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1984 INTERNATIONAL CONFERENCE ON COCOA AND COCONUTS
PROGRESS AND OUTLOOK

KUALA LUMPUR HILTON 15 - 17 OCTOBER

VOLUME I

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1984 INTERNATIONAL CONFERENCE ON COCOA AND COCONUTS
PROGRESS AND OUTLOOK

Kuala Lumpur Hilton 15 – 17 October

PROGRAMME

SUNDAY, 14 OCTOBER

1100 – 1700 Registration of Participants

MONDAY, 15 OCTOBER

0700 – 0815 Registration of Participants

0815 Assembly of Participants

0830 Arrival of Guests

0900 Arrival of YAB Datuk Musa Hitam, SPMJ, SSIT, BSI
Deputy Prime Minister, Malaysia

OPENING SESSION
Chairman: Dr Radzuan Abdul Rahman

Address by Encik M R Chandran
Chairman, Incorporated Society of Planters

Opening Address by YAB Datuk Musa Hitam SPMJ, SSIT, BSI
Deputy Prime Minister, Malaysia

0930 – 1015 COFFEE

COCOA

SESSION 1: BREEDING & SELECTION

1015 – 1030 1. **Promising Prang Besar cocoa clones**
C F Chong & R Shepherd

1030 – 1045 2. **Performance of control pollinated Brazilian progenies under Hilir Perak conditions**
Ibrahim Abdullah, Sapiyah Subali & Ali Bashah Saad

1045 – 1100 3. **Evaluation of early vigour of wild cocoa from the Amazon Region of Ecuador**
J B Allen

1100 – 1115 4. **Clonal cocoa work on BAL Plantations**
Y H Chan & David H K Lim

1115 – 1130 5. **Evaluation of clonal materials in MARDI Hilir Perak and MARDI Jerangau**
Ibrahim Abdullah & Sapiyah Subali

1130 – 1145	6.	**Pollination ecology of cocoa in Malaysia: identification of taxonomic composition and breeding sites, ecology and pollinating activities, and seasonal abundance** I Azhar & S M Wahi
1145 – 1215		DISCUSSION
1215 – 1345		LUNCH
		SESSION 2: PHYSIOLOGY
1345 – 1400	7.	**Trials on irrigation of cocoa on coastal soils in Peninsular Malaysia** K H Lim, C Y Ho & B J Wood
1400 – 1415	8.	**Recent advances in vegetative propagation techniques for *Theobroma cacao* L. under Malaysian conditions** K Ramadasan & Mohd Yunus Ahmad
1415 – 1430	9.	**Evaluation of several mature budding techniques of cocoa** Jelani Bahaudin, A Raub Maulud & Aleham Hambali
1430 – 1445		DISCUSSION
		SESSION 3: MANAGEMENT
1445 – 1500	10.	**Some aspects on spacing and thinning in cocoa** David H K Lim & Y H Chan
1500 – 1515	11.	**Intercropping cocoa and oil palm – 11 years of trial results** Nawi Che Yusoff, C W Leong & Jamaludin Lamin
1515 – 1530	12.	**Influence of timing and frequency of pruning on yield of hybrid cocoa** Jelani Bahaudin, Syed Kamaruddin Syed Wazir & Salehuddin Omar
1530 – 1545	13.	**Observations on cocoa planting under thinned jungle shade in Sabah** D K K Chok & K T Khoo
1545 – 1605		DISCUSSION
1605 – 1700		POSTER SESSION
2000		COCKTAIL PARTY

TUESDAY, 16 OCTOBER

		SESSION 4: ENTOMOLOGY
0815 – 0830	14.	**Use of an early warning system for the control of *Helopeltis theivora theobromae* in cocoa** G A Wills
0830 – 0845	15.	**Population dynamics of the cocoa pod borer *Acrocercops cramerella*: the importance of the host plant cropping cycle** R K Day

0830 – 0845	38.	**Some differences in cocoa bean quality requirements between chocolate manufacturers and cocoa powder and cocoa butter manufacturers** J L Terink
0845 – 0900	39.	**Long term developments in world cocoa 1985 – 1990 – 2000** D Crotty
0900 – 0915	40.	**The marketing mechanism for selling cocoa powder and cocoa butter in the Malaysian context and its implications on the industry as a whole** P Meijer
0915 – 0940		DISCUSSION
0940 – 0955		COFFEE
		COCONUT
		SESSION 10: BREEDING, SELECTION & PHYSIOLOGY
0955 – 1010	41.	**Genetic analysis of yield characters in some hybrids of coconut (*Cocos nucifera* L.)** J Meunier, A Sangare, J P Le Saint & F Bonnot
1010 – 1025	42.	**Recent advances in genetic improvement of coconut yield** J Meunier, J P Le Saint, J P Gascon & M de Nuce de Lamothe
1025 – 1040	43.	**The effect of climatic factors upon nut characteristics of the coconut palm (*Cocos nucifera* L.)** E E J Akpan & I O Obisesan
1040 – 1055	44.	**Comparison of precocity and yield of hybrid coconut varieties in Thailand** M Rattanapruk, J C Howl, A Thirakul, C Petchpiroon & J Dootson
1055 – 1110	45.	**Distribution and Morphology of roots of the Nigerian Tall coconut in relation to nutrient absorption and fertilizer placement** U Omoti, U C Amalu & D O Ataga
1110 – 1125	46.	**Clonal propagation of coconut palm** R L Branton & J Blake
1125 – 1155		DISCUSSION
		SESSION 11: CULTURAL PRACTICES, PESTS & DISEASES
1155 – 1210	47.	**Optimum density for MAWA hybrids** Y P Tan & E Chan
1210 – 1225	48.	**Dry matter production and macronutrient content of the Nigerian Tall coconut** U Omoti, D O Ataga & U C Amalu
1225 – 1240	49.	**Dry matter and nutrient composition in hybrid coconuts (MAWA) and cocoa on coastal clay soils** K C Teoh, K S Chan & P S Chew

SESSION 7: PROCESSING

1415 – 1430 27. **A survey of Ghanaian cocoa farmers fermentation and drying practices and their implication for Malaysian practices**
R J E Duncan

1430 – 1445 28. **Commercial production of low acid beans**
R Shepherd, C F Chong, J G Taylor & J D Menneer

1445 – 1550 29. **Cocoa fermentation – effect of surface area frequency of turning and depth of cocoa masses**
Mamot Said & R J Samarakhody

1500 – 1515 30. **The current practices of primary processing and the quality of cocoa beans in Sabah**
K Li & M T Lee

1515 – 1530 31. **Cocoa fermentation and the problem of acidity, over-fermentation and low cocoa flavour**
B Biehl

1530 – 1545 32. **Influence of steam and hot-air treatment and the effect to the winnowing and the bacteriology of cocoa beans**
F Koller

1545 – 1615 DISCUSSION

SESSION 8: GOVERNMENT POLICIES, FAMA & PAPUA NEW GUINEA GRADING SCHEMES

1615 – 1630 33. **Government policies in relation to production, processing, marketing and exportation of cocoa beans and products**
Ministry of Agriculture, Malaysia

1630 – 1645 34. **Pre-shipment inspection of Malaysian cocoa beans**
Othman Mohd Rijal

1645 – 1700 35. **Quality control of Papua New Guinea cocoa beans**
R B Duncan & J C Bond

1700 – 1715 DISCUSSION

1715 – 1800 POSTER SESSION

WEDNESDAY, 17 OCTOBER

SESSION 9: BY-PRODUCT, QUALITY & MARKETING

0800 – 0815 36. **Utilization of by-products of cocoa bean processing**
R Shepherd & T N Yap

0815 – 0830 37. **Chocolate and cocoa manufacturers quality requirements for cocoa beans**
B D Powell

0845 – 0900	16.	**The occurrence and status of *Acrocercops cramerella* Snellen in Peninsular Malaysia** W H Loke, Mohd Shamsudin Osman & Zam Karim
0900 – 0915	17.	**Control of the cocoa pod borer *(Acrocercops cramerella)*: a critical review** J D Mumford
0915 – 0930	18.	**Female sex Pheromone of the cocoa pod borer moth, *Acrocercops cramerella:* identification and field evaluation** P S Beevor, R K Day & J D Mumford
0930 – 0955		DISCUSSION
0955 – 1015		COFFEE
		SESSION 5: DISEASES
1015 – 1030	19.	**Problems of *Phytophthora* bark canker on cocoa in Papua New Guinea** C Prior
1030 – 1045	20.	**The potential for biological control of root disease of cocoa in Papua New Guinea** Philippa Jollands
1045 – 1100	21.	**Screening of some systemic fungicides against *Oncobasidium theobromae* and translocation studies of benomyl in cocoa** M J Musa & C C Tey
1100 – 1115	22.	**Possible methods to minimise losses due to Vascular Streak Dieback (VSD)** M P G S Jayawardena, E Mohan & M J Musa
1115 – 1130	23.	**Factors influencing the production of basidiocarps by *Crinipellis perniciosa*, the causal fungus of cocoa Witches' broom** H M Rocha
1130 – 1200		DISCUSSION
		SESSION 6: NUTRITION
1200 – 1215	24.	**Litter production and nutrient cycling in a mature cocoa plantation on inland soils of Peninsular Malaysia** A H Ling
1215 – 1230	25.	**Fertilizer and soil amelioration trials on inland and coastal soils in Malaysia** C H Teoh, A K Chang & C F Chong
1230 – 1245	26.	**Fertilizer responses on monocrop cocoa in Peninsular Malaysia on a Munchong Series soil** Nawi Che Yusoff & C W Leong
1245 – 1300		DISCUSSION
1300 – 1415		LUNCH

1240 – 1255	50.	**Foliar decay by Myndus taffini (FDMT)** J F Julia, M Dollet & C Calvez
1255 – 1310	51.	**Severe stem bleeding and frond fracture of MAWA hybrid coconuts in North Sumatra** D Kartika, F X Soebagyo, P D Turner & C J Breure
1310 – 1335		DISCUSSION
1335 – 1430		LUNCH
		SESSION 12: PROCESSING, BY-PRODUCT & END USES
1430 – 1445	52.	**Progress on copra drying and production of white edible copra** C F Chooi, A W Wanless & C W Siah
1445 – 1500	53.	**UPB's coconut dehusking machine** T S Toh, H K Jorgensen & Y P Tan
1500 – 1515	54	**Utilization of non-kernel products of the coconut** R Yatawara
1515 – 1530	55	**Coconut end uses for the chemical industry** R J de Vries
1530 – 1550		DISCUSSION
1550 – 1630		SUMMING UP by Dr Md Sharif Ahmad
1645 – 1700		CLOSING CEREMONY Chairman: Encik Ibrahim Amin Address by Dr. Radzuan Abdul Rahman Chairman, Conference Organising Committee
1700 – 1730		Closing Address by YB Encik Anwar Ibrahim Minister of Agriculture, Malaysia.
1730		TEA

THURSDAY, 18 OCTOBER

FIELD TOUR

FRIDAY, 19 OCTOBER

WORKSHOP

P

Scavina Combining Ability Trial at MARDI Hilir Perak

IBRAHIM ABDULLAH AND SAPIYAH SUBALI
Cocoa/Coconut Division, MARDI, Hilir Perak

The trial was set up in April 1977 at MARDI Hilir Perak in randomized block design, four replications, and 20 plants/plot under mature coconut trees. Planting distant of cocoa tree was 2.19 m x 3.1 m. Material used were progenies of ICS 40, ICS 60, Na 32 and Pa 7 (maternal parent) crossed with SCA 6, SCA 9 and SCA 20 (pollen source).

Results from this trial indicate that paternal influence is greater than the maternal parent. Even though the heritability estimates are very low, influences are due to additive genetic variance. Estimate of the amount of this genetic contribution from each parent is helpful in selecting parents for crosses. However, the major contribution of variance is due to genetic-environmental interaction.

The genotypic variance is partitioned into additive variance, dominance variance and interaction variance (Falconer, 1960). The most important component of these variance is the additive variance since it is the main cause of resemblance between relatives and is the only component that can be readily estimated from the observations made on the population. However, the concept of additive variance does not accommodate the assumption of additive gene action and its existence does not indicate that any of these genes act additively.

The ratio of additive genetic variance to total phenotypic variance is termed as heritability (Falconer, 1960). It is the proportion of the total variance that is attributable to the average effects of genes which in turn determines the degree of resemblance between relatives. However, genes cannot cause a character to develop unless they have the proper environment, and manipulation of the environment will not cause a characteristic to develop unless the necessary genes are present. Thus variability observed is caused by the differences in genes carried by individuals and by the environments to which individuals have been exposed.

Our objective is to identify heritability of vegetative and yield variate computed on the basis of the additive genetic variance because it better indicates the degree to which the progeny of these plants will resemble their parents. Thus it allows the identification of crosses that could be used for commercial use. Furthermore, if all the genetic variability of a population is due to additive gene action, improvement can be continued until all desirable alleles have been fixed within a population. The rate at which selection leads to fixation and zero variability depend on gene frequencies and gene numbers.

MATERIALS AND METHODS

The F1 progenies of the following crosses were analysed from the experiment. They were:

1. ICS 40 x SCA 6
2. ICS 40 x SCA 9
3. ICS 40 x SCA 20
4. ICS 60 x SCA 6
5. ICS 60 x SCA 9
6. ICS 60 x SCA 20
7. NA 32 x SCA 6
8. NA 32 x SCA 9
9. NA 32 x SCA 20
10. PA 7 x SCA 6
11. PA 7 x SCA 9
12. PA 7 x SCA 20

The trial was set up in April 1977 at MARDI Hilir Perak, in a randomized block design, 4 replications and 20 plants/plot, under mature coconut trees. The cocoa plants were spaced at 2.19 m x 3.1 m within the coconut avenue.

The data recorded were the first jorquette height, girth measurement, precocity value, (scoring method a described in the Brazilian Progeny Trial), number of pods on a monthly basis and pod index. The data were recorded on an individual plant basis.

The data was analysed by using the North Carolina Design 2 described by Mather and Zinks (1971).

RESULTS

The analysis of variance on the parameters measured is shown in *Table 1*. For the mean jorquette height, there was a very significant difference in the maternal effect. This indicates that the mother plant makes a significant contribution to the phenotype (jorquette height) of the progeny over and above that which results from the genes contributed to the zygote (additive genes). The presence of the maternal effect is further indicated by the result of the maternal variance in which the maternal variance mean is greater than that of the paternal mean (*Table 2*). Thus in the subsequent progeny, this additive gene effect leads to a greater resemblance of the progeny to the maternal parent. The maternal heritability estimate is 11%.

The analysis of variance of the precocity value indicates that there is a high significant difference due to replication. Irrespective of the progeny crosses, there is a significant variation in the time of the first flowering of each plant. This variability could be due to environmental effect on each plant of the crosses. The results also shows that there is a significant different ($P = 0.05$) in the paternal effect of the progeny in the precocity value. The pollen source was all from Scavina clones, and Scavinas are very precocious as indicated by earlier researches. Thus Scavina's additive genetic action influences its progeny to be early flowering. The paternal variance is very much greater than that of the maternal and the heritability estimate is 19% (*Table 2*).

There was no significant difference in the girth measurement of any of the progeny. This result indicates that girth is influenced more by the dominant and environmental variances.

The number of pods per tree per year was significantly different in the replications. There was a very high significant difference in the paternal effect and a significant diffe-

TABLE 1. ANALYSIS OF VARIANCE FOR JORQUETTE HEIGHT, PRECOCITY VALUE, GIRTH MEASUREMENT, POD YIELD, WEIGHT OF DRY BEANS/100 BEANS AND NUMBER OF BEANS PER POD.

Source	*df*	*Mean Square*					
		Mean Jorquette height (cm)	*Precocity value*	*Girth measurement (cm)*	*Yield (Pods/tree/ year)*	*Weight of 100 dry bean (g)*	*No. of beans/pod*
Rep	3	5577.50^{ns}	81.78^{**}	121.96^{ns}	69.37^{*}	3233.95^{ns}	8.77^{ns}
Paternal	2	14790.29^{ns}	49.99^{*}	96.89^{ns}	142.12^{**}	9395.60^{**}	22.99^{**}
Maternal	3	34124.05^{**}	5.80^{ns}	100.09^{ns}	71.10^{*}	8003.50^{*}	10.87^{ns}
Pat x Mat	6	7666.98^{ns}	16.25^{ns}	90.50^{ns}	23.61^{ns}	1726.08^{ns}	3.93^{ns}
Error	33	6091.77	12.56	48.75	21.19	1645.36	3.93

** Significant at $P < 0.01\%$

* Significant at $P < 0.05\%$

TABLE 2. VARIANCE COMPONENTS ESTIMATION OF MEAN, JORQUETTE HEIGHT, PRECOCITY VALUE, GIRTH MEASUREMENT, PODS YIELD, WEIGHT OF 100 BEANS AND NUMBER OF BEANS PER POD.

Variance component	*Mean Jorquette height (cm)*	*Precocity value*	*Girth measurement (cm)*	*Yield (Pods/tree/ year)*	*Weight/ 100 beans (g)*	*No. of beans/pod*
Paternal 0^2 p	593.60	2.81	0.53	9.87	639.12	1.58
Maternal 0^2 m	1653.56	0.65	0.59	2.96	392.34	0.43
Paternal x Maternal 0^2 p x m	393.80	0.92	10.43	0.60	20.17	0.003
Within Family 0^2	57120.98	55.09	257.49	225.11	11963.47	43.88
h^2p	0.0397	0.1933	0.0079	0.1656	0.1964	0.1384
	± 0.0564	± 0.1871	± 0.0944	± 0.1267	± 0.1538	± 0.1066
h^2m	0.1107	0.0449	0.0089	0.0498	0.1206	0.0378
	± 0.1022	± 0.0391	± 0.0781	± 0.0541	± 0.1100	± 0.0432

rence in its maternal effect (*Table 1*). These results indicate that variability within the progeny is due to genetic differences and the genes (additive genes) are contributed both paternally and maternally. However, the results also indicate that the paternal influence was more significant than the maternal. Nevertheless, the most important factor is that this trait is influenced by additive genes. The variance due to paternal effect is greater than the maternal, and the heritability estimate of the paternal effect is 16% compared to 4% of the maternal (*Table 2*).

The analysis of variance of the weight of dry bean and the number of beans per pod is very highly significant (*Table 1*). This indicates a very strong additive genetic action in these two correlated factors. A significant influence is also observed in the weight of dry beans by the maternal parent. The heritability estimates by the paternal for the weight of dry beans is 19% and for the number of beans per pods is 13%. The results indicate that for the weight of dry beans, both the maternal and paternal parents contribute in an additive genetic manner to the offspring. As to the number of beans per pod the paternal influence is significant.

Table 3 summarizes the pooled average progeny performance and the ranking of the crosses. PA 7 progenies have an average of 100.00 cm jorquette height and NA 32 progenies have a lower (92.41 cm) jorquette height. Low heritability estimate is from the maternal parent (11%). Variability is mainly due to within the family variance (*Table 3*) since each cross has three different paternal parent. ICS 40 progenies on the whole, are the latest to come into flowering. Flowering is influenced by the precocity of the paternal parent; however, the heritability of the additive gene is still low, thus the major influence is from the variance within family (genotype-environmental interaction). Nutritional and climatic factors are the commonest external causes of environmental variation. Progenies of ICS 60, have the highest dry bean weight and the major variability variance is from within family variance. Very low variability is due to paternal x maternal variance. However, from within the experiment, NA 32 progenies have the highest average of the number of beans per pod. Out of the whole population, individual tree selection could be carried out on the basis of progeny and individual tree performance.

DISCUSSION

The overall results indicate that paternal influences is greater than the maternal. Even though the relative variances and the heritability estimates of each parent were low, it indicates that the individual parental contributions are of great importance. This has been confirmed by Soria *et al.* (1974) in which they detected real difference between male and female parents. Factors that influence the productivity of a cross such as the precocity, pods per tree per years, weight of dry beans and number of beans per pod is controlled by additive gene contributed by the paternal parent. The male parents *i.e.* SCA 6, SCA 9, and SCA 20, have considerably good combining ability. This is confirmed by Bartley (1964) and Soria *et al.* (1974). Thus, theoretically, good combining ability of these Scavinas can be utilized as a reliable source for commercial hybrid seed production. Scavina clones are known to be precocious, and have high pod production (Bartley, *et al.*, 1981), high number of beans per pod and small seeds to be inherited by the offspring (Glendinning, 1963). The major drawback is the small pods and small seeds (Bartley *et al.*, 1981). Heritability estimates by the paternal parent for pods per tree per year is 16%, weight of dry beans 19% and number of beans per pod is considered low; however population improvement by selection could still be successful. The major percentage of the variation in this population is due to environmental variance and variance between progeny.

TABLE 3. POOLED AVERAGE PERFORMANCE AND RANKING OF THE CROSSES

Variables \ Cross	ICS 40 x SCA 20 SCA 9 SCA 6	ICS 60 x SCA 20 SCA 9 SCA 6	NA 32 x SCA 20 SCA 9 SCA 6	PA 7 x SCA 20 SCA 9 SCA 6
Mean Jorquette height (cm)	93.9^{ab}	98.0^{ab}	92.4^{b}	100.0^{a}
Precocity value	19.9^{a}	15.9^{b}	15.6^{b}	15.9^{b}
Girth measurement (cm)	97.0^{a}	105.6^{a}	98.0^{a}	97.6^{a}
Pods/tree/year	19.1^{b}	20.2^{b}	25.8^{a}	25.3^{a}
Wt. of 100 beans (g)	366.9^{b}	416.2^{a}	354.5^{b}	362.1^{b}
No. of beans/pod	33.0^{b}	37.9^{a}	38.4^{a}	37.5^{b}

The analysis is only on the limited number of crosses which does not illustrate the precise estimation of the general combining ability. However, the results from this F_1 progenies give some indications as to the nature of gene action that control the yield potential variates of cocoa trees. It indicates some genetic ability of the individual parent of the amount of genetic contributions to the yield of the progenies.

ACKNOWLEDGEMENT

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Response of Coconut Nursery Seedlings to Some Cultural Treatments in Nigeria

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Three nursery agronomic experiments were carried out separately for Nigerian Tall Green (NTG) and Nigerian Dwarf Yellow (NDY) coconut varieties.

At Nigerian Institute for Oil Palm Research Main Station, Benin City, similar growth occurred in polybag coconut seedlings mulched with oil palm bunch and those without mulch application. This was attributed to the thick husk of the intact nut which serves as a natural mulch and minimised the influence of the bunch refuse mulch. Seedling growth parameters, including total dry weight, were similar at spacing treatments of 30 x 30 cm, 45 x 45 cm, 60 x 60 cm and 75 x 75 cm, except for seedling height and leaf area index which decreased significantly with wider spacings. These were respectively due to etiolation and fewer seedlings per unit land area. The interactions between spacings and sowings in groundbeds and polybags were non-significant. Although growth parameters were also similar in seedlings sown in groundbeds and polybags, the latter system is favoured because of the lower seedling transplanting shock associated with it.

At NIFOR Coconut Substation, Abia, both watering at 2–5 litre/seedling/week and overhead shade in the dry season did not significantly influence seedling growth and non-significant interactions occurred.

It is recommended that both NTG and NDY coconut varieties should be grown in polybags in the nursery, at a spacing of 30 x 30 cm, without mulch application. Also, watering at the rate of 2 litres/seedling/week in the dry season, without overhead shade, appears adequate in the Abia area.

Coconut is mostly grown as a compound crop in Nigeria although it is widely found in both the riverine and dry areas of Southern Nigeria. It became one of the mandate crops of the Nigerian Institute for Oil Palm Research (NIFOR) in 1973 and work on its breeding and agronomy started respectively in 1975 and 1979 at both the NIFOR Main Station, Benin City, and NIFOR Coconut Substation, Abia, Badagry. These two locations lie in the rain forest zone of Nigeria which has a bimodal pattern of rainfall distribution with the major peak occurring from April to July and a minor peak from August to November. A distinct dry season occurs from December to March. The mean annual rainfall is heavier in Benin City than Abia – approximately 2000 and 1400 mm respectivelv – with annual water deficits of about 150 and 200 mm respectively.

This paper reports the results of early coconut experiments by NIFOR on mulching, spacing and sowing in groundbeds and polybags in Benin City, and on shading and irrigation at Abia. The recommendations used for growing oil palm seedlings in Nigeria formed the basis for planning most of the experiments.

METHODS

Nigerian Tall Green (NTG) and Nigerian Dwarf Yellow (NDY) coconut varieties were used separately for each experiment. The sowings in polybags were in black bags 40 x 40 cm laid flat, 0.013 cm gauge, and with a single 2.5 cm inverted V-cut drainage hole at the bottom line. Aya (1978) found that these were less susceptible to tearing than white polybags under Nigerian conditions. The polybags were filled with nursery top soil at least two weeks before sowing in order to allow the soil to consolidate.

Experiment 1 was conducted in 1979/80 at the NIFOR Main Station and the growth of coconut seedlings in mulched and unmulched polybags were compared in a randomized complete block design replicated 14 times. Each plot comprised 18 treatment stands spaced 45 cm between and within rows and peripherally guarded by a single row of palms. Sowing occurred on 27 April 1979 and the mulch treatment of finely divided oil palm bunch refuse was applied to the upper 2.5 cm of the polybag at sowing and replenished throughout the experiment.

Experiment 2 was carried out at the NIFOR Main Station in 1980/81 and 1981/82. It was a split – plot design replicated six times with spacing between coconut stands – 30 x 30 cm, 45 x 45 cm, 60 x 60 cm and 75 x 75 cm – as the main plots and sowing in polybags and groundbeds as the subplots. Each subplot had 24 coconut stands with a single row of peripheral guard palms. The polybags and groundbeds were mulched with bunch refuse throughout, and sowing was on 1 May 1980 and 20 May 1981 respectively. The data for both years were pooled together and analysed (*Tables 2* and *3*).

Experiment 3 was conducted at the Abia Coconut Substation in 1981/82. The effects of watering and shading on coconut seedlings grown in polybags were studied in a split – plot experiment replicated six times. The treatment in main plots were watering at 2, 3, 4 and 5 litres/seedling per week while the subplot treatments were differential shading (no shading vs shading at 2.5 m height) Each irrigation treatment was at the rate of 1 litre/seedling on consecutive days. The watering and shade treatments were carried out only in the dry season, that is, from end of November 1981 to mid – April 1982. Each subplot consisted of 40 seedlings, spaced 45 x 45 cm, and peripherally guarded by a single row of palms. The plots were sown on 15 May 1981 and the polybags mulched with bunch refuse.

In Experiments 1 and 2, watering in the dry season was carried out at the rate of 2 litres/seedling per week as recommended for polybag oil palm seedlings in Nigeria (Aya, 1972). This was the basis for omitting zero level of watering in the dry season in Experiment 3. The shade thickness in Experiment 3 consisted of five or six palm fronds placed on one another. The quantity of sunlight intercepted by these could not be measured because the facilities were not available. No fertilizer was applied in any of the experiments as there was no basic formulation yet for coconut in Nigeria. The nuts were intact with their husks at sowing in all the experiments and they were completely buried vertically in either the groundbed or polybag soil with their apical ends upwards and just below the ground level.

Only one sampling was done for the estimation of growth parameters in each experiment and this was at 15 months after sowing (10 months after sowing in Experiment 1), when the experiment was terminated and seedlings had attained sizes transplantable to the field. The number of leaves/plant and vacant stands/plot, due to seedling death, were counted and measurements of seedling height (from the base of the stem to the tip

TABLE 1. EFFECTS OF MULCHING ON COCONUT NURSERY SEEDLINGS AT 10 MONTHS AFTER SOWING

Item	*NIGERIAN DWARF YELLOW*			*NIGERIAN TALL GREEN*		
	Mulching	*No Mulching*	*S.E.*	*Mulching*	*No Mulching*	*S.E.*
No. of leaves/plant	6.4	6.0	0.14	5.9	5.9	0.09
Seedling height (cm)	106.4	102.0	2.46	103.0	100.4	3.04
Seedling girth (cm)	11.8	10.2	0.21	10.9	11.4	0.18
Leaf area index	2.8	2.7	0.12	2.9	3.0	0.15
Seedling dry wt. (g)	94.5	87.3	15.41	88.7	90.2	13.24
Vacant stands/plot	4.1	3.9	0.41	4.6	4.4	0.38

TABLE 2. EFFECTS OF SPACING (cm) ON COCONUT NURSERY SEEDLINGS AT 15 MONTHS AFTER SOWING

Item	NIGERIAN DWARF YELLOW					NIGERIAN TALL GREEN				
	30 x 30	45 x 45	60 x 60	75 x 75	S.E.	30 x 30	45 x 45	60 x 60	75 x 75	S.E.
No. of leaves/plant	9.3	9.0	9.4	9.2	0.35	7.2	7.6	7.6	7.7	0.18
Seedling height (cm)	119.0	111.8	107.1	103.3	3.85	121.8	105.0	103.0	93.3	5.22
Seedling girth (cm)	16.9	18.3	18.2	18.8	1.00	14.4	15.5	15.8	15.2	0.66
Leaf area/seedling (cm)	0.84	0.73	0.75	0.70	0.13	0.56	0.69	0.93	0.60	0.17
Leaf area index	9.3	3.3	2.3	1.5	0.92	5.3	3.4	2.4	0.9	0.76
Seedling dry wt. (g)	221.6	202.7	193.9	204.6	16.29	147.3	160.2	191.1	133.7	23.32
Seedling d.m. (%)	28.7	29.8	26.8	28.1	6.09	24.5	27.4	23.1	23.6	1.64
Vacant Stands/plot	4.0	5.2	5.0	6.0	0.72	3.7	4.3	4.7	4.3	0.77

TABLE 3. EFFECTS OF PLANTING IN POLYBAGS AND GROUNDBEDS ON COCONUT NURSERY SEEDLINGS AT 15 MONTHS AFTER SOWING

Item	*NIGERIAN DWARF YELLOW*		*S.E.*	*NIGERIAN TALL GREEN*		*S.E.*
	Polybags	*Groundbegs*		*Polybags*	*Groundbeds*	
No. of leaves/plant	9.3	9.1	0.27	7.5	7.5	0.25
Seedling height (cm)	112.8	107.8	4.23	101.6	109.9	6.15
Seedling girth (cm)	18.6	17.5	1.00	15.1	15.3	0.66
Leaf area/seedling (m)	0.75	0.76	0.11	0.72	0.68	0.10
Leaf area index	4.0	4.2	0.84	3.0	3.0	0.42
Seedling dry wt.	200.4	210.9	21.72	158.3	158.3	19.77
Seedling d.m. (%)	27.8	28.9	3.68	24.9	24.4	1.36
Vacant stands/plot	5.6	4.9	0.60	4.2	4.2	0.65

of the longest frond in a stretched position) and girth taken in the nursery after which five seedlings were randomly sampled from each plot in Experiment 1 and each subplot in Experiments 2 and 3. These were separated into leaf, stem and root components in the laboratory and weighed and later oven-dried for 72h to constant weights at 80°C. Leaf area determination was carried out using a leaf area meter, LICOR Model 3000.

RESULTS AND DISCUSSION

All the growth parameters measured and the vacant stands/plot were similar in mulched and unmulched seedlings of each variety in Experiment 1 (*Table 1*). Thus, mulching polybags with bunch refuse had no beneficial effects on seedling growth over no-mulching in coconut. In oil palm, mulching serves to protect the young shoot as it emerges from the soil and, also, enriches the soil nutrients (Hartley, 1977). The results of Experiment 1 show that the thick husk of the intact coconut could serve adequately as a natural mulch material to protect the emerging shoot. Also, mulching with bunch refuse might not have conferred any manurial advantage on the coconut seedlings in this experiment as Child (1974) reported that coconut husks enriched the soil nutrients, particularly K, while the roots of the seedlings could also absorb these directly from the husks (Purseglove, 1972). Although soil temperature and soil moisture measurements were not recorded in this study, any influence on seedling growth of these external factors related to mulching appeared to be minimized by the thick husks of the coconut seedlings.

In Experiment 2, the spacing treatments significantly influenced only the seedling height and leaf area index (*Table 2*) and these decreased with wider spacings while the values for the other growth parameters were the same at the various spacings. The differences for seedling height were significant between 30 x 30 cm and 60 x 60 cm ($P = 0.05$), 30 x 30 cm and 75 x 75 cm ($P = 0.001$) in NDY and between 30 x 30 cm and 75 x 75 cm ($P = 0.01$), 30 x 30 cm and 45 x 45 cm ($P = 0.05$) and, 30 x 30 cm and 60 x 60 cm ($P = 0.05$), in NTG. In NDY, differences in leaf area index between 30 x 30 cm and all other spacing treatments were significant at $P = 0.001$ while, in NTG, the significant differences were between 30 x 30 cm and 60 x 60 cm ($P = 0.05$), 30 x 30 cm and 75 x 75 cm ($P = 0.001$) and 45 x 45 cm and 75 x 75 cm ($P = 0.05$).

The taller seedlings that resulted with closer spacings in both varieties suggested a tendency towards etiolation as a result of the competition for light. The significant decline in leaf area index with wider spacings resulted from fewer plants per unit land area as this trend was not reflected in the mean leaf area of individual seedlings which was not significantly different in all the treatments (*Table 2*). The seedlings thus had similar potential for photosynthesis and, consequently, seedling dry weight was the same in all the spacing treatments despite the "crowding" at the closer spacings. Also, the seedling dry matter content which is a measure of physiological maturity was similar in all the spacing treatments. A spacing of 30 cm between and within rows is, therefore, recommended for both NTG and NDY in the nursery as the competition for light at this spacing did not adversely affect seedling grwoth and wider spacings will be wasteful of land. The trends of these results on spacing in coconut were similar to those obtained for *Raphia hookeri* and *Raphia vinifera* by Iremiren & Onwubuya (1984).

The growth parameters and vacant stands/plot were similar when the seedlings were grown in polybags and groundbegs (*Table 3*). There were no significant interactions between spacing and sowing in polybags and groundbeds in each variety (*Table 4*). Although the data of Experiment 2 indicate that coconut seedlings could be sown in

TABLE 4. VARIANCE RATIOS (F VALUES) FOR SOME GROWTH PARAMETERS IN EXPERIMENT 2

Item	*NIGERIAN DWARF YELLOW*				*NIGERIAN TALL GREEN*			
	Leaves/plant	*Seedling height*	*Seedling girth*	*Seedling dry wt.*	*Leaves/plant*	*Seedling height*	*Seedling girth*	*Seedling dry wt.*
Spacing (S)	0.36 NS	6.20**	1.19 NS	1.01 NS	3.05 NS	10.26***	1.72 NS	2.21 NS
Polybag/Groundbed (P/G)	0.33 NS	1.41 NS	1.17 NS	0.23 NS	0.01 NS	1.82 NS	0.05 NS	0.01 NS
S x P/G	1.26 NS	0.40 NS	1.37 NS	0.16 NS	1.33 NS	1.11 NS	0.92 NS	0.60 NS

** *** Significant at P = 0.01 and 0.001 respectively

either polybags or in the nursery, results from the oil palm in Nigeria (Aya, 1974) and coconut in Malaysia (Chang, 1980) showed that pronounced transplanting shock in the field was more associated with groundbed than polybag seedlings. It is therefore recommended that coconut should be sown in polybags in Nigeria because of this and the ease of transporting polybag seedlings to the field.

