
	0	1	2
Ammonium sulphate	0	2.25	4.50
Rock phosphate	0	2.00	4.00
Muriate of potash	0	2.25	4.50
Kieserite	—	1.50	3.00

To examine lesion development, surface tissues were excised to reveal the superficial extent of lesions. For internal development, three palms in K0 plots were felled and sectioned both transversely and longitudinally, tracing lesions to their apparent point of origin.

For pathological investigations, large pieces of diseased stem were taken to the Commonwealth Mycological Institute (CMI) at Kew, where isolations were made from advancing edges of lesions deep within the stem. Pure cultures of *Ceratocystis paradoxa* and *Phoma leveillei*, and a mixture of the two, were re-inoculated into healthy palms in an attempt to establish pathogenicity. Each fungus or mixture was replicated 20 times and lesions examined at three-month intervals. Cultures were also placed in undamaged stems

in K0 plots. Inoculation was by drilling a small hole (4 mm diameter x 5 mm deep) in a surface-sterilised section of stem in K0 palms, filling this with the culture, and sealing the surface with plasticine. Non-inoculated control holes were also made. Sub-cultures were made from developing lesions, with identification of isolates again made by the CMI. Isolations were similarly made from pieces of fronds with frond fracture but without re-inoculation.

RESULTS

Disease Symptoms

Stem bleeding. External symptoms of stem bleeding were very similar to those described by several authors. Briefly, a brown liquid exudes from cracks in the stem bark, this turning black and gradually drying up. Multiple patches of bleeding coalesced, especially in K0 palms (*Figure 1*). Pushing a knife into lesions sometimes resulted in a yellowish liquid flowing freely out. External symptoms gave little indication of the extent of internal decay. In K1 and K2 palms, most lesions tended to remain superficial, although sometimes quite extensive. In K0 Palms, the many lesions usually present gave no indication of internal development, which was often at considerable distances from the externally visible parts. Internal lesions were irregularly shaped but usually discrete, sometimes extending virtually from the stem base to an area just behind the apical meristem. Each lesion had a core of reddish-light brown conducting strands, which in later stages could be easily separated through decomposition of ground tissues. The core was surrounded by a darker brown zone, outside which was a softer, yellow-coloured zone. Smaller lesions were located at the periphery and the larger towards the palm base, but with no connection with roots. Tracing back lesions showed that they had arisen at the trunk exterior. From the extent of lesion disorganisation in the worst affected K0 palms it was evident that the infection must have been present for a long time.

Crowns of palms badly affected by stem bleeding were smaller than those of K1 and K2 palms (Rosenquist, 1980), even when they were not affected by the frond fracture described below. Progressively younger fronds decreased in size. It was noticeable that frond symptoms were much less noticeable in 1983, which did not have a pronounced dry season, than after the severe moisture deficit of 1982. Premature nut drip was very much associated with palms badly affected by stem bleeding and frond fracture. Where disease was particularly severe, then very few nuts remained on the palm. Those which had fallen were in an advanced state of development. Each fallen nut had a rot at the point of attachment and, when split, this rotting could be seen to have penetrated as far as the shell.

Frond fracture. A noticeable absence from published descriptions of stem bleeding is that of crown symptoms. In the trial described here, extensive frond fracture occurred in K0 plots but was virtually absent in others (*Figure 2*). In the worst affected palms, only 8–10 apparently healthy fronds remained. Fracture occurred at a variable distance between the point of insertion of the frond and where the pinnae are produced, often about 70–90 cm from the stem. Normally oldest fronds fracture first, but occasionally one higher in the crown will fracture prematurely. Before fracture occurs, a large, dark coloured to almost black, elongated lesion develops.

This is clearly visible from the ground on the underside of the rachis, and in such instances it is usually continuous through the adaxial surface. In other examples, lesion development was only on the upper surface. More often than not, the lesion was lateral-

3

*Figure 1. The stem exudate symptom of stem bleeding disease
on a MAWA hybrid palm.*

ly situated, with some disintegration at the edges of the rachis. However, apart from this edge effect, there was no obvious point of entry by a pathogen. Lesions extended along the rachis for a variable distance, often longer than 15 cm by the time fracture occurred. Fronds collapse and hang down around the palm in variable numbers according to the severity of the condition. Some portions remained green for some time but ultimately died, so badly affected palms were surrounded by a tent of brown, desiccated fronds.

Internal frond symptoms differed quantitatively rather than qualitatively. Light brown coloured lesions extended within the rachis to a variable distance on each side of the external position of the lesion. The internal spread tended to be in the form of longitudinal cores of affected tissue along the rachis, extending to 20 cm or more. Where diseased tissue was distinctly asymmetrically placed within the rachis then it had obvious effects on the pinnae closest to it. Where the lesion was more centrally placed, pinnae on both sides of the rachis were affected. Lesions did not extend into the stem.
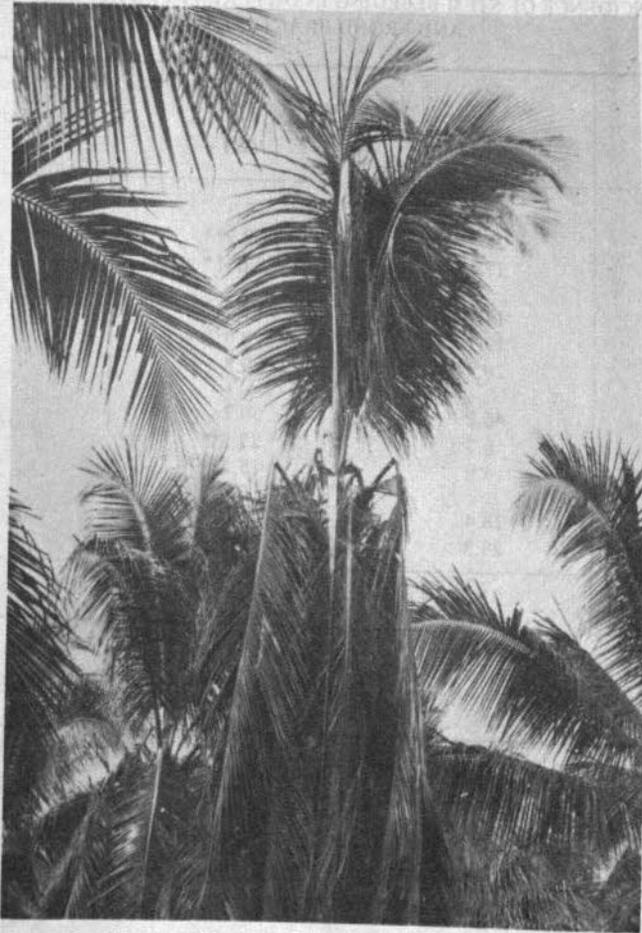
4

Figure 2. Multiple frond fracture of a MAWA hybrid palm in a zero potassium chloride plot.

Disease Incidence and Nutrition

The incidence of stem bleeding in 1982 and 1983, and frond fracture in 1983, is given in *Table 2*, relating to the MAWA fertiliser trial only. The effect of potassium chloride addition is very marked, with some enhancement of disease incidence also by nitrogen fertiliser application. The interrelationship between N and K is shown in *Table 3*.

In the remainder of the planting, *i.e.* non-experimental areas, disease incidence was generally low except in MAWA plots, which had incidence levels similar to K2 trial plots (*Table 4*). Most infections were classified as slight in all planting types except for 24% of MAWA palms, although external symptoms may not reflect internal extent.

Leaf analysis data are given in *Table 5*. Except for chlorine, there were no major difference between K0, K1 and K2 treatments, although high K level tended to suppress leaf B. It is considered highly significant that leaf K levels remained similar in all three K treatments throughout the 1979–1982 period. Soil chlorine availability was not deter-

5

TABLE 2. INCIDENCE OF STEM BLEEDING IN DIFFERENT FERTILISER TREATMENT, AND FROND FRACTURE IN 1983

Treatment	Stem bleeding (%)		Frond fracture (%) 1983
	1982	1983	
N0	15.1	23.5	–
N1	25.3	32.9**	–
N2	17.3	32.6**	–
P0	17.7	31.2	–
P1	19.1	28.0	–
P2	20.9	29.8	–
K0	46.2	50.7	11.6
K1	6.7	23.1**	1.7
K2	4.9	15.2***	1.2
Mg1	28.4	30.9	–
Mg2	29.3	29.5	–
Mean	21.0	29.7	

TABLE 3. INTERACTIONS OF N AND K(Cl) IN STEM BLEEDING INCIDENCE

N	K	Disease incidence (%)			
		K0	K1	K2	Mean
N0		40.5	15.7	14.4	23.5
N1		22.7	22.7	17.4	32.9
N2		52.9	31.0	13.9	32.6
Mean		50.7	23.1	15.2	29.7

TABLE 4. STEM BLEEDING INCIDENCE IN COCONUT VARIETIES RECEIVING NORMAL ESTATE FERTILISER APPLICATIONS, 1983

Variety	Total palms	No. diseased	Diseased (%)		
			slight	severe	total
MAWA	1227	180	11.9	2.8	14.7
MYD	812	34	4.0	0.2	4.2
Nias Dwarf	845	65	6.9	0.8	7.7
Local Tall	568	12	2.1	0.0	2.1

TABLE 5. MEAN LEAF NUTRIENT ANALYSIS DATA OF POTASSIUM CHLORIDE TREATMENTS

Treatment	N (%)				P (%)				K (%)			
	1979	1980	1981	1982	1979	1980	1981	1982	1979	1980	1981	1982
K0	1.87	1.93	1.91	1.90	0.150	0.148	0.134	0.112	1.60	1.50	1.61	1.70
K1	1.88	1.96	1.93	1.89	0.152	0.149	0.131	0.112	1.65	1.56	1.64	1.71
K2	1.85	1.92	1.89	1.88	0.147	0.143	0.130	0.102	1.68	1.60	1.66	1.78

Treatment	Mg (%)				Ca (%)				Cl (%)			
	1979	1980	1981	1982	1979	1980	1981	1982	1979	1980	1981	1982
K0	0.19	0.20	0.17	0.18	0.32	0.30	0.27	0.26	0.09	0.12	0.07	0.06
K1	0.20	0.22	0.18	0.19	0.32	0.30	0.26	0.28	0.42	0.43	0.41	0.53
K2	0.20	0.21	0.18	0.19	0.32	0.29	0.27	0.28	0.55	0.53	0.51	0.62

Treatment	Na (ppm)				B (ppm)				Mn (ppm)			
	1979	1980	1981	1982	1979	1980	1981	1982	1979	1980	1981	1982
K0	–	429	362	485	13.9	16.0	14.1	15.8	388	386	371	240
K1	–	444	401	535	13.8	14.6	13.5	13.1	444	419	407	293
K2	–	452	392	530	13.9	13.8	12.2	12.0	457	459	397	303

mined, but is likely to be low through leaching since this element is generally not fixed or absorped in the soil, despite a reasonably good cation exchange capacity.

Effects on Yield

Yield data are given in *Table 6*. These are not totally related to disease development but more to application of potassium chloride. In cumulative yield 1979–1981, the K1 and K2 plots produced 46% and 56% respectively more dry copra per hectare than the K0 plots.