The watering and shade treatments at Abia Coconut Substation (Experiment 3) did not significantly influence seedling growth and vacant stands/plot in both varieties (*Tables 6* and *7*). Seedling dry weight was, however, higher in the unshaded treatments of both varieties, while both seedling height and girth were higher in the shaded plots of NTG and unshaded plots of NDY. No significant interactions occurred between the watering and shade treatments (*Table 8*). Although zero water application was not a treatment in Experiment 3, the results indicated that minimal watering during the dry season would be adequate in the Abia Area. This is probably because the thick leaves of coconut reduce transpiration while the dependence of the seedling on the endosperm for sustenance for a long portion of the nursery period (Foale, 1968) makes it to survive and grow well on as little water as 2 litre/seedling/week in the dry season. For the former reason also, there was no beneficial advantage from shading and this should not be encouraged in coconut as it adds to the cost of production.

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TABLE 5. MONTHLY RAINFALL AT ABIA IN EXPERIMENT 3

Year	Monthly rainfall (mm)											
	Jan.	Feb.	Mar.	Apr.	May	Jun	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1981	–	–	–	–	144.1	284.8	107.2	107.1	138.2	91.8	72.4	0.4
1982	67.3	57.4	20.0	77.6	170.4	538.8	87.8	10.7	–	–	–	–

TABLE 6. EFFECTS OF WATERING ON COCONUT NURSERY SEEDLINGS AT 15 MONTHS AFTER SOWING

	NIGERIAN DWARF YELLOW (litres/seedling/week)					*NIGERIAN TALL GREEN (litres/seedling/week)*				
	2	*3*	*4*	*5*	*S.E.*	*2*	*3*	*4*	*5*	*S.E.*
No. of leaves/plant	8.5	8.5	8.7	8.7	0.23	8.0	8.6	8.1	8.3	0.64
Seedling height (cm)	142.0	143.5	135.7	127.6	4.26	153.5	150.6	143.4	149.6	10.73
Seedling girth (cm)	14.9	15.7	15.3	14.7	0.39	16.9	18.0	17.4	17.8	1.49
Leaf area index	3.0	3.1	3.2	2.9	0.16	3.3	3.7	3.4	3.6	0.49
Seedling dry wt. (g)	339.2	379.1	367.0	310.2	30.63	246.2	262.6	243.1	264.0	48.82
Seedling d.m. (%)	30.7	32.9	32.7	30.0	1.68	26.8	24.6	26.0	27.7	2.50
Vacant stands/plot	3.5	2.8	2.9	3.8	0.13	2.1	3.0	4.0	2.7	0.51

TABLE 7. EFFECTS OF SHADING ON COCONUT NURSERY SEEDLINGS AT 15 MONTHS AFTER SOWING

Item	*NIGERIAN DWARF YELLOW*			*NIGERIAN TALL GREEN*		
	Shading	*No Shading*	*S.E.*	*Shading*	*No Shading*	*S.E.*
No. of leaves/plant	8.5	8.6	0.17	8.2	8.3	0.32
Seedling height (cm)	136.3	138.0	3.85	151.2	147.4	6.14
Seedling girth (cm)	14.9	15.4	0.30	17.6	17.5	0.91
Leaf area index	3.1	3.0	0.11	3.6	3.4	0.30
Seedling dry wt. (g)	335.7	362.1	25.69	252.2	255.7	27.54
Seedling d.m. (%)	30.1	32.1	1.10	26.3	26.1	1.43
Vacant stands/plot	2.8	3.0	0.10	3.5	2.9	0.31

TABLE 8. VARIANCE RATIOS (F VALUES) FOR SOME GROWTH PARAMETERS IN EXPERIMENT 3

Source	*NIGERIAN DWARF YELLOW*				*NIGERIAN TALL GREEN*			
	Leaves/plant	*Seedling height*	*Seedling girth*	*Seedling dry wt.*	*Leaves/plant*	*Seedling height*	*Seedling girth*	*Seedling dry wt.*
Watering (W)	0.29 NS	5.73*	2.24 NS	2.01 NS	0.96 NS	1.15 NS	1.13 NS	0.34 NS
Shading (S)	0.38 NS	0.20 NS	1.85 NS	1.05 NS	0.01 NS	0.87 NS	0.04 NS	0.03 NS
W x S	0.54 NS	0.87 NS	1.43 NS	0.12 NS	0.20 NS	0.34 NS	0.48 NS	0.03 NS

* Significant at P = 0.05

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Coconut Palm Sugar

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SUMMARY

'Neera' or the coconut palm sap could be solidified by boiling continuously till it reaches 118°C to 120°C. At this temperature the viscous mass is moulded into 'blocks' of sugar. This sugar is locally known as 'gula melaka' or 'gula tuak'. The average sucrose content of the coconut sap is 17% and when it is made into sugar blocks percentage sucrose is between 70–80%. The quality of the sugar produced depend on the freshness of the sap, percentage of sugar in the original sap and the final temperature reached during boiling.

INTRODUCTION

Sugar (local palm sugars) had been traditionally produced in this country form various sources. The two most important palm sugars in this country are 'gula melaka' and 'gula kabong' or 'gula enau'. While 'gula kabong' is produced from the sap of sugar palm *(Arenga pinnata)*, 'gula melaka' has always been produced from the sap of the coconut palm (*Cocos nucifera*). Similar sugars are also produced from the sap of palmyra (*Borassus flabellifera*), Indian sago (*Caryota ureus L*), nipah (*Nipa fronticans*) and sago (*Metroxylan sp.*) (Abdul Aziz, 1974).

MATERIALS AND METHODS

Preparation of spathe and subsequent collection of sap and processing were carried out in Alai, Melaka as illustrated in the flow diagram (*Figure 1*). Trials were carried out at the processors premise to determine the factors influencing the formation of sugar in relation to the pH, °Brix of the sap and the optimum setting temperature. Available sugar on the market and samples from processors were analysed for moisture content, percentage total sugar, sucrose, ash, protein and impurities (non sugar solid), using standard analytical procedures as set by the Division of Food Technology, MARDI. The results were compared with sample using 100% coconut sap.

Packaging studies on sugar from pure coconut sap were carried out using oriented polyethylene, polypropylene, thermoform and dried coconut leaves (control). Dried coconut leaves were taken as the control as this is the normal packaging material used by local processors.

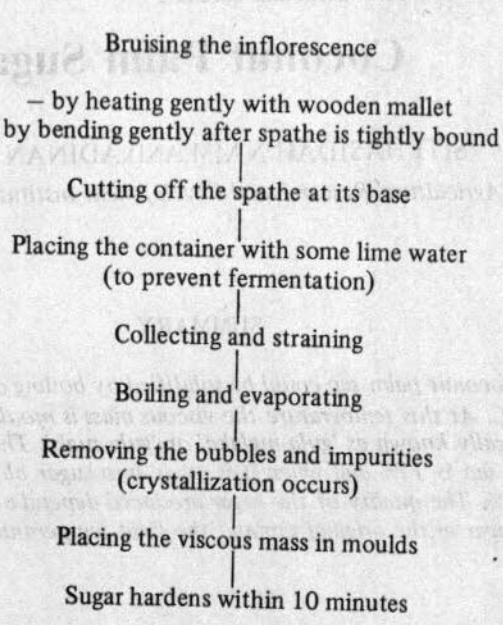


Figure 1. Sap Collection and Processing of Coconut Palm Sugar

RESULTS AND DISCUSSIONS

Factors Influencing the Formation of Coconut Palm Sugars.

Freshness of the sap is the main factor affecting the making of good 'gula melaka'. Fresh sap has a pH of 6 and any reduction in the pH is indicative of deterioration of freshness. When the brix reading of the sap is 17 and pH 6, the sugar will set nicely and give a brownish glossy appearance and be 'grainy' when broken. When the pH of the sap drops to 5, setting is difficult and at a pH of 4.3 setting is not possible.

The normal practice carried out by local processors is to add some dried latex from mangosteen bark to a mild solution of lime water. This is placed in the container about a quarter of the container's size where the sap drops from the cut spathe. This helps to prevent the sap from being fermented before processing is carried out the following morning. Another way is to boil the day's collection together with the night's collection before processing.

Proximate Analysis

Analysis of sugars from the local market, processors and the control samples, reveals a wide variation in moisture, percentage total sugar, sucrose, ash, protein and impurities (non sugar solids) (*Table 1*).

Moisture content. Moisture content of the samples analysed ranged between 5% to 10%. This is due to moulding the liquid at different temperature of the boiling liquid. The optimum moisture content of 8% could be obtained when moulding is carried out at the time the liquid is boiling at 12° ± 2°C.

TABLE 1. PROXIMATE ANALYSIS OF COCONUT PALM SUGARS

Code	*Source*	*Packaging*	*Moisture (%)*	*Total sugar (%)*	*Sucrose (%)*	*Ash (%)*	*Protein (%)*	*Solid non sugar (%)*
CS 424	Processor	Newspaper	10	85	78	1.8	1.2	2
CS 425	Market	Glass container	5	83	74	Trace	Trace	12
CS 426	Processor	Newspaper	9	81	57	1.3	0.5	8.2
CS 427	Market	Glass container	10	81	77	1.2	0.8	7
CS 428	Processor	Newspaper	8	72	57	2.2	1.1	16.7
CS 429	Processor	Newspaper	7	81	70	2.2	1.1	8.7
CS 430	Processor	Newspaper	8	81	72	2.5	1.2	7.3
CS 431	Control	Thermoform	8	88	81	1.4	1.3	1.3

CS – Coconut palm sugars

Total sugar, sucrose and solid non sugar. Percentage of total sugar ranged from 72% to 88% (control) and correspondingly the lowest sucrose content was observed in the sample having the lowest total sugar. This in turn relates to the high content of solid non sugar. In the control sample, solid non sugar was 1.3%. This represents the lowest value for all the samples analysed.

The high percentage of non sugar solids in certain samples may probably be due to either the addition of brown or granulated sugar or the impurities found in the sap. Furthermore, local processors have the habit of adding grated coconut or ground candle nut during the evaporation process. This was believed to act as 'crystallizer' which helps in the faster setting of the sugar. However, for the control this was not added at any time during the process.

Protein and ash. The sugar samples have reasonable amount of ash and protein. The control sample shows an ash content of 1.4% and protein content of 1.3%.

Packaging Studies

The coconut sugars produced from pure coconut sap were observed to keep well in all the three packaging materials used *(Table 2).* The traditional dried coconut leaves were good only for the first month and deformation of the sugars was observed at the beginning of the second month of the study. Changes in moisture content, insect infestation and discolouration are problems associated with packaging with dried coconut leaves.

TABLE 2. PROCESSING TRIALS OF COCONUT PALM SUGAR

Duration after collection	*pH*	*°Brix*	*Remarks*
Same day	6	17	Set nicely, brown in colour
2 days	5	17	Set with darker brown in colour and it takes longer time to set compared to the first trial.
7 days	5	17	Did not set and turned out to be dark brown concentrate.
8 days	5	13.5	–do–
13 days	4.35	13.5	–do–
14 days (the sap was heated to boiling on arrival)	6	10.5	Set, dark brown to blackish in colour, takes longer time to set, loose texture after cooling and quite bitter in taste.

TABLE 3. KEEPING QUALITY STUDIES OF COCONUT PALM SUGAR

Type of packaging material	*Moisture content change*	*Remarks*
OPP–PE	Decrease slightly	Sugar was still in good conditions even after six months storage.
PP	–do–	–do–
Thermoform	–do–	–do–
Dried coconut leaves	Decrease	Formation of air hole causing irregularities in shape after one month of storage.

OPE–PE Oriented polypropylene laminated with polyethylene
PP Polypropylene
The sugar sample were kept at room temperature.

CONCLUSION

Good coconut palm sugars could be obtained by gradually boiling fresh coconut sap (pH 6) to a temperature of 118°C to 120°C and cooled. This sugar having a moisture content of 8% could be hygienically bagged in oriented propylene laminated with polyethylene or polypropylene or thermoform container for a period of six months with slight loss of moisture.

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P

Effects of Fertilizer Application on Early Vegetative Growth and Precocity of MYD x WAT Hybrid Coconut in Thailand

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An experiment to determine nitrogen, potassium and magnesium requirements of MYD x WAT hybrid coconuts was set up in 1978. Vegetative characteristics were measured at six-monthly intervals, and nuts harvested monthly.

Fertilizer application did not significantly affect growth in the first year after planting. Absence of nitrogen significantly reduced girth, height and leaf length in the second year, and total frond production in the second and third years. Trunk length was reduced by nil nitrogen in the fourth and fifth years. Absence of potassium significantly reduced all growth parameters, except trunk length, from the second year. This could not be differentiated from the nil-fertilizer treatment. Magnesium did not affect growth.

Luxury levels of all three nutrients studied induced apparent precocity. This was reduced at 62 months, with the most pronounced observation being a reduction in early yield and percentage of palms bearing, caused by absence of potassium or nitrogen.

Foliar analyses were largely predictable. Nitrogen and potassium were mutually antagonistic, and antagonism amongst cations was observed. Phosphate levels were predominantly reduced in the 0000 treatment, but were also depressed by high levels of potassium.

Results of experiment in different coconut growing areas of the world indicate that nutrient requirement of coconut palms is highly variable, depending on the environment and soil. Nethsinghe (1962) considered that only nitrogen and phosphate were necessary in the first four years, with minimal potassium for maintenance. Fremond and Ouvrier (1971) stressed the necessity for nutrition of young palms from the time of planting, especially of potassium, as early potassium deficiency limits the plants ability to respond to nutrients at maturity. This was later confirmed by Coomans (1977) who showed that Dwarf x Tall hybrids could yield up to 3.4 tonnes of copra per hectare in the fifth year, if properly fertilized. He suggested the use of potassium chloride, kieserite and urea, in decreasing order of importance. Nelliat and Muliyar (1971) reported that of a number of Dwarf x Tall hybrids tested no palms from unfertilized plots were flowering at six years. In Jamaica, Romney and Smith (1965) stated that a high rate of nitrogen was desirable for young palms, but that it would be wrong to apply nitrogen alone. This was expanded by Smith (1968) who showed that early frond growth was influenced by nitrogen and that bearing was more strongly influenced by nitrogen than by potassium in the fifth year.

More specifically, Foale (1968) found that the contribution of the endosperm to coconut growth declined from the fourth month after germination, and that early uptake of nutrients could be expected. This was confirmed by Charles (1968) whose work indicated that nutrients applied at the time of planting were absorbed, but that the efficiency of uptake increased from later applications of fertilizer.

As there was no consistent result from nutrients applied to young coconuts, it was considered necessary that the response of coconuts to fertilizer should be studied in Thailand. MYD x WAT hybrids were selected for study, as these would be used as material for coconut replanting, and can be expected to give a response to fertilizer applied at high rates. Early growth was to be monitored, and the effects of nutrients applied on precocity of bearing studied.

As the level of available soil phosphate was extremely low, a response to phosphate application was anticipated. Phosphate would be expected to encourage the growth of the unfertilized cover crop that was to be planted, and would therefore enhance nodulation. This would raise soil nitrogen levels and lead to a confusing N/P interaction which could not be explained within the limitations of the design adopted. Nitrogen and phosphate are being tested factorially, with a cover crop, on the same soil type in order that the interaction may be assessed. Because of this, it was decided to test levels of nitrogen, potassium and magnesium.

MATERIALS AND METHODS

The trial was planted in 1978 with MYD x WAT hybrid seedlings, imported as seednuts from IRHO, with guard rows of similarly aged selected Thai Tall seedlings. It is located at Chumphon Horticultural Research Centre on the east coast of Southern Thailand. The rainfall is moderately well distributed (*Table 1*) but with a pronounced dry season in some years. The soil is Chumphon series, Typic Paleudult (USDA, 1970) or Red-Yellow Podzolic (Dudal & Moorman, 1964). It is defined as capability sub-class U VIe (Soil Survey Division, 1972) indicating unsuitability for upland agriculture, and susceptibility to erosion hazard or past erosion damage. Briefly, the soil is a sloping shallow sandy loam over gravelly clay, moderately drained and moderately permeable, with rapid run-off. It is moderately acidic, with low organic matter content, and is of low native fertility. The specific site analysis of Jiraporn & Valli (1983) is given (*Table 2*).

The experimental design is a randomised complete block with 11 treatments and four replications. Net plots are of 4 x 3 palms with a complete guard row. Spacing is 8.5 m triangular (159.82 points per hectare). A mixed leguminous cover crop was sown at the time of planting, consisting of a mixture of *Pueraria phaseoloides, Calopogonium muconoides* and *Centrosema pubescens.* This was not fertilized. The treatments are given in *Table 3.* Nitrogen, potassium and magnesium can each be compared at four levels at a constant rate of the other nutrients. This comparison is contentious as all comparisons merge in treatment 2122. Consequently, Duncan's New Multiple Range Test at the 5% level is used to compare treatment means if statistically significant differences are found by analysis of variance.

Palm girth was measured at 15 cm above ground level. Height was taken as the highest point of leaf 4 until the third year, the length of trunk from ground level to the lowest leaf base then becoming the criterion for height. The length of leaf rachis, number of green leaves on the palm and number of leaves produced with time were also measured. Fruiting characteristics were measured by monthly harvest and subsequent fruit component analysis of up to five nuts per tree. Foliar samples were taken in March or April, from all net plot palms. Leaf 4 was sampled in years 1 and 2, leaf 9 in years 3 and 4, and leaf 14 from the fifth year. Where treatment effects suppressed leaf production excessively, a younger, physiologically similar aged leaf was taken. Chemical analysis of foliar N, P, K, Ca, Mg and Na was carried out in the soil and plant analysis laboratory of the Kohong Rubber Research Centre in Hat Yai, Songkhla Province. It is outside the scope of this paper to correlate foliar nutrient levels with measured characteristics.

TABLE 1. EIGHT-YEAR MEAN RAINFALL DATA RECORDED AT SAWI HORTICULTURAL RESEARCH CENTRE

	Rainfall (mm)												
	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Total*
Mean	137	73	38	77	224	173	160	255	152	246	352	86	1973
Maximum	589	166	87	156	327	356	295	374	218	421	551	139	2631
Minimum	7	1	6	2	105	68	68	154	111	83	99	34	1599

TABLE 2. SOIL ANALYSIS OF TREATMENT 0000

Soil Property	*Depth*	
	0–15cm	*15–30cm*
Chemical		
pH	5.5	6.0
Electrical conductivity (1:5) at 25°C (mmhos)	0.039	0.022
Organic matter (%)	2.02	0.90
Available P (ppm)	8	5
Extractable K (ppm)	93	30
Extractable Ca (ppm)	379	355
Extractable Mg (ppm)	30	16
Physical		
Textural grade	sandy loam	sandy loam
Sand (%)	75	73
Silt (%)	19	20
Clay (%)	6	7

TABLE 3. ANNUAL RATES OF NUTRIENT APPLICATION AT FIVE YEARS FROM PLANTING

Treatment (NPKMg)	*Nutrient rates (kg/palm/year)*			
	N	P_2O_5	K_2O	*MgO*
0000	0	0	0	0
0122	0	0.	1.44	0.27
1122	0.2	0.28	1.44	0.27
2102	0.4	0.28	0	0.27
2112	0.4	0.28	0.72	0.27
2120	0.4	0.28	1.44	0
2121	0.4	0.28	1.44	0.135
2122	0.4	0.28	1.44	0.27
2123	0.4	0.28	1.44	0.405
2132	0.4	0.28	2.16	0.27
3122	0.6	0.28	1.44	0.27

N as ammonium sulphate: P_2O_5 as triple superphosphate:

K_2O as potassium chloride: MgO as kieserite

Fertilizer is applied at 12.5; 25; 50 and 75% of the final rate in years 1 to 4 respectively.

RESULTS AND DISCUSSION

Girth

Absence of nitrogen or potassium resulted in significantly reduced palm girth in year 2. Omission of both nutrients caused a further reduction in girth (*Table 4*). This indicates a cumulative effect, but could also be associated with retarded development in the absence of phosphate. From year 3, treatments 2102 and 0000 were significantly lower than all others. They were not different from each other indicating that potassium governed girth expansion under the conditions of this experiment. The early response to nitrogen was anticipated but of short duration in the presence of a legume.

TABLE 4. GIRTH AT 15 cm FROM GROUND LEVEL

Treatment (NPKMg)	*Girth (m) Years from planting*				
	1	*2*	*3*	*4*	*5*
0000	0.43	0.61e	0.77c	0.92b	0.98c
0122	0.46	0.81d	1.06b	1.29a	1.36ab
1122	0.57	1.07abc	1.19ab	1.4a	1.44ab
2102	0.51	0.79d	0.87c	0.93b	0.97c
2112	0.54	1.04bc	1.18ab	1.35a	1.4ab
2120	0.56	1.03bc	1.12ab	1.29a	1.3b
2121	0.58	1.1ab	1.21ab	1.36a	1.39ab
2122	0.54	1.04bc	1.21ab	1.35a	1.39ab
2123	0.54	1.09ab	1.3a	1.42a	1.45ab
2132	0.61	1.16a	1.31a	1.46a	1.5a
3122	0.51	0.95c	1.15ab	1.28a	1.32b

Lower case letters indicate significantly similar groups using Duncan's New Multiple Range Test, at the 5% level, in this and *Tables 5* to *8* and *10* to *15*.

Height

Both nitrogen and potassium increased height in year 2. Treatment 0122 was not different from 0000 suggesting that the effect of nitrogen was dominant (*Table 5*). In year 3 potassium became the predominant influence on height when measured to leaf 4. Nitrogen application increased the length of trunk in years 4 and 5, which may reflect early superiority in rate of leaf emission. Only potassium had an effect on trunk length in the 5th year. A similar pattern to that of girth can be seen, with an early response to nitrogen rapidly being superceded by dominance of potassium. The effect of nitrogen is likely to be persistent, and carried forward.

TABLE 5. HEIGHT OF PALM MEASURED TO APEX OF LEAF 4 AND LENGTH OF TRUNK

Treatment (NPKMg)	*Height of leaf 4 (m)*			*Length of trunk (m)*	
	Year 1	*Year 2*	*Year 3*	*Year 4*	*Year 5*
0000	2.13	2.78e	3.44d	0.27b	0.51d
0122	2.02	3.04de	4.2bcd	0.26b	0.74cd
1122	2.48	4ab	4.89abc	0.54a	1.31ab
2102	2.39	3.42cd	4cd	0.57a	0.91bc
2112	2.45	3.98ab	4.99abc	0.61a	1.28ab
2120	2.48	3.78bc	4.88abc	0.58a	1.17ab
2121	2.57	4.02ab	4.98abc	0.58a	1.22ab
2122	2.44	3.95ab	5.05ab	0.58a	1.28ab
2123	2.39	4.06ab	5.18ab	0.66a	1.45a
2132	2.65	4.32a	5.34a	0.74a	1.36a
3122	2.31	3.56bc	4.7bc	0.61a	1.21ab

Leaf Length

Both nitrogen and potassium increased leaf length (*Table 6*) in year 2. Nitrogen was predominant at that stage again showing early benefit from this nutrient. From the third year, potassium again became the chief nutrient of those tested, the early response to

nitrogen having disappeared. This short-lived nitrogen response is contrary to the findings of Nethsinghe (1962) and Smith (1968). The suggestion is that the leguminous cover crop, although not directly fertilized, is supplying sufficient nitrogen for the palms' needs once a root system is developed. The strength of the reaction to applied potassium is largely anticipated, given the low native status of the element.

TABLE 6. LENGTH OF LEAF 4 EXCLUDING PETIOLE

Treatment	*Leaf length (m)*				
(NPKMg)	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*
0000	1.42	1.83d	2.25c	2.72b	2.76b
0122	1.32	1.89d	2.62abc	3.51a	3.63a
1122	1.63	2.45ab	2.94ab	3.72a	3.81a
2102	1.67	2.11cd	2.46bc	2.89b	2.99b
2112	1.64	2.43ab	2.9ab	3.72a	3.69a
2120	1.64	2.3abc	2.98a	3.46a	3.63a
2121	1.72	2.46ab	3a	3.63a	3.7a
2122	1.61	2.43ab	3.03a	3.65a	3.75a
2123	1.56	2.46ab	3.04a	3.73a	3.79a
2132	1.72	2.59a	3.08a	3.77a	3.78a
3122	1.55	2.2bc	2.82ab	3.56a	3.62a

Green Leaves on Palm

Nitrogen did not statistically influence the number of green leaves per palm at any time of counting. Treatment 0122 had fewer leaves than 2121 and 2123 in year 2, but this cannot be interpreted as a nitrogen effect. *Table 7* shows that potassium is the principal nutrient governing green leaves on the palm from year 2. There was no indication that luxury levels of potassium were necessary. Surprisingly, gross visual symptoms of deficiency were rare. Yellowing of fronds in treatment 0122 was not observed even before cover crop establishment. Potassium deficiency symptoms were mild and not confined to treatment 2102, it being more associated with aging. As the palms were stressed from planting in the infertile soil used, they compensated for nutrient shortage by reduced vegetative production, and therefore did not show gross visual symptoms. These is anticipated when a healthy palm is stressed at maturity.

TABLE 7. GREEN LEAVES ON PALM

Treatment	*Number of green leaves on palm*				
(NPKMg)	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*
0000	6.6	7.1c	8.9b	9.8b	11.9b
0122	7.1	10.1b	14.1a	18.9a	20.4a
1122	8.2	12.3ab	16.3a	21.9a	19.8a
2102	7.6	7.2c	8.6b	10.4b	10.8b
2112	7.9	12.2ab	16.2a	21a	19.4a
2120	7.9	12.4ab	14.9a	18.7a	17.8a
2121	8	12.9a	16.5a	21.5a	20.1a
2122	7.7	12ab	16.2a	21.3a	19.8a
2123	7.7	12.5ab	17.6a	22.2a	19.3a
2132	8.7	13.3a	18a	21.7a	20.7a
3122	7.4	11.8ab	15.7a	19.7a	17.9a

Cumulative Leaf Production

The early stimulation of growth by nitrogen is shown in leaf production (*Table 8*). Interestingly this was not reflected in green leaves on the palm; so nitrogen influences production but not retention of leaves. The effect of nitrogen was persistent as a result of this early increase in production, but the response ceased to be significant in the fifth year. Potassium application positively affected leaf production from the second year. Treatment 2102 was not different from 0000 from the fourth year, again showing the predominant effect of potassium, and confirming Fremond & Ouvrier (1981) in their observation of the absolute necessity of early potassium nutrition. Early benefits from the highest rate of potassium declined, with presence or absence of the nutrient being the dominant effect.

TABLE 8. CUMULATIVE LEAF PRODUCTION

Treatment (NPKMg)	*Total number of leaves since planting*					
	Year 1	*Year 2*	*Year 3*	*Year 4*	*Year 4*	*Year 5*
0000	5.9	12.3	19.4d	26.9c	36.2d	45d
0122	5.5	11.5	19.1d	29c	42.6bc	54bc
1122	5.7	13.3	22.7bc	34.3ab	49.4a	61ab
2102	5.9	13	21.4c	30.5bc	41.7cd	51.3cd
2112	6	13.4	23.1ab	34.7ab	49.4a	61.2ab
2120	5.9	13.3	22.9ab	33.9ab	48ab	58.7ab
2121	6	13.5	23.4ab	35a	50.1a	61.8a
2122	5.8	13	22.4bc	33.9ab	48.6ab	60.6ab
2123	5.7	12.3	22.5bc	34.7ab	50.2a	61.7a
2132	5.7	13.6	24.2a	36.6a	52.3a	63.4a
3122	5.5	12.4	22bc	33.3ab	47.8ab	59.1ab

Precocity

Precocity was apparently enhanced by the highest rate of each of the three nutrients under investigation, by up to seven months. This superiority over other complete fertilizer treatments was diminished at 62 months (*Table 9*). The extra early yield was insuf-

TABLE 9. COMPARATIVE PRECOCITY OF COCONUTS DUE TO DIFFERENT FERTILIZER RATES

Treatment (NPKMg)	*Age at first harvest (months)*	*Palms bearing at six monthly intervals (%)*		
		50	*56*	*62*
0000	57	–	–	4.17
0122	55	–	2.08	16.67
1122	51	–	12.5	77.08
2102	58	–	–	4.17
2112	51	–	8.33	66.67
2120	53	–	4.17	58.33
2121	51	–	10.42	70.83
2122	55	–	12.5	77.08
2123	48	8.33	22.92	81.25
2132	48	4.17	35.42	83.33
3122	49	4.17	22.92	62.5

ficient to justify luxury rates. Omission of nitrogen or potassium exerted the predominant effect, and treatment 2102 was not different from 0000 at 62 months. It is anticipated that the performance of treatment 0122 will improve with time similarly to improved vegetative development. This can be expected if fertilizer treatments influence flowering primordia which precede bearing by two years.

Foliar Analyses

Foliar samples were taken annually from 1979 (year 1) to 1983. These were analysed for N, P, K, Ca, Mg and Na. Results are given in *Tables 10–15*. Foliar nitrogen was influenced by nitrogen application, except in 1979. The predominant feature was that the three higher rates of nitrogen gave higher levels of foliar nitrogen than treatment 0122, but were not themselves different. In 1983, treatment 0122 was lower than the other three N treatments but higher than 0000. This can be interpreted as due to the effect of phosphate on vigour of the leguminous cover crop in 0122 causing greater nitrogen availability. The indications are that 0.2 kg of nitrogen per year is sufficient for normal palm development when a legume is grown. Treatment 2102 increased foliar N in 1980 and 1982. This is probably a function of reduction in the number of green leaves caused by this treatment. Magnesium caused a significant effect in 1980, but this does not relate to any effect on vegetative characteristics, and may be a function of metabolism.

Foliar phosphate levels were predictably and consistently the lowest in the 0000 treatment, the only one having no phosphate. From 1980, increased levels of potassium

TABLE 10. FOLIAR NITROGEN AS PERCENTAGE OF DRY MATTER

Treatment	*1979*	*1980*	*1981*	*1982*	*1983*
0000	1.89	1.86bcd	1.71b	1.4de	1.37c
0122	1.79	1.54d	1.4c	1.38e	1.64b
1122	2.05	1.78bcd	1.75b	1.5cde	1.87a
2102	1.94	2.26a	1.87ab	1.86a	1.89a
2112	1.85	1.94abc	1.85ab	1.63bc	1.88a
2120	1.9	2.08ab	1.9ab	1.47cde	1.91a
2121	2.06	1.84bcd	1.84ab	1.58bc	1.87a
2122	1.96	1.89bc	1.9ab	1.6bc	1.9a
2123	1.87	1.64cd	1.97ab	1.58bc	1.92a
2132	2.06	1.94abc	2.1a	1.55bcd	1.93a
3122	1.84	1.93abc	1.98ab	1.69b	1.93a

TABLE 11. FOLIAR PHOSPHORUS AS PERCENTAGE OF DRY MATTER

Treatment	*1979*	*1980*	*1981*	*1982*	*1983*
0000	0.095e	0.081d	0.08e	0.065d	0.088b
0122	0.104de	0.12bc	0.097d	0.106abc	0.138a
1122	0.105cd	0.119bc	0.113abcd	0.111a	0.136a
2102	0.111bcd	0.137a	0.123ab	0.111a	0.142a
2112	0.108bcd	0.123bc	0.125a	0.099abc	0.145a
2120	0.115abc	0.126b	0.105cd	0.09c	0.135a
2121	0.123a	0.117bc	0.109bcd	0.096abc	0.128a
2122	0.116abc	0.112c	0.107cd	0.092bc	0.137a
2123	0.114abcd	0.12bc	0.115abc	0.105abc	0.134a
2132	0.118ab	0.122bc	0.108cd	0.099abc	0.103b
3122	0.109bcd	0.114c	0.111abcd	0.108ab	0.137a

TABLE 12. FOLIAR POTASSIUM AS PERCENTAGE OF DRY MATTER

Treatment	*1979*	*1980*	*1981*	*1982*	*1983*
0000	1.28b	1.04e	0.35g	0.64d	0.71d
0122	1.54a	2.48ab	1.17ef	1.72a	1.75ab
1122	1.16bc	2.45ab	0.96f	1.6a	1.44bc
2102	0.92cd	0.38f	0.2g	0.24e	0.39e
2112	1.13bc	2.06d	1.3de	1.22c	1.41c
2120	1.24b	2.33bc	1.8a	1.44abc	1.63abc
2121	1.18bc	2.46ab	1.69ab	1.54ab	1.71abc
2122	0.81d	2.13cd	1.56abc	1.46abc	1.6abc
2123	1bcd	2.17cd	1.24e	1.24c	1.47bc
2132	1.22b	2.64a	1.51bcd	1.43abc	1.81a
3122	1.14bc	2.15cd	1.39cde	1.29bc	1.58abc

TABLE 13. FOLIAR CALCIUM AS PERCENTAGE OF DRY MATTER

Treatment	*1979*	*1980*	*1981*	*1982*	*1983*
0000	0.325e	0.361b	0.362b	0.318ab	0.295bc
0122	0.341de	0.238d	0.238d	0.17d	0.157d
1122	0.462ab	0.233d	0.288bcd	0.178cd	0.22cd
2102	0.487a	0.501a	0.462a	0.38a	0.45a
2112	0.463ab	0.321bc	0.313bcd	0.271bc	0.315bc
2120	0.388bcde	0.287c	0.293bcd	0.23bcd	0.298bc
2121	0.382bcde	0.232d	0.301bcd	0.23bcd	0.286bc
2122	0.366cde	0.249d	0.259cd	0.89cd	0.279bc
2123	0.423abcd	0.284c	0.34bc	0.265bcd	0.374ab
2132	0.432abc	0.249d	0.296bcd	0.24bcd	0.328bc
3122	o.391bcde	0.328bc	0.296bcd	0.243bcd	0.298bc

TABLE 14. FOLIAR MAGNESIUM AS PERCENTAGE OF DRY MATTER

Treatment	*1979*	*1980*	*1981*	*1982*	*1983*
0000	0.209e	0.222b	0.203bc	0.239b	0.198bc
0122	0.230de	0.169de	0.155de	0.186bcd	0.171bcd
1122	0.266bc	0.181cde	0.173cde	0.183bcd	0.194bc
2102	0.28b	0.407a	0.36a	0.393a	0.298a
2112	0.276bc	0.23b	0.187cd	0.208bc	0.193bc
2120	0.247cd	0.153e	0.078g	0.084e	0.1e
2121	0.273bc	0.155e	0.11f	0.131de	0.127de
2122	0.313a	0.212bc	0.164de	0.162cd	0.177bcd
2123	0.298ab	0.238b	0.218b	0.223b	0.223b
2132	0.276bc	0.166de	0.154e	0.154cd	0.154cd
3122	0.278bc	0.2bcd	0.178cde	0.165cd	0.184bc

caused depressed phosphate levels, presumably because of increased leaf production. The significant effects of nitrogen on foliar phosphate in 1979 and 1982 were irregular and difficult to rationalise, they not being associated with any measured characteristic.