TABLE 6. YIELD DATA FROM TREATMENTS WITH AND WITH MURIATE
OF POTASH APPLICATION

Fertiliser schedule	No. nuts/palm			Dry copra (g/nut)			Dry copra/ha (kg)		
	1979	1980	1981	1978	1980	1981	1979	1980	1981
K0	88	87	73	105	131	148	1432	1764	1678
K1	93	94	86	134	177	192	1932	2608	2575
K2	89	101	85	144	187	204	1986	2921	2718

Possible Pathogens

Numerous fungal isolates were identified, including the following: *Botrodiplodia theobromae, Ceratocystis paradoxa, Cladosporium* sp., *Pestalotiopsis* sp., *Phoma leveillei* (syn. *Pyrenochaeta acicola*). Of these *C. paradoxa* and *P. leveillei* occurred most frequently and were subsequently used for re-inoculation.

Lesions developed rapidly at all inoculation points and had become quite large and with bleeding by the end of three months. Lesions at points which had been inoculated with *C. paradoxa* appeared similar to those found deep within naturally diseased palms, with a light reddish-brown centre and an outer yellow zone (*Figure 3*). Lesions at points inoculated with *P. leveillei* were much drier, elongated and tended to lack the yellow outer zone (*Figure 4*). Internally, lesion development in all instances became more elongated and subdivided, with most growth up the stem. Lesions also developed in control damaged tissues which had not been inoculated.

Further sampling failed to yield either *C. paradoxa* or *P. leveillei* from any of the 15 lesions sampled at the end of three months. Lesions inoculated with *P. leveillei* only yielded *Acremonium recefei, Ceratocystis fimbriata*, an underscribed species of *Cylindrocarpon* (close to *C. ambisporium*) and *Fusarium solani*. Those inoculated with *C. paradoxa* yielded mainly *A. recefei* and the unidentified *Cylindrocarpon* sp., whilst lesions from points inoculated with both fungi yielded *A. recefei, F. solani* and *Melanospora* sp.

Frond fracture samples gave the following fungi: *B. theobromae, Curvularia* state of *Cochliobolus, F. tabacinum* and *P. leveillei*.

DISCUSSION

There can be no doubt as to the economic importance of severe attacks of stem bleeding disease and frond fracture, both through stem damage and loss of fronds. In the worst
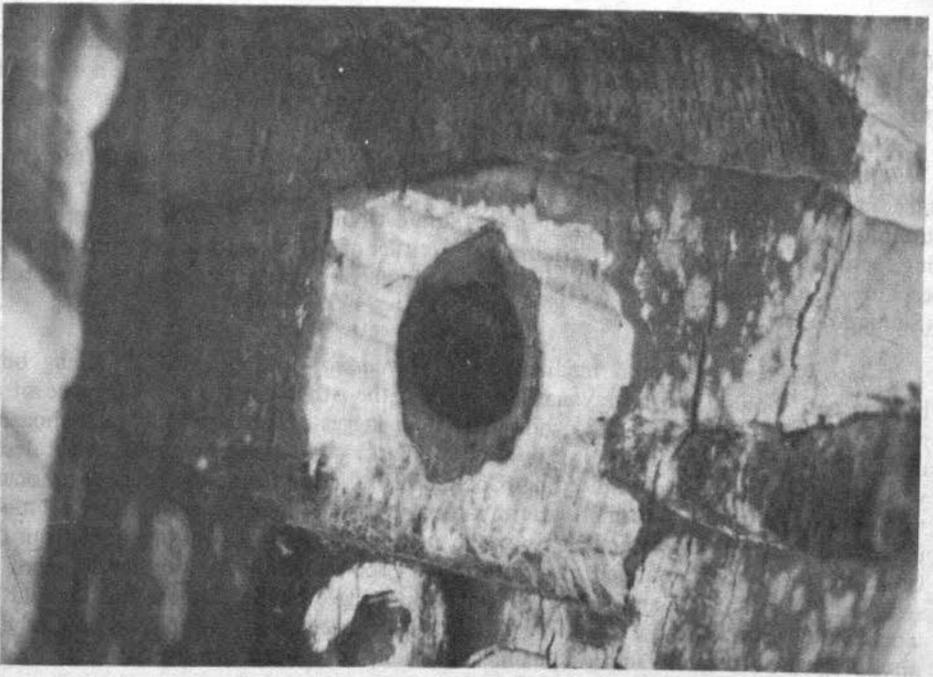
Figure 3. Stem lesion following inoculation with Ceratocystis paradoxa.
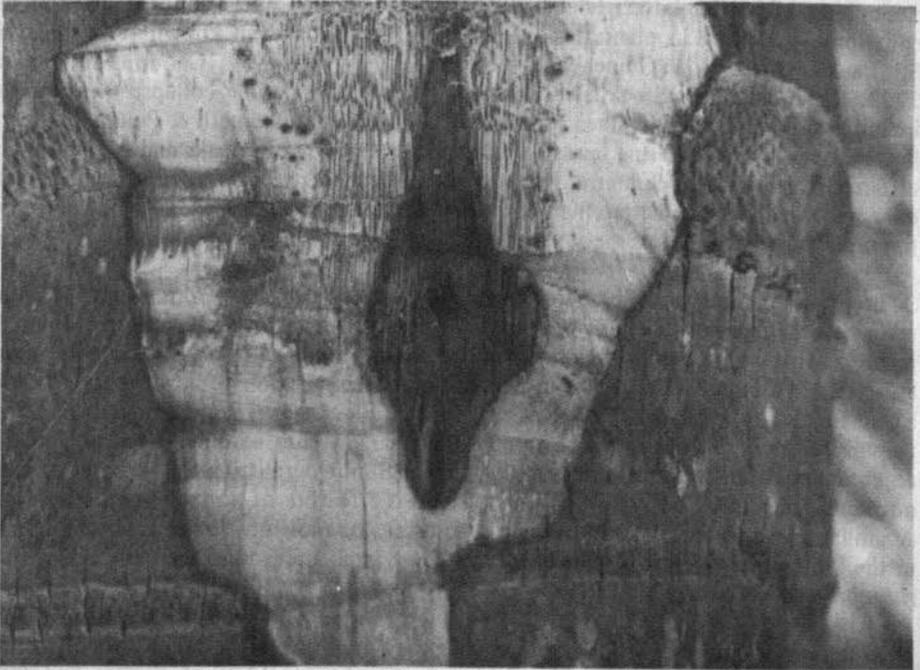

Figure 4. Stem lesion following inoculation with Phoma leveillei.

affected palms it seemed highly likely that death would ultimately result. Yield is affected, with mean differences between treatments being very significant. This is not entirely due to disease. Overall nutrition is an important factor.

Pathogens. The inability to demonstrate pathogenicity of fungi isolated from stem bleeding tissues was similar to the report of Sharples (1923). In that *C. paradoxa* is one of the most frequently occurring fungi in the humid tropics, the occurrence of a predisposing factor to infection is strongly indicated. Neither of the possible pathogens tested was capable of inducing a lesion on intact bark, a finding also previously recorded from India (Sundararaman, 1922).

Trunk exudate is a good medium for *C. paradoxa* development, containing both hyphae and spores (Venkatarayanan, 1929). On the other hand, the occurrence of *C. paradoxa* and *P. leveillei* so deep within the stem suggests that they could be pathogenic under these conditions. There is a possibility that *C. paradoxa* can cause internal decay without any associated stem bleeding (Cook, 1924). Lesion formation following inoculation seemed to follow a normal pattern, and it is possible that the re-isolation technique used was incorrect for pathogenicity to be proven. However, it was apparent from the isolations made that wounded tissue formed a good substrate for the development of several fungi in K0, K1 and K2 palms. Further testing of some of these fungi would be worthwhile, especially *A. recefei*, together with those already tested, but underlying physiological-nutritional factors will almost certainly complicate investigations.

Frond fracture. It is not known whether the symptoms of frond fracture were directly linked to stem bleeding or whether fracture is a distinct manifestation of chlorine deficiency; probably the latter. Leaf break, usually described as a supposed disorder and commonly occurring in plants lacking in vigour, has long been known from Malaysia, Sri Lanka, Papua New Guinea and West Indies (Dwyer, 1937; Gadd, 1920; Nowell, 1923; Richards, 1917; Stockdale, 1907). More recently, petiole collapse was recorded in India and Papua New Guinea (Shaw & Booth, 1967; Sulladmath & Ponnappa, 1978) but analyses of leaf chlorine levels were not made in these outbreaks and symptoms also differed from those in Sumatra. Nor was the associated pathogen, *Anthostomella fusispora*, recorded from Sumatran material, where the fungi isolated seemed to be invaders of fractured tissues and not primary pathogens.

In the Sumatran palms, based on the appearance of collapsed fronds, actual fracture seemed to be due to weakening of the tissues through fungal attack to a degree where the rachis at that point could no longer support frond weight. Typical buckling symptoms associated with such stress were present. Pinna discolouration some distance from the advancing lesion edge could have several causes. Blockage of conducting tissue is one possibility and translocation of a toxin is another. Disease of older fronds is likely to accentuate an already poor nutrient status through not permitting the removal of many nutrients from older to younger fronds, which is a feature of normal frond senescence. A similar frond fracture situation under conditions of moisture stress has been observed in the Philippines, with low chlorine status being implicated, together with similar *Fusarium* presence (Von Uexkull, 1983).

Function of chlorine. Whilst there could be no doubt as to the association of chlorine deficiency and both the frequency and severity of stem bleeding disease and frond fracture, the mode of action of chlorine can only be speculative at this stage. The importance of chlorine for early growth, balanced mineral nutrition and optimising yield in coconuts was confirmed in the Philippines (Oguis *et al.*, 1979; Von Uexkull, 1972),

10

confirming earlier indications in other countries (Ollagnier *et al.*, 1976). Deficiency symptoms include reduced nut size, with nuts often being deformed; reduced frond number, with pinnae being limper and paler than normal; and elongated yellowing patches on affected pinnae which become necrotic with age (Ollagnier *et al.*, 1976). These were all visible in the Sumatran planting. The occurrence of severe symptoms, together with frond wilting, following a prolonged dry period, point to moisture relations being important; unfortunately, soil moisture measurements could not be taken. One general effect of chlorine is that of influencing the water balance of a plant and thus its resistance to the adverse effects of moisture stress. Hence one very likely influence of chlorine is through predisposition to fungal attack through sub-optimal tissue moisture relations, although much more investigation is required to confirm this. There are few published references to disease incidence being related to chlorine, although in these few there are indications of the importance of water potential components (Christensen *et al.*, 1982; Christensen, *et al.*, 1981; Garvin *et al.*, 1981; Powelson & Jackson, 1978; Russell, 1978). Application of sodium chloride has been found in the Philippines to reduce the intensity of leaf attack by *Pestalotiopsis palmarum* (Magat *et al.*, 1977) and there are early indications in Sumatra that a similar effect is occurring in relation to both *P. palmarum* and *Drechslera* leaf spot severity.

Treatment and disease avoidance. In the situation described in this paper, stem bleeding lesions were so extensive and often so numerous that standard treatment would be ineffective for all but small lesions. Normal treatment recommendations have remained virtually unchanged for over 60 years, when treatment by scorching an exposed surface after lesion excision, followed by application of hot tar, was mandatory in Sri Lanka; alternatively, Bordeaux paste could be applied (Anon., 1921; Briton-Jones, 1940; Child, 1974).

Clearly, for MAWA hybrids which were chlorine-deficient this treatment would be inadequate, even if lesions could be located at an early age. Disease avoidance through maintaining an adequate nutrient status, particularly that of chlorine, would seem to be the only practical control method.

This in itself has quite far-reaching consequences with regard to the suitability of MAWA hybrids as planting material in areas where there is a deficit of naturally available chlorine. Under conditions of well run estates, necessary supplements could be made, possibly through application of sodium chloride instead of the more expensive potassium chloride. Routine use of sea salt has been practised in some Indian coconut plantations for many years, although for no definite reason (Child, 1974; Menon & Pandalai, 1958). However, use of the hybrid for smallholders in chlorine-deficient areas could be inadvisable since this group of growers is normally very reluctant to apply any form of fertiliser. It is possible that repeated applications of chlorine would not be required since it seems from unpublished data from oil palm in Sumatra, which are also probably relev~   coconut, that chlorine recycling from pruned fronds in the interrow occurs efficient₁

A more practical approach, especially for smallholders, would seem to be the use of planting material relatively tolerant or resistant to the disease. A range of varietal susceptibility was found in India, where incidence in fifteen cultivars was found to be in the range 10–40% (Radhakrishnan & Potti, 1980). Results from the rather limited range of planting materials within the experimental area clearly indicate that a range of susceptibility exists, with Indonesian-derived material showing lower infection levels.

ACKNOWLEDGEMENT

REFERENCES

ANON. (1921) Summary of laws and regulations in force in Ceylon in respect of plant pests and diseases. *Dep. Agric. Ceylon Bull.*, 48, 6.

ANON. (1924) Division of Plant Pathology. *Admin. Rep. Dep. Agric. Trinidad & Tobago, 1923:* 14–15.

ANON. (1927) Annual Report. *Bureau Agric. Philipp. Isl. 1926*, 95 pp.

BAIN, F.M. (1940) Report on the coconut growing areas of Jamaica. *Bull. Dep. Agric. Jamaica, 22*, 12 pp.

BRITON-JONES, H.R. (1940) *The Diseases of the Coconut Palm*, pp. 119–133. London: Bailliere, Tindall & Cox.

BUTLER, L. (1972) Coconut diseases. *In the coconut industry in Fiji*, 62–70.

CHILD, R. (1974) *Coconuts*, pp. 227. London: Longman.

CHONA, B.L. & ADANSI, M.A. (Eds.) (1970) Coconut in Ghana. *Bull. Crops Res. Inst. CSIR Ghana*, 3, 20 pp.

CHRISTENSEN, N.W.; JACKSON, T.L. & POWELSON, R.L. (1982) Suppression of take-all root rot and stripe rust disease of wheat with chloride fertilizers. *Oregon Agric. Exp. Sta. Tech. Pap. No. 6379*, 6.

CHRISTENSEN, N.W.; TAYLOR, R.G.; JACKSON, T.L. & MITCHELL, B.L. (1981) Chlorine effect on water potentials and yield of winter wheat infected with take-all root rot. *Agron. J.*, 73, 1053–1058.

COOK, M.T. (1924) Coconut fall. (Preliminary paper). *J. Dep. Agric. Porto Rico*, 8 (4), 12–14.

DADANT, R. (1954) Contribution a l'etude des maladies du cocotier, du cacaoyer, et de cafeier aux Nouvelles-Hebrides. *Agron. trop. Nugent*, 9 (1), 41–48.

DASH, J.S. (1922) Insectes et maladies. *Rep. Sta. Agron. Guadeloupe 1920–1921*, 14–16.

DE MEL, C.N.E.J. (1927) Pests and diseases of coconuts in the North-Western Province. *Trop. Agricst.*, 68 (4), 252–256.

DWYER, R.E.P. (1937) The diseases of coco-nuts (*Cocos nucifera*) in New Guinea. *New Guinea agric. Gaz.*, 3 (1), 28–93.

EATON, B.J. (1922) *Rep. Dir. Agric. S.S. & F.M.S. 1921*, 14 pp.

FULTON, H.R. (1922) Occurrence of *Thielaviopsis paradoxa* on the coconut-palm in Florida. *Phytopath.*, 12, 398–399.

GADD, L.H. (1920) A leaf break disease of coconut. *Trop. Agricst.*, 55, 106–108.

GARVIN, J.P., HABY, V.A. & KRESGE, P.O. (1981) Effect of fertilizer N, P, K, Cl and S on yield, protein percentage, nutrient content and root rot of barley. *Proc. 32nd Annual Northwest Fertilizer Conf., Billings, Montana, 1981*, 87–96.

GOBERDHAN, L.C. (1961) Coconut diseases in Trinidad and Tobago. I. 'Bleeding stem'. *J. agric. Soc. Trin. Tob.*, **61 (1)**, 33–38.

LEE, H.A. (1922) Observations on previously unreported or noteworthy diseases in the Philippines. *Philipp. agric. Rev.*, **4**, 422–434.

MARTYN, E.B. (1945) Coconut diseases in Jamaica (2). Diseases affecting the leaves, crown and stem of coconuts. *Trop. Agric. Trin.*, **22 (4)**, 69–76.

MC PAUL, J.W. (1962) Coconut growing in Fiji. *Bull. Dep. Agric. Fiji*, **38**, 99 pp.

MAGAT, S.S., MARGATE, R.Z. & PRUDENTE, R.L. (1977) Utilization of common salt (sodium chloride) as a fertilizer and for the control of leaf spot disease of coconut seedlings. *Philipp. J. cocon. Stud.*, **2 (3)**, 39–45.

MATHEWS, A.S. & RAMANANDAN, P.L. (1980) Incidence of stem bleeding disease of coconut palm in relation to pH and electrical conductivity of soils. *J. Plant. Crops*, **8 (1)**, 40–42.

MENON, K.P.V. & PANDALAI, K.M. (1958) *The Coconut Palm*. Bombay: Indian Central Coconut Committee, 384 pp.

MITRA, M. (1929) Some diseases of crops in the Andaman Islands. *Agric. Res. Inst. Pusa Bull. 195*, 14 pp.

NOWELL, W. (1923) *Diseases of Crop Plants in the Lesser Antilles*. The West Indies Committee, London.

OGUIS, L.G., MAGAT, S.S. & MARGATE, R.Z. (1979) The effect of chlorine sources and ammonium sulphate on the growth of coconut seedlings. *Philipp. J. cocon. Stud.*, **4 (3)**, 25–38.

OLLAGNIER, M.; OCHS, R. & DANIEL, C. (1976) The chlorine nutrition of oil palm and coconut. Application to fertilization. *Institut de Recherches poure les Huiles et Oleagineux, Doc. 1297*, 44 pp.

ORIAN, A.J.E. (1959) Report on a visit to Diego Garcia. *Rev. agric. sucr. Maurice*, **38 (3)**, 127–143.

POWELSON, R.L. & JACKSON, T.L. (1978) Suppression of take-all (*Gaeumanomyces graminis*) root of wheat with fall applied chloride fertilizers. *Proc. 29th Annual Northwest Fertilizer Conf., Beaverton, Oregon, 1978*: 175–182.

RADHAKRISHNAN, T.C. & POTTI, N.N. (1980) Varietal reaction to coconut stem bleeding disease. *Agric. Res. J. Kerala*, **18 (1)**, 118–119.

RICHARDS, R.M. (1917) The diseases and pests of the coconut palm. *Agric. Bull. F.M.S. 5*.

ROSENQUIST, E.A. (1980) A coconut fertiliser trial on the podsolic soils of North Sumatra. *Oleagineux*, **35**, 241–246.

RUSSEL, G.E. (1978) Some effects of applied sodium and potassium chloride on yellow rust in winter wheat. *Ann. appl. Biol.*, **90**: 163–168.

SALGADO, M.L.M. (1942) Note on the physiological stem bleeding of mature coconut palm. *Trop. Agricst.*, **98**, 31–35.

SCHIEBER, E. (1970) Enfermedades importantes del cocotero (*Cocos nucifera* L.) en la Republica Dominicana. *Turrialba*, **20 (2)**, 171–176.

SHARPLES, A. (1923) Annual report of the Mycologist for 1922. *Malay. agric. J.*, **11 (10)**, 267–272.

SHAW, D.E. & BOOTH, C. (1967) Petiole disease of coconut in Papua. *Papua New Guinea Agric. J.*, **(19 (2)**, 89–93.

STOCKDALE, F.A. (1907) Coconut palm disease in Trinidad. *Bull. Dep. Agric. Jamaica*, **5**, 111–139.

SULLADMATH, V.V. & PONNAPPA, K.M. (1978) Petiole disease of coconut palm caused by *Anthostomella fusispora* Booth & Shaw. *J. Plant. Crops*, **6 (2)**, 65–66.

SULLADMATH, V.V. & SHANTHAPPA, P.D. & RAJANNA, H.P. (1980) Aetiology of stem bleeding disease of coconut in semi-dry tract of Karnataka. *Curr. Res.*, **9 (5)**, 73–75.

SUNDARARAMAN, S. (1922) The coconut-bleeding disease. *Agric. Res. Inst. Pusa Bull.* **127**, 8 pp.

SUNDARARAMAN, S. (1928) Administration report of the Government Mycologist, Coimbatore, for 1927–28, *Rep. Dep. Agric. Madras, 1927–28*: 355–372.

SUNDARARAMAN, S.; KRISNAN NAYAR, C. & RAMAKRISHNAN, T.S. (1928) The stem-bleeding disease of arecanut (*Areca catechu*) caused by *Thielaviopsis paradoxa* von Hohn. *Agric. Res. Inst. Pusa Bull. 169*, 12 pp.

THOMPSON, A. (1924) Annual report for the Mycologist for 1923. *Malay. agric. J.* **12 (8)**, 246–251.

VENKATARAYANAN, S.V. (1929) How to distinguish between the stem bleeding disease and anabe roga of cocoanuts. *Mysore agric. Calendar 1929*, **13**, 17.

VON UEXKULL, H.R. (1972) Response of coconuts to (potassium) chloride in the Philippines. *Oleagineux*, **27**, 13–19.

VON UEXKULL, H.R. (1983) Personal communication.

WALTERS, E.A. (1930) *Rep. Agric. Res. Sta. St. Lucia, 1929*, 29 pp.

Progress on Copra Drying and Production of White Edible Copra

C.F. CHOOI, A.W. WANLESS AND C.W. SIAH

Boustead Estates Agency Sdn. Bhd., Kuala Lumpur

This paper discusses the design criteria, operational regime and the economics of the reversible air flow tunnel (R.A.F.T.) batch-dryer, a dual fuel copra dryer, built and successfully operated by the Highlands and Lowlands Bhd.

The conclusion is that the R.A.F.T. batch-dryer has justified its outlay. However, the vagaries of the white edible copra (W.E.C.) market would affect the rate of return on its outlay.

Copra production methods largely remain very traditional. Sun drying and/or "Ceylon-kilns" prevail. These traditional methods require a high labour input, are of low capacities, and produce a finished copra of variable quality.

There was little impetus to improvements due primarily to two factors, *viz.*

- Availability of relatively inexpensive labour willing to work non-social hours.
- The low acreages of coconut plantings compounded by low yields, in most estates.

These two factors no longer hold true. Labour is no longer inexpensive and is not willing to work non-social hours. For the same acreages on an estate, new high yielding hybrids can push coconut yields over twice as much higher, resulting in a greater demand on labour and drying facilities.