Potassium exercised the greatest influence on foliar K content. From 1980 the pattern of depressed levels of foliar K in treatment 2102 was established, in most years below

TABLE 15. FOLIAR SODIUM AS PERCENTAGE OF DRY MATTER

Treatment	*1980*	*1981*	*1982*	*1983*
0000	0.151a	0.109a	0.144a	0.127a
0122	0.079bc	0.035f	0.072b	0.052c
1122	0.079bc	0.068cde	0.058bc	0.059c
2101	0.103b	0.1ab	0.077b	0.077bc
2112	0.087bc	0.09abc	0.072b	0.068bc
2120	0.064c	0.058def	0.069b	0.06bc
2121	0.064c	0.088abc	0.06bc	0.058c
2122	0.077c	0.085abcd	0.053bc	0.066bc
2123	0.08bc	0.73bcde	0.062bc	0.087b
2132	0.062c	0.048ef	0.034c	0.065bc
3122	0.074c	0.055ef	0.047bc	0.06bc

0000. This is presumably because of nitrogen depression and magnesium antagonism of potassium. In 1982, the three highest levels of potassium were not different in respect of foliar K content, but in 1983 a strongly linear effect was observed. This can be explained if one considers that 1983 was the first time of sampling leaf 14, which was more mature than leaf 9. As potassium is preferentially translocated to younger, physiologically more active tissue it is drained from older leaves, except where sufficient amount is supplied as fertilizer. Treatment 2132 therefore caused a higher leaf K level than 2112 in 1983, whereas both supplied the requirements of leaf 9 in 1982. Magnesium consistently depressed K content through cation antagonism. The tendency was for nitrogen to reduce foliar potassium although this did not relate to increased leaf production. In 1979, treatment 0122 raised the level of foliar K above that for 0000. This may be associated with the non-significant reduction in leaves produced by this treatment in that year.

Foliar calcium levels were most significantly affected by potassium application. This was typical cation antagonism leading to lower levels of one in the presence of increasing quantities of the other. The highest foliar calcium level was in treatment 2102 in all years. The effect of magnesium was only noted in one year and is not easily explained. Nitrogen increased foliar Ca in three of the five years studied. Possibly this is reciprocal to the noted decreases of foliar potassium due to increased nitrogen, in some years.

Nitrogen increased the level of foliar magnesium in 1979 and 1980. This may be seen as reciprocal to the corresponding decrease in foliar potassium during the same period. Other treatment effects on foliar magnesium were predictable, with increasing rates of applied magnesium increasing the level of this nutrient in all years. Similarly, increased potassium rates led to cation antagonism and consequent reduction in foliar Mg. As a result of greater levels of production, treatments 2121 and 2122 often had a lower magnesium content than 0000. From 1980, the treatment with the highest magnesium content was 2102, combining applied magnesium with no potassium and a low level of vegetative growth.

All treatments depressed foliar sodium levels in all years below treatment 0000. This was due to cation antagonism, all other treatments containing potassium, magnesium or both. Increased rates of potassium typically lowered sodium levels, but responses to nitrogen and magnesium were sporadic and erratic.

CONCLUSION

Nitrogen is necessary for the early vegetative growth of MYD x WAT hybrid coconuts on infertile P and K-deficient soils in Thailand. In the presence of a leguminous cover crop, the requirement for nitrogen declines as the root system of the coconut becomes better established. The quadratic nature of nitrogen responses determines that the requirement is only for a small quantity of the nutrient. Enhanced early growth as a result of nitrogen application is reflected in early bearing. The amount required to sustain yield is expected to decline.

From year 3, potassium determines vegetative production partly as a result of application in earlier years. This suggests that the situation reported by Fremond & Ouvrier (1971) is the most comparable with conditions in Thailand. The requirement for potassium can be expected to increase from planting, but super-optimal levels are not indicated particularly on soils with limitations other than low native fertility, despite the observed slight benefit of enhanced precocity.

There has been no significant response to magnesium application, despite the apparent superiority of treatment 2123. This is not better than 2120, so no real effect can be determined. This means that Coomans (1977) observation that magnesium is of greater importance than nitrogen does not hold true in Thailand. Maintenance levels of magnesium application should be made, as continued application of large quantities of potassium can be expected to induce future cation deficiency. This could also be used as pH adjustment using kieserite in areas having neutral or alkaline soils, but using the cheap, locally available dolomitic limestone where pH is excessively low.

Visual symptoms of gross nutrient deficiency were confined to reduced physical dimensions with no colour indicators. This is largely predictable where a nutrient has been consistently omitted from planting on an infertile soil. Symptoms of colour aberration are expected when a healthy plant is deprived of a previously plentiful nutrient.

Foliar analysis results show that many factors influence levels of one element in the leaf, and that increased application of that element may not be the solution to observed nutritional imbalance. The suggestion is that inter-relationships among the foliar nutrients should be more closely studied to determine more precisely fertilizer requirements rather than using absolute levels.

Phosphate was not studied, but the very low phosphate status of many soil series in southern Thailand, together with a requirement to maintain a healthy cover crop, indicates that at least a low level of this nutrient will be required.

Levels of early nutrient uptake could be detected as being significantly different by foliar analysis, confirming the observations of Foale (1968) and Charles (1968), but this did not relate to significant early vegetative differences.

The results of Nelliat & Muliyar (1971) seem strange in the light of the data presented in this paper. Even in treatments 0000 and 2102, more than 4% of palms were bearing at 62 months, yet they stated that no unfertilized palms were flowering at six years. Possibly the soils used were even less fertile than those of the current study, or the high yielding varieties they used were not notably precocious.

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P

REPLANTING COCONUT IN THE COCOA-COCONUT INTERCROPPING SYSTEM

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Summary

In the cocoa-coconut double cropping system, the replacement of the aged and low yielding Malayan Tall coconut with the MAWA hybrid appeared an attractive venture. 3 procedures of replanting were attempted. In all cases the density of the MAWA hybrid was standardised at 100 palms per hectare, and the cocoa stand maintained with minimal disturbance.

The first replanting procedure, called the FeRe system involved poisoning, felling, cutting and stacking the trunks of the old coconut stand before replanting. The other 2 systems, viz. PoRe and RePo systems, allowed the trunks to rot in situ. The difference between them lies in the timing of poisoning the old coconut stand - before planting in the former and after planting in the latter.

Cocoa production increased soon after poisoning the old coconut stand, especially in the FeRe system, but this yield advantage was considered a short term benefit.

The MAWA seedlings suffered from etiolation and production of nuts was delayed by about one year.

Currently the RePo system is preferred, but rhinoceros beetle infestation remained a matter of concern and further research into the effective control of this insect under the environment discussed, is advocated.

* Presently in Australia.

Introduction

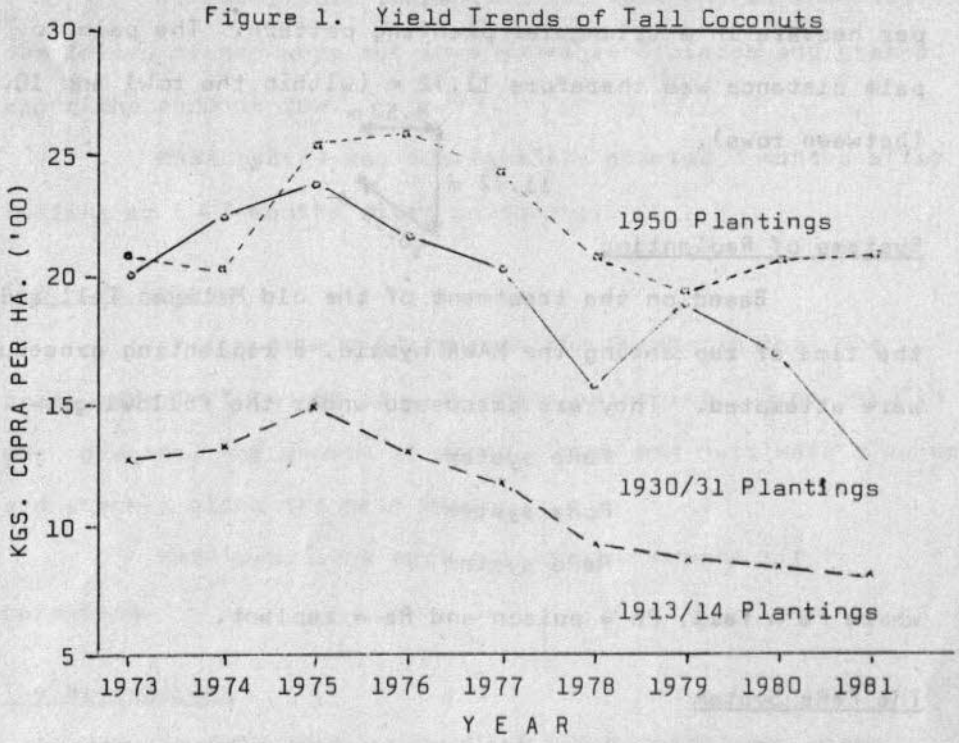
Estates in the Bagan Datoh delta of Lower Perak began small scale observations to assess the performance of cocoa under coconuts at the turn of the 1950's. Early results were sufficiently encouraging to maintain interest in this intercropping system, but it was only a decade later that confidence in commercial planting was established. Since then planting cocoa under mature coconut became increasingly popular, to the extent that it has become a standard practice amongst estates, and is also popular amongst smallholders.

United Plantations Berhad's first major underplanting programme was established in the mid 1960's in fields with coconuts planted in 1912/13. Thus by the mid 1970's, when the cocoa trees were 10 years or younger and therefore either in their prime or increasing in production, the ageing Malayan Tall coconut yield was declining (Figure 1). By then cocoa had became the main money earner and the coconut was relegated to the role of a shade tree for cocoa. It was noted that in 1977 the returns from copra was less than 20% of the total cocoa-copra profits as compared to 41% in 1973 (UPB Financial Report, unpublished).

The introduction of the MAWA hybrid was seen as a possible saviour of the coconut. It was assumed that the replacement of the ageing and low yielding Malayan Tall with the MAWA hybrid should improve the role of the coconut in this coconut-cocoa intercropping system.

This paper describes the experiences of United Plantations Berhad in such an endeavour.

Figure 1. Yield Trends of Tall Coconuts



Consideration

Cocoa:

To minimise loss in revenue during the immature period of the coconut, care was taken to ensure that the cocoa plants were not unduly damaged during the process of replanting the coconuts. Assuming that the removal of top shade from the old coconut stand would increase photosynthetic activity of the cocoa, and therefore, greater nutritional demand, additional nitrogen at 70 gm/tree was applied to the cocoa. Cocoa trees surrounding the young MAWA seedlings were pruned back to reduce excessive shading of the coconut seedlings.

Coconut:

The old Malayan Talls were planted at 8.53 m (28 ft.) square (thus giving 137 palms per hectare or 55.6 palms per acre) and the rows run along the East-West direction. The MAWA seedlings were planted along the old coconut rows and the

expenditure incurred in the cleaning up of fallen crown and nuts in the other 2 systems. The total cost of replanting in FeRe system was therefore $2\frac{1}{2}$ times that of the PoRe and RePo systems.

Table 1. Cost of Replanting

	Cost/palm ($)			Cost/hectare ($)*		
	System			System		
	FeRe	PoRe	RePo	FeRe	PoRe	RePo
Poisoning	0.65	0.65	0.65	70.20	70.20	70.20
Felling/Cutting/ Stacking	3.50	-	-	378.00	-	-
Clearing#	-	0.60	0.60	-	64.80	64.80
Planting MAWA including transport	0.66	0.66	0.66	66.00	66.00	66.00
Total	4.81	1.91	1.91	514.20	201.00	201.00

Ref.: * Assuming 80% stand, ∴ 108 palms/hectare.
Fallen crown and nuts.

Another significant expenditure item was the collection of Oryctes rhinoceros to contain the damage to MAWA seedlings. The direct advantage of the RePo system is the grace period of 8 months after replanting when no beetle collection was necessary. The expenditure incurred in beetle control over the first 2 years after planting is given in Table 2 (winkling for beetles from seedlings) and Table 3 (collection of grubs from decaying log heaps). Costs incurred thereafter are not discussed because beetle damage by then is assumed to be comparatively less critical and winkling also less efficient because of the size of the plants. Compared to the FeRe system, which had the highest expenditure, the PoRe and RePo systems showed savings of 30% and 36% in winkling respectively. Savings was much greater when expenditure on grub collection is included.

Table 2. Expenditure in Beetle Collection

System	1st Year		2nd Year		Total	
	Beetle per ha.	Expenditure per ha.	Beetle per ha.	Expenditure per ha.	Beetle per ha.	Expenditure per ha.
FeRe	22	$61	118	$144	140	$205
PoRe	7	$22	240	$121	247	$143
RePo	3	$ 8	109	$124	112	$132

Table 3. Cost of Larvae Collection

System	Year 1		Year 2		Total	
	No. of larvae per ha.	Cost per ha.	No. of larvae per ha.	Cost per ha.	No. of larvae per ha.	Cost per ha.
FeRe	1,560	$35	8,930	$101	10,490	$136
PoRe	-	-	945	$ 9	945	$ 9
RePo	-	-	1,009	$ 9	1,009	$ 9

Note: Costs quoted is actual expenditure incurred and not corrected for inflation etc.

Other management and agronomic practices may also vary between the 3 systems but the differences are considered to be of minor significance in the context of this paper and therefore not discussed here.

Observation

The FeRe System:

The most obvious disadvantage of this system is the precision felling which was necessary to minimise damage to the existing cocoa trees. Even with the great care exercised, 15% of the cocoa trees were damaged to varying degree of severity, but no death was encountered and the cocoa trees recovered within a year.

It was noted that progress in felling and stacking was rather slow, due not only to the lack of skilled labour for felling, but also to the tedious job of stacking the cut trunks manually. Labour requirement was 3 chainsaw operators per hectare for felling and sectioning the coconut palms, and 18 mandays per hectare for stacking them.

Beetle infestation was considered a major problem in coconut replants; in this case, made worse by the creation of additional breeding sites, from decaying trunks. Based on field observations on the incidence of seedlings attacked by the beetle, it was decided to commence daily winkling for the beetles 3 months after planting or 7 months after poisoning of the old coconut stand. Table 2 shows that a total of 140 beetles per hectare were winkled out from the seedlings during the first 2 years since the MAWA seedlings were planted. The incidence would likely be much greater had the grub population not been collected from the decaying trunks. Probably the potential of adult beetle population can be gauged by the number of grubs collected (Table 3).

Being a commercial replant, the growth of the MAWA seedlings was not monitored closely, and therefore etiolation effect cannot be objectively discussed. Experienced personnel would however, be convinced of the adverse effect of the heavy shade, even with the additional bi-monthly pruning of the cocoa trees surrounding the MAWA seedlings. Perhaps the delay in flowering and thus subsequent harvesting could be taken as an indication of the etiolation effect. It was noted that coconut harvesting could only commence at the 53rd month after planting, which is about a year later than the mono-MAWA field a short distance away, and planted on the same soil type.

Nut production during the 1st 12 months of harvest averaged 3,420 nuts/hectare per year, or 0.6 tons of copra per hectare per year (conversion rate being 5,770 nuts per tonne of copra during the 1st year of production).

In the absence of a properly laid out experiment, the effect of thinning of the overhead shade on cocoa yield can be gauged only by comparing the yield trend of a neighbouring area with the same age of cocoa. Dry bean production, as shown in Table 4 below, improved within a year after poisoning of the old coconut stand. The highest benefit was during the 2nd year after thinning, when a yield advantage of > 50% was recorded. This benefit disappeared completely the following year. However, over the 4 years since removal of the old coconut stand mean dry bean production managed to maintain an 18% advantage. It is as yet too early to discuss the effect of the MAWA hybrid on cocoa yield.

Table 4. Cocoa Dry Bean Production in the FeRe System of Replanting

Year	Period*	Kgs. dry bean per ha.		% (Year -1 = 100)		% Yield advantage(+)/ disadvantage(-)
		Replanted area (24 ha.)	Control (22 ha.)	Replanted area (24 ha.)	Control (22 ha.)	
1979	-1 year	593	628	100	100	-
1980	0 year	720	744	121.4	118.5	+ 2.9
1981	+1 year	819	762	138.1	121.3	+16.8
1982	+2 years	958	678	161.6	108.0	+53.6
1983	+3 years	693	741	116.9	118.0	- 1.1
Mean/year (0,+1,+2 & +3)		798	731	134.6	116.4	+18.2

Ref.: * -1 year = the calendar year prior to poisoning of the Malayan Tall coconut.
0 year = the calendar year when the palms were poisoned.
+1 year = 1 calendar year after the palms were poisoned.
+2 years = 2 calendar years after the palms were poisoned.
+3 years = 3 calendar years after the palms were poisoned.

The PoRe System:

Although the crown of most palms had fallen off around 3 months after poisoning, the trunk took a much longer time to decay; the lower half of 70% of the palms were still standing 3 years later. This gradual collapse caused only minimal damage to the cocoa plants, but presumably would increase the period with ideal medium for the rhinoceros beetle to breed. Beetle population during the first year was considered low enough to warrant weekly winkling rounds, commencing 3 months after planting.

Referring to Table 2, it can be assumed that the adult beetle population in this system was larger than the first system over the 2-year period. This is probably a reflection on the effectiveness of grub collection which was possible in the first system, but not practical in this second system.

Since growth of the MAWA seedlings appeared to be similar to the FeRe system, copra yield prospects is not expected to be significantly different.

Cocoa yield, in terms of dry beans per hectare, showed a 23% advantage one year after poisoning of the palms (Table 5) but the response observed during the second year in the FeRe system, was absent here.

Table 5. Cocoa Dry Bean Production in the PoRe System of Replanting

Year	Period	Kgs. dry bean per ha.		% (Year -1 = 100)		% Yield advantage(+)/ disadvantage(-)
		Re-planted area (53 ha.)	Control (47 ha.)	Re-planted area (53 ha.)	Control (47 ha.)	
1980	-1 year	917	962	100	100	-
1981	0 year	1,027	1,078	112.0	112.0	0
1982	+1 year	1,102	935	120.2	97.2	+23.0
1983	+2 years	814	848	88.8	88.1	+ 0.7
Mean/year (0,+1 & +2)		981	954	107.0	99.2	+ 7.8

The RePo System:

This system, where the MAWA seedlings were under-planted some 6 months prior to poisoning of the old coconut stand, was attempted only 2 years ago, and as such limited data is available.

The fallen crowns had so far not caused any severe damage to the MAWA seedlings nor the cocoa plants.

The 6+ months of shade from the old coconut stand seemed to have limited adverse effect on the MAWA seedlings and etiolation appeared to be similar to the other 2 systems. Cocoa production during the year of poisoning showed only a 7.7% yield advantage (Table 6).

Beetle population, based on winkling records was much lower and fewer seedlings were attacked by the beetles during the 1st and 2nd year of field planting.

Table 6. Cocoa Dry Bean Production in the RePo System of Replanting

Year	Period	Kgs. dry bean per ha.		%		% Yield advantage/ disadvantage
		Re-planted area	Control	Re-planted area	Control	
1982	-1	896	1,004	100	100	-
1983	0	863	890	96.3	88.6	+7.7

Discussion

The 3 systems described above, were in fact, evolved with experiences gained from each succeeding system, and guided by 2 objectives; viz.:-

- the cocoa in the area concerned must continue to generate revenue.
- the MAWA hybrid coconut must replace the old Malayan Tall as the stable long term overhead shade.

The first FeRe system was not favoured mainly because of the very high cost and the large labour requirement. The opportunity for mechanisation of the felling and stacking operations were limited by the lack of suitable machinery for working among the dense cocoa population. Since there was no known serious root disease in coconut, it was decided that the replanting system be modified - thus the second PoRe system.

In the PoRe system, felling and stacking of the trunks were dispensed with, and cleaning up the debris (fallen nuts, fronds etc. from the old coconuts) costed much less. It was therefore an attractive system. Attention was then directed to the control of rhinoceros beetle infestation on coconut seedlings since grub collection from the standing palm trunks was not practical. The high incidence of beetle infestation prompted the search for alternative system. It was decided that the simple approach, though not necessarily the best, was to underplant before poisoning; thus the RePo system. As described earlier, this system gave the MAWA seedlings more than 6 months head start before poisoning as against the FeRe and PoRe systems where the MAWA seedlings were planted 6 months and 2 months after poisoning respectively, and accordingly the period of exposure of the seedlings to beetle attack. However both the PoRe and RePo systems of replanting the coconut would probably pose similar problems with beetles when replanting programmes are continuous and in continguous blocks.

Beetle attack on the MAWA hybrid will obviously be of major concern in the coconut replanting programmes, and research into control measures under the conditions described above, would be most welcomed and should be valuable to the coconut industry as a whole.

The MAWA hybrid, planted in a triangular system at a spacing of 8.53 m x 11.72 m (or 100 palms/hectare) should not experience any interpalm competition for light since Tan & Chan (1984) have shown that drip circle (or the maximum extension of fronds on one side) is expected to be around 5.11 m only. It is projected that the MAWA production would plateau at above 160 nuts per palm per year, and assuming a conversion rate of 5,000 nuts (Tan & Chan, 1984), replants under similar conditions should yield at least 3.2 tons of copra per hectare per year at full maturity. This yield is more than double the production from the old Malayan Tall.

The boost in dry bean production, soon after the removal of the old Malayan Tall is assumed to be a short term benefit and does not reflect the superiority of mono-cocoa, because past experience with mono-cocoa had been discouraging. Although the differences in yield response between the 3 systems as shown in Tables 4, 5 and 6 appear large, the compounding effect of different years of replanting and different locations makes comparison unrealistic. The long term effect of replanting on cocoa yield is not expected to be different among the 3 systems, since the MAWA planting density and system are the same.

The RePo system is currently preferred over the PoRe system because of the flexibility in the schedule for planting of the MAWA seedlings and for the poisoning of the old coconuts. The relatively shorter period of the presumably 'over exposure' of the cocoa to sunlight is assumed to be an additional advantage.

Acknowledgement

The authors wish to thank United Plantations Berhad for permission to present this paper.

References:

1) Tan Y.P. & Chan E. (1984). Optimum Density for MAWA Hybrid. Conf. on Cocoa and Coconuts, Kuala Lumpur, October 1984.

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Tissue Culture of *Cocos nucifera* — Biochemical Changes Preceding Embryogenesis

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We are developing methods for the clonal propagation of selected coconut palms using tissue culture techniques.

Callus was produced, and morphogenic events which occur in this callus were studied.

This paper discusses the comparisons between the events which occur in coconut callus and those which occur during somatic embryogenesis of selected palm species. It also explains the use of probes for embryogenic markers, in order to monitor differentiation events.

The main areas in which further research is necessary before the techniques can be exploited fully are identified as:–

- *Initiating morphogenetic changes in the callus cultures and*
- *Obtaining plants with balanced root and shoot systems.*

When selected coconut palms are crossed to produce seeds, the genetic characteristics of the parents segregate, resulting in offspring with a wide range of characteristics. The yield characteristics of crosses, even among hybrids with relatively inbred parental lines (*e.g.* West African Tall x Malaysian Red Dwarf) are such that many lower yielding palms are found within a normal plantation. If planters could eliminate the lower yielding palms from their planting material, it is obvious that the same area could enjoy a higher yield. Some form of vegetative propagation is clearly appropriate.

Vegetative propagation of many crops can be achieved by taking cuttings or grafting scions onto rootstocks. In palms where no side-branches or suckers exist, it is necessary to achieve vegetative propagation using the relatively complex techniques of tissue culture. L.H. Jones, of the Colworth Laboratory, was among those who pioneered the tissue culture of the oil palm (Rabechault & Martin, 1976; Jones, 1983). We are now among workers at several laboratories throughout the world who are attempting to develop techniques for the tissue culture of coconut palms which are appropriate for large-scale production. Branton and Blake (1983) succeeded in producing a small number of coconut palms for tissue culture: feasibility of the process has therefore been demonstrated.

Our aim is to propagate the best palms from the population of superior hybrid varieties. The techniques we develop must be suitable for a large-scale operation.

METHODS AND RESULTS

Tissue culture involves taking explants from the palms, growing callus from these explants and then regenerating plants from the callus.

Various tissues can be used as explants – roots, apical meristems, young leaf tissue or young inflorescence tissue. All explants must be disinfected before use and callus is initiated on sterile semi-solid medium. Methods which allow callus initiation and proliferation have been found by the Unilever Research team at Colworth House. Callus is routinely initiated from inflorescence material at Colworth House. Our methods produce callus from up to 80% of inflorescence explants but are less successful with root or leaf tissue. We do not use apical meristems as explants since sampling would destroy the valuable selected palms. It is, however, much more difficult to initiate "embryoid" (*i.e.* embryo-like structures which develop into plants) production in the cultures, or directly on the explants.

We are therefore searching for stimuli (nutritional, hormonal and environmental) which will induce the desired morphogenic changes in the callus cultures. Our experimentation is designed to discover a process which will encourage embryogenesis in a high proportion of the cultures. We are therefore continually monitoring a very large number of cultures *in vitro*. Interpretation of our experimental results can be extremely difficult since we have been unable to monitor the progress of embryogenesis *before* the appearance of visible embryoids. Effective stimuli may therefore have been overlooked.

However, before embryoids appear in the cultures, various biochemical changes will have occurred, and new "embryogenic" proteins should be detectable. "Embryogenic" proteins may be enzymes or structural proteins; cytoplasmic or membrane bound. It is unnecessary to identify the proteins to use them as markers.

We have therefore developed techniques involving electrophoresis, isoelectric focussing and immunological probes to detect embryogenic proteins in cultures of palm species.

It is likely that only a very small proportion of cells in a palm culture will develop embryogenic characteristics. Any detection techniques we develop must therefore be extremely sensitive.

Electrophoresis

There are certainly differences in the proteins which can be isolated from callus and embryos as revealed by SDS-polyacrylamide Gel Electrophoresis (SDS-PAGE). However, proteins which are characteristic of embryos are very difficult to identify against the background of the enormous range of proteins which appear in all cells. We therefore use immunological probes to identify the proteins which are specific to embryos.

Immunological Probes

If foreign substances are injected into the bloodstream of an animal, the animal will produced antibodies to those substances. These antibodies can then be isolated from serum. Polyclonal antisera have been raised in rabbits against palm zygotic embryos. Some antisera preparations have been absorbed with non-embryogenic oil palm or coconut palm callus to remove antibodies which react with non-embryogenic proteins. The remaining antisera components should then recognise specific proteins present in "embryoids" or



Figure 1. Plantlet regenerated from callus Selected Red Malayan Dwarf x Rennell Tall Hybria.

Characteristics of Malaysian Cocoa Butter

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Cocoa butter is the most valuable ingredient of the cocoa bean and its physical and chemical characteristics dictate the final quality of the end product, for example, chocolate. As Malaysia is beginning to produce more and more cocoa it becomes necessary to look into the properties of Malaysian cocoa butter in comparison with presently accepted butters such as Ghanaian cocoa butter. Furthermore cocoa butter characteristics may vary from location to location, or among different genetic types. In this study cocoa beans were collected from various locations throughout East and West Malaysia and from different clones through one calendar year. Analyses done include iodine value, saponification value, unsaponifiable matter, melting point, free fatty acid, fatty acid composition, triglyceride composition, Jensen cooling turve and solid fat content.

The analytical results obtained are within draft Malaysian standard specifications except for unsaponifiable matter which has high values in some cases. Malaysian cocoa butter is harder than Ghanaian cocoa butter, having higher saturation due to higher C18 and lower C18:1 and C18:2 acids. This results in higher solid fat content and melting point.

Significant variations in cocoa butter characteristics exist between the clones studied; Na33 generally having softer butter when compared with UIT1, Pa7 and ICS60.

Multilocational differences are also seen to be significant for FFA, melting point, C16, C18 and C18:1 acids, C54 triglycerides, Tmax, tmax and tmin in Jensen cooling curves, and solid fat content at 20° C. The effects from location, soil series, cocoa type, and depth of fermentation are, however, confounded with each other.

No definite trends are given by regression analysis to determine correlations between cocoa butter characteristics and climatic conditions. An exploratory analysis show that rainfall and temperature during the maturing period of the cocoa beans are positively correlated with fat content of the bean and FFA of cocoa butter. C18 and C18:1 acids are also influenced by rainfall, the latter being also affected by sunshine during the period.

The most valuable ingredient of the cocoa bean is considered to be cocoa butter and it is used mainly in the manufacture of chocolate and confectionery. The physical and chemical characteristics of cocoa butter actually dictates the final quality and behaviour of the end product since chocolate fundamentally consists of a continuous fat phase with a suspension of cocoa solids, sugar, and milk solids, if used.

As Malaysia is beginning to produce more and more cocoa it becomes necessary to look into the properties of Malaysian cocoa butter. Furthermore these characteristics may vary from location to location, or among different genetic types. Malaysian cocoa butter has been found to be harder at ambient temperature than Ghanaian cocoa butter (Mohd Nordin & Kheiri, 1980), and Nigerian and Brazilian cocoa butter (Sukla *et. al.*, 1983). This gives Malaysian cocoa bitter an edge over the others which may be a little too soft for the right melt-in-the-mouth and not-in-the-hand quality especially in summer

or in tropical climates. This hardness is due to the higher degree of saturation of Malaysian cocoa butter. It has been shown that cocoa beans maturing in cooler climates have a higher content of unsaturation (Lehrian & Keeney, 1980). Cocoa from different origins are also known to differ in fat content, as well as in the fatty acid and triglyceride compositions of their fats (Kattenberg, 1980). However, it is not clear whether these are due to genetic, environmental or processing effects.

In Malaysia there are notably two peak periods of rainfall and two dry periods (or troughs) in a year. Rain is necessary from about three to five months age (peak) to enable the cherelles to grow and mature followed by one to two months of sunshine (trough) for the ripening of the mature fruit (Mainstone, 1983). During this maturation there is a filling up of the cells with fat, starting with free fatty acids, which later convert into globules of neutral fat and eventually into fats with higher degree of unsaturated fatty acids as the fruit ripens (CHATT, 1953).

In this study the composition and characteristics of Malaysian cocoa butter of different genetic origins and multilocational sources were determined over one seasonal year to take into account the different climatic variations.

MATERIALS AND METHODS

Dried Fermented Cocoa Beans

Samples of commercial seales fermented dried cocoa beans from four parent clones, which have been extensively used for production of hybrid progenies for commercial plantings, were collected at two-monthly intervals for one calendar year to cover the peak and trough periods of the year. These were selected after discussions with Shepherd, 1980 to be:

UIT1 (unidentified Trinitario)
Na33 (representing Nanay UA populations)
Pa7 (representing Parinari UA populations)
and ICS60 (Trinitario clone produced by ICTA, Trinidad)

Samples of dried commercial scale fermented cocoa beans of mixed UA hybrids (representing commercial planting materials) were also collected from 13 sources throughout West and East Malaysia, at two-monthly intervals for one calendar year to cover the peak and trough periods of the year. These were selected after discussions with Shepherd, 1980 to be:

Extraction of Cocoa Butter by Hydraulic Press

A 500 g cocoa bean sample was roasted at 150°C for 30 mins. The roasted beans were then deshelled and degermed to obtain only the nibs. These were ground on a Waring commercial blender (New Hartford, Conn. USA) at low speed for 2–3 min. The ground nibs were divided into two lots and each lot was then wrapped in several layers of cheesecloth. The bundles were heated in an oven at 100°C for 30 mins, and only one was placed at a time between two heated plates (100°C) of a 10-tonne hydraulic press (Apex Construction Ltd, London W1 and Dartford). The pressure was maintained at 10,000 kg on a 5.4 cm dia. ram and the temperature at 100°C for 24 h. The cocoa butter collected from the two bundles was combined and filtered before analysis. The percentage cocoa butter extracted maybe calculated from the weight of cocoa butter obtained.

Empirical Tests

These tests were carried out to determine the characteristics of the extracted fat and may be compared with the values given in the draft Malaysian standard specifications for cocoa butter (S.I.R.I.M. D71 (ICS A), 1984).

Free fatty acid. The content of free fatty acids (FFA %) was determined by titrating 5 g of fat with standardised sodium hydroxide using thymol blue indicator (Mohd Nordin & Kheiri, 1980).

Iodine value. The mg Iodine/100g fat or IV was determined according to Wi js method (Cocks & Van Rede, 1966).

Saponification value and unsaponifiable matter. Five grams of melted fat was saponified with alcoholic potash and the saponification value determined by titration with a standard acid. After the titration the mixture was made alkaline with more alcoholic potash and the unsaponifiable matter was extracted with diethyl ether. The extract was washed, dried and weighed to constant weight (Pearson, 1973).

Clear melting point. Capilliary melting point tubes were filled with approximately 10 mm of sample by dipping into the melted fat at 70°C. One end of each tube was sealed by fusion. The samples were next stabilised at 0°C for 90 min, at 26°C for 40 h and then again at 0°C for 90 min. The melting point of the samples was determined on a Buchi 510 (Switzerland) melting point apparatus fitted with a thermometer with a range of −5 to 105°C (x0.1°C). Heating was carried on through the opalescent stage to the temperature when the sample became completely clear. This was taken as the clear melting point (Mohd Nordin & Kheiri, 1980).

Composition

Fatty acid composition. Fatty acid methyl esters (FAME) were prepared according to the rapid method (Timms, 1978) in which 25 mg of the melted fat sample was shaken vigorously for 5–10 sec with 0.45 ml petroleum ether and 0.05 ml N sodium methoxide in a closed tube. From the separated clear petroleum ether layer, 1 μl was taken and injected into a Hewlett Packard Gas Chromatograph Model 5840 A (USA) fitted with a flame ionisation detector (FID) and a 2.44 m long stainless steel column, 6.35 mm int. diam., filled with 10% diethylene glycol succinate (DEGS) coated on 100/120 mesh chromosorb WHP.

Triglyceride composition. A 10% solution of the fat was prepared and shaken vigorously. 0.5 μl was injected into the above Hewlett Packard gas chromatograph fitted with FID and a 60.96 cm long glass column, 3.175 mm int. diam., filled with 2.5% OV 1 coated on 100/120 mesh Gaschrom Q. (Kheiri & Mohd Nordin, 1980).

Cooling and Solidification Behaviour

Jensen cooling curve. Cocoa butter of 40–50 g was melted in a Jensen cooling curve (JCC) sample tube and maintained at 50–60°C for 15 min. The sample was then air cooled to 40°C with stirring, and placed into the air jacket of the JCC apparatus, which was then surrounded by a cooling bath of water and ice in a beaker. At 35°C stirring was carried out at every 5, 20, 35 and 50 sec past the minute. At 35°C, readings of the thermometer were taken at every minute until five consecutive readings remained constant. The temperature versus time curve was plotted and the following were noted from

the graph (Mohd Nordin & Kheiri, 1980):

Tmax	= highest temperature of cooling curve
Tmin	= lowest temperature of cooling curve
ΔT	= Tmax – Tmin
tmin	= number of minutes to reach Tmin from 32°C
tmax	= number of minutes to reach Tmax from 32°C
Δt	= tmax - tmin
Q	= $\Delta T/\Delta t$

Solid fat content. The percentage of solid fat was determined by wide line Nuclear Magnetic Resonance (NMR) using a Newport Analyser Mark II (Buckinghamshire, England). Samples were first melted at 70°C for 30 min. Then 2 ± 0.01 g of sample was taken in a 2 ml NMR tube. In the case of the untempered samples (UT), stabilising of the sample at each measuring temperature was carried out by holding the samples at 20, 30, 32.5 and 35°C for 30 min before taking the reading at that temperature. Tempered samples (T) however were held at 0°C for 90 min, at 26°C for 40 h, and again at 0°C for 90 min. The samples were then stabilised successively at each measuring temperature of 20, 25, 30, 32.5 and 35°C for 1 h before taking the reading. The instrument was set with gate width at 1 and RF value at 70 μA. It was calibrated (AF gain adjustment) to 100% liquid signal at each measuring temperature with a standard olive oil. Integration time (sec) was set according to the requirements of each sample. The SFC_t % = 100–NMR_t reading at the temperature t°C.