The need to compete in the export market competitively and advantageously with a quality product had to be faced. "White edible copra" is a premium grade and is beyond the capability of kiln-dryers to produce in quantity and quality.

These factors led to the decision to design and build a copra dryer which would meet the following objectives:

- A simple, rugged, automated but not overly sophisticated (estate labour still has to work it) dryer, requiring the minimum of operational labour input.
- To dry a batch within 24 h to match turnover to that of daily working thereby maximising utilisation of the dryer.

- A dual-fuel system using either solid or liquid fuel to take advantage of the most economic fuel available.

- Achieving a high percentage of premium product, *i.e.* white edible copra as well as achieving cleaner and all round superior quality normal copra.

- A high throughput.

DESIGN CONCEPTS

The Dryer was built on a property of Highlands & Lowlands Bhd. Messrs. Sphere Corporation Sdn. Bhd. had earlier built a modern copra dryer at another estate in the same district, but the requirement for the new unit was for a more "open" and simpler unit. This firm was retained to build the unit, with design planning in consultation with the Group Engineer's Department of Boustead Estates Agency Sdn. Bhd.

The composition of shell to copra, moisture in wet meat, are variable depending very much on age and type of nuts. For the design these were adopted as:

shell to copra ratio of 1 : 1
moisture in wet meat 45%
solid fuel consumption of 0.8 tonnes shell per tonne dried copra
or about
1 tonne shell to evaporate 1.0 tonne water.

It was subsequently found in practice that the average ratios were:

shell to copra ratio of 1 : 1.38
solid fuel consumption of 0.87 tonnes shell per tonne dried copra.

It must be stressed here that the word "average" is used. As has been pointed out, coconut composition changes with age even within the same type.

For solid fuel burning, a heat-exchanger was incorporated to exclude all risk of ash deposition on the copra and risk of fire started by carry-over of glowing ambers. Kiln fires are common occurrences with the traditional kiln-dryers.

For diesolene fuel burning, a direct high-low flame burner was used.

The fan was of adequate c.f.m. to "blanket" completely the half-nuts and subject all surfaces to heat, eliminating hot and cold spots in the half-nuts. This concept of uniform drying was further enhanced by having the special feature of an automatic timer-controlled airflow reversal valve that reversed the airflow through the trollies of wet half-nuts at pre-set intervals. In traditional kiln dryers this is done by manually turning the layers of half-nuts over.

The dryer was of a tunnel type, drying one batch of half-nuts to yield 2.5 tonnes dried copra at about 6% moisture content. The trollies were run on rails and easily shunted into and out of the dryer-tunnel by simple mechanical means.

The trollies totalled four in number with heavy wire-mesh bottom and side panels to permit free airflows. The side panels were hinged to allow ease of unloading.

The solid fuel (shell) system was designed for self-feeding of shell into the furnace at intervals to maintain the weight of shell in the furnace between two set limits. The shell silo stores some 3.5 tonnes of shell which are fed to the furnace by an inclined drag-chain conveyor.

A fire-fighting water line was run along the whole length of the tunnel, controlled by a manually operated valve to drench and extinguish any fire in the dryer.

All these concepts were incorporated and successfully effected into the working dryer.

WORKING THE DRYER

Drying cycles are worked to:

- Day 1, around 1.00 p.m. The four trollies filled with wet half-nuts and charged into the dryer. Firing up the dryer commences.

- Day 2, around 10.00 a.m. Firing stops, the trollies are pulled out of the dryer onto the shelling-shed. The dried half-nuts are unloaded onto the shelling-shed. The dried half-nuts are unloaded onto the concrete floor of the shelling-shed.

- By 11.00 a.m., all the trollies are emptied and ready for filling up with fresh half-nuts.

- By around 12.45 p.m., trollies are filled, and a new batch is ready for drying.

- Shelling is done by the shelling-gang which also sorts out the W.E.C. (white edible copra) from the normal copra.

An actual drying time of 20 h is employed.

Moisture content averaged at between 6% and 7%, which levels do not always allow for long storage without risks of mould development. Practice was evolved to have all the week's (Monday to Saturday) production of W.E.C. redried in their bagged form in the dryer on Sunday over 5 to 6 h to achieve a moisture in the meat of below 5%. This was found to be a workable system with the dried W.E.C. being able to keep mould free for more than six weeks under ordinary storage.

Drying regimes were:—

- First 8 h at 94°C

- Remaining 12 h at 75°C

Various drying regimes were tried, with that as stated above proving the most suitable. Fuel (diesolene) consumption averaged 80 gallons per batch and power (electricity) consumption averaged 251 KWhr per batch of 2.5 tonnes dried copra.

Solid fuel (shell) firing was not used on any extensive scale due to:

- Shell fetching a high price.

- Problems were encountered in hard-scale depositions on the furnace grate due to the high silica content in the shell. This factor, we believe, is a common problem with other types of solid fuel burners utilising high intense fires and

3

coconut shells. However, when solid-fuel firing was employed, figures obtained were:—

0.87 tonnes shell to produce 1.0 m.t. dried copra, aided by 20 gallons (90.9 litres) diesolene for the first hour of start up when high heat inputs are required and when the solid fuel furnace has yet to attain a good working temperature.

It can be deduced, therefore, that with a shell to copra composition averaging at 1 : 1.38 (or 0.72 : 1.00), dependence on shell as the only fuel cannot be relied on.

The design parameter adopted of 1 : 1 ratio shell : copra has been thrown awry by the higher meat and moisture content in the newer hybrid materials, and by the fact that nuts from younger palms have higher water content in meat.

As the dryer is a dual-fuel unit, the shell deficiency is not of particular concern as the difference in heat demand can be easily compensated by diesel-fuel burning.

For the whole of the year 1983, the dryer produced:

W.E.C.	424.01 m.t.	(64.4%)
Normal copra	234.83 m.t.	(35.6%)
	658.84 m.t.	(100.0%)

and for the period January — March 1984:

W.E.C.	225.84 m.t.	(75.9%)
Normal copra	71.74 m.t.	(24.1%)
	297.58 m.t.	(100.0%)

The percentages of W.E.C. obtained are satisfactory considering that the nut material are of mixed types and mixed ages; the Dwarfs are more than 40 years old and the Talls are more than 50 years old. High percentages of germinated nuts are common from these older materials. However, in reference to the figure above, approximately 65% of the throughput consisted of nuts from hybrid plantings.

The various nut types as in the estates are felt to be capable of yielding W.E.C. percentages as:—

Hybrids, up to 85% W.E.C.
Malayan Talls, up to 55% W.E.C. (probably 80% for young Talls)
Malayan Dwarfs, up to 50% W.E.C. (probably 80% for young Dwarfs)

COSTINGS

To arrive at a like-to-like basis of comparison, the capital outlay and depreciation are considered first: Three units of Ceylon kilns are the equivalent in terms of capacity to one unit R.A.F.T. dryer, as a Ceylon kiln is capable only of 0.75—1.0 tonnes copra per day production.

4

	1 unit R.A.F.T. Batch-Dryer	3 units Ceylon Kiln
Dryer	$175,000.00	$135,000.00
Dryer Shed	20,000.00	28,000.00
Electrical Works	7,000.00	—
	$202,000.00	$163,000.00
Difference in Capital Cost		$39,000.00
Depreciation at 10% per annum	$ 20,200.00	$ 16,300.00
Depreciation per tonne based on the 1983 gross production of 658.84 m.t. copra	$ 30.66	$ 24.74

Extended costings from January 1983 to June 1984 have turned out meaningful figures:—

- Manufacturing cost of $126.34 per tonne copra on the R.A.F.T. dryer; this includes a return from sales of shell off the dryer at an average nett $40.00 per tonne.

- Manufacturing cost of $80.80 per tonne copra on the Ceylon Kiln; the cost is inclusive of 50% available shell used as fuel at $40.00 per tonne and 50% balance of available shell fetching a sale value of $40.00 per tonne.

- Depreciation calculated earlier to be $30.66 and $24.74 per tonne copra respectively for the R.A.F.T. dryer and the Ceylon Kilns.

- A weighted average selling price of W.E.C. at $1,573.25.

- A weighted average selling price of normal copra at $1,032.85.

- A premium of $540.40 per tonne for W.E.C. over normal copra was secured for the period.

	R.A.F.T. Dryer	Ceylon Kiln Dryer
Sales		
649.85 m.t. W.E.C. @ $1,573.25	$1,022,376.50	—
306.57 m.t. normal copra @ $1,032.85	316,640.82	—
956.42 m.t. normal copra @ $1,032.85	—	$987,838.39
Gross Returns	$1,339,017.30	$987,838.39
Gross Returns b/forward	$1,339,017.30	$987,838.39
LESS: Costs:—		
Manufacture, $126.34 x 956.42 m.t.	120,834.10	—
Depreciation, $30.66 x 956.42 m.t.	29,323.84	—
Manufacture, $80.80 x 956.42 m.t.	—	77,278.74
Depreciation, $24.74 x 956.42 m.t.	—	23,661.83
Margins	$1,188,859.40	$886,897.82
Difference in Margins		$301,961.58

Based on the above exercise, the R.A.F.T. dryer would have achieved a difference in margin compared to Ceylon Kilns of $301,961.58 over 956.42 m.t. copra through the production and sales of 649.85 m.t. (67.9%) of white edible copra.

The higher capital cost of the R.A.F.T. dryer over the equivalent three numbers of Ceylon Kiln at $39,000 is seen as being paid back within three months.

This costing exercise also points out that a minimum premium of $51.46 per tonne copra is required for the R.A.F.T. dryer to be justified in terms of costs compared to Ceylon Kilns.

At the premiums prevailing the last 18 months, the capital outlay on the R.A.F.T. dryer had been recovered in 8 months.

CONCLUSION

The results obtained from the operations of R.A.F.T. dryer at Torkington Estate showed that the quality of the product was achieved at a higher capacity than that of a Ceylon Kiln.

The additional returns achieved, as indicated above, is dependent upon W.E.C. continuing to attract the same level of premium over normal copra. The break-even point on the 1983 figures over which W.E.C. will attract a higher return will be at a premium level of $51.46 per tonne.

The premium on W.E.C. will vary according to the irregular demands of the limited market for the product.

ACKNOWLEDGEMENT

6

Utilization of Non-Kernel Products of the Coconuts

R. YATAWARA
Hayleys Limited, Sri Lanka

In theory, laboratory research studies, and folklore, the versatile coconut has a myriad uses. This paper, however, is confined to the less romantic applications — where the magnitude of the commercial uses is sufficient to contribute materially to rural and national economies. The coir fibre industry and activated carbon from charcoal, dealt with, in some depth, and only a few examples of others are cited.

Sri Lanka has been chosen as the model because, although it ranks fourth in production, it probably has the most advanced by-products utilization industries due to historical, plantation density and socio-economic reasons.

Project Prospects

Those in other producer countries contemplating export-based ventures using coconut by-products may find some of the subsequent remarks discouraging. Unplanned, uncoordinated proliferation of fibre based or activated carbon industries in the region are not encouraged because they will contribute to market depressions through over-supply. Many such projects flounder on the rocks of economic non-viability.