Statistical Analysis

The analytical data were examined for differences between clones, sample sources, cocoa type, soil series and depth of fermentation by analysis of variance (ANOVA) and Duncan's Multiple Range test calculated separately for each variable using the Statistical Analytical System (SAS).

A regression analysis was carried out over all sample sources to determine the possible correlation between the cocoa butter characteristics and the climatic conditions of rainfall, sunshine and temperature in each location.

RESULTS AND DISCUSSIONS

Overall Characteristics of Malaysian Cocoa Butter

From the analytical data obtained the overall mean values of the Malaysian cocoa butter characteristics were compiled (*Table 1*) in comparison with those of Ghanaian cocoa butter and the draft Malaysian standard specifications for cocoa butter. Malaysian cocoa butter was found to conform to Malaysian standards in all aspects except for unsaponifiable matter. In this respect Ghanaian cocoa butter fell within Malaysian standard specifications except for the unsaponifiable matter. Thus it may be that the Malaysian standard specification for unsaponifiable matter is a little too stringent. In comparing the two butters we note that Malaysian cocoa butter has lower iodine value and higher melting point than the Ghanaian type indicating that Malaysian cocoa butter had a higher degree of saturation and is harder, as was shown earlier by Mohd Nordin & Kheiri (1980). If one considers the biosynthetic pathway of fat in the maturing and ripening cocoa to progress from FFA to triglycerides and then to more unsaturated triglycerides, then the higher saturation indicates possibly that either Malaysian cocoa butter is harves-

TABLE 1. CHARACTERISTICS OF MALAYSIAN COCOA BUTTER IN COMPARISON WITH GHANAIAN COCOA BUTTER AND DRAFT MALAYSIAN STANDARD SPECICICATIONS (SIRIM, 1984)

Characteristics	*Malaysian Cocoa Butter*		*Ghanaian Cocoa Butter*	*SIRIM (1984)*
	Mean	*Coeff. of Variation (± %)*		
Iodine value (mgI_2/100 g fat)	34.6	3.1	36.9	33 – 42
Saponification value (mg KOH/g fat)	191.4	1.15	190.2	188 – 198
Unsaponifiable matter (%)	0.59	18.88	0.52	0.35 (for press cocoa butter)
Clear melting point (^{o}C)	34.5	1.09	33.4	32 – 36
Free fatty acid (% oleic. acid)	0.79	15.26	1.18	Not more than 1.75

ted a little early or the biosynthetic pathway of its lipid constituents have progressed less rapidly in the Malaysian environment when compared with Ghanaian cocoa.

Table 2 shows the fatty acid and triglyceride composition results form Malaysian cocoa butter in comparison with those from Ghanaian cocoa butter. The fatty acid composition shows a higher degree of saturation in Malaysian cocoa butter, which confirms the earlier findings from melting point and iodine value. This may be attributed to the higher content of C18 and lower amounts of C18:1 and 18:2 acids. Triglycerides on the other hand did not show much differences between the two types of butters; only slightly higher C54 and C56 in Malaysian cocoa butter probably due to the higher C18 and C20 acids and lower C50 and C52 which could be due to lower C18:1 and C18:2 acids (*Figure 1*).

TABLE 2. COMPOSITION OF MALAYSIAN COCOA BUTTER IN COMPARISON WITH GHANAIAN COCOA BUTTER

Composition	*Malayian Cocoa Butter Mean*	*Coeff. of Variation (± %)*	*Ghanaian Cocoa Bulletin*
Fatty Acid (%)			
C 14	0.07	14.34	0.11
C 16	25.27	3.43	25.44
C 16:1	0.31	17.92	0.32
C 17	0.33	20.66	0.27
C 18	36.78	2.29	34.76
C 18:1	33.42	1.22	34.73
C 18:2	2.57	19.13	3.10
C 18:3	0.20	41.10	0.23
C 20	1.18	15.37	1.06
Saturation	63.53		61.29
Unsaturation	36.50		38.38
Triglyceride (%)			
C 50	16.46	6.49	17.27
C 52	44.60	13.10	45.94
C 54	35.56	3.01	34.68
C 56	2.34	40.78	2.11

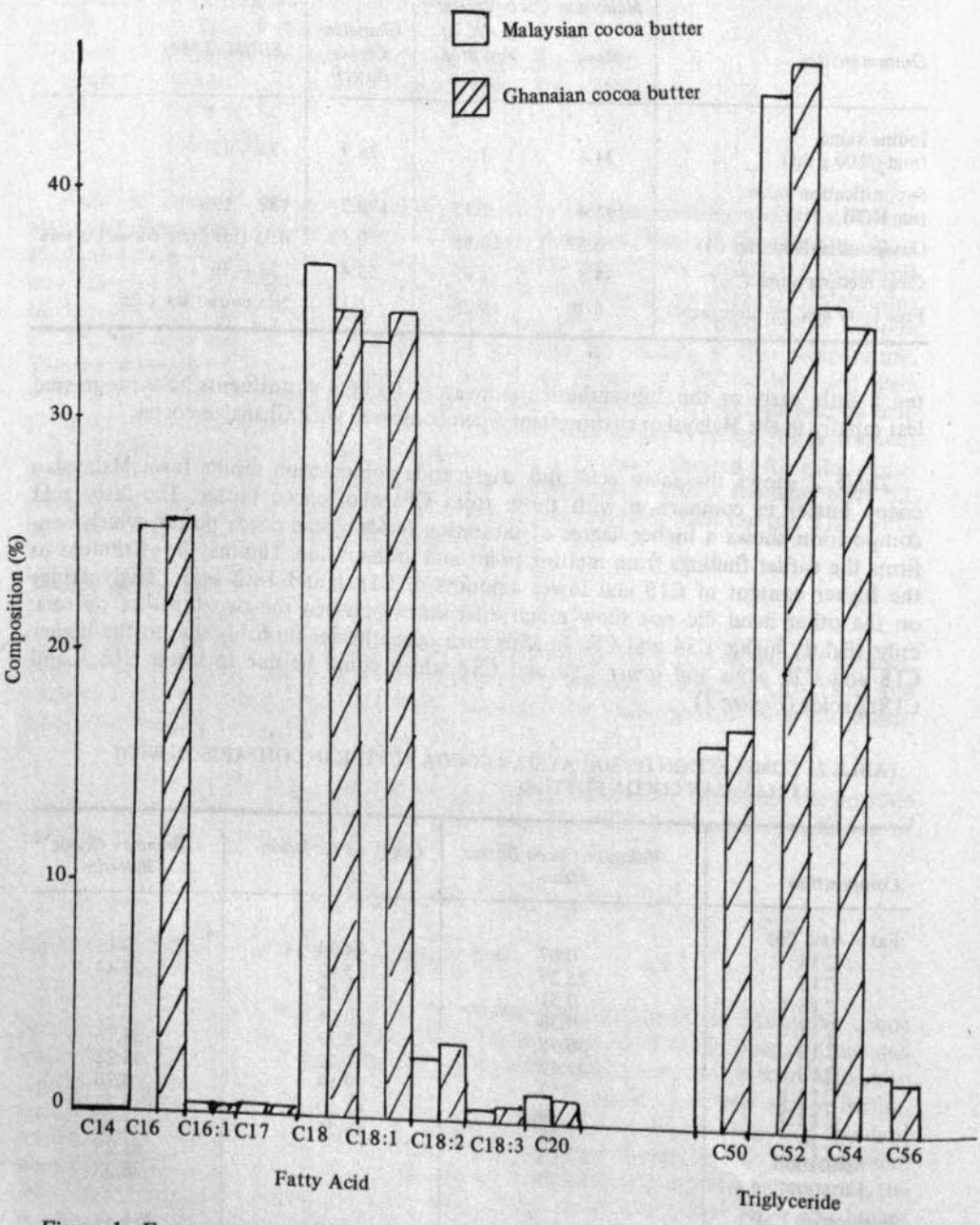


Figure 1. Fatty acid and Triglyceride Composition of Malaysian and Ghanaian cocoa butter.

From *Table 3* the Jensen cooling curves of the two butters do not show marked differences in the Tmax or the Q values. This indicates that Malaysian cocoa butter is as good as Ghanaian cocoa butter in its tempering performance. On the other hand the solid fat content of tempered Malaysian cocoa butter (T) at different temperatures are all higher than those of Ghanaian cocoa butter but the untempered samples are only different at 20 and 25°C as seen in *Figure 2.* Tempered Malaysian cocoa butter (T) has much higher SFC at 32.5°C of 27.3 (than Ghanaian cocoa butter with 13.4 at the same temperature), tapering to a mere 0.2 at 35°C (body temperature). This shows that Malaysian cocoa butter has a better 'snap' quality than Ghanaian cocoa butter.

TABLE 3. COOLING AND SOLIDIFICATION BEHAVIOUR OF MALAYSIAN COCOA BUTTER IN COMPARISON WITH GHANAIAN COCOA BUTTER

Item	*Malaysian cocoa butter*				*Ghanaian cocoa butter*	
	Mean	*Coeff. of Variation (± %)*				
Jensen cooling curve						
T max	29.63		1.33		29.95	
T min	24.15		2.30		24.40	
t max	44.13		10.12		44.8	
t min	23.62		14.77		25.0	
Q = T/t	0.27		19.66		0.28	
	T	*Coeff. of Variation (± %)*	*UT*	*Coeff. of Variation (± %)*	*T*	*UT*
Solid Fat Content (%) by NMR at						
20°C	81.9	1.99	74.0	5.29	76.1	62.3
25	76.6	7.85	34.9	22.4	70.7	24.7
30	61.5	10.82	3.3	140.27	51.2	3.0
32.5	27.3	30.99	0.31	447.13	13.4	0
35	0.2		0		0	0

T = Tempered
UT = Untempered

Clonal Variations

The analytical data were examined for differences between clones by analysis of variance calculated separately for each variable. *Table 4* shows that there are significant differences amongst the clones for solid fat content at 20°C (SFC 20, T), ΔT in Jensen cooling curve, C54 triglycerides, and C16, C18:1 and C18:2 acids. Other variables are not significantly different. Duncan's Multiple Range test for the different variables showed that clone Na33 was generally significantly different from the other clones in having the highest FFA, C18:1 and the lowest C16 acids, C54 triglycerides and unsaturation content as well as the least solid fat content (tempered). This indicates that Na33 has the softest cocoa butter in this group. Clones PA7, UIT1 and ICS60 tend to have harder butters since they have lower C18:1 and higher C16 acids, as well as higher solid fat (*Figure 3*). In comparison with the overall mean value of Malaysian cocoa butter clone Na33 has softer butter whilst the others are harder than or close to the mean.

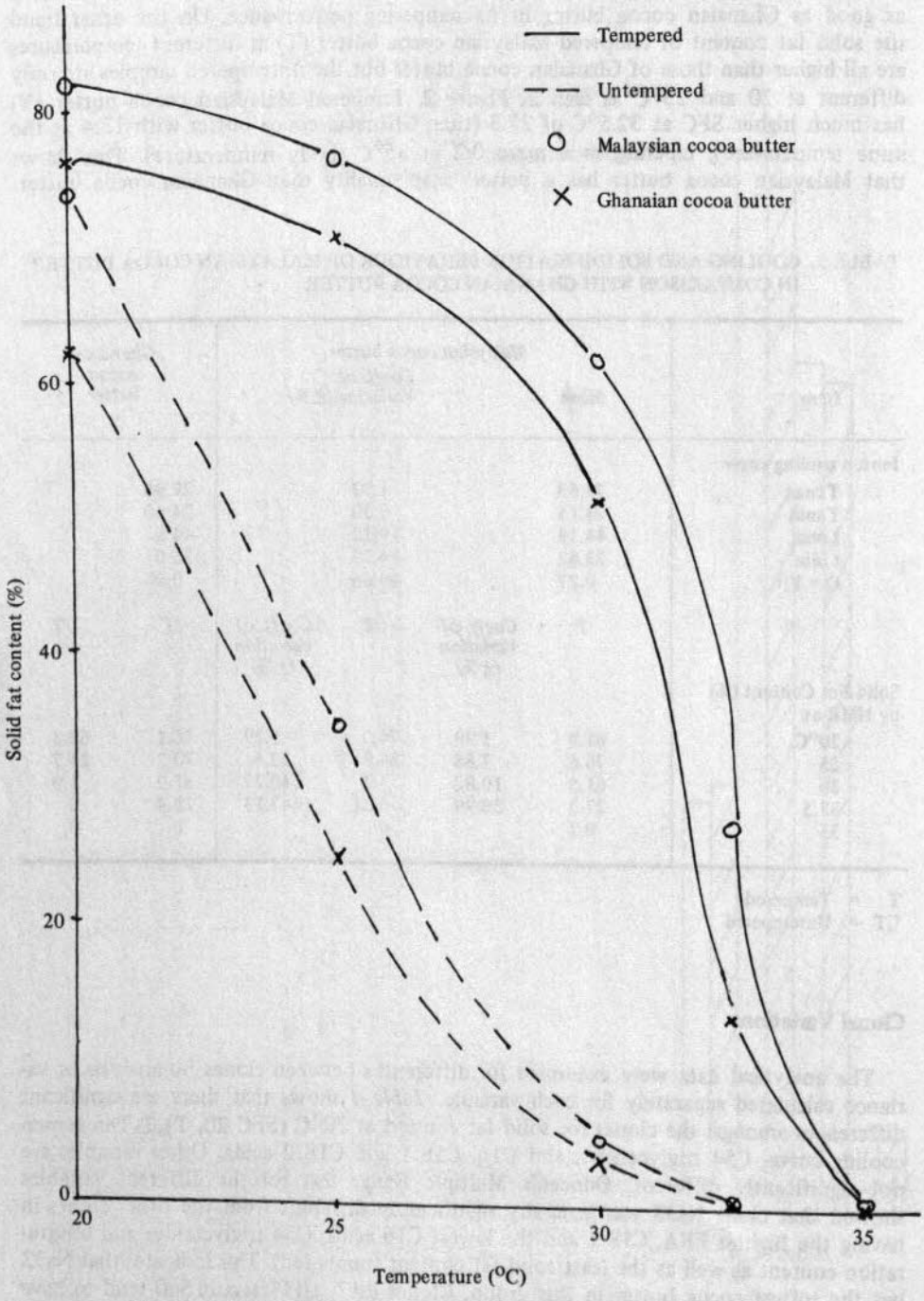


Figure 2. Solid Fat Content of Malaysian and Ghanaian cocoa butter

TABLE 4. ANALYSIS OF CLONAL COCOA BUTTER – ANOVA TABLE OF SIGNIFICANCE AND HEAD VALUES

Variable	*Clonal Effects*	*Mean values of clone*				*Mean value of Malaysian Multilocational samples*
		Na33	*UITI*	*Pa 7*	*ICS 60*	
FFA	ns	0.79a	0.55b	0.62ab	0.65ab	0.79
IV, UM, MP	ns					
SFC (UT) at 20, 25, 30, 32.5 & 35°C	ns					
SFC (T) at						
20°C	**	80.1b	84.1a	84.3a	82.0a	81.9
25°C	ns	73.7b	81.1a	78.5ab	78.7ab	76.0
30°C	ns	58.7b	70.4a	61.6ab	65.0ab	61.5
32.5°C	ns	31.4a	36.6a	29.2a	34.9a	27.3
35°C		0	0.9	4.9	0.2	0.2
Jensen Cooling Curve						
T max	ns	30.6a	30.4ab	30.2ab	29.8b	29.63
T min	ns					
AT	*	6.01a	6.18a	5.53ab	5.27ab	5.49
t max, t min, At, Q	ns					
Fatty acid composition (%)						
C 12	ns					
C 14	ns	0.08a	0.08a	0.03b	0.08a	0.07
C 16	**	22.12b	24.15a	24.07a	24.10a	25.17
C 16:1	ns					
C 17	ns	0.28b	0.30ab	0.37a	0.38ab	0.33
C 18	ns	39.51a	38.22b	38.83ab	38.10b	36.78
C 18:1	***	34.18	32.94b	32.70b	33.18b	33.42
C 18:2	*	2.15b	2.65a	2.33ab	2.51a	2.57
C 18:3, C 20	ns					
Saturation		63.21	63.95	64.49	63.53	63.53
Unsaturation		36.81	36.02	35.49	36.09	36.50
Triglyceride Composition (%)						
C 50	ns					
C 52	ns	43.9b	45.4a	44.8ab	45.0ab	44.60
C 54	**	40.0a	37.2b	37.4b	37.7b	35.56
C 56	ns					

*** 0.1% level of significance
** 1% level of significance
* 5% level of significance
ns non significant

Variables with mean values having the same letters are not significant at 5% level.

Numerical results of variables with all mean values having the same letters are not shown.

Multilocational Variations

It can be seen from *Table 5* that there are significant differences between cocoa butter from different environments (made up of the effects from locations, soil series, cocoa types, C54 triglycerides, SFC (UT) at 20°C and Jensen cooling curve Tmax, tmax and tmin values. These same variables have been shown earlier to give significant insight into the quality of cocoa butter, being significantly different among clones and between Malaysian and Ghanaian cocoa butter. However the sources of these differences cannot be specifically identified since these effects are confounded with each other because the

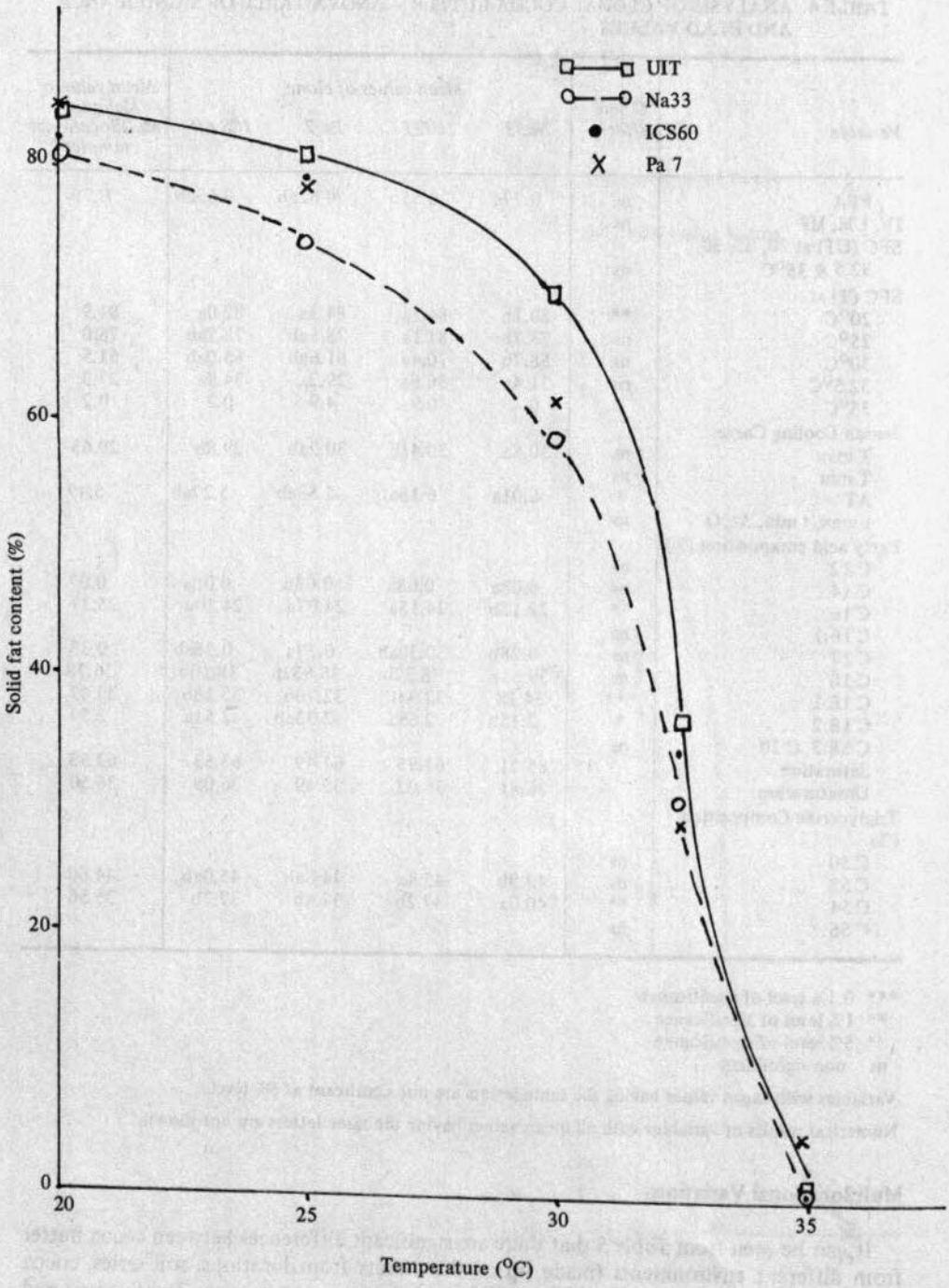


Figure 3. Solid Fat Content of Clonal Cocoa Butter

TABLE 5. ANALYSIS OF COCOA BUTTER FROM VARIOUS ENVIRONMENTS – ANOVA TABLE OF SIGNIFICANT DIFFERENCES

Variable	*Overall Mean*	*Coeff. of Variation (± %)*	*Sources of Variation*			
			Location	*Soil Science*	*Cocoa Type*	*Depth of Fermentation*
FFA (% as oleic acid)	0.79*	15.26	ns	ns	ns	ns
mp (°C)	34.5*	1.09	**	ns	ns	ns
IV, SV, UM	ns		ns	ns	ns	ns
Fatty acid composition (%)						
C 16	25.17*	3.43	ns	ns	ns	ns
C 16:1	0.31	17.29	ns	*	ns	ns
C 18	36.78*	2.29	ns	ns	ns	ns
C 18:1	33.42**	1.22	ns	ns	ns	ns
C 14, C 17, C 18:2, C 18:3	ns		ns	ns	ns	ns
C 20	1.18	15.37	*	ns	ns	ns
Triglyceride composition (%)						
C 50, C 52, C 56	ns		ns	ns	ns	ns
C 54	35.56**		ns	ns	ns	ns
Solid fat content (UT) at						
20°C	73.95*	15.26				
25, 30, 32.5, 35°C	ns		ns	ns	ns	ns
Solid fat content (T) at						
20, 25, 30, 32.5, 35°C	ns		ns	ns	ns	ns
Jensen Cooling curve						
T max	29.63*	1.33	ns	ns	ns	ns
t max	44.13*	10.12	ns	ns	ns	ns
t min	23.62*	14.77	ns	ns	ns	ns
T min AT, At, Q	ns		ns	ns	ns	ns

** significant at 1% level
* significant at 5% level
ns non significant

Numerical values for non-significantly different variables are given in *Tables 1, 2 & 3.*

Location : Bornion, Chersonese Flemington, MARDI, Jerangau KOP, MAI, PPPTR Felda, Merlimau, Sungei Buloh, Torkington, MARDI, Hilir Perak.

Soil Series : Acrisols, briah, jerangau, kertam, lungmanis association, rengam, Selangor, various.

Cocoa Type : Mixed upper amazon, mixed Sabah, mixed Sabah/Bagan Datoh, amelonado/UA/Trinitario mixed.

Depth of Fermentation : Deep, shallow, Shallow/deep.

correlations were made with small numbers of samples per location. Only melting point and C 20 acid are found to be influenced by location, MHP and MAI having the highest melting point and Flemington the lowest.

Correlation studies to determine the possible influence of rainfall, temperature, and sunshine conditions (during the maturing and ripening period of the cocoa bean) on the cocoa butter characteristics did not show a significantly marked trend among all the samples. An exploratory analysis on the effects of these climatic conditions is shown in *Table 6*. From this table it is seen that rainfall has a strongly positive influence on the FFA, C18 and C18:1 acids and C56 triglycerides of cocoa butter. In the case of fat content and FFA this is coupled with a positive effect from temperature as well. This indicates the necessity of rainfall and a warm environment for the biosythesis of the

TABLE 6. EXPLORATORY ANALYSIS ON THE EFFECTS OF CLIMATIC CONDITIONS ON COCOA BUTTER CHARACTERISTICS FROM FOUR LOCATIONS

Variables	*Rainfall*	*Effects of Temperature*	*Sunshine (h)*
FFA (% as oleic acid)	+	+	
Fatty acid composition (%)			
C 16			−
C 16:1	−		
C 18	+		+
C 18:1	+		
C 18-2	−		
C 20	−		
Triglyceride composition (%)			
C 56	+		
Solid Fat Content (T) at 20°C		−	
Jensen cooling curve			
AT	−		
At	−		
T min	+		

− negatively significant
+ positively significant

Variables which are not significantly influenced are not shown.

Locations: MARDI Hilir Perak
PPPTR(Felda)
Flemington
Chersonese

fat (starting with FFA) in the growing cocoa bean. Sunshine hours are also seen to positively affect C18:1, but negatively for C16. Some contrasting effects of rainfall are also noted for Jensen cooling curve and SFC (T) at 20°C values.

CONCLUSION

Malaysian cocoa butter has been shown to conform to the draft Malaysian standard specifications for cocoa butter (S.I.R.I.M., 1984) in all variables studied except for unsaponifiable matter. In this respect it agrees with Ghanaian cocoa butter. However Malaysian cocoa butter is harder than Ghanaian cocoa butter due to its composition of more saturated fatty acids (C18) and less unsaturated acids (C18:1 and C18:2). This is seen by its higher melting point and solid fat content.

Significant variations exist between the clones studied, clone Na33 having the softer butter when compared with other clones such as UIT1, Pa7 and ICS60.

Multilocational differences are also seen in melting point, FFA, C16, C18, and C18:1 acids, C54 triglycerides, Tmax, tmax and tmin in Jensen cooling curves, and solid fat content at 20°C, but the effects from location, soil series, cocoa type and depth of fermentation are confounded with each other.

No significant trends could be found from regression analysis to determine correlations between cocoa butter characteristics and climatic conditions. An exploratory analysis shows that rainfall and temperature during the maturing period of the cocoa bean have a positive influence on the FFA (%) of its cocoa butter. C18 and C18:1 acids are also affected by rainfall, the latter being also influenced by sunshine during the same period.

ACKNOWLEDGEMENT

The authors wish to thank Encik Misli bin Sulaiman, Puan Saharum binte Yahaya, Puan Yeap Swee Kee and Encik Hussin bin Ali for technical assistance. Grateful thanks are also due to our MARDI statistician Dr. Lee Chong Soon for his assistance.

The authors also wish to thank all those who not only contributed cocoa, but also their valuable time to compile all the environmental data required for the study (see *Appendix II*).

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Appendix I. Environmental effects of various locations

Location	*Soil Series*	*Cocoa type*	*Depth of fermentation*
Bornion	Lungmanis	mixed Sabah	deep
Chersonese	Selangor	mixed Sabah	shallow/deep
FAMA Bagan Datoh	–	mixed UA	shallow/deep
Flemington	Selangor	mixed UA	shallow/deep
KOP	mixed Kertam	mixed	deep
MAI	acrisols/ Lungmanis	mixed	deep
MARDI Hilir Perak (MHP)	Selangor	mixed	shallow
MARDI Jerangau	Jerangau	mixed	shallow
Merlimau	Rengam	Sabah/Bagan Datoh	shallow
PPPTR FELDA	various	mixed	deep
Sungei Buloh	Selangor	mixed	shallow/deep
Tawau	–	mixed Amelonado	deep
Torkington	Briah	mixed UA	deep

Appendix II. List of cocoa bean contributors

1. Agriculture Research Centre
   Tuaran, Sabah.

2. Chersonese Estate,
   Kuala Kurau, Perak.

3. Flemington Estate,
   Sungei Sumun, Teluk Intan, Perak.

4. Merlimau Estate,
   Merlimau, Malacca.

5. Plantation Services (Sabah) Sdn Bhd.,
   Sandakan, Sabah.

6. Pusat Memproses Kelapa Kering FAMA,
   Bagan Datoh, Perak.

7. Pusat Penyelidikan Pertanian Tun Razak,
   FELDA, Sungei Tekam, Pahang.

8. Stesen Penyelidikan MARDI,
   Hilir Perak, Hutan Melintang, Perak.

9. Stesen Penyelidikan MARDI,
   Jerangau, Trengganu.

10. Sungie Buloh Estate,
    Bukit Rotan, Selangor.

11. Torkington Estate,
    Sabah Bernan, Selangor.

P

THE DEVELOPMENT OF COCOA PROCESSING TECHNOLOGY AND THE DESIGNING OF A COMPLETE LINE FOR SEMI-FINISHED COCOA PRODUCTS

by

BENITO BONORA & OTTORINO CHIAPPA

It started with the preparation of 'Chocolatl', a drink the Aztecs obtained from roasted cocoa beans which were then stone-ground and mixed with water and considered 'Nectar Deorum' at the time of the Spanish conquest in the 16th century. The next step was the European version of this beverage which involved the addition of honey to render it more pleasant to the taste. The consumption of chocolate spread from Spain to other European countries thanks to the monks, the custodians of the recipes and technique of preparation, who introduced it among the upper classes - the courts, aristocracy, doctors and higher clergy.

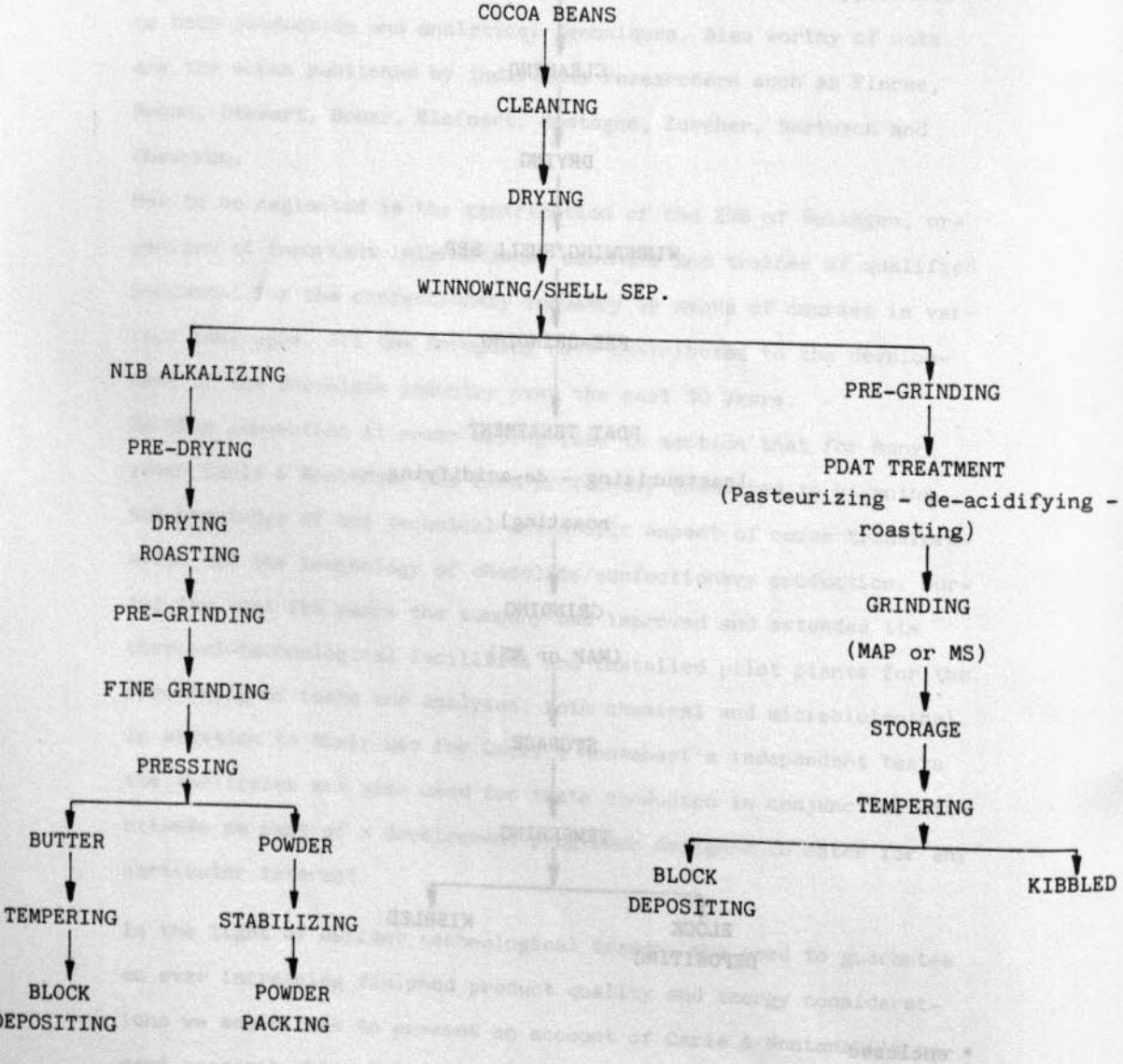
In the 17th century the Spanish monopoly of the cultivation and commerce of cocoa came to an end as a result of its introduction by the English and French in their colonies. The first chocolate industry was born in Europe in the 18th century, a period of industrial revolution and exotic culinary discoveries.

This was the period of the first chocolate tablets, the first conches and the first mention of conching, a chocolate affining process which at that time took several days.

We have come a long way since those first uncertain steps and both manufacturing technology and product quality have been improved. The development of processing techniques is due to a great extent to the co-operation between chocolate producers and machinery manufacturers. As in many other areas of the food industry, a determining factor has been the interest in cocoa recently manifested by scientists, together with the insights and accumulated experience of confectionery industry experts. We acknowledge the importance, from both scientific and practical standpoints, of the work performed by the following research centres:

FIG. 2 -
(FLOWSHEET 8571N/UI*)

MODERN PROCESS FOR THE PRODUCTION OF
COCOA LIQUOR, COCOA BUTTER AND COCOA POWDER



* enclosed

The flow illustrated in fig. 1 is used to produce blocks of cocoa liquor of internationally-accepted quality (de-acidified & pasteurized and, if desired, liquid roasted). The flow shown in fig. 2, in addition to cocoa liquor blocks, also permits the production of cocoa powder of an excellent colour and quality cocoa butter. Rather than comment on the diagrams mentioned we wish to relate the experiences in the cocoa processing field. The aim of our recent research has been to study the processes involved in liquid 'roasting' in the PDAT reactor. The PDAT also offers the possibility of enhancing the cocoa flavour by:

- Pasteurizing/De-acidifying
- Alkalizing
- Addition of reducing sugars (permitted by prevailing regulations) to enhance the flavour by the development of the Maillard reaction.

Liquor roasting obviously requires liquor prepared from raw cocoa. By 'raw cocoa' we mean that it may be dried but not roasted. The stages involved in the process are:

1. Breaking & separation of the raw cocoa from the shell after slight drying.
2. Pre-grinding of the nibs thus obtained
3. Roasting of the raw cocoa liquor
4. Enhancement/Affination treatment of the cocoa liquor

BREAKING AND SEPARATION FROM THE SHELL WITH SLIGHT DRYING

In an up-to-date process (whether it be nib, or, more correctly, liquor roasting), the effective separation of the nibs from the shells is a determining factor. Modern cocoa breakers permit efficient winnowing with percentages of shells in the nibs (and nibs in the shells) comparable to those of the 'traditional' lines used when roasting the cocoa beans.

Here are figures for cocoa beans of Ghana, Arriba, Venezuela and São Thome origins with a moisture content of 4 - 6%.

Shell in nibs: 1.8 - 3%

Nibs in the shell: 0.3% (max.)

It should be pointed out that modern cocoa winnowers break and separate efficiently with a 'standardizing' of the moisture content rather than a true drying process to ensure that it is kept within a certain range.

PRE-GRINDING OF RAW OR DRIED COCOA

When preparing cocoa for liquor roasting in the PDAT the next step is pre-grinding.

The MAP Pin Mills (fig. 4) provide an excellent solution to the problem. Due to the particular type of product and the need to obtain good results from an industrial standpoint, certain modifications have been made to the standard machines. These modifications involve the grinding chamber and the discharge hopper which has been equipped with a 'plastifying' system to make the product pumpable.

As the application of shear stress to products of the cocoa family improves their rheological characteristics a plastifier with a high shear rate has been used. This permits a 20-25% viscosity reduction to make the product pumpable. Fig. 5 shows in detail the results obtainable in terms of fineness and output with MAP series mills (traditional type using roasted cocoa and modified type as described above, using raw cocoa).

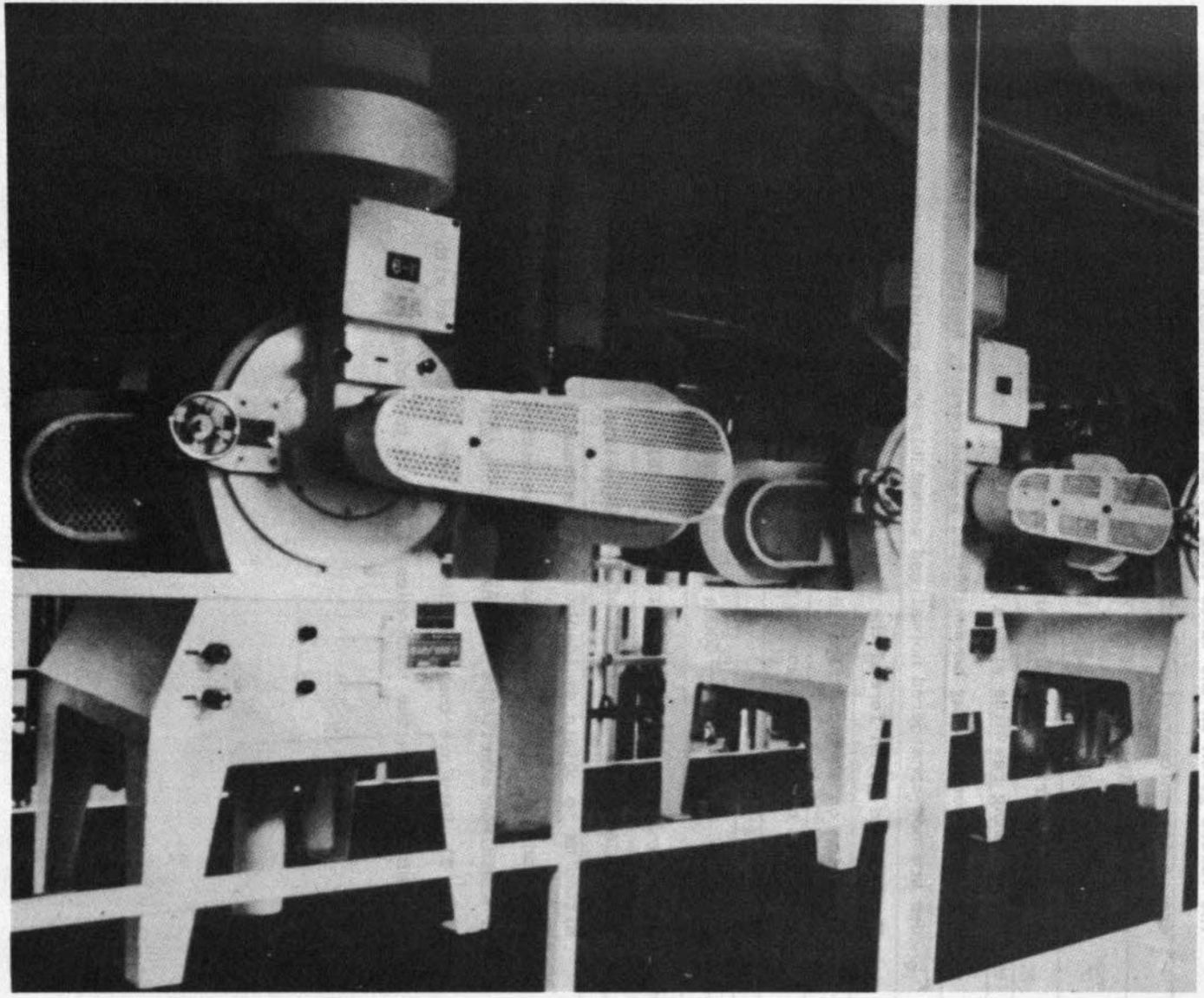


Fig. 4) Line of Carle & Montanari MAP.1000.S mills installed at Hershey Chocolate Co. USA

The values given in the table (fig 5) are indispensable points of reference for an overall analysis of the actual situation when considering the pre-grinding of roasted or raw cocoa. It may be seen that the output of the mills is reduced by about 30% when passing from roasted nib to raw nib grinding. In numerical terms, a cocoa liquor obtained by pre-grinding raw nibs with a residue of more than about 7% on 200 mesh (natural product) may be considered a good result. Residues of this order are now considered normal and acceptable when grinding roasted cocoa. The results given formed the basis, first, for tests, and then for verification on an industrial level, of the feasibility of roasting and/or treatment of cocoa liquor in the PDAT Plant.

COCOA LIQUOR TREATMENT

Before going into the details of the problem of roasting cocoa liquor here is a rapid description of the PDAT Plant (fig. 6) which has permitted us to obtain decidedly positive results, both in the pilot plant and in full-scale production. The entire reactor is constructed of stainless steel. The various operations are controlled by computer (fig. 7). Here are the objectives which may be obtained with the PDAT reactor (based on the tendencies of modern technology):

PRE-GRINDING: TRADITIONAL COCOA AND RAW COCOA
TABLE SHOWING RESULTS OF GRINDING IN MAP.400.S

SAMPLE / TYPE OF COCOA	HOURLY OUTPUT	MOISTURE %	FAT %	SHELL %	RES. % 200 MESH NATURAL PRODUCT	VISCOSITY mPa.sec.	IRON p.p.m. NATURAL PRODUCT	TEMP. °C
MAP.400.S Pre-grinding of traditional cocoa								
Ivory coast cocoa nibs	-	2,0	54.60	1,4	-	-	36	25
Ivory coast cocoa liquor	400	1,2	54.60	-	3.5	6.400	66	98
Cocoa nibs (987/L/81) Mix-Nigeria and Ghana	-	1,2	55.20	1.8	-	-	52	27
Cocoa liquor (987/M/81) Mix-Nigeria and Ghana	350	0,7	55.20		3,1	3.050	92	99
Cocoa nibs (1311/A/83) Mix-Ivory Coast and Carupano	-	2.81	53.66	3.05	-	-	43.6	24
Cocoa liquor (1311/C/83) Mix-Ivory Coast and Carupano	460	1,98	53.66	-	4.20	9.487	87.0	95
MAP.400.S. Pre-grinding of raw cocoa								
Ivory Coast cocoa nibs (1284/83)	-	5,7	54.90	3.32	-	-	38.4	25
Ivory Coast cocoa liquor	240	3,2	54.90	-	6.41	9.816	67.3	76
Ivory Coast cocoa nibs	-	6,10	51,76	4.20	-	-	-	-
Ivory Coast cocoa liquor	320	4,17	51,76	-	6.82	27.000	-	75
Bahia cocoa nibs	-	6,52	51,50	4,55	-	-	-	-
Bahia cocoa liquor	380	5,05	51.50	-	8.32	16.327	-	76
Ghana cocoa nibs	-	6,15	51,76	5.50	-	-	-	-
Ghana cocoa liquor	206	4,08	51,76	-	11.36	26.119	-	76

Fig. 5) Pre-grinding of traditional cocoa and raw cocoa. Table of pre-grinding results in MAP.400.S

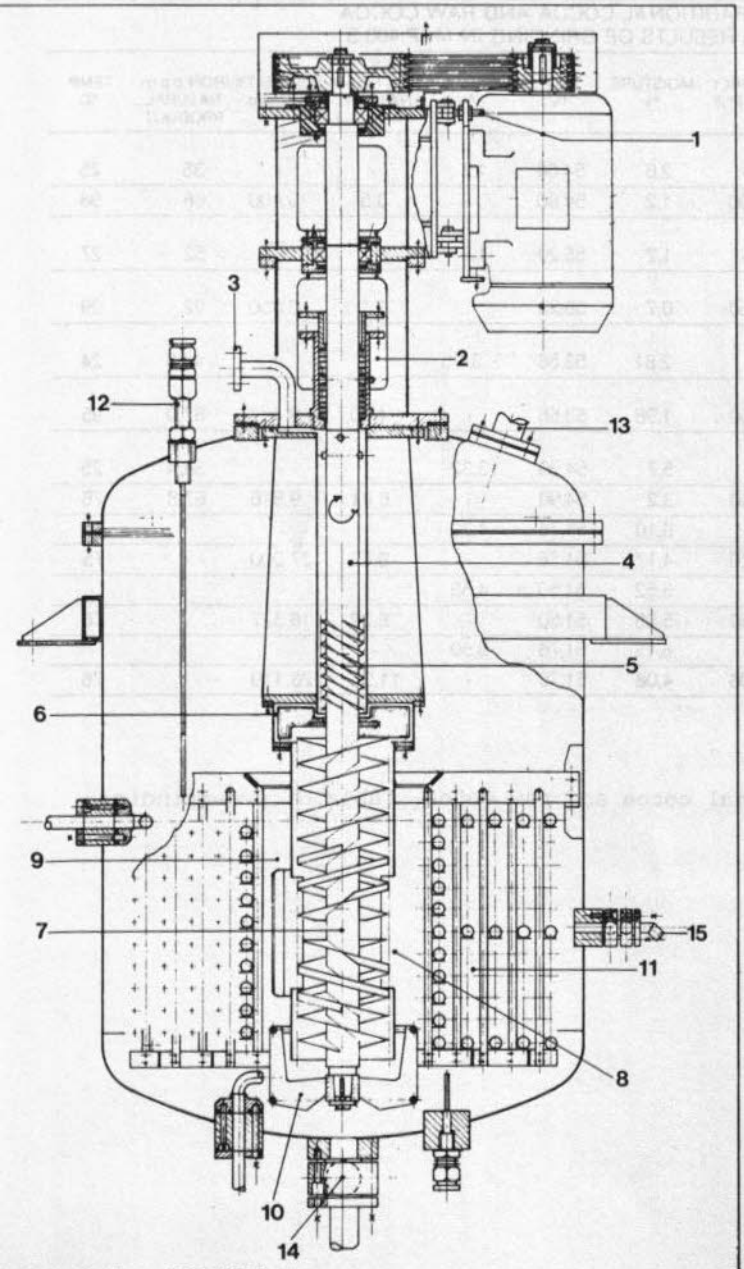


Fig. 6) Section of PDAT Reactor

PDAT REACTOR SECTION

1) Transmission group
2) Seals
3) Liquid & gas inlet pipe
4) Agitator shaft
5) 4-start screw pump for feeding liquids to the spray group
6) Spray chamber
7) Multi-start (opposed) screw pump
8) Product inlets
9) Product feed diverters
10) Centrifuging agitator
11) Heat exchanger
12) Level control probe
13) Product loading
14) Product discharge
15) Sample taking

Fig. 6) Section of PDAT Reactor

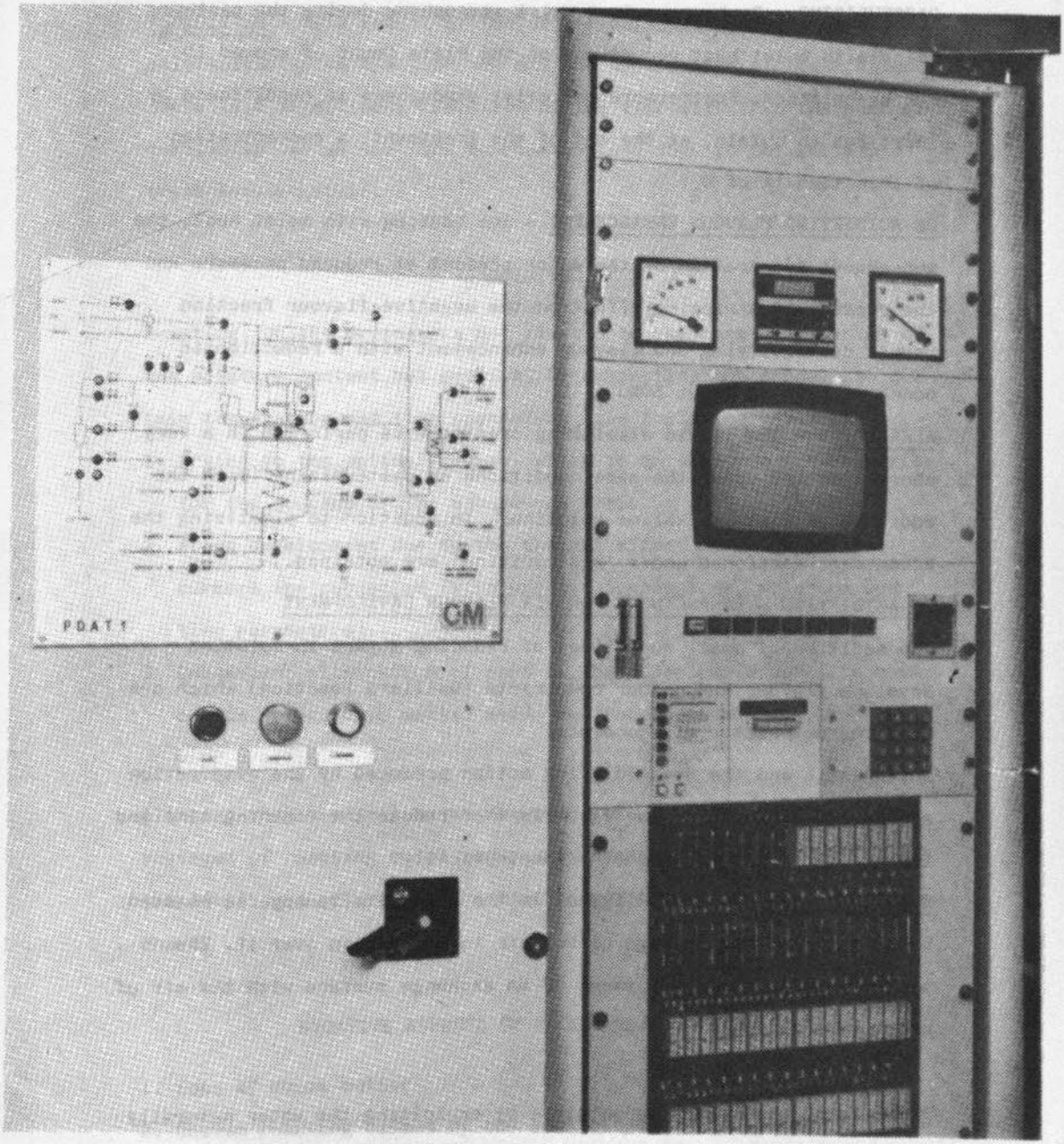


Fig. 7) Control panel with computer

3. Little possibility of eliminating the undesirable volatile substances, especially acetic acid (it is important to note that we are treating a product in the solid phase enclosed in its shell).
4. Wasteful of energy due to the indirect type of heating and the heating of the shells which create an obstacle to the heating of the bean and are then eliminated.

In terms of energy use the treatment can be diagrammed as shown in the graph (fig. 8).

NEGATIVE ASPECTS OF NIB ROASTING

1. Even though the dimensions of the product are smaller and much more consistent, thus making treatment more uniform there are still differences in the degree of roasting between the larger and smaller particles (dried, broken and shelled cocoa always gives rather heterogeneous nibs).
2. The possibility of removing undesirable volatile substances is certainly greater than when the bean is treated but they are never of the ideal dimensions, being granular in nature.
3. High energy consumption, especially if the bean is to be dried before breaking. The total energy consumption is thus the sum of bean drying + nib roasting.

   In terms of energy use the treatment can be diagrammed as shown in the graph (fig. 9).

POSITIVE ASPECTS OF COCOA LIQUOR ROASTING

1. Elimination of the loss of butter to the shells.

2. The heat exchange in the liquid phase guarantees constant treatment and uniform results. Furthermore the PDAT spray system functions in such a way that a turbulence regime is created (similar to that in a thin film process) which increases contact with the air. The turbulence regime also permits a more rapid heat exchange. With a liquid phase process all the parameters are more easily checked and thus more 'real'.
3. The physical state of the product and its fine dispersion permit its correct conditioning with the following results:
   a. precise, correct roasting
   b. simultaneous de-acidifying (for cocoa with a high free acetic acid level the total reduction is about 30-40%)
4. Even with a partial drying of the cocoa bean the energy consumption is still considerably lower.

The tendency is shown in the diagram (fig. 10) and by the relative values.

Measurement of specific energy consumption for the 3 cocoa roasting systems mentioned have shown, if the total consumption (calorific energy + electrical energy) consumed during cocoa bean roasting is 100 the specific consumptions for bean drying + nib roasting against bean drying + liquor roasting in the PDAT are 90 - 95 and 65 - 70 respectively. These figures were obtained with beans having a 7% initial moisture content. This demonstrates that the cost of roasting in the PDAT is 30 - 35% lower than that of other systems.

- Cooling	60 - 80°C	6 - 10
- Treated liquor discharge		5 - 6
Total duration (average)		about 65 min.

For roasting in the PDAT the cocoa must have the following characteristics: moisture content of about 3 - 5%, an 8% residue on 200 mesh (natural state), a max. shell content of about 3% and a max. viscosity of 25,000 mPa.s (centipoise).

Quantity of liquor per batch: 1000 kg

Comparing the results given in the table (fig. 11) it may be concluded that the products treated in the PDAT develop better flavour characteristics than those roasted in the traditional way.

In particular the reduction in the acetic acid content compared with that obtained by traditional roasting is significant.

From a microbiological standpoint there is a considerable reduction in the total count after treatment of Ivory Coast cocoa in the PDAT (pasteurizing at 125°C for 3 min. and roasting at 125°C for 15 min.).

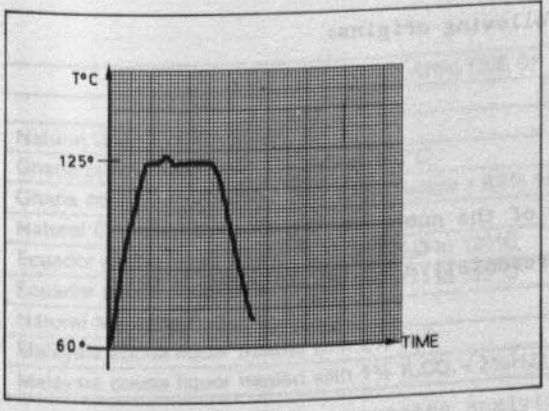
COCOA LIQUOR ENHANCEMENT

As an example here is a pasteurizing/de-acidifying cycle which is also suitable, generally speaking, for flavour enhancement (with the addition of reducing sugars) in the PDAT, and alkalizing, if required.(see pag. 12)

SUMMARY TABLE COMPARING PRODUCTS ROASTED
TRADITIONALLY WITH THOSE ROASTED IN LIQUID FORM IN THE PDAT

SAMPLE	Total reduc. sugars ppm	Acetic acid ppm	TBA index	Aroma index	Moisture %	Viscosity mPa.sec.	Flow limit Pa	Viscosity Mac Michael	% fat	pH	ml NaOH 0,1N/100g	Natural fineness %>75 µm	Bacteria plate count Germs/g
IVORY COAST COCOA - TRADITIONAL ROASTING													
Raw nibs	7979	2870	0,133	27,55	5,30	-	-	-	52,24	5,69	68,3	-	2.200.000
Roasted nibs	3119	2436	0,476	81,10	1,73	-	-	-	54,33	5,47	84,8	-	80.000
IVORY COAST COCOA - GROUND RAW IN MAP AND LIQUOR ROAST IN PDAT													
Raw nibs	7979	2870	0,133	27,55	5,30	-	-	-	52,24	5,69	68,3	-	2.200.000
Cocoa liquor ground raw	6781	2721	0,174	22,20	3,17	9816	4,49	139,4	53,02	5,81	76,1	6,13	2.000.000
Cocoa liquor pasteurized at 125°C for 3 min. and roasted 125°C for 15 min. in PDAT	1188	1772	0,778	50,8	1,05	3347	2,16	88,4	54,33	5,74	80,5	6,13	3.000
Graph A													
BAHIA COCOA ROAST TRADITIONALLY													
Raw nibs	13719	7683	0,110	16,7	5,94	-	-	-	53,04	5,12	93,4	-	2.750.000
Standard roast cocoa liquor	3619	6095	0,540	78,5	2,16	2130	1,52	52,7	54,10	5,16	101	-	98.000
BAHIA COCOA - GROUND RAW IN MAP AND LIQUOR ROAST IN PDAT													
Raw nibs	13719	7683	0,110	16,7	5,94	-	-	-	53,04	5,12	93,4	-	2.750.000
Cocoa liquor ground raw	12069	6778	0,117	16,7	4,33	3266	3,03	93,5	53,04	5,22	115	7,95	1.700.000
Cocoa liquor dried at 80° C for 15 min. and roasted in PDAT at 125°C for 15 min.	3830	5039	0,812	62,0	2,18	1976	1,85	57,8	54,10	5,29	125	7,95	30.000
Graph B													

(Graph A) Conditions of treatment of Ivory Coast cocoa. Pasteurizing at 125°C for 3 min. and roasting at 125°C for 15 min.



(Graph B) Conditions of treatment of Bahia. Drying at 80°C for 15 min. and roasting at 125°C for 15 min.

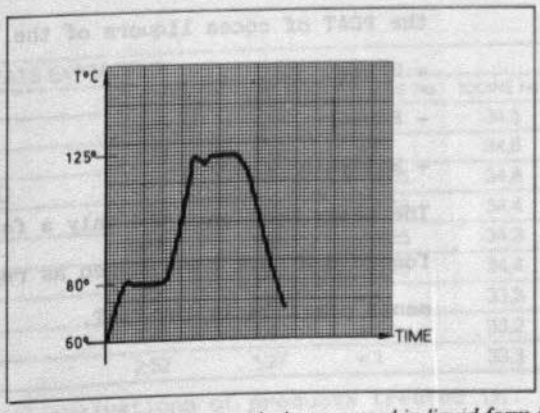


Fig. 11) Bean drying comparing analytical evaluations of products roasted traditionally with those roasted in liquid form in the PDAT.

PASTEURIZING/DE-ALKALIZING/FLAVOUR ENHANCING

WITH REDUCING SUGARS

	Temperature (°C)	Time (min)
- Loading of liquor to be treated	60 - 80	4 - 5
- Elimination of air		2 - 4
- Inlet of inert gas		1½
- Heating and addition of H_2O *	125 - 140	12 - 18
- Holding-pasteurizing	125 - 140	3 - 6
- Internal pressure venting		1 - 3
- Drying-vacuum	60 - 80	5 - 6
Total duration		about 70

* Instead of H_2O alkaline solution or reducing sugars may be added, depending on the type of treatment.

For a pasteurizing/de-acidifying/flavour enhancement treatment with reducing sugars the cocoa liquor must be as follows:

Initial moisture content 1.5 - 2%

Max. residue on 200 mesh (natural product) 8%

Water added 1.5 - 2%

Final residual moisture content after treatment 1 - 1.5%

Quantity of liquor treated per batch 1000 kg

Fig. 12 shows the results obtained with the various treatments in the PDAT of cocoa liquors of the following origins:

- Ghana
- Ecuador
- Malaysia

The cases mentioned are only a few of the numerous treatments performed and have been chosen as representative of the various treatments possible in the PDAT.

SUMMARY TABLE COMPARING ANALYTICAL EVALUATIONS OF PRODUCTS TREATED IN PDAT UNDER VARIOUS CONDITIONS

GHANA COCOA LIQUOR

SAMPLE	Total reduc. sugars ppm	Acetic acid ppm	TBA index	Aroma index	Moisture %	Viscosity mPa.sec	Flow limit Pa	Viscosity Mac Michael	% fat	pH	ml NaOH 0.1N/100g	Natural fineness %>75 µm	Bacteria plate count Germs/g
Natural cocoa liquor	353	1365	0,628	71,1	1,46	3025	1,6	74,8	53,8	5,55	-	3,22	120.000
Treated cocoa liquor with 1% H_2O	217	1118	0,718	84,6	0,83	2406	1,72	64,6	53,8	5,36	-	3,22	100
Treated cocoa liquor with 2,1% glucose + 0,9% H_2O	362	1160	1,607	118,4	0,79	2954	1,6	73,1	52,9	5,34	-	3,22	800

Graph C1 - C2

ECUADOR COCOA LIQUOR

SAMPLE	Total reduc. sugars ppm	Acetic acid ppm	TBA index	Aroma index	Moisture %	Viscosity mPa.sec	Flow limit Pa	Viscosity Mac Michael	% fat	pH	ml NaOH 0.1N/100g	Natural fineness %>75 µm	Bacteria plate count Germs/g
Natural cocoa liquor	532	1915	0,498	87,7	1,81	4872	2,6	121,4	52,97	5,82	79,5	3,70	13.000
Treated cocoa liquor with 2% H_2O at 120°C	523	1620	0,507	74,8	1,53	2976	1,98	78,0	52,97	5,80	77,0	3,70	350
Treated cocoa liquor with 2% H_2O at 125°C	374	1651	0,510	68,9	1,39	3047	2,12	80,4	52,97	5,77	75,0	3,70	50

Graph D1 - D2

MALAYSIA COCOA LIQUOR

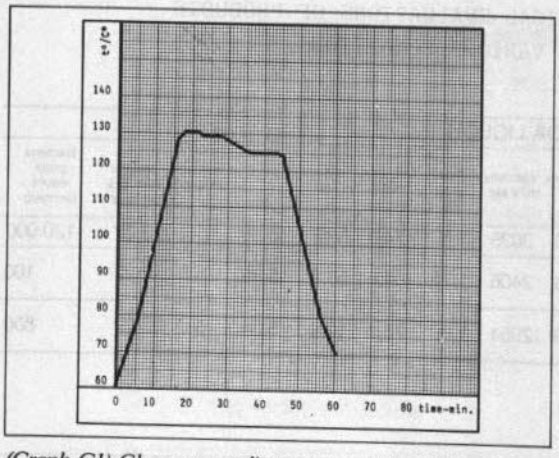
SAMPLE	Total reduc. sugars ppm	Acetic acid ppm	TBA index	Aroma index	Moisture %	Viscosity mPa.sec	Flow limit Pa	Viscosity Mac Michael	% fat	pH	ml NaOH 0.1N/100g	Natural fineness %>75 µm	Bacteria plate count Germs/g
Natural cocoa liquor	755	3379	0,464	116,8	1,98	876	1,56	31,8	55,74	5,29	112,7	1,10	1.500.000
Treated cocoa liquor with 2% H_2O	239	2480	0,481	111,4	1,25	1139	1,56	38,3	55,74	5,37	100,3	1,10	600
Cocoa liquor treated with 1% K_2CO_3 + 2% H_2O	291	3109	0,497	119,2	1,60	970	2,12	38,7	55,22	6,37	31,1	1,10	7.700

Graph E1 - E2

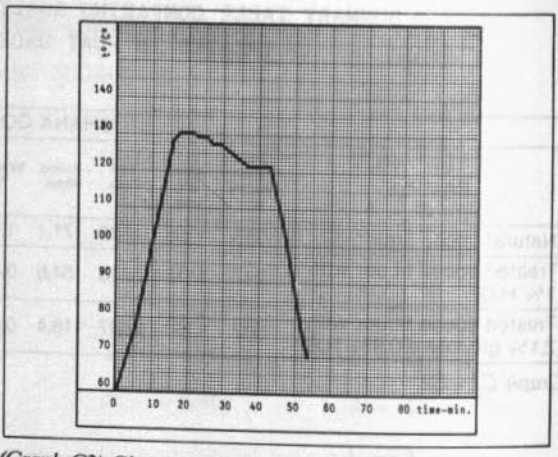
ANALYSIS OF FATS EXTRACTED

	ACIDITY No.	% OLEIC ACID	PEROXIDE No.	IODINE No.
Natural Ghana cocoa liquor	3,05	1,53	1,5	34,5
Ghana cocoa liquor with 1% H_2O at 130°C	2,79	1,40	< 1	34,8
Ghana cocoa liquor treated with 2,1% glucose + 0,9% H_2O	2,92	1,47	1,05	34,8
Natural Ecuador cocoa liquor	2,58	1,30	1,39	34,4
Ecuador cocoa liquor treated with 2% H_2O at 120°C	2,55	1,28	1,35	34,3
Ecuador cocoa liquor treated with 2% H_2O at 125°C	2,51	1,26	1,15	34,4
Natural Malaysia cocoa liquor	2,50	1,26	< 1	33,3
Malaysia cocoa liquor treated with 2% H_2O	2,48	1,25	< 1	33,2
Malaysia cocoa liquor treated with 1% K_2CO_3 + 2% H_2O	2,52	1,27	< 1	33,3

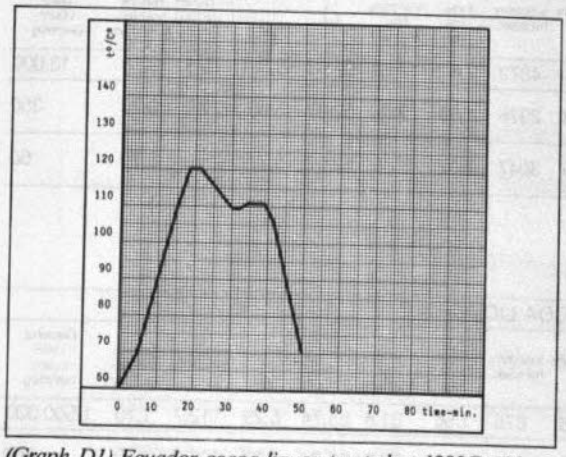
Fig. 12) Summary table comparing analytical evaluations of products treated in PDAT under various conditions.



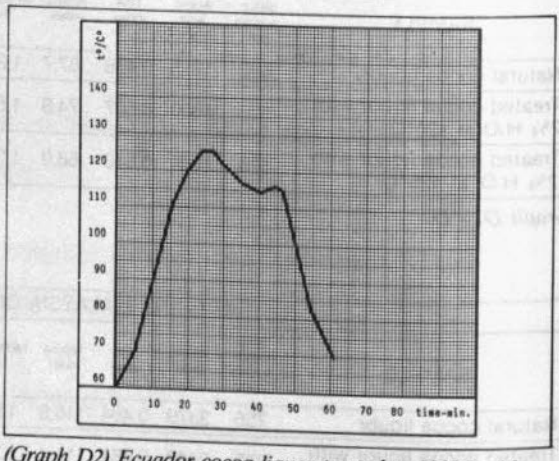
(Graph C1) Ghana cocoa liquor treated at 130°C with the addition of 1% of H_2O



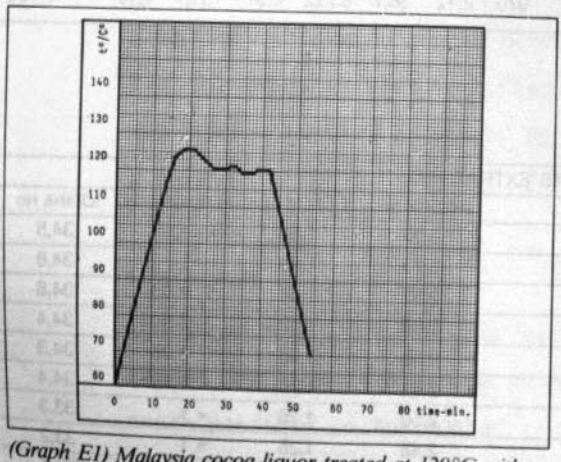
(Graph C2) Ghana cocoa liquor treated at 130°C with the addition of 2.1% glucose and 0.9% H_2O



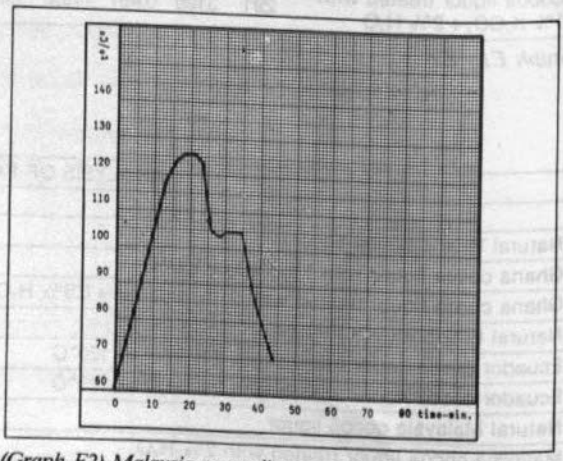
(Graph D1) Ecuador cocoa liquor treated at 120°C with the addition of 2% H_2O



(Graph D2) Ecuador cocoa liquor treated at 125°C with the addition of 2% H_2O



(Graph E1) Malaysia cocoa liquor treated at 120°C with the addition of 2% H_2O



(Graph E2) Malaysia cocoa liquor treated at 125°C with the addition of 1% K_2CO_3 and 2% H_2O

Comparing the analytical results given in fig. 12 the following conclusions may be made:

Microbiological aspect: in all the treatments carried out in average conditions the reduction of the bacteria count is around 10^{-3} and, in certain cases, as high as 10^{-4}

Flavour aspect: Overall the flavour indices - TBA (1) and Aroma (2) are significantly increased while the total content of reducing sugars is decreased (3). The increase detected in the products treated with the addition of reducing sugars is particularly significant.

Acetic acid (4): The total acetic acid content undergoes, as expected, considerable decreases (around 30 - 40%).

Fats extracted: The analytic indices obtained from the fats extracted by centrifuging rule out any significant change in their nature.