Aspects in feasibility studies that are often overlooked are:—

- Socio-economic conditions in the region and sensitivity/survivability of the primary raw material generating industries, through depressions in the supply/demand cycle, which is characteristic. (*e.g.* the 600 fibre extraction mills in Sri Lanka cannot, sometimes, cope with a five to six day week, whilst at other times of the year, no more than 400 mills function and that for just three to four days a week.)

- The investments/technology required for international marketing of a product, in competition with reputed existing suppliers, is often underated or not included in evaluations. (*e.g.* a producer of activated carbon in a developing country cannot acquire the specialised absorption engineering *service* capability of suppliers in the industrialised countries, which enable them to sell product at 200–300% margins over costs.)

All too often we have witnessed the uninitiated, plunging into ventures after only relating the shop shelf price of a finished product to the abundance in availability, at no cost, of its raw material.

Therefore, if entirely domestic market are envisaged for the end products, or international selling rights are granted, we would be willing to evaluate joint venture proposals. My mission here today, however, is non-commercial and seeks only to share experiences and knowledge on a subject of common interest.

SRI LANKA COCONUT CROP

The hundred square mile triangular area North of the capital Colombo, is where coconut growing is the densest (*Figure 1*). Seventy-five to eighty percent of the 450,000 ha under coconut are small-holdings of less than 20 ha, and consequently are not very adversely affected by the Land Reform Laws of 1971 which limited individual ownership to 20 ha. Notwithstanding this, uncertainties at the time caused neglect of properties — no fertilizer application, etc; erratic weather patterns in the past decade, urbanisation of rural areas, etc. contributed to frequent shortfall in crops. With 65% of the island's crops used domestically as an essential constituent of the Sri Lankan diet (90 nuts/capital), it was politically expedient to legislatively control exports of copra/desiccated coconut/nuts during periods of shortfalls, so as to contain price to consumer. These strategies were counter-productive and precipitated a decline in coconut cultivation. A more liberal outlook — with subsidies on fertilizer and irrigation, farmer education on intercropping, etc. — is now being adopted, including attempts at converting the domestic consumer to alternatives.
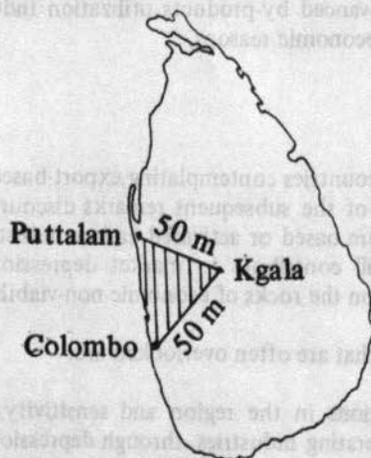
Figure 1. Map of Sri Lanka showing coconut growing region

NON KERNEL PRODUCTS UTILIZATION

The title of the paper may be a trifle misleading. The following are not dealt in detail:—

- Use of sap of the flower for toddy extraction which, upon distillation, produces "Arrack', the Sri Lankan whisky, or Candy;

- Mid rib of the leaf — ekels — of which some 7000 tonnes are exported, and probably an equal amount used locally for garden brooms, $700 k p.a. in For. Exch.

- Leaves/fronds — which, upon weaving, is used as thatching for roofs and fences, bullock carts, baskets, etc.

- Trunk — debarked and core removed is very popular as rafters and beams for roofing; trunk as a whole is also used for fueling brick and tile factories.

Figure 2 portrays the utilization of various components of the nut, two of which — the husk or fibrous mesocarp and the hard shell (endocarp) — directly provide the livelihoods of maybe 20,000 — 30,000 people of Sri Lanka. Surprisingly, little is known that the end products of this very humble 'cast away' waste, influence the lives of practically everyone on this globe, even in a small way.

Husk Utilization

The 'destination' of the husk and shell is often determined at the dehusking stage. The skill of the husker (some of whom achieve output rates of 2000—2500 nuts/8-h) ensures that: —

- Some fibre is retained over the shell as protection against shock, etc., for nuts intended for domestic consumption or export, and when the husk is unlikely to be used for fibre extraction.

- The nut is 'clean shaven' if it is intended to convert the shell to charcoal (fibres contribute to high ash in char), and the maximum amount of fibre is retained in the husk.

White fibre industry. India is the leader in this area with some 130,000 tonnes produced and 30,000 tonnes export in the form of yarn, rope, mats and mattings. Sri Lanka produces about 7000 tonnes and exports 2000 tonnes. Availability of low cost labour, abundance of husk and brackish backwaters typify this cottage industry.

In Sri Lanka, the manufacture goes back 70—80 years and is concentrated in the Southern Province where the typical infrastructures exist. As it is today, 'yarn-spinning' has been a woman's vocation! Sadly, over the decades, the vagaries of commodity markets, changes in rural lifestyles, etc., have seen the replacement of handspinning skills by rat & wheel spinning, and we now face a future where this in turn may be replaced by mechanised factory type spinning — borne of economic necessity.

Husks (usually green — ex nuts for domestic consumption) are 'retted' in brackish backwaters, held by 'pens' for over six to nine months. The consequent biochemical processes result in leaching of tannins. Investment in inventories of husk being so treated provides a role for the village merchant/financier who then sells the retted husks to households. The fibre is extracted by manual beating of the husk with a wooden mallet — which, upon drying, results in a white matrix of mixed short and long fibres. Mechanised, decorticator type fibre extraction is being practised in some parts, but generally results in a lower percentage of the long fibres in the matrix and consequently affects the breaking strength of the twine subsequently manufactured p. cap. Output (approx. dry weight) on manual extraction of fibre from husks is 10—15 kg/8 h; but it must be remembered that as a woman's past time between household chores, both fibre extraction and spinning cannot be cost out as any other process. One can reckon on US$0.50 per day as a reasonable income today for this exercise.

The fibre is first spun into individual plys by a stationery wooden frame carrying two hooked spindles which are turned by a control wheel. Two women holding fibre bundles under their arms release controlled amounts of fibre whilst walking backwards. At the subsequent moveable spinning wheel the plys are wound around each other, resulting in a

Figure 2. Economic uses of the coconut

two-ply yarn 15–18 m which is then made up into hanks between the elbow and palm. Outputs of three persons in 8 h varies from 5 to 15 kg, depending on the thickness. The short hanks are sold to traders who make them up into bundles and deliver to a processor or shipper. It is astonishing that even now the yarn is graded according to colour, texture, purity, uniformity of twist and thickness, etc., into no less than 25 to 30 qualities, and the names (as do the properties), typified the region from which they came. Type of soil and water used on retting, and style of spinning influence these aspects of quality.

At any exporters' warehouse, yarn is sold according to its type and colour (which is the basis of payment to the supplier who is permitted to observe [and object] to the grading of his product – one to two–day process).

Graded yarn is next spliced into longer strands and hanked up to 3 kg in weight. Packaging of the yarn is a compromise overseas buyers make – depending on cost economics of freight saving via densification (such as hydraulic pressing) versus the lower costs of having the yarn packed at source in a manner which facilitates dispensing at the point of use. Pressed bales, coils or rolls, 50–100 kg, spools of 3 kg with centre or end drawing – single or upto six strands, are available.

Domestic purchase prices of yarn range from US$320 to US$500 per 1000 kg whilst export realisations are $400 to $900 PMT FOB; freight at $112 to $350 PMT, depending on pack, is a high element in C+F costs.

Export markets include agricultural stringing, notably hop growing (from which beer is made), in the UK and USA. The quality criteria here are not colour or appearance so much as: –

(a) processing and packing form which makes it convenient for farmers to string large acreages at speed without the yarn 'kinking' or pack collapsing. In UK, it is spools of 3 kg each containing approx. 600 m, whilst in USA cut lengths of 6 m are supplied.

(b) runnage – maximum yarn length/unit weight purchased; economics of usage usually 180–220 m/kg subject to (c),

(c) breaking strength/requirement varies with quality of hops and climatic extremes and wind velocities: varies 50 to 75 lb.

Usually, (b) and (c) have inverse relationships and price is naturally lower for thicker yarns. Products offered cannot be overspecified for there is no net advantage to user.

Although synthetics are popular, the preference for the natural product is that after harvesting, the strings are cut loose and allowed to biodegrade. Use is seasonal, perhaps lasting a month of stringing each year.

There is a fair market in Pakistan for Sri Lanka yarn (Indian embargoes), as a general purpose cordage – tying scaffolding, stringing woven beds, etc. Cheap qualities predominate here. It is also used to wrap around suction points of tube/deep well pipes to act as a filter. In Italy, it was extensively used in filtration of olive oil. Apart from indigenous use within India and Sri Lanka, as a general purpose cordage (either in two-ply or multiply/rope form), the major outlets for coir yarn are in the manufacture of coir rugs, mattings and carpetting manufactured on both hand and power looms. Belgium, France,

Germany, Italy and Netherlands are large users of Indian coir yarn for this purpose. Infinite variations both in construction/design and texture are achieved, sometimes in conjunction with other natural fibres. Still others have tufts of supple yarn embedded in PVC matrix. Coir is deemed to have all-weather durability over alternatives. Colour purity, which also facilitates uniformity in dyeing and evenness of spin are important properties for this application. Funnily, it is used as the warp or weft or tuft.

A fair volume of finished carpeting has also been generated within India for export, but growth in this sector has been limited by the South Indian State Government's commitment to discourage automation which accompanies power-loom industries. Sri Lanka has filled this breach in the market to a modest extent, with two coir mat projects in 1982–83. With Government assistance, the setting up of many mechanised white fibre production units in Sri Lanka, will, together with mat loom production, add a new thrust to the flagging coir yarn industry; but in macro terms, India's policy makers would determine the fate of coir yarn in the world markets in future.

The growing domestic demand, rising labour costs, Governmental aversion to mechanisation are likely to see a decline in exportable surplusses of coir yarn and finished products from India in the long term. Spasmodic price/supply constraints are likely to cause some users overseas to switch to synthetics or alternative types of natural fibres. Sri Lanka's production, with increased accent now on establishment of export production, with increased accent now on establishment of export production villages, is likely to grow. If mechanised extraction and spinning of coir yarn develops, there is prospect for other coconut producing countries to engage in yarn, ropes, mats and mattings manufacture, at least for indigenous consumption.

Brown fibre. An 80-year-old product, in supplies of which Sri Lanka dominates with annual tonnages of 90,000 or 95% of world supply. The survival of this industry for many decades is attributable to the diversity of the end applications and resilience of those engaged in producing it, as well as the continuing discovery of new applications for the product.

Almost all of the brown fibre is produced from matured brown husk of nuts used in copra and desiccated coconut making. Accordingly, the 600 odd fibre mills are located in the Coconut Triangle, as are the copra and DC Mills. Whether husking is at plantation cropping point or at the kernel extraction stations, the husks must be transported to the fibre mills. This could be a significant element of cost.

Husk prices range from US$4 to US$10, depending solely on the fibre prices *vis-a-vis* crops. Transport costs with 8000 husks per 15 CBM truck with roof loading and transitting say 20–30 miles is US$1.2 per 1000. So, although it is claimed that Sri Lanka uses only 30% of her coconut husks to produce 90,000 tonnes fibre per year (this happens to be from within the Coconut Triangle), and that a great potential exists for expanding this further, one must not forget that husks collected from further afield would be too expensive on transport to make the prospect viable, and the existing mills working five-day week have the capacity to produce 50% more than the peak demand the industry has serviced in any one year.