As may be deduced from the results of the analyses, the values obtained from the treatment of Malaysian cocoa liquor are of particular interest.

Another important aspect is the reduction of the conching times when producing semi-milk chocolate from cocoa liquor treated with the addition of water alone followed by the addition of reducing sugar solution. The product treated with water permitted the reduction of the conching time from about 24 hours to 12 hours.

The product thus obtained is qualitatively and organoleptically standard. When subject to testing by internal and in-house experts (triangular test) it proved practically unrecognizable when compared with the standard after 24 hours' conching. The product treated with the addition of reducing sugars permitted the reduction of conching time from the original 24 to a total of 8 hours. In this case too the finished chocolate, subjected to a triangular test, was practically unrecognizable when compared with the standard.

As regards roasting the studies published by Mohr and others demonstrate that there are good theoretical premises supporting the roasting of the nibs rather than the cocoa beans. This advantage must be added to the economic/energy considerations ranging from the loss of butter to the shells to the waste of energy in the heating of the shells (which, in addition to impeding the heat exchange are subsequently eliminated anyway).

Rather than roast the beans it is thus preferable, for both economic and technological reasons, to dry the beans, break them and separate the shells (an operation which is made possible by modern winnowers) followed by the roasting of the nibs.

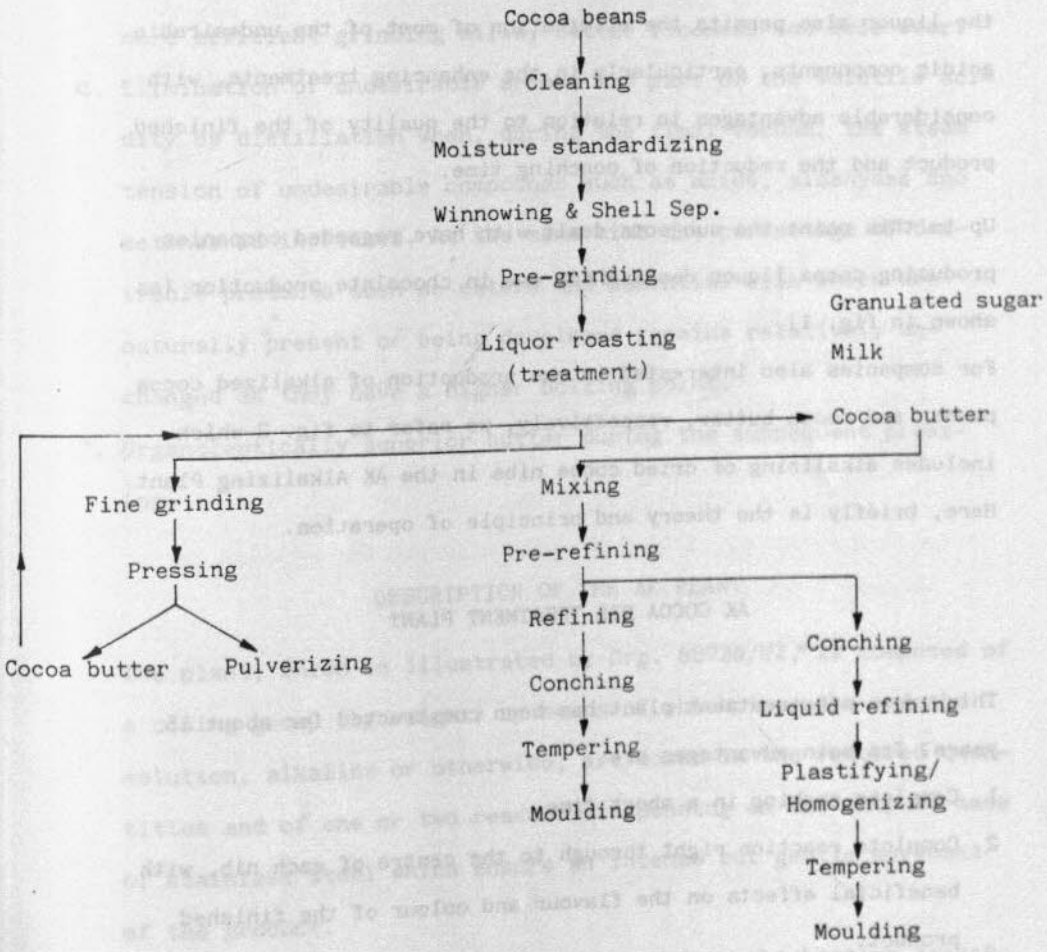
Let us consider the latest developments in the research which has contributed to the creation of the 'more advanced cycle' shown in fig. 3. The stages are:

A. Pre-grinding of raw nibs

B. Liquor roasting

As already described and on the basis of the documentation referred to, the roasting of cocoa liquor is still a considerable challenge. To do so the prime requirement is the pre-grinding of the nibs in slightly dried, or even better, in the **raw state.** This permits the roasting of the liquor and offers the possibility

FIG. 3 - "MORE ADVANCED" CYCLE



The entire plant is completely automatic and the operating cycles may be varied by the technical personnel according to the product to be treated and the results desired. The result is a very versatile plant.

Here are examples of the times of a cycle (note that all the operations are set and timed by the operator, thus permitting complete repeatability and constant product quality).

OPERATING PHASES

- Vacuum time: 2 min. 30 sec. at 700 mm Hg. During this time a vacuum is created in the canaliculi of the cotyledon or seed.
- Solution load time: 2 min; 30 sec.
- Mixing & soaking: 2 min. The vacuum causes the solution to penetrate the product and begin the reaction.
- Direct steam: 2 atm ; 7 min. This makes an important contribution to the impregnation of the entire tissue, permits the moist sterilization and accelerates the reaction by increasing the temperature.
- Rest from mixing - direct steam : 16 min.
  sterilization and reaction to heat of the entire product continues
- Free venting: 2 min.
  Undesirable aromas, part of the volatile acidity and the aroma present are eliminated as there is the passage from overpressure to atmospheric pressure
- Vacuum-drying: 12 min. (1st stage)
  The elimination of the undesirable flavours and volatile acids by distillation continues. The evaporation of the superficial water continues and part of the water which has penetrated to the centre returns to the surface.

- Vacuum/drying: 12 min. (2nd stage)

  This completes the elimination of the undesirable volatile compounds and the free water

- Discharge: 2 min.
- Total time: 56 min 30 sec.
- Initial water content (referred to dry product): 45% - at discharge: 25%
- Total count reduction factor is around: 10^{-3}

The cycle may be repeated infinitely or varied on the basis of results obtained (either time or proportion of solution) in order to obtain different flavours or colours.

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In addition to the bibliography composed of the work of the authors and the centres mentioned in the text we call the readers' attention to the following bibliography which appeared in the publication entitled: "COCOA LIQUOR TREATMENT - SCIENTIFIC AND TECHNICAL DOCUMENTATION ON THE PRINCIPLES OF TREATMENT IN THE CARLE & MONTANARI PDAT"*

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- Maillard reaction from the nutritional standpoint. I. Scope of Maillard reaction by Jean Adrian, from the magazine 'Industries Alimentaires et Agricoles', 1972
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* This volume is published courtesy of the authors and editors and may be requested from Carle & Montanari.

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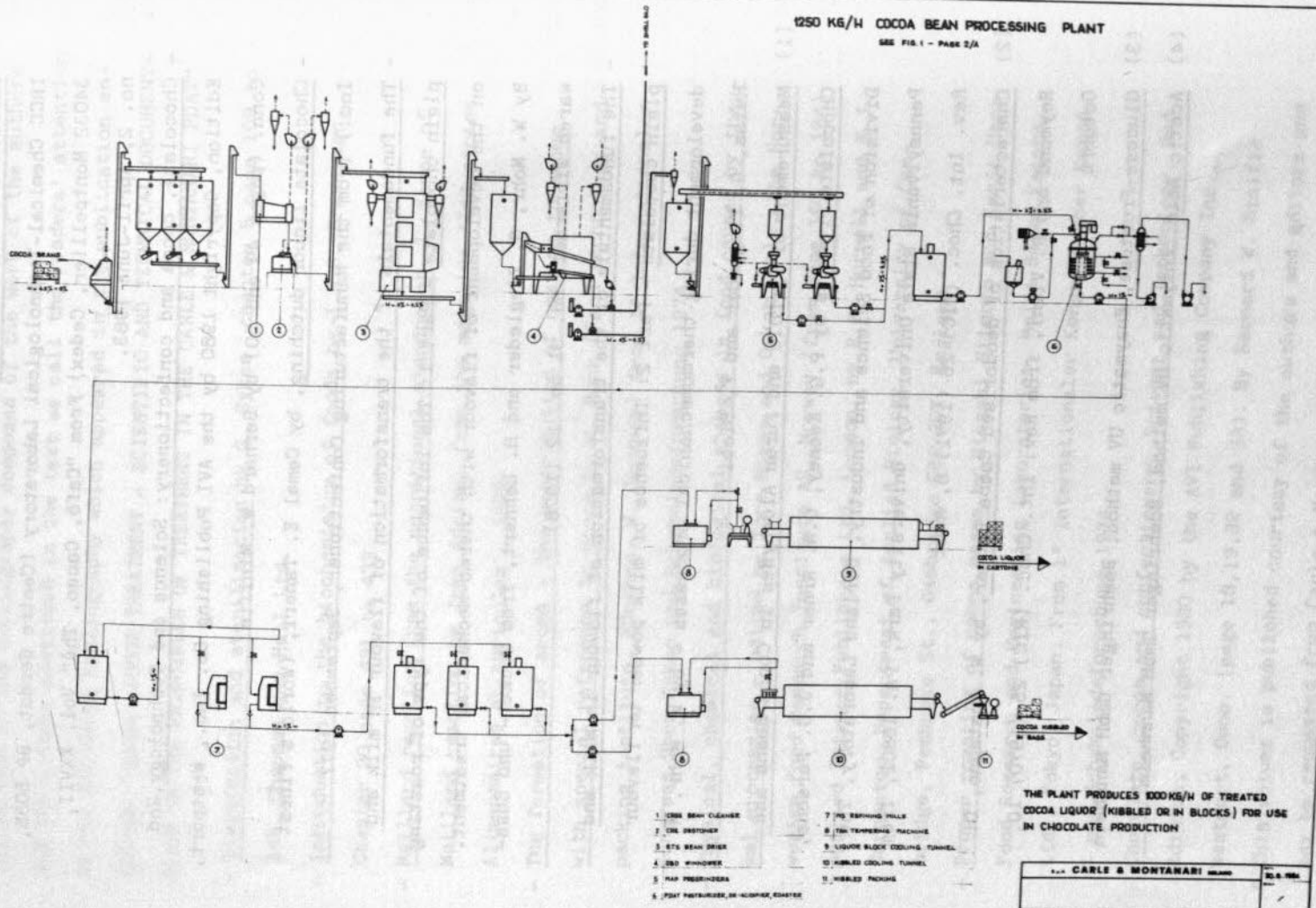
(2) Characteristics of deodorised Cocoa Butter, by W. Rostagno, D. Reymond and R. Viani, from Rev. Int. Choc. (RIC) 25 (1970) 10, Octobre

(3) Glucose-Fructose, Enzymatic UV method, Boehringer GmbH Mannheim

(4) Acetic Acid, Enzymatic UV method, Boehringer GmbH Mannheim

1250 KG/H COCOA BEAN PROCESSING PLANT

SEE FIG. 1 – PAGE 2/A



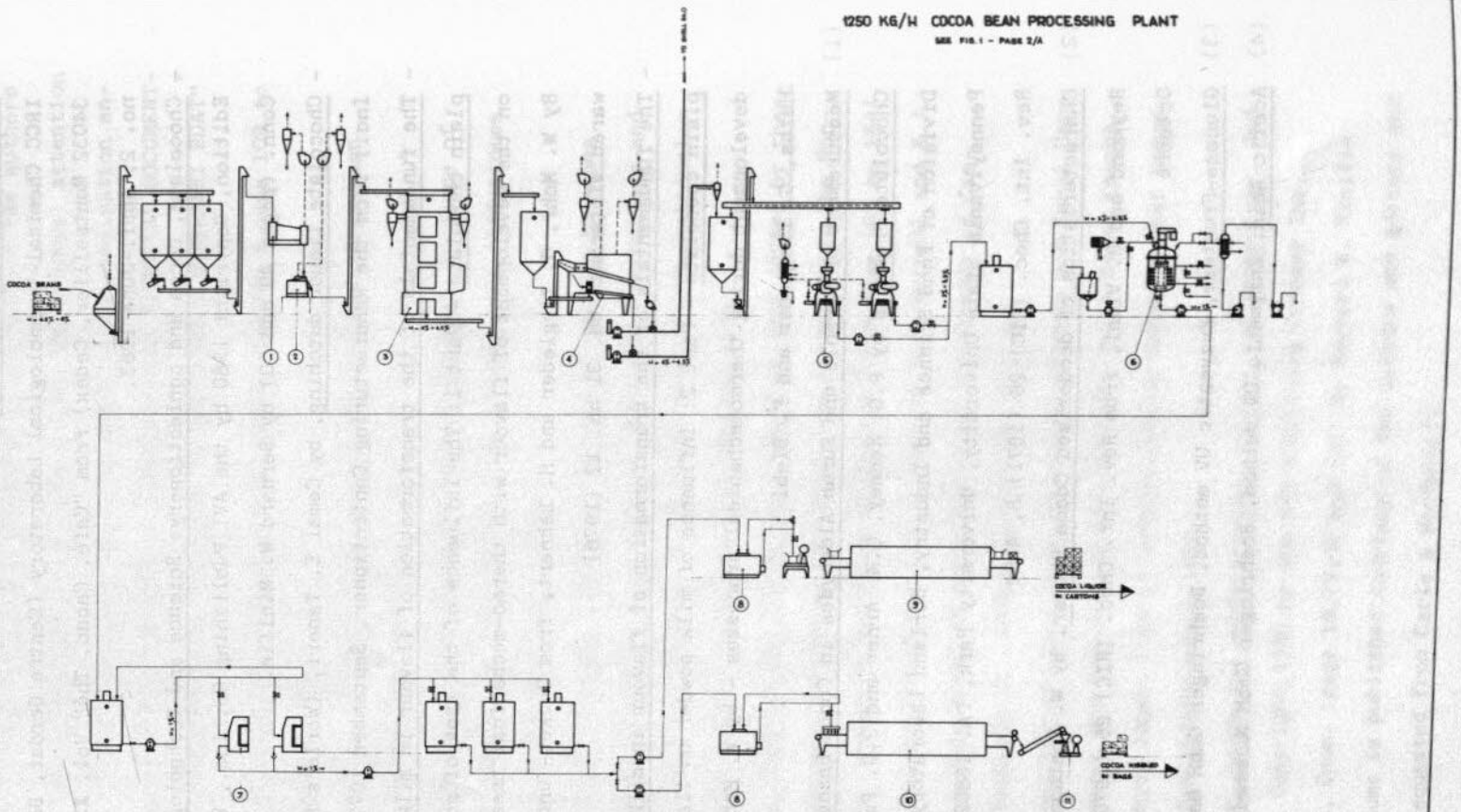
THE PLANT PRODUCES 1000 KG/H OF TREATED COCOA LIQUOR (KIBBLED OR IN BLOCKS) FOR USE IN CHOCOLATE PRODUCTION

CARLE & MONTANARI

8570 N/UI

1250 KG/H COCOA BEAN PROCESSING PLANT

SEE FIG. 1 - PAGE 2/A

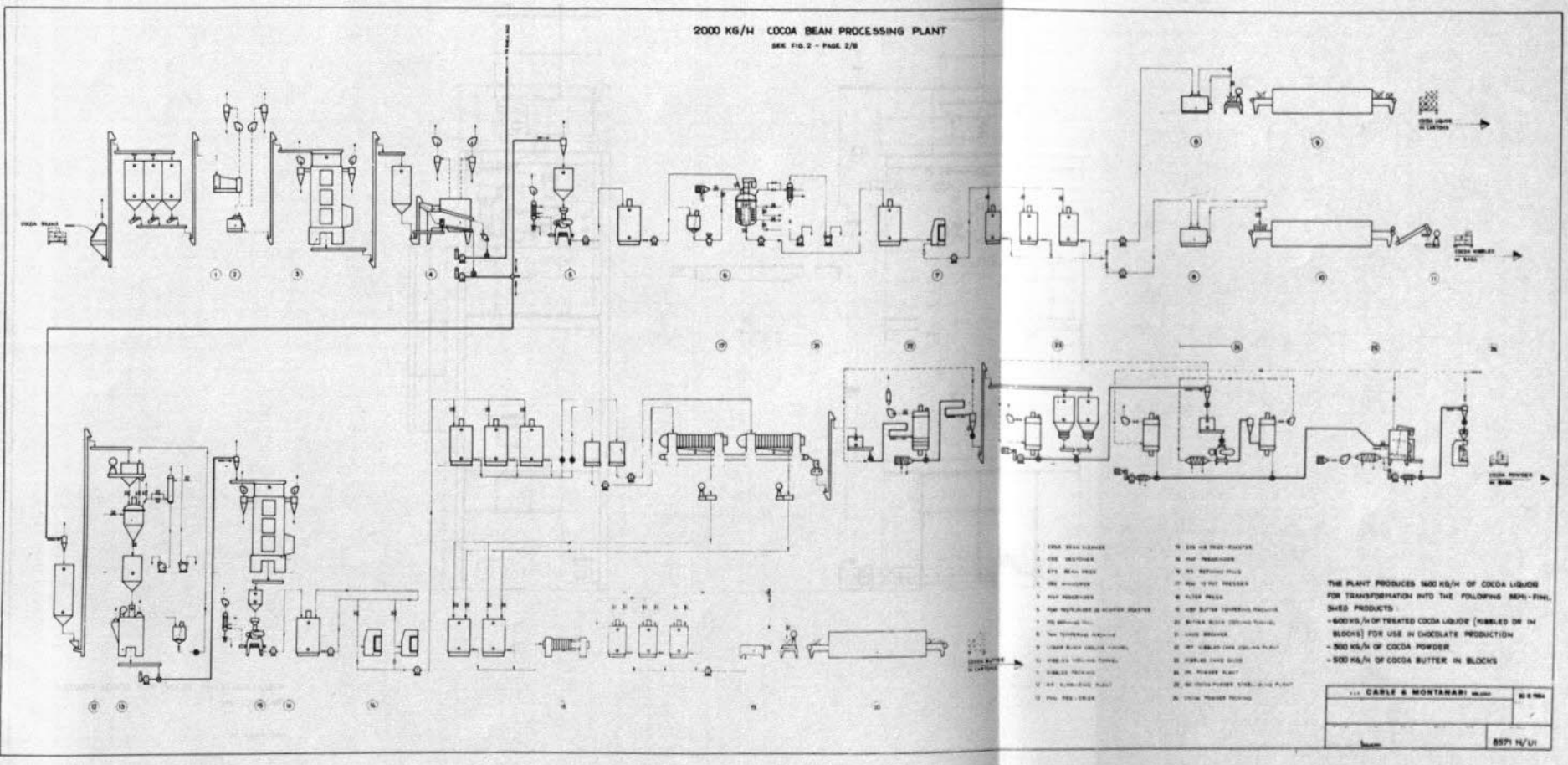


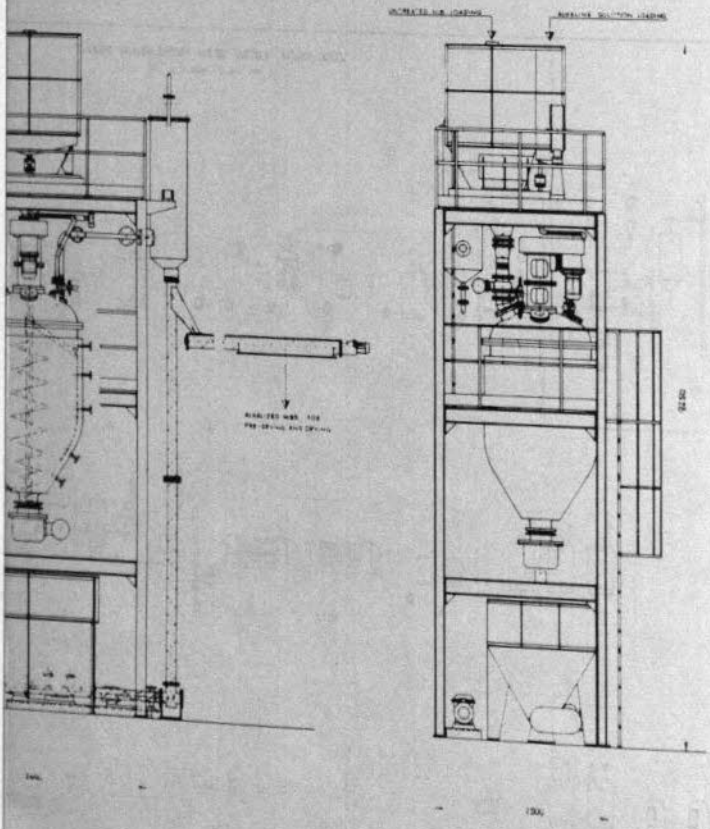
1 CRBK BEAN CLEANER
2 CRL DESTONER
3 ETA BEAN DRIER
4 DBD WINNOWER
5 MAP PREGRINDERS
6 (FOR PASTEURIZED OR HIGHFAT CONTENT)
7 MG REFINING MILLS
8 TAN TEMPERING MACHINE
9 LIQUOR BLOCK COOLING TUNNEL
10 NIBBLES COOLING TUNNEL
11 NIBBLES PACKING

THE PLANT PRODUCES 1000 KG/H OF TREATED COCOA LIQUOR (NIBBLES OR IN BLOCKS) FOR USE IN CHOCOLATE PRODUCTION

CARLE & MONTANARI MILANO

8670 N/U1


2000 KG/H COCOA BEAN PROCESSING PLANT
SEE FIG. 2 - PAGE 2/8
THE PLANT PRODUCES 1400 KG/H OF COCOA LIQUOR FOR TRANSFORMATION INTO THE FOLLOWING SEMI-FINISHED PRODUCTS :
- 600 KG/H OF TREATED COCOA LIQUOR (RIBBLED OR IN BLOCKS) FOR USE IN CHOCOLATE PRODUCTION
- 500 KG/H OF COCOA POWDER
- 300 KG/H OF COCOA BUTTER IN BLOCKS
... CASLE & MONTANARI
8571 H/U1



NIB ALKALIZING PLANT FOR COCOA POWDER PRODUCTION

SEE PAGE 16

CARLE & MONTANARI

AK. 1250

8572 N/UI

P

Influence of Water Table Depth on Root Growth and Development of Cocoa

HJ. MOHD NOH BIN HJ. JALIL
Malaysian Agricultural Research and Development Institute, Hilir, Perak.

In this experiment cocoa plants were grown in soil contained in cylindrical drums of 50 cm (diameter) x 75 cm (depth). By varying the water levels in these drums, the effect of water-table depth on growth and development of the cocoa plant was studied, i.e., *at 25 cm, 38 cm, 51 cm and 64 cm from the soil surface. Amelonado seedlings were used in this experiment. It was found that water level strongly influenced the root growth and development. Under these experimental conditions, water-table depth of 51 cm provided the most optimum soil environment for roots growth and development for twelve months from the commencement of the treatments.*

Examination on the influence of water-table depth on root growth and development was also carried out on mature cocoa plants grown under field conditions on the coastal clay of Lower Perak, Malaysia. Similar patterns of root growth and development were observed but the optimum field water table was not necessarily similar to those observed in the experiment.

Presently, there are more than 80,000 ha of cocoa planted under coconut. The areas mainly consists of coastal alluvial soils and organic soils (Yik, 1978). These soils have mainly poor drainage and high water-table at about 50 cm to 100 cm, and many areas are subjected to flooding and/or waterlogging during rainy seasons. A high water-table often restricts root penetration and distribution to a shallow layer of surface soil.

Cocoa trees are sensitive to a deficiency of water (Alvim, 1959; Lemee, 1955) and excess water affects their growth and yield. At present, there is a lack of information on the effect of water-table depth on growth development and performance of cocoa. This paper reports results of an experiment on the effect of various water-table depth treatments on cocoa seedling growth and development.

MATERIALS AND METHODS

The experiment was carried out at the MARDI Research Station, Lower Perak, Malaysia on seedling of Amelonado. Amelonado seeds were obtained from MARDI Research Station, Jerangau, Trengganu, Malaysia. They were sown in the black perforated polybags (size of 15 cm x 22.5 cm) for the period of two months. The seedlings were then transplanted into cylindrical drums (50 cm diameter x 75 cm depth) containing top soil. They were allowed to grow in the drum under normal maintenance procedure for about one month before being subjected to various water-table treatments, *i.e.*, at 25 cm, 38 cm, 51 cm and 64 cm from the soil surface. There were 15 plants in each treatment arranged in a triangular manner, 1 m apart from one plant to another. The experiment was arranged in a completely randomized block design consisting of three replicates. The experiment

was located under reasonably uniform *Gliricidia* providing about 60% to 70% shade. Each drum was covered with a white plastic sheet to protect against direct heating of sunlight, the temperature in the drums ranging between 30°C and 31°C at midday. Water-table depth in each treatment was maintained throughout the experiment by means of a rubber hose (*Figure 1*). Non-destructive data were taken for height (measured from soil level to highest shoot tip) and girth (measured as circumference of stem at surface soil) of the seedlings. These were taken at monthly intervals commencing from the date of planting. Destructive analysis was carried out for dry matter of shoot (leaves plus stem), dry matter of roots and the total dry matter production (shoot plus roots). The shoot to roots ratio (S/R) was then calculated. The destructive analysis was performed at three-months, nine-months and fifteen-months from the date of the treatment initiation.

RESULTS

Effect of Water-table Depth on Shoot Growth of Cocoa Seedlings

Table 1 shows the effect of water-table depth on height, girth and number of leaves for the Amelonado seedlings during the nine-month from the treatment (four-month to twelve-month age for seedlings). The effect of various water-table depth on shoot dry matter at three-month, nine-month and fifteen-month from treatment is shown in *Table 2*. No significant effect of water-table treatment was observed on shoot growth of Amelonado seedlings throughout the experiment.

Effect of Water-table Depth on Roots Growth of Cocoa Seedlings

The growth and performance of cocoa roots were visually influenced by various water-table treatments. *Figure 2* shows the effect of various water-table depth on the roots growth of Amelonado seedlings at twelve-month from treatment. The extent of roots growth increased as the water-table depth increased (see *Figure 2*).

Water-table treatment was also found to influence the dry matter of roots significantly (*Table 2*). At three months from treatment the root dry matter production of Amelonado seedlings was optimum at a water-table depth of 38 cm from the soil surface, while those grown at 64 cm produced significantly small amount of roots (*Table 2*). At nine months and fifteen-months from treatment, the optimum levels were shifted to the seedlings grown at water-table depth of 51 cm.

Effect of Water-Table Depth on Total Dry Matter Production of Cocoa Seedlings.

Water-table depth treatment was found to have significant effect on the total dry matter production of Amelonado seedlings. The significant effect was clearly observed at three months, nine months and fifteen months from treatment (*Table 2*). The optimum level of seedlings dry matter was obtained with plants grown at water-table depth of 51 cm at all sample harvest times – *i.e.*, at three months, nine months and fifteen months from treatment.

Effect of Water-Table Depth on Shoot to Roots Ratio.

The ratio between shoot dry weight to root dry weight is termed shoot to root ratio or S/R. *Figure 3* shows the effect of various water-table depth on S/R of Amelonado seedlings at three months, nine months and fifteen months from treatment.

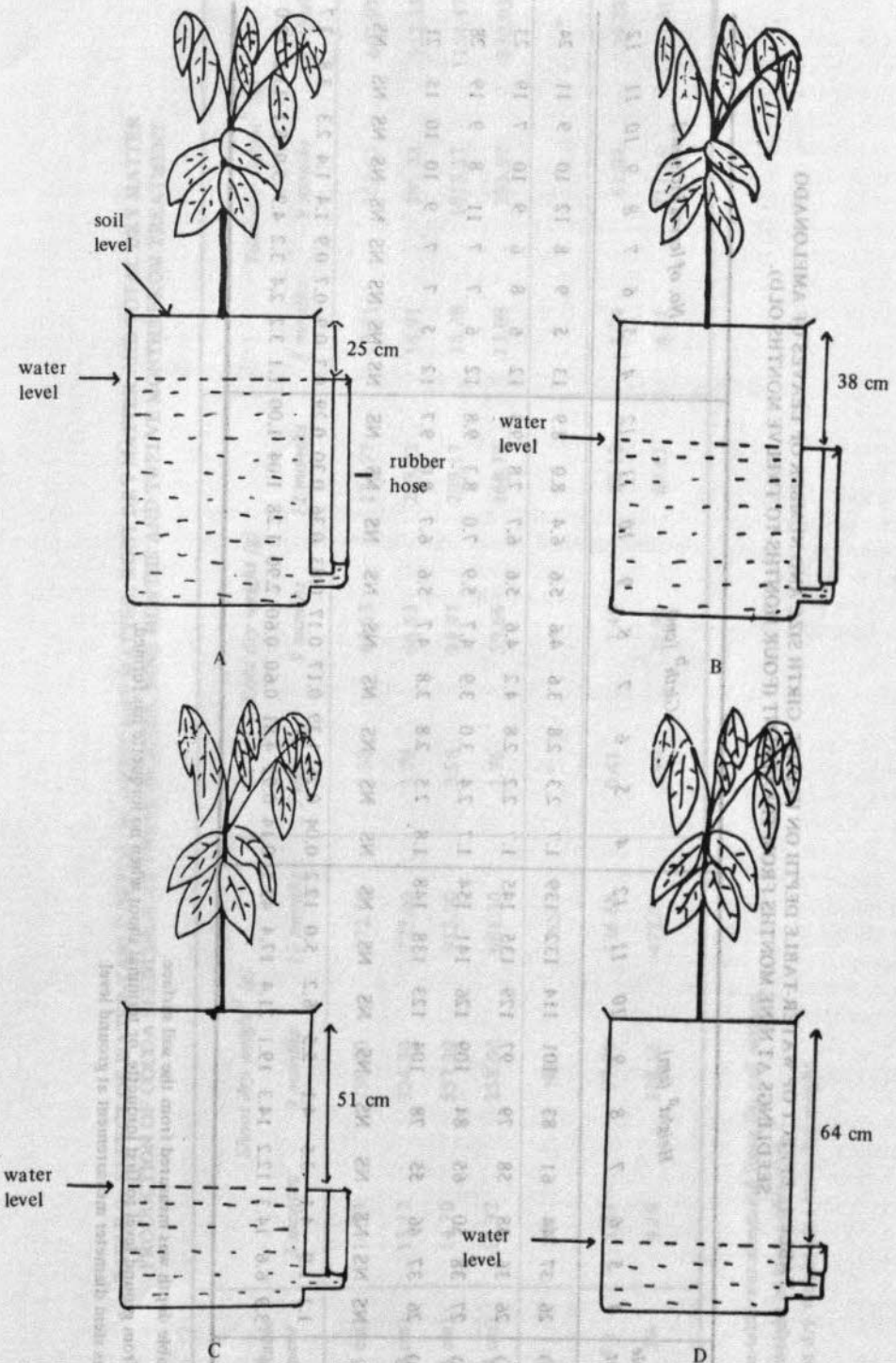


Figure 1. Water-table in each treatment was maintained throughout the experiment.

TABLE 1. EFFECT OF WATER-TABLE DEPTH ON HEIGHT, GIRTH SIZE AND NUMBER OF LEAVES OF AMELONADO SEEDLINGS AT NINE MONTHS FROM TREATMENT (FOUR MONTHS TO TWELVE MONTHS OLD).

Water-table Treatment	*Height[a] (cm)*									*Girth[b] (cm)*									*No. of leaves increased*								
	4	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
A (25 cm)	26	37	44	61	83	101	114	132	139	1.7	2.3	2.8	3.6	4.6	5.6	6.4	8.0	8.9	13	5	9	8	12	10	9	11	24
B (38 cm)	26	36	48	58	79	97	129	135	145	1.7	2.2	2.8	4.2	4.6	5.6	6.7	7.8	9.3	12	6	8	6	9	10	7	19	23
C (51 cm)	27	38	50	65	84	109	126	141	154	1.7	2.4	3.0	3.9	4.7	5.9	7.0	8.3	9.8	12	6	7	7	11	8	9	19	28
D (64 cm)	26	37	46	55	78	104	123	138	148	1.8	2.5	2.8	3.8	4.7	5.6	6.7	8.0	9.7	12	5	7	7	9	10	10	15	21
P 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S.E. (±)	1.1	1.9	4.1	3.5	4.1	5.5	6.2	5.0	12.2	0.04	0.26	1.39	0.17	0.17	0.83	0.36	0.30	0.29	0.3	0.9	0.7	0.9	1.4	1.4	2.3	3.8	3.7
L.S.D. 5%	3.9	6.6	14.3	12.2	14.3	19.1	21.4	17.4	42.3	0.14	0.92	4.81	0.60	0.60	2.90	1.28	1.04	1.00	1.1	3.2	2.4	3.2	4.9	5.0	8.1	13.2	13.0

Water-table depth was measured from the soil surface.

[a] Taken from ground level to first jorquette, or terminal shoot when no jorquette has formed.

[b] Taken as stem diameter measurement at ground level.

TABLE 2. EFFECT OF WATER-TABLE DEPTH ON SHOOT DRY MATTER, ROOT DRY MATTER AND TOTAL DRY MATTER PRODUCTION OF COCOA SEEDLINGS AT THREE MONTHS, NINE MONTHS AND TWELVE MONTHS FROM TREATMENT

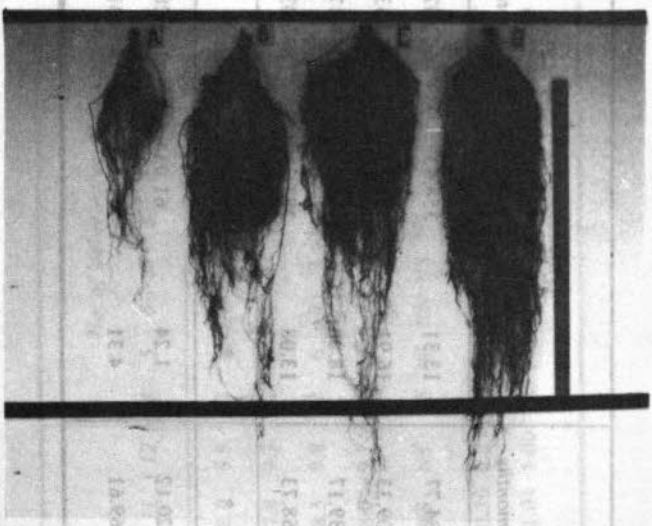
Water-table Treatment	*Shoot dry weight[a] (g)*			*Root dry weight (g)*			*Total dry weight[b] (g)*		
	3 months	*9 months*	*12 months*	*3 months*	*9 months*	*12 months*	*3 months*	*9 months*	*12 months*
A (25 cm)	10.93	290.00	472.30	2.38	68.63	134.77	13.31	358.63	607.07
B (38 cm)	13.12	324.70	723.00	3.79	66.53	209.33	16.91	391.23	932.33
C (51 cm)	14.70	557.30	915.30	3.58	99.97	239.17	18.28	1015.27	1154.47
D (64 cm)	11.32	258.00	661.30	1.76	59.66	168.73	13.08	283.27	830.03
P 5%	NS	NS	NS	*	*	*	*	*	*
S.E. (±)	1.21	97.79	136.68	0.41	7.49	20.12	1.24	61.03	129.28
L.S.D. 5%	4.19	338.35	472.91	1.40	25.90	69.61	4.31	211.16	447.31

Water-table was measured from the soil surface.