A peculiar thing about the fibre industry is that too much rain prevents drying of fibre and too little causes a water shortage for soaking.

A majority of the mills have still to be hooked to the national grid and hence, motive power continues to be a significant cost factor. Attempts at modernising the extraction

6

and preparation of fibre have been unsuccessful partly due to ingrained habits, yet low costs of labour, but also because, with variable sizes and constitution of husks, the facility of "selective" defibering possible with manual/semi-automatic would be lost.

Few mills operate the decorticating system — where dry husks are fed into beater and de-fibering machine. This produces a "matted" fibre with all the long bristles broken up in the process and mixed with the mattress. Revenue is low on such an operation as it ranks only slightly ahead of mattress fibre in quality and is used almost exclusively for making twisted fibre. The project's sensitivity, therefore, to the vagaries in demand from just one market, is also high. Thankfully, the wet milling process yields both mattress and bristle fibre and their subsequent processing presents many options of applications.

It is not proposed to describe the various processes and end applications of brown fibre here.

Originally, about 300—400 fibre mills merely extracted the bristle mattress fibres from the husks. Six to ten fibre processors/exporters then converted the bristle, depending on length of fibres, colour and cleanliness, into the more sophisticated forms — dyed, hackled, cut, etc., making them ready for immediate use by brush makers, especially in Europe. The mattress fibre was merely pressed and baled. Over the years, twisted fibre and more processed forms of brush fibres evolved. It was quite a juggling act for exporters to balance their sales of fibre to the same proportions as mattress and bristle yielded by the mills, since fibre is too cheap and bulky a commodity to stockpile. Purchasing is on "spot basis" (purchase contracts do not mean anything). Shippers can hence make money only on a falling market against forward contracts, but since oil crisis, even these are open for renegotiation.

Rising costs in the organised industrial sector, to which fibre processors/exporters belong, paved the way for a new breed of intermediate processor — typically individual entrepreneurs or the fibre millers themselves. Ability to circumvent Government floor price regulations (both local buying and export), taxes, etc., as also low wage costs, achievability of higher productivity, lack of confinement by regulations to hire/fire employees — all contributed to a proliferation of producers/exporters. With it came of course a decline in overall quality standards. Erratic weather patterns, users whose quality consciousness varies inversely with supply/demand situation, caused further deteriorations.

Today, the old established exporters have phased out all labour-intensive processing operations and are engaged in value addition activities which warrant investment in equipment and technology and require some professional management. Amortised investments in old hydraulic presses give them an 'edge' over newcomers to the industry whose role is, therefore, limited to mainly manual processes.

Use of twisted fibre in automobile seats was a major break-through in the late 50's and early 60's, if not for which, the fibre industry could well have been extinct. It provided an alternative use for lower grades of bristle fibre and later, even mattress, both of which were otherwise totally dependent on the "see-saw" vagaries in demand from the bedding and brush industries which were progressively shifting towards synthetic substitutes. Bristle fibre used in Wakayama Valley in Japan for spinning twine for nets has since been taken over almost entirely by synthetics.

The trend and legislation towards fire retardant materials in autos was a setback for the twisted fibre business, as petroleum-based alternative took their place — oil crisis

7

notwithstanding. To lend greater stability to the demand for bristle fibre, and hence the fibre industry as a whole, four advances were made by Hayleys, *viz.,*

(a) Establishment of a bannister brush and broom industry,

(b) Manufacture of flagged fibre and cream white bleached fibre as substitutes in texture and colour for other fibres used previously in brushes,

(c) Treatments to soften and polish fibre to provide a twisted fibre simulating animal hair, previously used in the more exotic upholstery,

(d) Import of two-ply twine making machines from Japan and their low cost duplication locally, to produce a uniform twine from brown fibre to replace white Indian coir yarn in many overseas applications which were looking for alternatives.

Fortuitously, the use of mattress fibre (after hand twisting), in lining draining pipes developed — to take up the slack from traditional outlets in the bedding industry.

Considerable research work has been done on commercially exploiting the coirdust by-product. Its use as a filter for roofing sheets particle board briquetting as a fuel, extraction of furfural, production of activated carbon, etc., have been investigated. More recently, studies into its use as a soil additive/moisture retaining medium have been made. One of the principal drawbacks appears to be below the top surface of the dust mountains. Although the dust is at zero value, handling/de-moisturising it for any useful purpose thereafter, appears to be expensive. Mechanical pressing, solar and air draft are being researched.

The future of brown fibre industry depends on both external and domestic factors.

High inflation rates within Sri Lanka over the past decade, urbanisation of rural areas, and aversion of younger generations to arduous jobs in primitive processes are likely to militate against keeping production costs low enough to be attractive to overseas buyers. Availability of jute waste and cotton wastes, as a substitute for mattress fibre, and the high incidence of freight (50–100% on delivered user costs), are of concern. Sadly, unlike most other products where progressive transfer of technology and manufacturing facilities from the developed countries to lower cost developing ones, and organized industrial sector to lower cost individual entrepreneur operations have helped sustain demand for certain products; in the case of fibre, there are certain limitations.

Unless new applications with potential for large volume consumption are developed, one could say we have reached *the end of the road* as far as forward integration of fibre products are concerned; the manufacture of needled pads for the mattresses themselves, or rubberised auto seats, results in an expansion of volume of product by the creation of voids, and the consequent freight cost makes any such venture totally uneconomic. Growth prospects, therefore, appear to be in improving the quality of all primary products exported, and expanding in the lines of brush, carpet and twine manufacture — possibly also, making inroads into unconventional uses for their products.

Coconut Shell Utilization

In many coconut-producing countries, the "finger-cut" method of removing meat from the nut leaves the shell in the husk and there is little utility except as a fuel. Attempting to change the traditional processing methods would be futile unless the "net backs" are very rewarding — which it appears not.

8

When coconut consumption (especially in households) is widely dispersed, it is natural that the shell be used as a domestic fuel in hearth cooking. To divert this for a more 'industrial' purpose, one must not only provide a substitute fuel to the householder, but also be contend with the high costs (relative to the end purpose), of collection/packaging, if any, and transport to a central location, of this cheap bulky material.

Handicrafts/ornaments, cooking spoons and other decorative applications excluded, as also its use as a collecting cup for latex rubber, commercial scale use of shell is in areas where it is surplus to the fuel needs of the region.

Coconut shell is a hard, dense material and this property is made use of in the following applications:

- Granules/chips used in shot blasting chimney stacks to remove soot and scale,

- Finely pulverised forms 75 and 45 microns, used as a dense 'filler' in thermoplastics, and as a filler in adhesive glues for wood/furniture.

Fuel. Contrary to popular opinion, the shell charcoal does not have any more heat value than the raw shell:

1 kg shell = 7700 − 8220 KCal/kg = 1/3 kg charcoal = 2600 KCal
(1 kg shell produces approx. 0.3 kg charcoal)

The shell really comprises:

Moisture	=	8 − 16%
Volatiles	=	62 − 72%
Fixed carbon	=	25 − 35%
Incombustible ash	=	0.1 − 0.5%

Depending on the extent to which partial sun drying is possible, anything from 35 to 50% of the shells generated at a copra drying centre is used to provide the heat − shells being laid in overlapped rows to provide a steady supply of heat. Coconut shell is believed to provide a cleaner copra than if wood or alternatives are used, since firing is direct unlike DC drying. Sadly, the Sri Lanka copra driers/chambers are so "heat inefficient" in design (originating from days when char/heat energy was cheap), that much heat is lost and the shell is needlessly burnt to an ash. The balance 50 to 65% shell is converted to charcoal in lined pits, quite independently, and the heat generated is lost to atmosphere. Although this has already been accomplished in other copra-producing countries, experiments with prototypes are now underway in Sri Lanka, attempting to devolatalise shell, combust the off gases against a heat exchanger and use the indirectly heated air to cure copra in better designed driers. This could mean using more than 70−80% of the shell since heat is utilised only from the volatiles. Balancing heat generation rates with heat needed for slow curing of copra is critical. If successful, it would mean

- Superior quality copra − clean, non-smoky, hot air having being used.

- No atmospheric pollution either in copra or char making.

- Ability to produce charcoal even in rainy weather.

- An extra 35 to 50% char can be made from shells that would otherwise have been burnt to an ash.

- Sand and foreign matter contamination of char is avoided.

- Control of the charring process might be easier.

9

It is true that in theory, and as war-time practice, the distillates of coconut shell pyrolysis can be used to produce acetic acid, coal tars, creosote, etc., but today this route to the end products are believed less economic than alternatives.

Charcoal. In Sri Lanka and the Philippines, the surplus shells from copra and desiccated coconut manufacture are converted to charcoal. Sri Lanka, the pioneers at this game has been carbonising shell from sometime between the two wars and producing and exporting coconut char for many decades.

The process of converting coconut shell to charcoal is one of really raising the temperature of the shell to above 500°C in an oxygen-free atmosphere so that volatiles are driven out and a pure form of carbon remains. *This is easier said than done.* The product price is such that 'no way' can another fuel be used to provide the heat nor can the end product justify the employment of exotic refractory metals and high technology process equipment for indirect heating. On the other hand, the low temperature, slow carbonisation yields a better activatable material, hence the rate of pyrolysis or destructive distillation cannot be overly accelerated by employing higher temperature.

The equipment that is designed for carbonisation should, therefore, enable controlled amounts of air (O_2) to be added to combust the volatiles that are liberated by initial heating to 500°C$^+$. This combustion reaction generates more heat and the cycle goes on. Uniform distribution of the hot gases/temperature is also vital because if there is localised temperature-drops, the volatalised tars will recondense on some parts of the Char, contributing to high percentage of volatiles and excessive temperatures in zones are attended by high risks of carbon burn-off as well as graphitisation of the carbon atoms and loss of capability for activation.
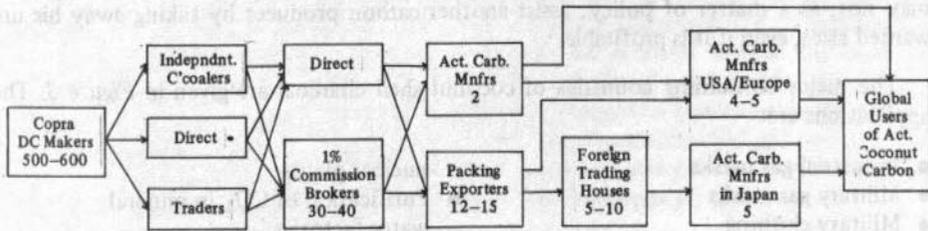
In Sri Lanka, the pit system is employed. This consists of a cylindrical hole in the ground 1.8 m to 3 m in diameter and 1.2 to 2.4 m depth — usually bricklined. In the Philippines, old 204-litre drums are more popular either due to the size of shell collections of individual copra producers and cash flow, or because this form has been popularised in recent times in the notion it is cleaner! But actually, the chances of greater variability in quality is higher when 1 tonne of char is made in 20—30 drums, rather than 1 pit.

Charcoal-making is a skill that must be acquired.

Each Sri Lankan copra or desiccated coconut producer has two to six lined pits in his compound, if it is not in an urbanised area; if it is, they usually haul the shell to a desolate area or sell the shells to those who take it away for carbonisation. This is because of the very acrid smoke that is liberated in carbonisation, and protests from nearby households. It is, in any case, carried out in the night. Shells are at a premium always — and cannot be bought for much cheaper than their charcoal value equivalent. There is, hence, no role for an independent charcoal making factory, dependent on buying up shell. Skilled charcoalers — usually a family unit — living gypsy style, move from one copra/DC mill to another, for periods of three to ten days. Copra/DC millers — owners of shell byproduct — depending on their individual affluence and assessment of charcoal markets, can afford to collect coconut shell in piles in their compounds almost indefinitely, as it is not perishable as such. In favourable markets, they hire charcoalers on contract at rates of US$4 — 6 per tonne char, to transfer shells to pits, carbonise, unload pits, sort, screen product, pack into bags and load. Transport costs are usually another $3 — 5 per tonne and the rest of the proceeds on sale of coconut shell charcoal is net profit to the

10

producer. Small time copra (and hence charcoal), producers of 1 – 3 tonnes per month have their product bought by dealers who advance cash and provide the transport.

There are more than 500 charcoal producers/dealers and the supply route is as follows:

Copra DC Makers 500–600	Indepndnt. C'coalers	Direct	Act. Carb. Mnfrs 2	Act. Carb. Mnfrs USA/Europe 4–5	Global Users of Act. Coconut Carbon
	Direct	1% Commission Brokers 30–40	Packing Exporters 12–15	Foreign Trading Houses 5–10	Act. Carb. Mnfrs in Japan 5
	Traders				

A typical costing of a copra producer is given in the *Appendix.*

Charcoal prices can fall to Rs$1000 per tonne and husks to Rs$75 per 1000. In such a situation, the net earnings from these 'by products' can be $800 per day. That is still good ... but producers often get caught with high priced inventory of nuts on a market where copra and DC prices *should* rise in sympathy with world markets, *but in effect do not* – because of Government controls on exports to safeguard the local food nut consumer, for political reasons.

Conversely, crop shortfalls due to adverse weather a year previous will raise nut prices, but coconut oil/DC markets may not be dictated by the same considerations. Millionaires/bankruptcy abounds.

All coconut product prices are published in the daily newspapers. Prices of charcoal are obtained by the Coconut Development Authority by making inquiries from the trade. Producers/dealers of charcoal make sales to exporters either on a spot basis or on forward supply contracts, direct or *via* brokers. The exporters also take "positions" in trading; however, it is one sided. Forward supply contracts go completely in default as domestic prices escalate, whilst exporters have to honour their own commitments to overseas buyers. Litigation is almost impossible, with costly delays. Suppliers always make contracts under spurious names to avoid turnover and income tax liabilities, and an exporter who does not fall in line with the trade practices just does not get any charcoal. Trading is not easy because of the following:

● Local suppliers default on forward contracts when market escalates.

● Anticipated price increases must exceed storage/finance costs of this bulky material if one is to trade off the physical stock positions only.

● In a stable market situation, if one were to decide to increase his daily intake from 50 to 100 tonnes/day to build a stockpile or service a new business, one has to raise the price by Rs. 100–200/=; but then, after a day or two, one will not get even 20 tonnes/day because suppliers believe market is on the rise and prefer to hold on.

● In a collapsing market, naturally the number of overseas buyers falls off exponentially.

Ordinary charcoal in naturally occurring 'chips' of 0.63 cm to 5.1–7.6 cm is what is normally exported, in woven PP sacks or coir bags of 50-kg. This enables the activated

carbon manufacturer to change his crushing intensity to suit the orders for the end product. However, ordinary charcoal stows at 10 to 11 tonnes/6 m container and freight is often equal to the FOB value. Some buyers, therefore, purchase pre-crushed and sized (granulated) material where stowage improves to 15-tonnes/6 m container. If one can successfully balance the sales of various fractions that are formed in a crushing operation, this can be rather profitable. However, the activated carbon world is so small, a competitor may not, as a matter of policy, assist another carbon producer by taking away his unwanted sizes, even if it is profitable.

The major consuming countries of coconut shell charcoal are given in *Figure 3*. The applications are:

- Industrial gas masks
- Military gas masks
- Military clothing
- Air conditioning
  Domestic
  Industrial
  Naval/Aircraft
- Toxic gas exposure
  Personal sensors
- Foods pads for odour removal
- Evaporation loss
  Control in autos
- Cigarette filters
- Solvent recovery in various industries
- Manufacture of pharmaceuticals
- Medicinal applications
- Veterinary applications
- Agricultural applications
- Absorption of radioactive gases in

  nuclear plants
- Purification of CO_2 in mineral water factories
- Decolourisation of sugar
- Purification of glucose
- Odour removal in cooker hoods
- Recovery of precious metals from ore
- Dechlorination & Purification of water
  Domestic water filters
  Municipal water filters
  Mineral water factories & breweries
- Industrial water/effluent treatment
- Purification of dry cleaning solvents
- Decolourisation of mineral, vegetable & animal oils
- Treatment of alcoholic beverages
- Aquarium filters
- As a catalyst or catalyst support
- Purification of electrolytes

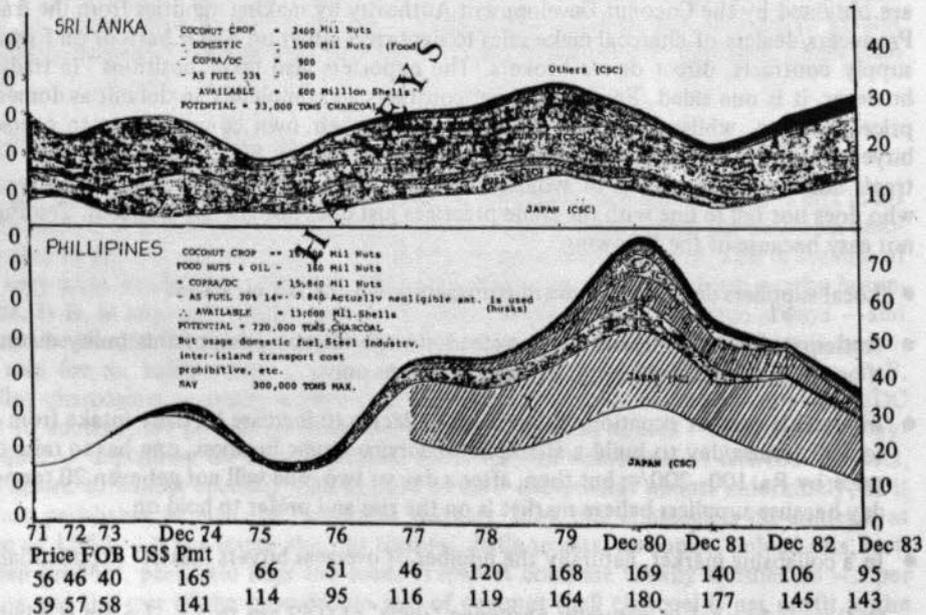|		71 72 73	Dec 74	75	76	77	78	79	Dec 80	Dec 81	Dec 82	Dec 83
Price FOB US$ Pmt		56 46 40	165	66	51	46	120	168	169	140	106	95
		59 57 58	141	114	95	116	119	164	180	177	145	143

*Figure 3 Coconut shell charcoal exports (as IS/as A.C.)*

12

In a market upswing situation, a multitude of traders get into the act and a 100-tonne inquiry by one user of charcoal, channelled through five sources, appears as demand for 500 tonnes, and both in the producer countries and even third party ones, everyone talks of charcoal and gets pretty excited.

Price fluctuations (*Figure 4*) in charcoal within a short period, are attributable to the speculative element referred to earlier or to temporary shortages due to incessant rains which preclude production; or even to droughts when water needed for controlling carbonisation process is inadequate. The major crests/troughs are attributable, to world supply demand phenomena. Natural disasters and droughts which can contribute to crop shortfalls are the majors — for example, a 35% crop shortfall in Sri Lanka means a 100% shortage of DC/copra, and hence, charcoal. Changes in end product (activated carbon) demand also influence prices. As prices escalate, two reactions are catalysed:
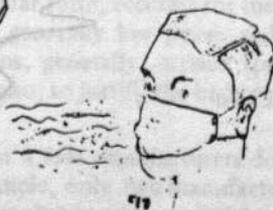
- There is increased generation of charcoal from shells which were previously wasted in Philippines, Malaysia, Indonesia, etc.

- Users of coconut based activated carbon sensitive to price, switch over to coal based types.

This then results in oversupply and collapse of prices.

Activated carbon. Activated carbon is firstly a molecular sieve which is illustrated below.
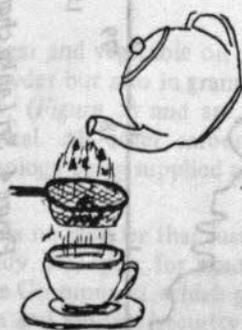
A wire mesh traps large *particles* say 1.0 – 0.5 mm	Closer woven filter cloth traps finer *particles*, say down to 0.045 mm	Activated Carbon removes *molecules* of 0.000002 mm size present, dissolved in a liquid or gas stream

Activated carbons normally available as cylindrical pellets or irregular shaped granules of 5 mm to 0.5 mm size, or even as powders of 0.040 mm or finer, all have an extensive network of pores within them. The pores range from 0.01 mm down to 5 to 10 A° (angstrom = 10^{-6} mm). The carbon particle type and size are important only from the standpoint of how it is applied, *e.g.* one cannot have a 4-mm piece of carbon in a cigarette filter as the air stream carrying the obnoxious gas may by-pass it; nor can one have a plug of very fine powder as it will impede inhalation. What is more important is, the total volume of pores in a carbon and the distribution of pores of various sizes in this volume,
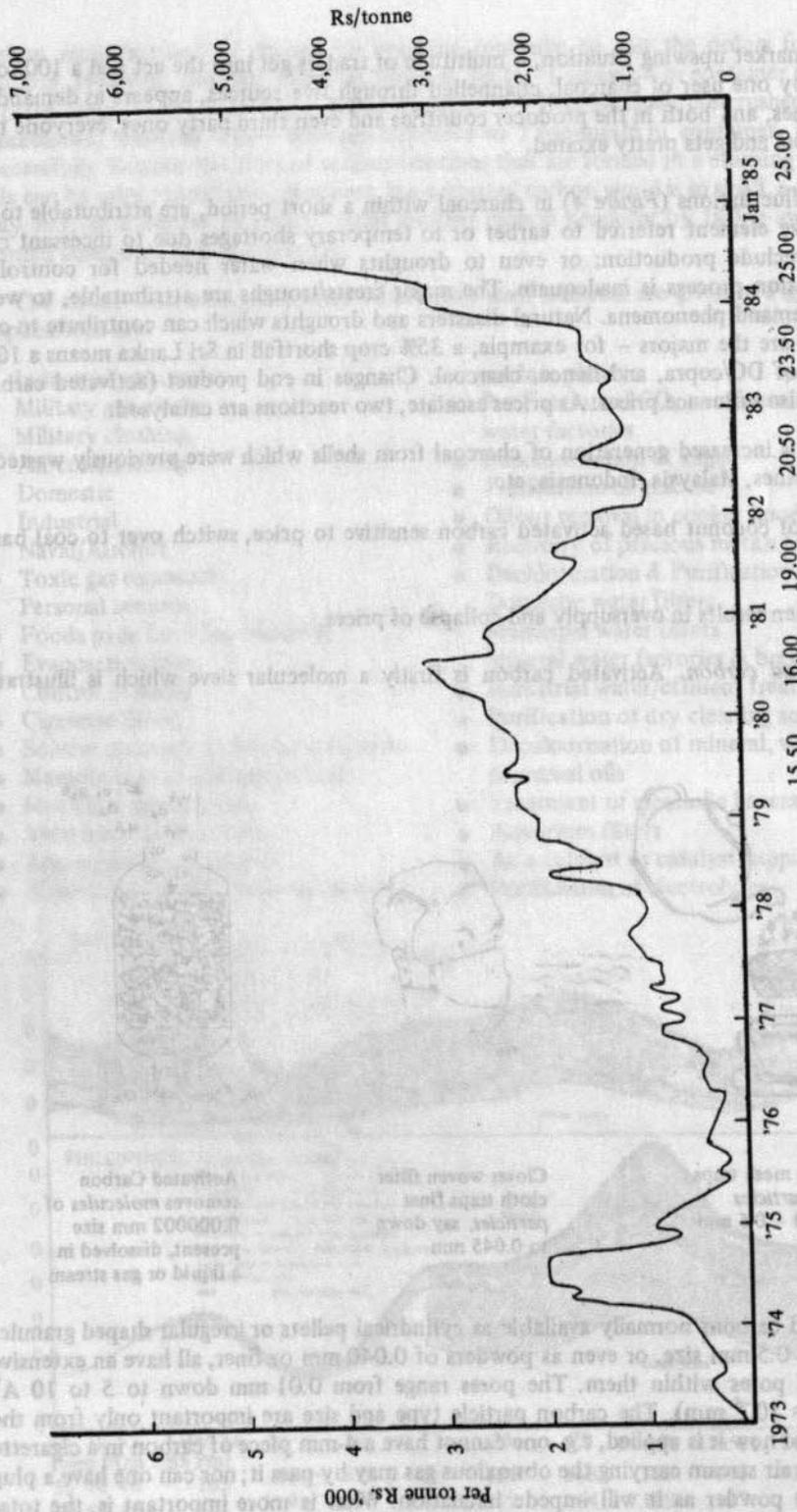
Figure 4. Sri Lanka charcoal price to exporters.