[a] Dry weight of leaves plus stem.

[b] Shoot dry weight plus roots dry weight.

Figure 2A



A – Water-table at 25 cm. C – Water-table at 51 cm.
B – Water-table at 38 cm. D – Water-table at 64 cm.

Figure 2B

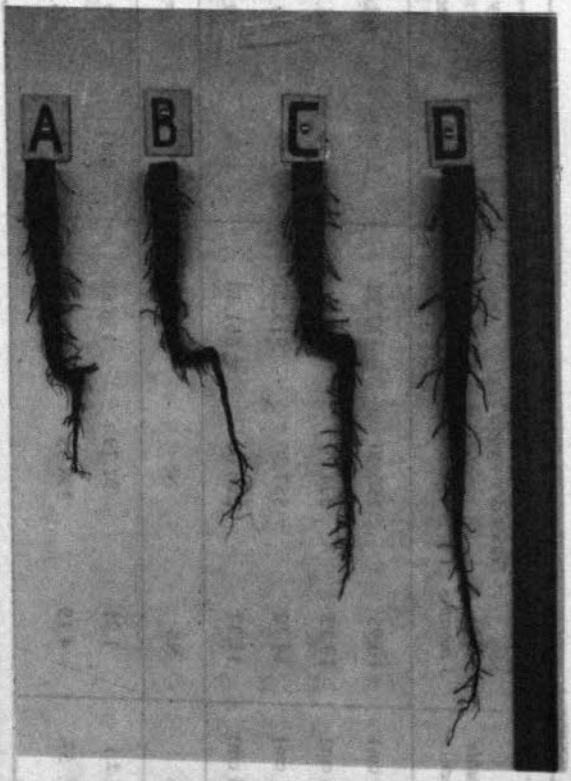


Figure 2. Effect of Water-table Depth on Roots Growth of Amelonado Seedlings after Twelve Months from Treatment.

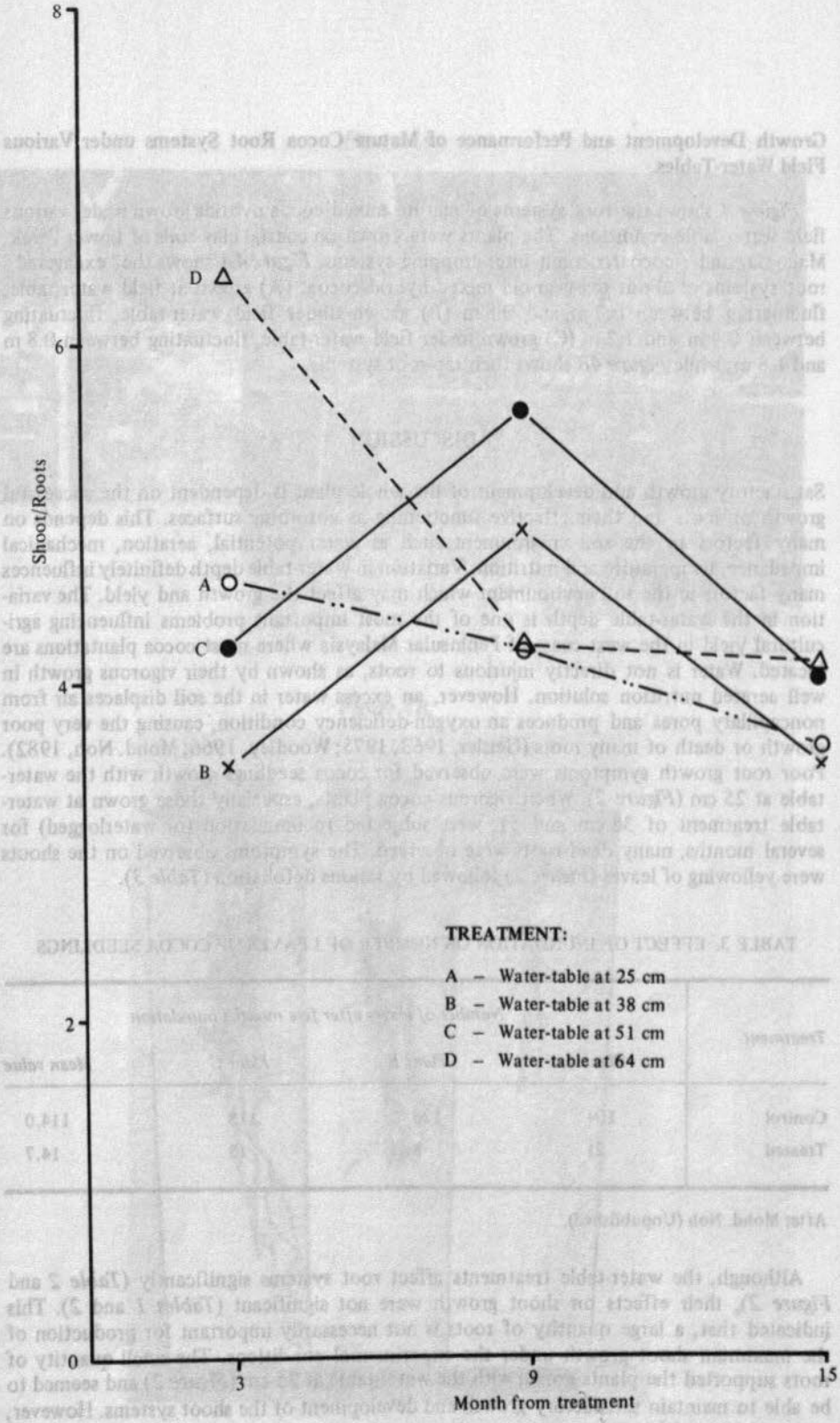


Figure 3. Effect of Water-table Depth on Shoot to Roots Ratio of Amelonado Seedlings.

Growth Development and Performance of Mature Cocoa Root Systems under Various Field Water-Tables.

Figure 4 shows the root systems of mature mixed cocoa hybrids grown under various field water-table conditions. The plants were grown on coastal clay soils of Lower Perak, Malaysia, under cocoa/coconut inter-cropping systems. *Figure 4A* shows the "excavated" root systems of about ten-year-old mixed hybrid cocoa: (A) grown at field water table, fluctuating between 0.2 m and 0.8 m (B) grown under field water-table, fluctuating between 0.4 m and 1.2 m (C) grown under field water-table, fluctuating between 0.8 m and 1.8 m; while *Figure 4B* shows their tap-root systems.

DISCUSSION

Satisfactory growth and development of the whole plant is dependent on the successful growth of roots and their effective functioning as absorbing surfaces. This depends on many factors in the soil environment such as water potential, aeration, mechanical impedance, temperature and nutrition. Variation in water-table depth definitely influences many factors in the soil environment which may affect the growth and yield. The variation in the water-table depth is one of the most important problems influencing agricultural yield in the west coast of Peninsular Malaysia where most cocoa plantations are located. Water is not directly injurious to roots, as shown by their vigorous growth in well aerated nutrition solution. However, an excess water in the soil displaces air from noncapillary pores and produces an oxygen-deficiency condition, causing the very poor growth or death of many roots (Geisler, 1963, 1975; Woodley, 1966; Mohd. Noh, 1982). Poor root growth symptoms were observed for cocoa seedlings growth with the water-table at 25 cm (*Figure 2*). When vigorous cocoa plants, especially those grown at water-table treatment of 38 cm and 51, were subjected to inundation (or waterlogged) for several months, many dead roots were observed. The symptoms observed on the shoots were yellowing of leaves (*Figure 5*) followed by serious defoliation (*Table 3*).

TABLE 3. EFFECT OF INUNDATION ON NUMBER OF LEAVES OF COCOA SEEDLINGS.

Treatment	*Number of leaves after five months inundation*			
	Plant A	*Plant B*	*Plant C*	*Mean value*
Control	104	120	118	114.0
Treated	21	8	15	14.7

After Mohd. Noh (Unpublished).

Although, the water-table treatments affect root systems significantly (*Table 2* and *Figure 2*), their effects on shoot growth were not significant (*Tables 1* and *2*). This indicated that, a large quantity of roots is not necessarily important for production of the maximum shoot growth under the experimental conditions. The small quantity of roots supported the plants grown with the water-table at 25 cm (*Figure 2*) and seemed to be able to maintain satisfactory growth and development of the shoot systems. However, it should be noted in this experiment that, Amelonado seedlings grown with water-table at 25 cm produced a large number of very fine root systems (like a cushion) on the soil

Figure 4A.

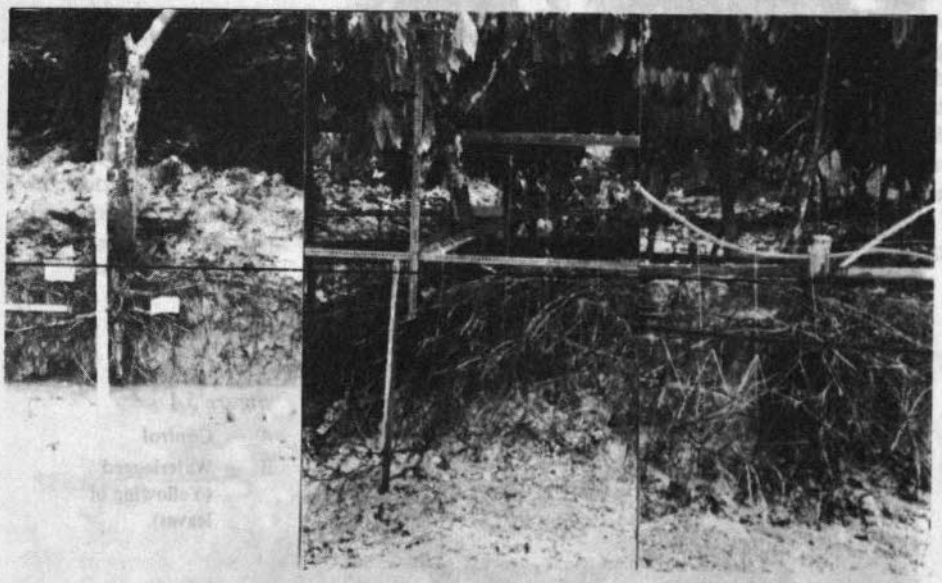


Figure 4B.

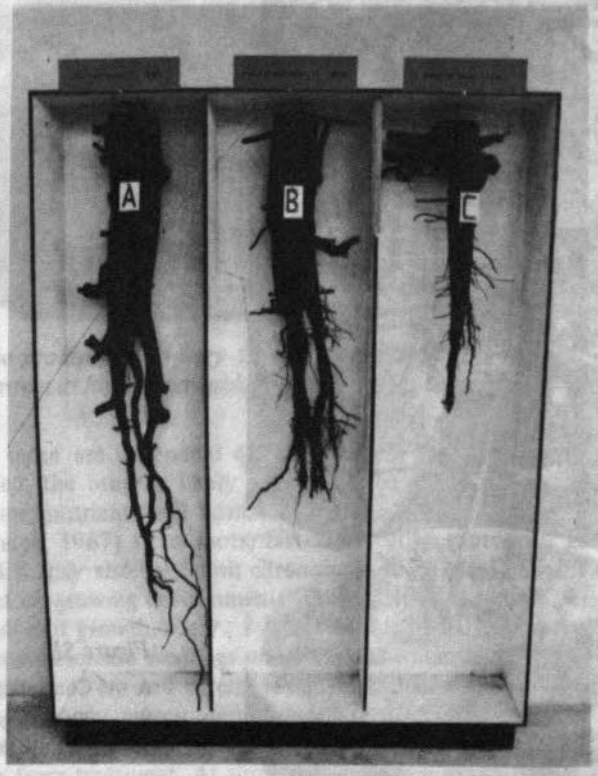


Figure 4. Effect of Water-table (Field Conditions) on Roots Growth of about ten year-old Mixed Hybrid Cocoa under Coconut Systems.



Figure 5A

A – Control

B – Waterlogged (Yellowing of leaves).



Figure 5B

A – Control

B – Waterlogged (Defoliation).

Figure 5. Effect of waterlogging on growth of cocoa seedlings.

surface during later stage of growth (*Figure 6*). This surface "modified root system", probably functions in supporting the nutrient and oxygen uptake by the plant grown at restricted "root room" (at high water-table). It was observed that Amelonado seedlings tend to produce roots on the stem above the soil surface after being subjected to flooding or waterlogging. This is probably a mechanism to obtain nutrients and oxygen under such anaerobic conditions. Soil aeration affects root growth in plants (Russel, 1979) especially their elongation and branching (Mohd. Noh, unpublished). Thus the maximum amount of roots produced by plants with water-table at 51 cm (*Table 2, Figure 2*) indicates that this treatment provides an optimum root environment. However, as mentioned earlier it is not necessarily important for production of the maximum shoot growth of cocoa seedlings.

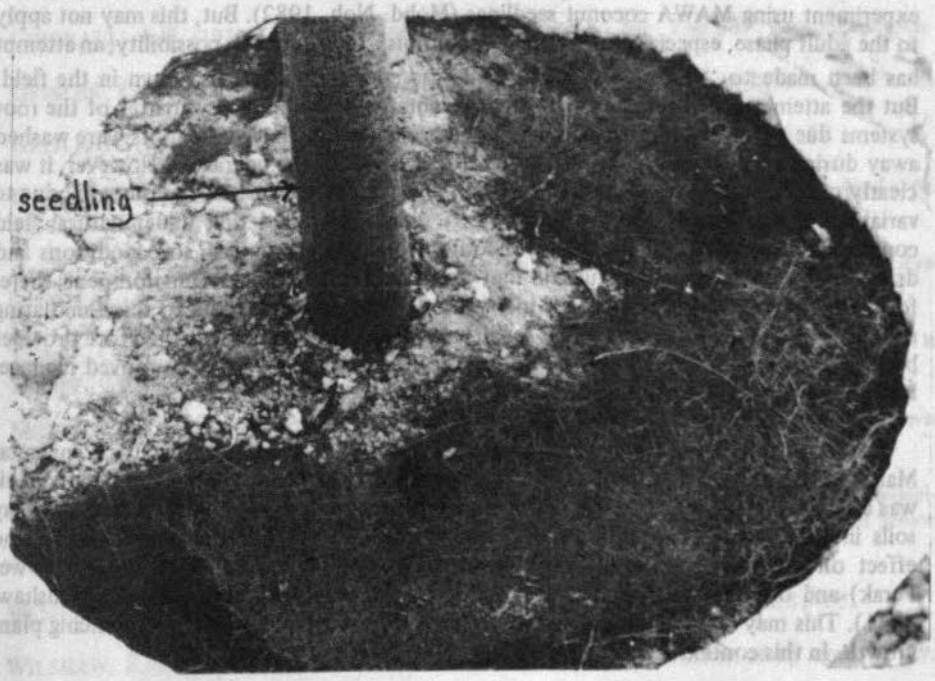


Figure 6. The production of very fine root systems on the soil surface from seedlings grown at high water-table at 25 cm during later stage of growth.

Roots and shoot are dependent on each other in various ways, and if the growth of one is modified, the other is likely to be affected. Since shoot growth depends on a supply of water, nutrients and hormones (Chibnall, 1939; Went, 1943; Kende, 1965; Skene & Kerridge, 1967) from roots, factors affecting roots may also influence shoot growth. The S/R may also vary with chronological age, stage of morphological development and kind of growing environments. This variation is termed periodicity and alternate shoot and root growth. *Figure 3* indicates this periodicity and alternate shoot and root growth in Amelonado seedlings under various water-table treatments. Plant growth with water-table at 38 cm and 51 cm, for example, possessed root dry matter of 28.9% and 24.4%, respectively, which were reduced to 20.5% and 17.9, respectively at nine months from treatment and finally increased again to 29.0% and 26.1%, respectively, at fifteen months from treatment. At three months from treatment, the smallest number of roots with water-table at 64 cm is probably because of the lack of water to the roots, while excess of water (at high water-table, *e.g.*, at 25 cm) also caused poor rooting. At

nine months from treatment the roots with water-table at 64 cm increased significantly (from 15.6% to 23.1%), presumbly, due to the penetration of roots to the lower layer of soil, thus more water and oxygen being available to the roots. The slight increase in roots of plants with high water-table at 25 cm might indicate the restricted "root room" in this treatment. Therefore, the variation in the pattern of S/R responses to water-table treatments is due to the variation in adaphic environment, presumably, in this case, due to water regime and oxygen availability.

It is interesting to note that the optimum water-table for cocoa root growth and development found in this experiment, ranged between 25 cm and 64 cm. The optimum effect was at a water-table of 51 cm (*Table 2*). Similar results were observed in the experiment using MAWA coconut seedlings (Mohd. Noh, 1982). But, this may not apply to the adult phase, especially under field conditions. To ensure this possibility, an attempt has been made to "excavate" the whole mature cocoa root systems grown in the field. But the attempt failed to exactly estimate quantatively the total dry matter of the root systems due to various problems. One of the problems was that many roots were washed away during excavation due to strong jet of water used in the operation. However, it was clearly observed that the difference in root growth and distribution is presumably due to variation in water-table depth (*Figure 4*). It should be noted that under natural field conditions the water-table fluctuates, the rate depending on rainfall, soil conditions and drainage. The water-table fluctuation may give rise to unstable roots environment; therefore, the pattern of growth shown in *Figure 4* is accounted for due to this fluctuating regime. Water-table depth influences fertilizer uptake. This experiment therefore provides basic information which would be very useful in the development of improved management practices in the fields of water control and fertilizer application.

Earlier fertilizer experiment on coastal clay soils on the west coast of Peninsular Malaysia (Belgrave & Lamborne, 1933) showed no response in yield of coconuts. This was attributable to poor drainage in the area, so that waterlogging prevailed. In heavy clay soils in Bagan Datoh area of Lower Perak, it was found that fertilizer by itself had no effect on the yield of cocoa (example MARDI fertilizer experimental plot in Lower Perak) and of coconuts, but that drainage had a beneficial effect in coconuts (Wilshaw, 1941). This may be indicative of the importance of water-table depth in influencing plant growth. In this context, basic physiological studies merit attention.

It should also be noted that drainage *per se* does not necessarily improve growth and yield. In potentially acid-sulphate and acid-sulphate conditions, it is evident that the water-table should be maintained above the pyritic horizon (Mohd. Zahari *et al.*, 1981).

CONCLUSION

It was found that water-table strongly influenced root growth and development, but, the reduction in root growth within the range of water-table treatment between 25 cm and 64 cm did not significantly affect shoot growth. Under these experimental conditions the optimum effects were at the majority demonstrated by plants grown at water-table depth of 51 cm in terms of dry matter and total dry matter. Water-table was also observed to influence the structure and distribution of mature cocoa root systems in the field. Although the optimum water-table under field conditions was not determined in this investigation water-table fluctuation between 0.4 m and 1.2 m seemed to be satisfactory for cocoa growth in the field. The effect of water-table was mainly presumed due to aeration and perhaps, soil water status.

ACKNOWLEDGEMENT

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Studies on Some Cocoa Diseases in Sarawak

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Black pod and stem canker occurred in all the major cocoa-growing areas in Sarawak. It was confirmed that Phytophtora palmivora *was the causal agent. Morphology studies of the fungus revealed that it conformed the description of* P. palmivora *m.f.l. Pods from hybrids of U1T1 x SCA12, NA32 x U1T1, and PA35 x NA32 were less susceptible to infection. Fungicide, metalaxyl at 0.06% a.i. chlorothalonil at 0.2% a.i., matalaxyl 10% plus manozeb 48% at 0.2% a.i. and fentin-acetate 54% plus maneb 18% at 0.1% a.i. significantly reduced pod infection.*

Pink disease (Corticium salmonicolor) was serious in cocoa under coconut in coastal areas. Field evaluation of fungicides showed that tridemorph and cuprous oxide, at 0.2% a.i. spray application significantly reduced disease index.

Vascular streak die-back was recorded in Sarawak in 1978. Field trials (1978 – 83) showed that when the fertilizer application rate for the affected cocoa was at 132.7 gm N: 81.7 gm P_2O_5: 176.9 gm K_2O: 22.7 g MgO per tree per annum the infection was reduced to 1.7% (on tree counts) two years later.

Cocoa is a rapidly expanding plantation crop in Malaysia. The area under cocoa cultivation was only about 12,000 ha in 1971, but reached 27,000 ha in 1975; it is estimated to reach 250,000 ha by the turn of the century (Ishak, 1980).

In Sarawak the area under cocoa planting was 2,809 ha in 1975 and this is be expected to reach 12,500 ha in 1985. Along with the increased hectarage in cocoa planting in Sarawak, disease incidences of the crop also increased. Previous incidences of cocoa diseases in Sarawak were reported by Johnston (1960), Dunsmore & Ngui (1969), Turner (1970), Ahmed Haji Ebow *et al.*, (1980), and Kueh (1979).

Black pod and stem canker (*P. palmivora*) were the two common diseases in the coastal and inland cocoa-growing areas of the First, Fourth and Sixth Divisions in Sarawak especially during and after the monsoon rain in October – February. In severe cases 30% pod destruction was experienced (Kueh, 1979). Pink disease (*Corticium salmonicolor*) was another common disease in most cocoa holdings partly because of the poor pruning practices and partly because of heavy overhead shading. If control was not taken in time, death of the whole tree could occur (Tiong, 1978). Shoot die-back disease of cocoa was first reported by Johnston (1960). In 1978 a shoot die-back disease was recorded in a cocoa plantation in Sarawak. Symptoms of the disease were chlorosis of a mature leaf (with green islets/spots) at one or two flushes below the current shoot, browning of vascular bundles in the petiole of the chlorotic leaf, enlargement of lenticels and rapid browning of the cambium on the wood, upon bark removal from the branch carrying the chlorotic leaf. When the branch was split longitudinally, browning of vascular vessels could be seen. These phenomena resembled the symptoms of vascular streak die-back (VSD) caused by *Oncobasidium theobromae* described by Keane and Turner (1972). Microscopic examination of longitudinal section of infected petiole revealed that the fungal hypae were thin walled, hyaline, smooth, nongranular and without clamp connection. Septation of the hypae was irregular but dolipores at the septa were quite

prominent. Hypae diameter varied between 5 and 6 *um*. Branching of hypae was common and at wide angles. A septum occurred on the side branch varying between 5 and 10*um*. from the branching junction. Attempt to culture the fungus on water agar has not been successful. Wong (1980) reported that a fungus from the diseased tissues in culture had similar mycelial characteristics of *O. theobromae* (Talbot & Keane, 1971) but no fructification was observed, confirming the disease as VSD.

This paper reports on the studies on some aspects of the four cocoa diseases mentioned, namely black pod, stem canker, pink disease and VSD.

METHODS

Black Pod and Stem Canker

Diagnosis. Pods and stem barks suspected of infection by *Phytophthora* spp were collected from various cocoa-growing areas in Sarawak. Laboratory confirmation of the fungus was by microscopy as follows:–

- Scraping off whitish mycelia from lesions on pods and barks onto slides each having a drop of lactophenol.
- Treating five pieces of infected tissues from each pod and bark samples with Petri solution for 24 hours.
- Plating 10 pieces of infected tissues from lesions margin of the respective pod and bark in benomyl-PCNB agar (benomyl 50 mg/1, PCNB 50 g/l and agar 17 g/l) in two Petri dishes for three days and then subculturing the fungus on oatmeal agar for identification.

Pathogen morphology. Ten slides were prepared by placing a drop of lactophenol at the centre of each slide and gently dipping a piece of the infected tissues from the centre of pod lesion. The lactophenol and its content were covered with a slip and sealed for morphology study of the fungus. The diseased pods were collected from cocoa holdings in Moyan and Subi, First Division, and Kedup and Jakar, Sixth Division. Another 10 slides were similarly prepared from cocoa *Phytophthora* isolates which had been cultured on carrot agar under 24 h of light (18,000 lux) at 25°C for three days. Pieces of the so prepared cultures used for dipping were taken from near the centre of the isolate colony in each case. Morphology study of the fungus allowed the Tabular Key to the species of *Phytophthora* (Newhook *et al.*, 1978).

Resistance. In assessing the reaction of the different cocoa hybrids to the fungus, 20 mature pods of each hybrid were divided into four groups and each pod was inoculated with a 5 mm diameter carrot agar culture disc of the cocoa *Phytophthora* which had been treated with Petri solution for 24 h to induce sporangial production. The advantages of the culture disc inoculation were that the discs were uniform in size and easy to handle and prepare. The surface area of pod exposed to the inoculum was almost equal in each case, besides the fact that lesions so formed could easily be measured. Inoculated pods were kept in high humidity chamber at room temperature (26 ± 2°C). Thereafter two diametrical sections, perpendicular to each other, were taken daily from each lesion formed on the pod for three days.

Fungicide trial. A cocoa holding in Sarikei, Sixth Division, was selected for trial of fungicides against black pod. The site had serious black pod in previous years. The trees were six to seven years old mixed hybrid monocrop.

The experimental area was divided into three blocks each having five treatment plots. Each plot consisted of about 60 trees. Forty trees in the centre were taken for recording. Fungicides were applied onto pod bearing branches twice a month from October to March and once a month from April to September using knapsack sprayer. Pods were harvested once every two weeks during the trial period. Both healthy and diseased pods from each treatment plot were separately counted during each harvest.

Pink Disease. Four fungicides were evaluated in a cocoa holding in Muara Tuang District, First Division. The trees were five year old mixed hybrid planted under coconut. Due to uneven disease infection on the trees, the experimental area had to be divided into three large blocks each with four treatment plots and a control. Ten recently infected trees in each plot were selected for fungicide treatment. The two ends of the infected zone on the branch were ringed with white paint. Outside these marks were three consecutive similar white markings at 10 cm interval. Appropriate fungicide was sprayed twice onto the infected zones of the branches at monthly intervals. The other unselected but infected trees within the plot was thoroughly sprayed with the same fungicide to reduce inoculum source. Infected trees in the control plot were similarly marked but without fungicide treatment. One month after the second fungicide treatment, all the marked diseased zones of the selected trees within a plot were assessed by the following scoring system:–

Severity of infection	*Rating*
No obvious extention of infection	0
Extension of infection within 10 cm	1
Extension of infection between 10 and 20 cm	2
Extension of infection between 20 and 30 cm	3
Extension of infection within 10 cm plus one or more infected branches	4
Extension of infection between 10 and 20 cm plus one or more infected branches	5
Extension of infection between 20 and 30 cm plus one or more infected branches	6

Vascular streak die-back. This trial was conducted at Sarawak Land Development Board Ladang Koko, Fourth Division. The infected trees were three year old mixed hybrid in 3.04 x 3.04 m square planting monocrop. A 10-ha section of the plantation was marked for observation. The centre core of the section was divided into eight transect lines (rows), each consisting of a range of 47–242 trees. There were three rows in between the marked transects acting as guards. Each transect was treated as a replicate. Disease severity in each replicate was assessed by the number of trees inflicted by the disease. A tree was considered disease-infected when 1.0% (visual assessment) of its canopy foliar exhibited VSD symptoms. The diseased materials on the trees in the trial section were pruned at bimonthly intervals. It was assumed that the unpruned VSD-infected trees in the surrounding would provide sufficient inoculum to cause infection to the pruned trees. Tree-infection was assessed at four-monthly intervals in March, July and December of 1978–1983. No control treatment was imposed. All the trees in each transect were for recording.

RESULTS AND DISCUSSIONS

Black Pod and Stem Canker

Diagnosis. Using the three techniques of microscopy, namely (a) scraping of mycelia

from infected pods and barks onto glass slides, (b) treating the infected tissues in Petri solution for 24 h and (c) plating out the infected tissues, it was found that scraping of mycelia off the infected tissues directly for microscopy was the most convenient diagnostic technique. It was easier to isolate the pathogen from infected pods then from barks. This could probably be attributed to the fact that cocoa pod is a more suitable food base than the bark for the fungus and under the favourable natural environment of optimum temperature and high humidity as normally prevalent during the monsoon, the fungus was stimulated to sporulate profusely.

Pathogen morphology. Morphology study on the sporangia produced on naturally infected pods and those produced by the fungus in carrot agar revealed that the fungus causing black pod from various cocoa growing areas in Sarawak under the present studies, matched closely to the sporangia description of *P. palmivora* m.f.1. The morphology of the sporangia was based on their length, breadth, length/breadth (L/B) ratio and predicel length (*Table 1*).

Though *P. palmivora* m.f. 4, the causal agent of black pepper (*Piper nigrum*) foot rot, occurred widely in Sarawak (Kueh, 1977) and many currently *Phytophthora* infected cocoa holdings were planted on land which had previous pepper foot rot history, there was no recovery of *P. palmivora* m.f. 4 from either black pod or stem canker of cocoa in the present studies. Nevertheless Brasier & Griffin (1979) reported that *P. palmivora* m.f. 4 had been isolated from cocoa in Central and South America, and West Indies.

Resistance. Innoculation on uninjured mature pods of various cocoa hybrids under laboratory conditions indicated that the pods of all the hybrids tested were susceptible to *Phytophthora* infection. However, hybrids of U1T1 x SCA12, NA32 x U1T1 and PA35 x NA32 had the least average lesion size three days after inoculation (*Table 2*).

Fungicide trial. Of the four fungicides evaluated, metalaxyl, a systemic fungicide, at 0.06% a.i. was found to reduce the percentage of black pod incidence significantly (0.05). Metalaxyl 10% plus manozeb 48% at 0.2% a.i. followed by fentin acetate 54% plus maneb 18% at 0.1% a.i. and chlorotholanil at 0.1% a.i. were also promising in reducing disease incidence (*Table 3*).

The outstanding effect of metalaxyl on the control of cocoa black pod was expected because it had also been reported to control *P. megasperma* var. *sojae* of soya bean (Lazarovits *et al.*, 1980), *P. parasitica* var. *nicotianae* of tobacco (Reilly, 1980), *P. parasitica* and *P. citrophthora* of citrus (Farih *et al.*, 1981 a and b), P. palmivora m.f. 4 of black pepper (Kueh, 1983) and black pod of cocoa (Mc Gregor, 1983).

Pink Disease

Results (Table 4) of the evaluation of the effect of four fungicides on the control of pink disease (*Corticium salmonicolor)* on cocoa planted under coconut showed that tridemorph at 0.2% a.i., cuprous oxide at 0.2% a.i., copper oxychloride at 0.2% a.i. and catafol at 0.2% a.i. scored significantly ($P = 0.05$) lower disease index than control. Amongst the four fungicides evaluated, tridemorph and cuprous oxide yielded significantly lower ($P = 0.05$) disease index than copper oxychloride and captafol at 0.2% a.i. Users of these fungicides should therefore be cautious of such difference in the efficacy of the respective fungicides when selecting them for large-scale application, so as to make the expenditure justifiable.

Vascular streak die-back. In this study, it was found that when that fertilizers appli-

TABLE 1. DIMENSION OF SPORANGIA PRODUCED BY DIFFERENT *PHYTOPHTHORA* ISOLATES OF COCOA

Isolates	*Locality*	*Length*		*Breadth*		*L/B*		*Pedicel*	
		Range	*μm (L) Mean*	*Range*	*μm (B) Mean*	*Range*	*Mean*	*Range*	*μm Mean*
F446A	Moyan	29–52	37	19–36	27	1.1–2.0	1.4	2.9–20.0	5
F447	Moyan	32–60	46	20–34	26	1.3–2.2	1.8	2.9–22.9	5
F450	Kedup	32–63	47	20–32	26	1.4–2.2	1.8	1.4– 5.7	3
F451	Jakar	32–57	43	20–33	27	1.2–2.1	1.6	1.4– 2.9	2
Cocoa 1	Subi	34–46	40	20–26	23	1.4–2.0	1.8	2.0– 4.0	3
Cocoa 1	Subi	29–46	37	20–23	23	1.3–2.0	1.7	1.4– 5.2	3

Results based on 50 readings
Cocoa 1 & Cocoa 2 were isolates grown in carrot agar at 25°C for 3 days under 24 h light (18,000) lux)
F446A, F447, F450 were under isolation from diseased pods.

TABLE 2. *PHYTOPHTHORA* GROWTH ON UNINJURED MATURE COCOA POD SURFACE

Cocoa hybrid	*Lesion diameter on pod surface 3 days after inoculation (mm)*	*Duncan's multiple Range Test**
AML x NA 32	23.8	cde
AML x NA 34	24.3	de
AML x PA 7	23.5	cde
NA 32 x PA 7	27.3	e
NA 32 x PA 35	23.6	cde
NA 32 x SCA 6	26.0	e
NA 32 x SCA 12	19.4	abc
NA 32 x ULT 1	17.3	a
PA 7 x NA 32	18.3	ab
PA 34 x NA 32	16.1	a
SCA 6 x NA 32	17.9	ab
SCA 12 x NA 32	23.1	bcde
SCA 12 x UIT 1	20.4	abcd
UIT 1 x NA 32	27.0	e
UIT 1 x SCA 12	17.2	a

* Means with similar alphabet do not differ significantly at (P = 0.05)

TABLE 3. EFFICACY OF FUNGICIDES AGAINST COCOA BLACK POD DISEASE

Treatment	*Concentration (% a.i.)*	*Black pod infection (%)*	*Duncan's Multiple Range Test**
Control	–	8.5	c
Chlorothalonil	0.20	6.9	bc
Metalaxyl	0.06	2.8	a
Metalaxyl 10% + Manozeb 48% Fentinacetate 54% + Maneb 18%	0.20	3.5	ab
	0.10	4.7	abc

* Means with similar alphabet do not differ significantly at (P=0.05).

TABLE 4. EFFICACY OF FUNGICIDES AGAINST COCOA PINK DISEASE

Treatment	*Concentration (% a.i.)*	*Disease index*	*Duncan's Multiple Range Test**
Control	–	7.8	c
Captafol	0.20	2.9	b
Copper oxychloride	0.20	2.9	b
Cuprous oxide	0.20	2.4	a
Tridemorph	0.20	2.4	a

* Means with similar alphabet do not differ significantly at (P=0.05).

cation in terms of N: P_2O_5: K_2O: MgO was increased from 54.4: 54.4: 77.1: 9.1 to 132.7:81.7:176.9:22.7 g per tree per annum respectively in 1978, 1979 and 1980, disease incidence in terms of percentage of infected trees was reduced markedly in the two subsequent years *i.e.* 1981 and 1982. When the fertilizer (N: P_2O_5: K_2O: MgO) application was decreased from 132.7: 81.7: 176.9: 22.7 to 81.6: 81.6: 115.7: 13.6 g or less per tree per annum respectively in 1981 and 1982, disease incidence increased again in the third year 1983 (*Table 5*).