because *that* will influence what molecules that particular carbon is capable or not of adsorbing.

Colour bodies such as which give the colour to molasses or vegetable oil or complex organics present in waste waters, are large molecules, requiring, for efficient removal, pores of a diameter such as found in activated carbons by chemical activation of sawdust. Gas molecules are smaller and coconut shell carbons made by steam activation are the most cost-effective if the intention is to trap the absorbed gas, as in gas masks. Where the absorbed vapour/gas must also be recovered cheaply, coconut carbon is unsuitable and certain types of coal carbons are imperative. It is not a question of molecules just slotting into pores, but entering pores which are more than double their own sizes and, due to proximity to the pore wall surfaces, get attached to them by certain physico-chemical forces. Therefore, internal surface areas of carbon are an indication of capacity and this runs as high as $1600 \, m^2/g$ or 160 areas/lb. Carbons are sometimes specifically treated with various chemicals to improve their selective adsorptive powers for certain molecules in a mixture. *Figure 5* depicts some uses of activated carbon.

As can be seen, therefore, it is not a product that can be universally applied but has to be tailor-made for individual customer purposes, not even a general application field. The research and technology for carbon applications are to be provided by suppliers, very often with custom-designed equipment.

Although numerous test methods and specifications exist for quality or process control, and may be for preliminary evaluations, final selection of a carbon is based on duplicating actual process conditions or under simulated lab scales.

Sugar and vegetable oil decolourising and some waste water treatment carbons, mainly in powder but also in granular form, account for the larger share of all markets in volume terms, (*Figure 5*) and are generally low prices and may be classified as a commodity chemical. All other carbons, generally, service speciality small volume markets, with technology being supplied also, to justify the higher prices obtained.

It is no wonder that just a few manufacturers dominate the coconut carbon markets globally. In Japan, for example, only two manufacturers have been approved as suppliers to the Government, which probably takes up 7000 to 8000 tonnes of carbon for cigarette filters and military/security applications. In many other countries, notably in Europe and USA, research work into the use of carbon in military/nuclear application are funded by the respective Governments and conducted by a carbon manufacturer who is not only the single approved source for product but also authorised/proven as a supplier of technology and carbon to other countries.

Against such odds, the chances of survival of an activated carbon manufacturing facility which is not *tied* to one of the existing suppliers, is remote.

Fortuitously, the use of activated carbon in CIP process for recovery of gold from ore, commenced at the same time. This was an area of carbon application where the users (mining companies), knew as much or more than suppliers of carbon, because there was free exchange of technology development information amongst mining houses all over the world. The gold industry therefor, knew precisely what they wanted of a carbon and were guided by quality and price criteria only, without the need for technical support on sales as carbon users did.

Figure 5. Activated carbon markets.

ACSC PRODUCTION LOCATIONS AVAILABLE

CHARCOAL SOURCE — PHILLIPINES 55000 T — SRI-LANKA 35000 T

MARKETPEACE — PHILLIPINES — SRI-LANKA

MARKETEER

KUR 3000 · TAK 3000 · CAT 3000 · 3-4 JAP

CAL/CHEM 3000 S/B AVLB · BC 500 · SS 1000 · PIC 4000 · VAR SALES AGENTS/DISTRIBUTORS

MUST POSSESS REPUTN IN MARKETPEACE, SUPPLY CAPABILITY FOR ALL TYPES OF ACT. CARBON, DELIVERY, REACTIV-ATION FACILITIES, CUSTOMER SERVICE, ADSORPTION ENGINEERING, EQUIPMENT DESIGN, SUPPLY ETC. TO GET PREM MARKETS

JAPAN · REST OF WORLD

COCONUT 25,000 T

COAL, PEAT, SAWDUST, WOOD CHAR 250,000 T, MAINLY EUROPE/USA

DECOLORISING & WATER TREATM'T

GAS PHASE & GOLD RECOVERY

KEY
— ACTIVATED CARBON
— COC CHARCOAL USED AT SOURCE
— COC CHARCOAL EXPORTED

In summary, therefore, the mere availability of cheap labour, cheap energy and no cost coconut shell, or even 20–30% export incentives from a Government, as also the know-how for activated carbon manufacture, all amount to only 20–30% of the considerations needed for being in the activated carbon business, unless collaboration/co-operation agreements with one of the existing coconut carbon makers is included.
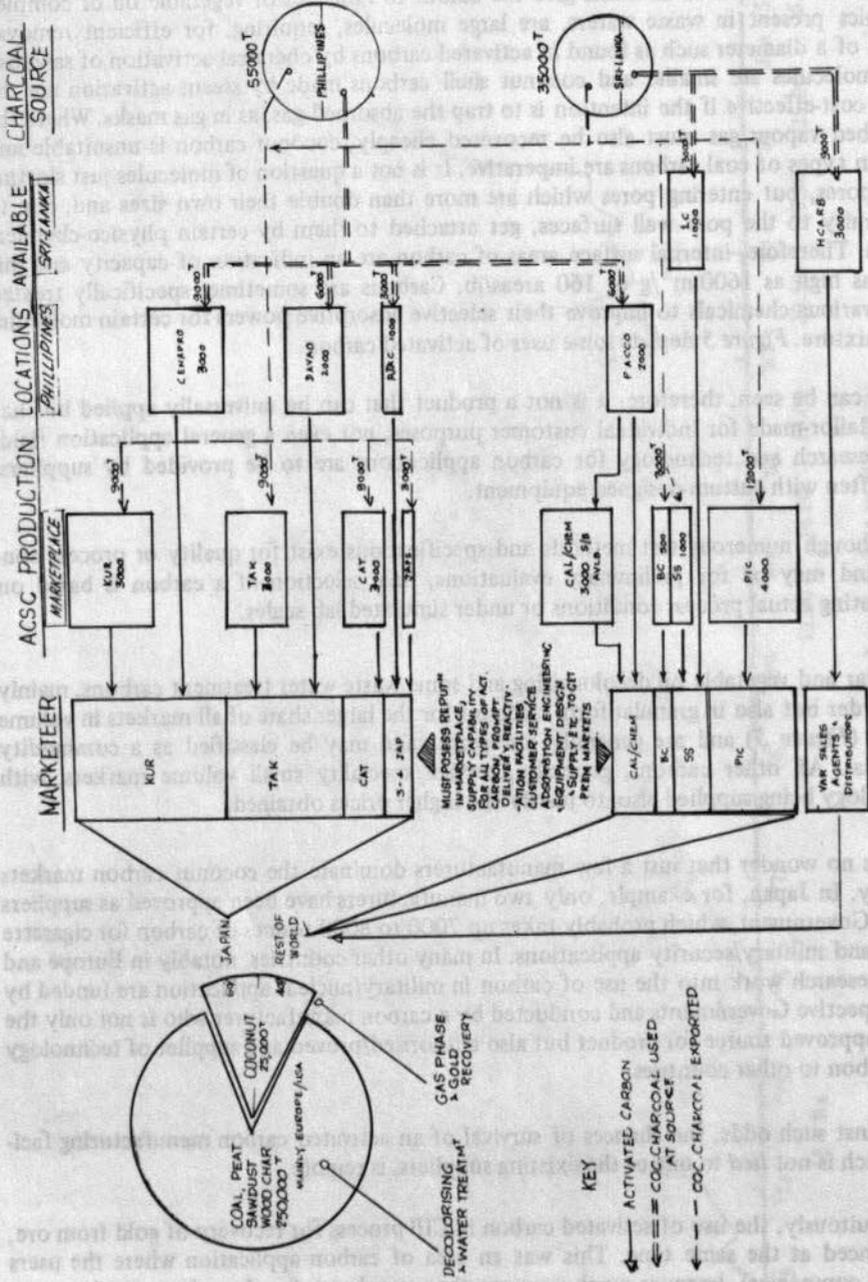
Medium-Small Copra Miller

3-Acres – Char Pits – Copra Kilns – 1 Tractor Trailer
Inventory 200,000 nuts (Rs. 500,000/=)
10,000 nuts z 22 days/month

Daily Average Operations

10,000 nuts @ Rs. 2/90	29,000	Sale of 10,000 Husked nuts @		
Lorry/Trailer Costs 200/= per		@ 150/= per ton	= Rs.	1,500
3600 nuts	550	Copra sale 3700 x 4 = 14,800/=		
Labour – Unloading/Loading 3 x 30	90	per ton – 10,000 nuts		
Husking 30/– per 1000		= 2 Tons	= Rs.	29,600
(1 man max. 2000/=)	300	Sale of Charcoal 0.3 Tons		
Splitting Sun drying, kiln drying,		@ 4000/= per ton	= Rs.	1,200
bagging 38/= per 1000	300			
Charcoaling @ Rs. 125/= per ton				
(20,000 shells) 60% of 10,000				
nuts = 6000 shells	40			
Transport of Copra to Oil Mills				
800/= per 5T	320			
Brokerage on Copra Sales and				
Finance, etc. 1½%	450			
Bags used (1 per 8 times)	60			
Transport of Char 600/6	100			
	31,210		Rs.	32,300
Profit	1,090	– x 22 days = 24,000/= pm (US$900)		
	32,300			–

(Interest 500,000 @ 2% pm approx. 10,000/=)