TABLE 5. EFFECT OF FERTILISER APPLICATION RATES AND RAINFALL ON COCOA SHOOT DIE-BACK INCIDENCE

Year	*Annual rainfall (mm)*	*Fertiliser application (gm/tree/year)*				*Trees infected by shoot die-back (%)*	
		N	P_2O_5	K_2O	*MgO*	*range*	*mean*
1977	2946	52.7	52.7	64.1	4.5	–	–
1978	2885	54.4	54.4	77.1	9.1	19.8–54.7	37.3
1979	2772	54.4	54.4	77.1	9.1	49.7–100	81.4
1980	3168	132.7	81.7	176.9	22.7	80.6–100	93.0
1981	2689	81.6	81.6	115.7	13.6	2.5–100	35.41
1982	2155	65.8	63.5	108.7	11.3	0–3.3	1.7
1983	2266	65.3	63.0	45.0	11.3	24.6–68.9	57.4

There was no correlation between disease incidence and the level of any specific nutrient applied (*Figure 1*).

Figure 1 also shows that there was no correlation between disease incidence and the quantum of annual rainfall.

CONCLUSION

Phytophthora palmivora m.f.1 was for the first time reported to cause black pod and stem canker of cocoa in Sarawak.

Although these diseases of cocoa had been reported elsewhere in Sabah and Peninsular Malaysia previously (Liu & Liew, 1975; Liu 1977; Turner & Shepherd, 1980), the pathogen has been identified as *Phytophthora* sp., *P. heveae, P. meadii, P. nicotianae* var. *parasition* and *P. palmivora.* It was shown in the present studies that metalaxyl was effective for the control of cocoa black pod disease. This concurred with the report of Mc Gregor (1983). The cost effective aspect of this treatment has not been examined in details. Mature pods of hybrids U1T1 x SCA12, NA32 x U1T1 and PA35 x NA32 were less susceptible to *Phytophthora palmivora* m.f.1. infection than the pods of other hybrids tested under laboratory conditions.

Spraying the pink disease-infected branches of cocoa trees with 0.2% a.i. of tridemorph or cuprous oxide reduced lesion extension from the court of infection, indicating their potency against the disease.

When mature cocoa trees which had been suffering from VSD were applied with compound fertilizer of N: P_2O_5: K_2O: MgO at 132.7: 81.7: 176.9: 22.7 g per tree per annum the disease incidence were reduced from 93.0% – 1.7% in two years. Jayawardena *et al.*, (1980) was of the opinion that VSD in any particular situation was complex and

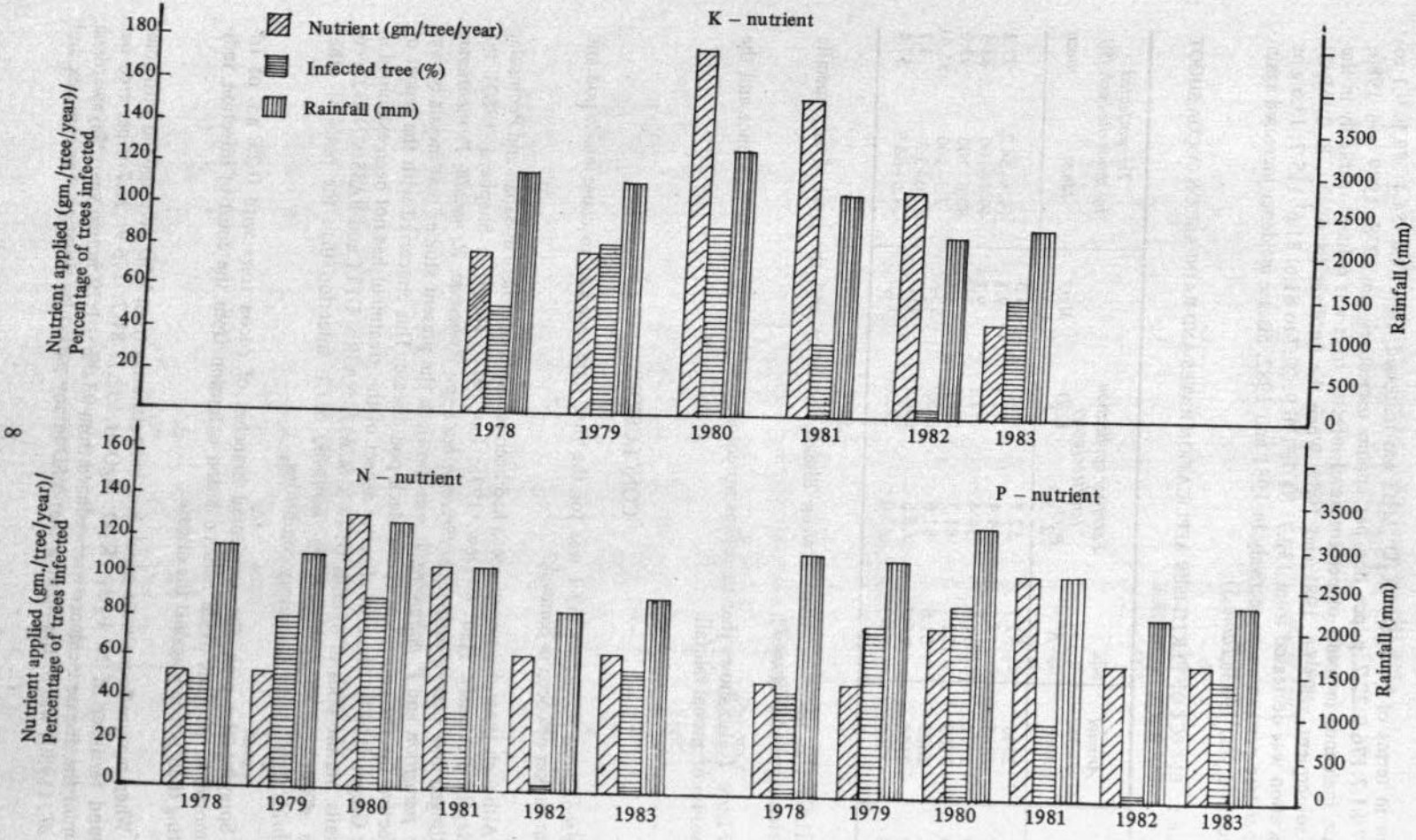


Figure 1. The effect of fertilizer rates and rainfall on cocoa shoot die-back incidence.

possibly attributable to a combination or interaction of several factors though any single factor could be overriding. In the present studies, it was demonstrative that nutrient stress would predispose cocoa trees to VSD incidence.

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ASPECTS OF THE EPIDEMIOLOGY OF VASCULAR STREAK DIEBACK OF COCOA IN MALAYSIA

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Eradicative pruning of vascular streak dieback (VSD) at three weekly intervals was compared with an unpruned control, in a well replicated trial, in mature monoculture cocoa on inland soil. Pruning had no appreciable limiting influence on numbers of new infections during, the first four months. During the subsequent eight months, there was an increase in the number of new infections in pruned trees, compared to the control. This indicated that regular pruning at three weekly intervals is not acceptable. A marked increase in infections were recorded coinciding with rainfall above 200 mm two to three months prior to symptom expression and assessment. The above observations suggest a possible new approach to limit VSD infections in mature cocoa, by pruning affected branches twice per year just before disease favourable periods - heavy rain associated with flushing and an increase in susceptible sites for infection, and a peak for sporulation of the fungus.

In the nursery, initially, VSD symptoms appeared in seedlings sporadically. Infections increased rapidly in the next three months reaching up to 50%.

The fungal pathogen, Oncobasidium theobromae, which causes vascular streak dieback (VSD) of cocoa, remains for most part of its life cycle within the vascular tissues of the host. Appearance of the fungus outside the host occurs only for a brief period during sporulation - infection phase, which coincides with prolonged wet weather conditions (Keane et al, 1972). This aspect of the pathogen, together with the delay in the appearance of symptoms due to a long incubation period of more than two months, makes control of the disease by application of contact fungicides impractical. Hence, eradicative pruning is popularly practised by estates and smallholders. The effectiveness of pruning varies with the system followed. Although critical assessment of pruning as a control measure has not been reported, a pruning interval of three months was suggested as being effective (Chan and Syed, 1976), while others had recommended monthly pruning rounds (Jayawardena et al, 1978; Prior, 1980). Pruning however is

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not feasible for controlling VSD infections in the nursery. Therefore, there is a need to find alternative control measure. Generally, a lack of knowledge of the epidemiology of VSD has hampered improvement of control measures. Hence the authors investigated some aspects of the epidemiology of the disease in Malaysia in field plantings and in the nursery.

MATERIALS AND METHODS

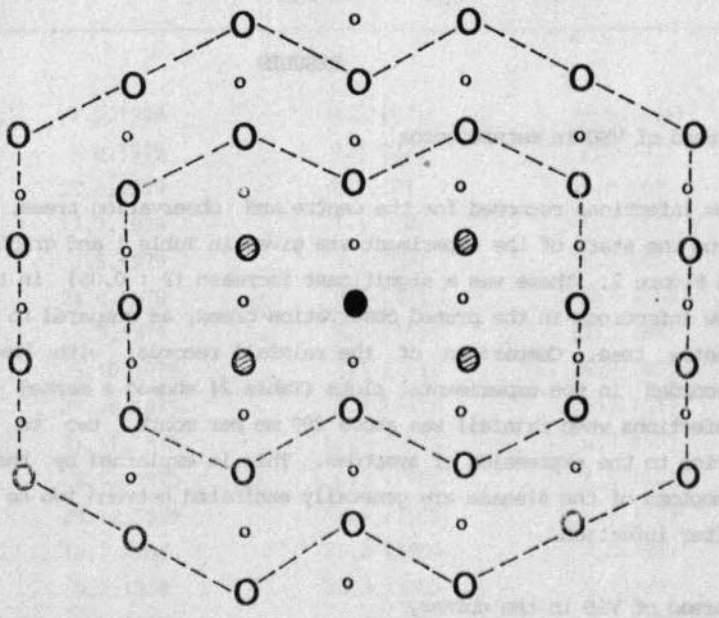
VSD in mature cocoa

A trial was laid out to record the incidence and spread of VSD in a mature stand of mixed hybrid cocoa (1973 planting) in Sagil Estate, Johore. Growth and vigour of trees in the area were very uniform at the start of the trial. No eradicative pruning for VSD control had been carried out in the experimental site for at least one year prior to the trial.

The lay out consisted of experimental plots containing a confirmed VSD infected tree in the centre (providing a natural source of infection) surrounded by four trees (observation trees) marked for recording of all new infections. Thirty trees at the periphery formed two guard rows (See - Figure 1). This was replicated eight times randomly in the field. The mean number of VSD infections for the centre and observation trees were determined at the beginning of the experiment. The mean number of VSD infections for the centre tree was seven while that of the observation trees was four. The centre tree was maintained without eradicative pruning, while the adjacent observation trees and guard row trees were subjected to VSD pruning at three-weekly intervals. Two out of the four observation trees were selected for detailed recording and confirmation of new infections (for reasons of practicality) along with recording of new infections in the centre tree. Recording of each new infection was done by tagging with round aluminium discs and confirmation by isolation of the VSD pathogen. A colour code was used to distinguish each tagging excercise.

Eradicative pruning consisted of cutting of infected branches 15 cm away from the last visible brown streak in the tissue, based on the observation of Keane (1972) that hyphae of the fungus generally did not extend beyond this limit. New infection points were confirmed by isolation of *O. theobromae* on 2% water agar with incorporated streptomycin (0.1 mg per ml).

Figure 1. Lay out of experimental plot in the VSD trial area, Sagil Estate, Johor.



Key:-

- ● Centre tree with confirmed VSD, maintained unpruned.
- O Adjacent trees subjected to eradicative pruning.
- O--O Guard rows.
- o Shade tree - Gliricidia maculata.

VSD in the nursery

Incidence and spread of VSD was recorded in a batch of 2839 seedlings (mixed hybrids) planted in November 1980, in Sagil Estate, Johore, for supplying vacant points. A monthly census of new infections was carried out by the leaf isolation technique (Varghese et al, 1981).

RESULTS

Spread of VSD in mature cocoa

New infections recorded for the centre and observation trees, for one year from the start of the experiment are given in Table 1 and graphically shown in Figure 2. There was a significant increase ($P < 0.05$) in the number of new infections in the pruned observation trees, as compared to the unpruned centre tree. Comparison of the rainfall records, with new infections recorded in the experimental plots (Table 2) showed a marked increase in infections when rainfall was above 200 mm per month, two to three months prior to the expression of symptoms. This is explained by the fact that symptoms of the disease are generally exhibited between two to three months after infection.

Spread of VSD in the nursery

The number of seedlings infected by VSD recorded monthly for a period of 10 months from planting is shown in Table 3. It is interesting to observe that VSD symptoms were not observed during the first six months of planting. However, symptoms of the disease started appearing after this period, coinciding with higher rainfall two to three months prior to expression of symptoms. The disease showed a gradual increase initially, giving rise to a more rapid increase three months after infections were first recorded in the nursery. The pattern of infections in the nursery appeared to be sporadic and random and not aggregated into zones.

Table 1: New VSD infections in pruned and unpruned mature cocoa plantings in epidermiology trial, Sagil Estate, Johore.

Number of recording	Date	Number of new infections per tree	
		Pruned (mean of 16 trees)	Unpruned (mean of 8 trees)
1	11.5.1979	4.2 (67)*	6.6 (53)*
2	1.6.1979	1.4 (23)	2.9 (23)
3	22.6.1979	0.1 (2)	0.8 (6)
4	13.7.1979	1.1 (18)	1.9 (15)
5	3.8.1979	3.7 (59)	3.5 (28)
6	24.8.1979	2.9 (47)	3.1 (25)
7	14.9.1979	9.9 (159)	11.0 (88)
8	5.10.1979	7.1 (114)	6.0 (48)
9	27.10.1979	8.8 (141)	6.0 (48)
10	17.11.1979	10.4 (167)	6.3 (50)
11	8.12.1979	6.3 (101)	6.5 (52)
12	29.12.1979	9.4 (151)	8.8 (70)
13	19.1.1980	21.8 (348)	9.5 (76)
14	9.2.1980	20.3 (325)	8.1 (65)
15	1.3.1980	6.4 (103)	3.4 (27)
16	22.3.1980	7.7 (124)	5.3 (42)
17	12.4.1980	5.0 (80)	2.8 (22)
18	3.5.1980	3.1 (49)	1.5 (12)

* Total number of infections recorded are given in brackets.
Comparison of mean number of new infections (pruned and unpruned) from 5th recording significant at $P < 0.05$.

Figure 2. Mean number of VSD infection points recorded at three week interval.

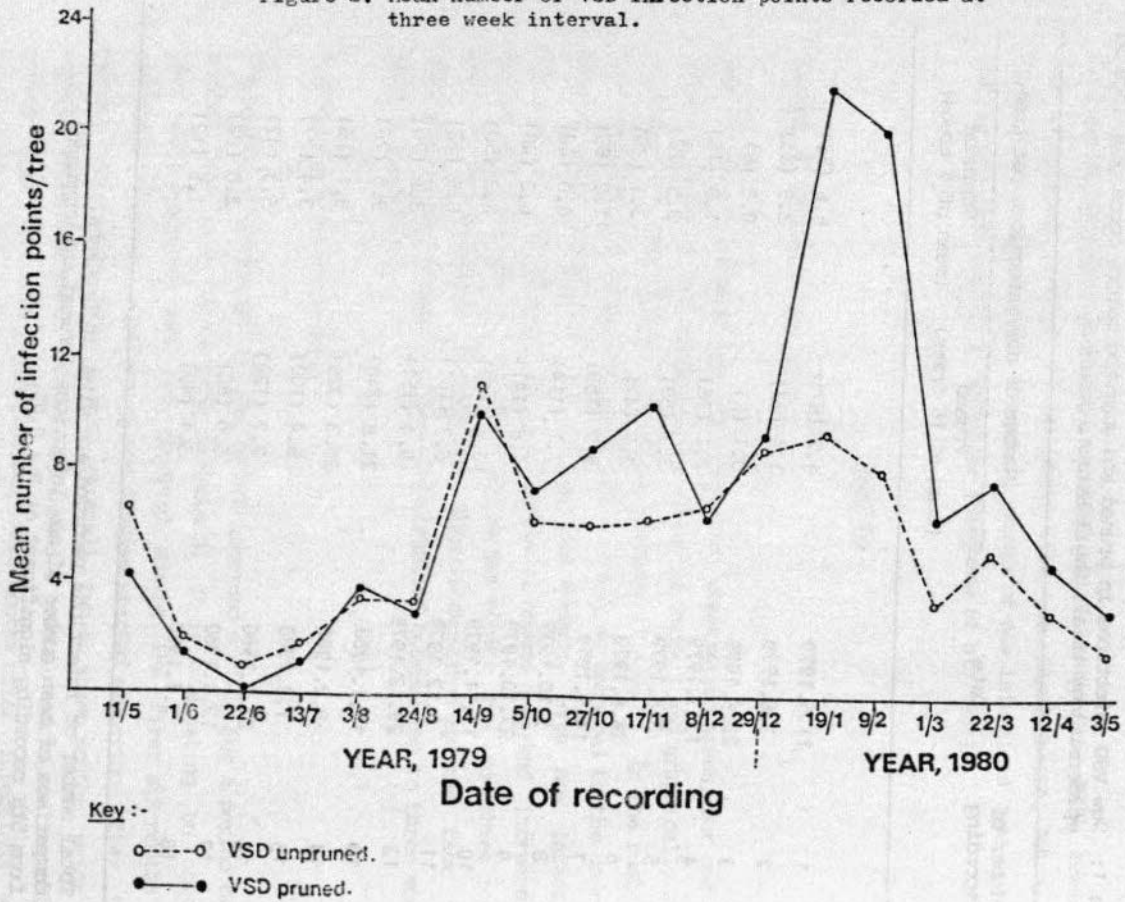


Table 2: Total rainfall recorded in relation to number of infections in VSD-pruned cocoa, epidemiology trial, Sagil Estate, Johore.

Week of recording	Rainfall* (mm)	Number of infections in VSD pruned trees (Total of 16 trees)
3.8.1979	64	59
24.8.1979	189	47
14.9.1979	119	159
5.10.1979	158.5	114
27.10.1979	93	141
17.11.1979	207	167
8.12.1979	157.5	101
29.12.1979	247	151
19.1.1980	293.5	348
9.2.1980	307.5	325
1.3.1980	0	103
22.3.1980	89.5	124
12.4.1980	65	80
3.5.1980	133.5	49

* Total rainfall, recorded between 2 and 3 months prior to recording of infection at Sagil Estate.

Table 3: Incidence of VSD in the cocoa nursery, observed for 10 months at Sagil Estate, Johore (total no of seedlings in the nursery was 2839).

Time after planting (months)	Number of seedlings infected with VSD	Percentage of infected seedlings
1 - 6	0	0
7	36	1.2
8	380	13.4
9	905	31.8
10	1664	58.6

DISCUSSION

Number of new infections in trees subjected to pruning was generally higher than in unpruned trees. The results suggest that pruning at 3-week-interval had not reduced number of new VSD infections when inoculum was available in the vicinity, during disease favourable periods. Presumably, increased frequency of pruning (at shorter intervals) contributed to increase in production of new flushes, providing more susceptible sites for infection. On the other hand, in an unpruned tree there was no such abnormal increase in new flushes and susceptible sites for infection. Infections increased markedly in relation to rainfall when rainfall was above 200 mm per month between two and three months prior to recording of symptoms. Rainfall below 200 mm per month had apparently no influence on new infections.

As pruning is the most popular and practical control measure practised against VSD infection in field plantings, the present results suggest a possible new approach to pruning. Firstly, eradicative pruning for VSD can be carried out at longer intervals. Secondly, since increase in infections was related to a higher rainfall which increased flushing and more susceptible sites for infection, and provided a condusive environment for peak sporulation of the fungus, it appears that ideally, eradicative pruning should be most effective if carried out immediately prior to disease favourable period. Keane et al (1972) had reported that infection by O. theobromae occurred on young flushes by spores of the fungus, which were produced on leaf scars during wet weather period. Thus, pruning carried out just before the wet weather period would greatly reduce inoculum production, and in turn new infections. Therefore, it may be more logical to limit eradicative pruning for VSD, to two times during the year, prior to the two marked rainy seasons experienced in Malaysia. This would not only reduce pruning costs but also the ill effects of excessive pruning. The new approach would however require further field evaluation before it can be recommended as an estate practice.

The incidence of VSD infection in the nursery showed two phases. The first was characterised by a slow rate of increase of the disease while the second consisted of more rapid rate of increase seen three months after infections were first observed. Keane (1981), had attributed the slow

increase to inoculum from outside i.e. from adjacent infected mature cocoa, and the rapid increase to inoculum produced within the stand of seedlings. Therefore, it follows that control measures against the disease in the nursery should consider the following approaches. First, a reduction of external source of inoculum which can be achieved by eradicative pruning of mature cocoa in the vicinity. Second, reduce inoculum generated within the nursery, by roguing infected seedlings in the nursery as early as the symptoms are detected. Third, site the nurseries away from infected mature cocoa. Coupled with these measures, there is also scope for chemical control in the nursery as a preventive and eradicative measure. Screening of several systemic fungicides had shown bitertanol to be the most promising among fungicides tested (Zainal Abidin, 1982; Chung, 1983; Mainstone, et al, 1983). Further research now in progress is envisaged to provide more information on improving the efficacy of chemical control before it can be adopted for practical use.

ACKNOWLEDGEMENT

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P

Photosynthesis and Transpiration of Cocoa Leaves

by

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ABSTRACT

Photosynthesis and transpiration of attached cocoa leaves under controlled conditions were measured using infrared gas analysers for carbon dioxide and water vapour. Photosynthetic rates obtained correspond to that for shade plants. Maximum photosynthesis was 17.1×10^{-5} g $m^{-2} s^{-1}$ at about 400 μ Einsteins $s^{-1} m^{-2}$ which corresponds to about 20% full sunlight. Stomata resistance decreased gradually with increasing light intensities to reach 320 s m^{-1} at light saturation point. The amount of water transpired at this point was 5.37×10^{-3} g $m^{-2} s^{-1}$.

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INTRODUCTION

Photosynthesis of cocoa leaves was previously determined indirectly by growth analysis methods and expressed as Nett Assimilation Rates (Raja Harun & Ismail 1983; Okali and Owusu, 1975; Goodal, 1955) or directly by the use of $^{14}CO_2$ on field plants (Hutcheon 1976) or by the use of leaf discs under laboratory conditions (Okali and Owusu, 1975). In addition to being destructive these techniques did not allow for elaborate control over leaf temperatures and humidities which play an important role in transpiration and photosynthesis.

The following investigation sets out to determine photosynthesis and transpiration of attached cocoa leaves under more controlled environmental conditions of temperature, humidity and ambient carbon dioxide.

MATERIALS & METHODS

Five-month old cocoa seedlings of the Amelonado type grown in 15 cm diameter pots raised under heated glass house conditions at the Botany Department, University of Liverpool, Liverpool, England were used in this experiment.

The most recent hardened flush leaf, still attached to each plant, was enclosed in a water-jacketed leaf chamber supplied by air (at 5 l min^{-1}) of known CO_2 concentration and humidity level. Air within the chamber was circulated by a fan to reduce boundary layer resistance.

Air supplied to the leaf was pumped from the roof of the three-storey building and mixed in two 180 litre drums to even out short term fluctuations in CO_2 levels. To generate air at known water vapour pressure (humidity levels) air was bubbled through two 2.5 litre flasks of water, 1 meter of coiled copper tubing and two empty flasks in a water bath at preset temperature to saturate and condense the water vapour respectively.

Chamber temperature was maintained by circulating water at the desired temperature in the upper and lower jackets of the leaf chamber using a thermochiller. Leaf temperature was monitored using a thermocouple pressed against the under surface of the leaf. This thermocouple was attached to a cold-joint compensator and connected to a chart recorder. Calibration of this themocouple was done against a mercury-in-glass thermometer with an accuracy of $0.2^{o}C$.

Lights used in the experiment were two high pressure mercury lamps with a 10 cm water screen to reduce their heating effects. Light intensities were varied by using muslin screens and monitored using a quantum sensor placed within the chamber.

The measurement of photosynthesis and transpiration was carried out using ADC Infra red gas analysers for carbon dioxide and water vapour and were calibrated in differential mode. Adaptation time of 24 hours was allowed for each leaf to equilibrate within the chamber before any measurements were taken and at least 20 minutes were allowed for stabilization at each light intensity. The measurements were made on three intact leaves and averaged.

Details of the calculations can be obtained in Sestak et al (1971b) and Long (1982).

Experimental set up is represented in Fig. 1 and conditions during the experiment can be summarized as follows :

Ambient CO_2 = 360 µl l^{-1}, ambient water vapour pressure = 19.5 mb, average leaf temperature at saturating light intensity = 21.38°C and water vapour pressure deficit at this intensity = 6.16 mb (76% RH).

RESULTS AND DISCUSSION

The light saturation curve obtained (Fig. 2) corresponds to the usual light saturation curves for other species (Zelitch, 1971) where photosynthesis increases linearly at low light intensities and reaches a plateau at higher light levels. Values achieved are as for shade plants where 85% of maximum net photosynthesis (P_{max}) is reached at the low light intensity of 105 µE $s^{-1}m^{-2}$ corresponding to 5.25% full sunlight. P_{max} obtained was 17.1 g CO_2 $m^{-2}s^{-1}$ at 400 µE $s^{-1}m^{-2}$ which is approximately 20% full sunlight. P_{max} value observed is within the range obtained for other shade plants (Sestak et al 1971a) or for cocoa seedlings (Okali & Owusu, 1975; Hutcheon, 1976). Saturation at about 20% full sunlight was previously observed by Raja Harun & Ismail (1983) and Okali & Owusu (1975). Also, similar to other shade plants, light compensation point obtained was at a very low light intensity of 4 µE $s^{-1}m^{-2}$.

Stomatal response to increasing light intensities can be seen in Fig. 3. Stomatal resistance (R_s) is high (1,200 sm^{-1}) under low light, gradually decreasing to a value of 320 sm^{-1} at 400 $\mu E\ s^{-1}m^{-2}$, i.e. at P_{max}. Increasing stomatal aperture (i.e. decreasing R_s) with increasing light intensity is reflected in increasing net photosynthesis (Fig. 4). This relationship is linear and is very significant.

The average amount of water transpired at 400 $\mu E\ s^{-1}m^{-2}$ i.e. at maximum stomatal aperture (minimum R_s) was calculated to be 5.37×10^{-3} g $H_2O\ m^{-2}s^{-1}$ which is 31 times relative to the amount of CO_2 uptake. Although the amount of water transpired for other "sun" plants (Cucumis sativus, spinacea oleracea and Phaseolus vulgaris (Bull, 1969) is considerably larger, transpiration to photosynthesis ratios at light saturation level are of the same order. A reduction in leaf temperature by $1^{o}C$ which correspondingly reduces water vapour pressure deficit in the leaf environment from the present 6.2 mb (76% Relative Humidity) to 4.5 mb (81% Relative Humidity) reduces water usage. The amount of water used was 4.01×10^{-3} g $H_2C\ m^{-2}s^{-1}$ which corresponds to 24 times the amount of CO_2 fixed.

CONCLUSION

Cocoa is a typical shade plant. Leaves from recent hardened flush achieves maximum photosynthesis and maximum stomatal aperture at about 20% full sunlight. 85 percent maximum photosynthesis can be attained at 5% full sunlight. Water use efficiency is similar to other C_3 species and can be increased by lowered water vapour pressure deficit through lower leaf temperatures.

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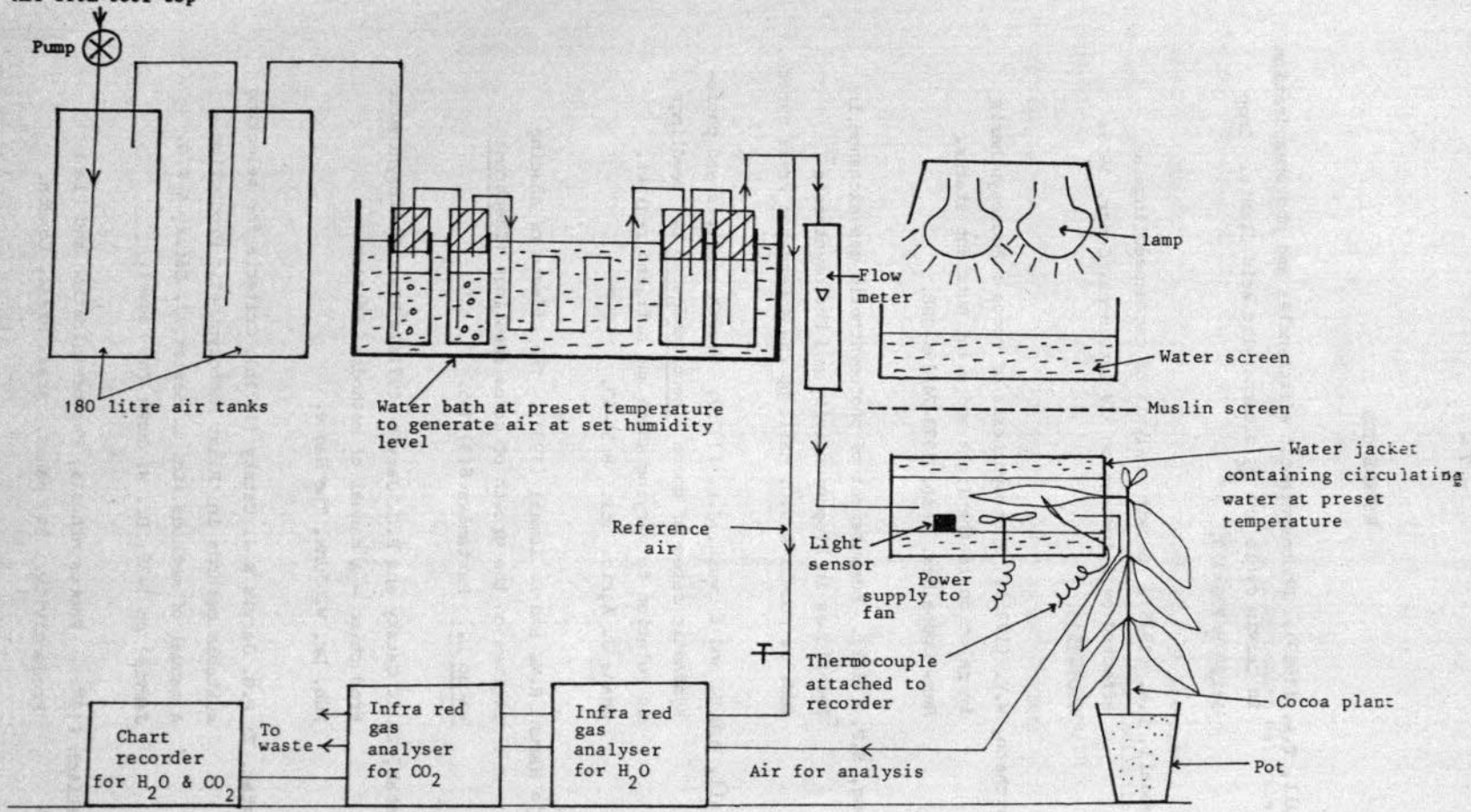


Fig.1 Schematic diagram of the system for measurement of photosynthesis and transpiration of cocoa leaves.

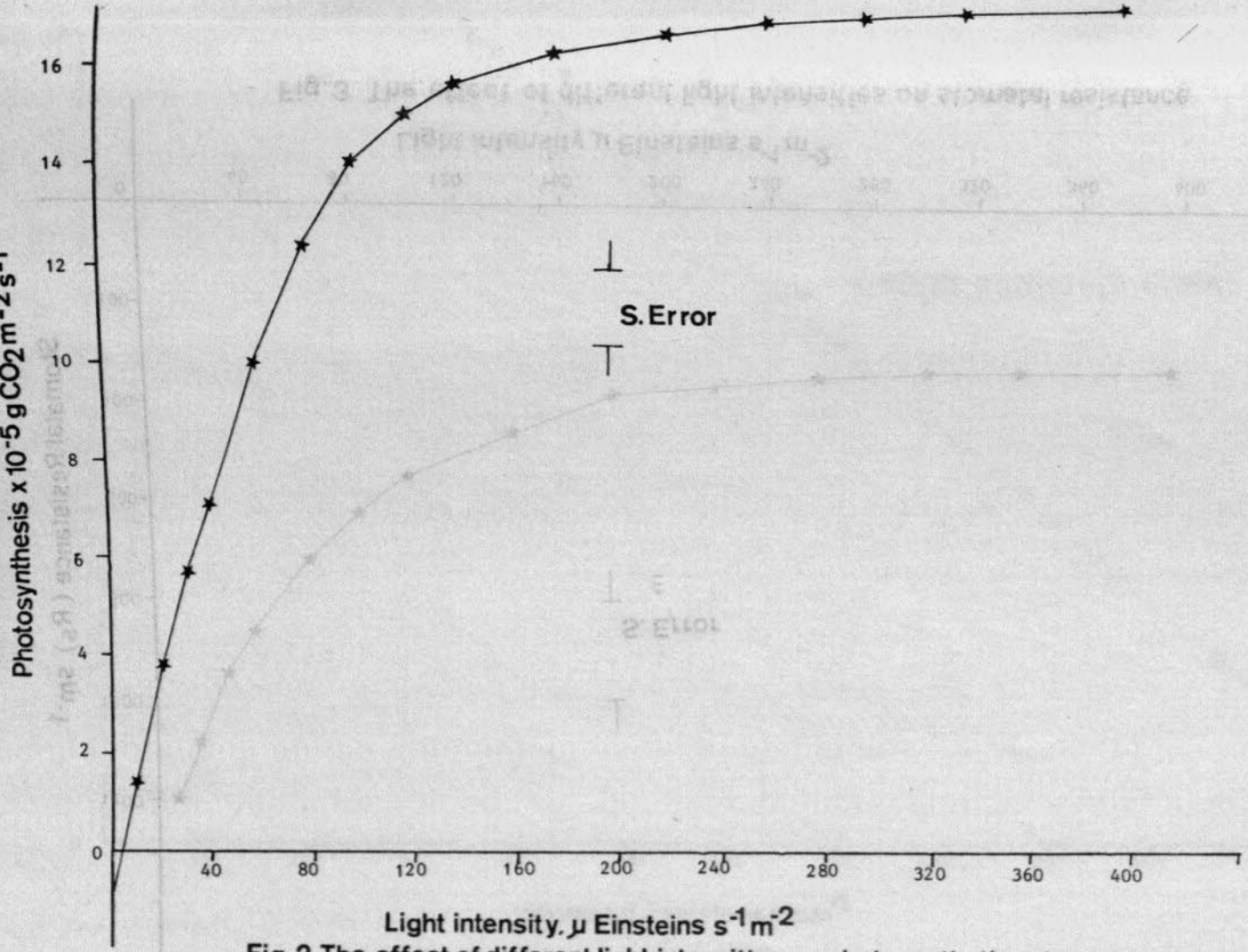


Fig. 2 The effect of different light intensities on photosynthetic rates

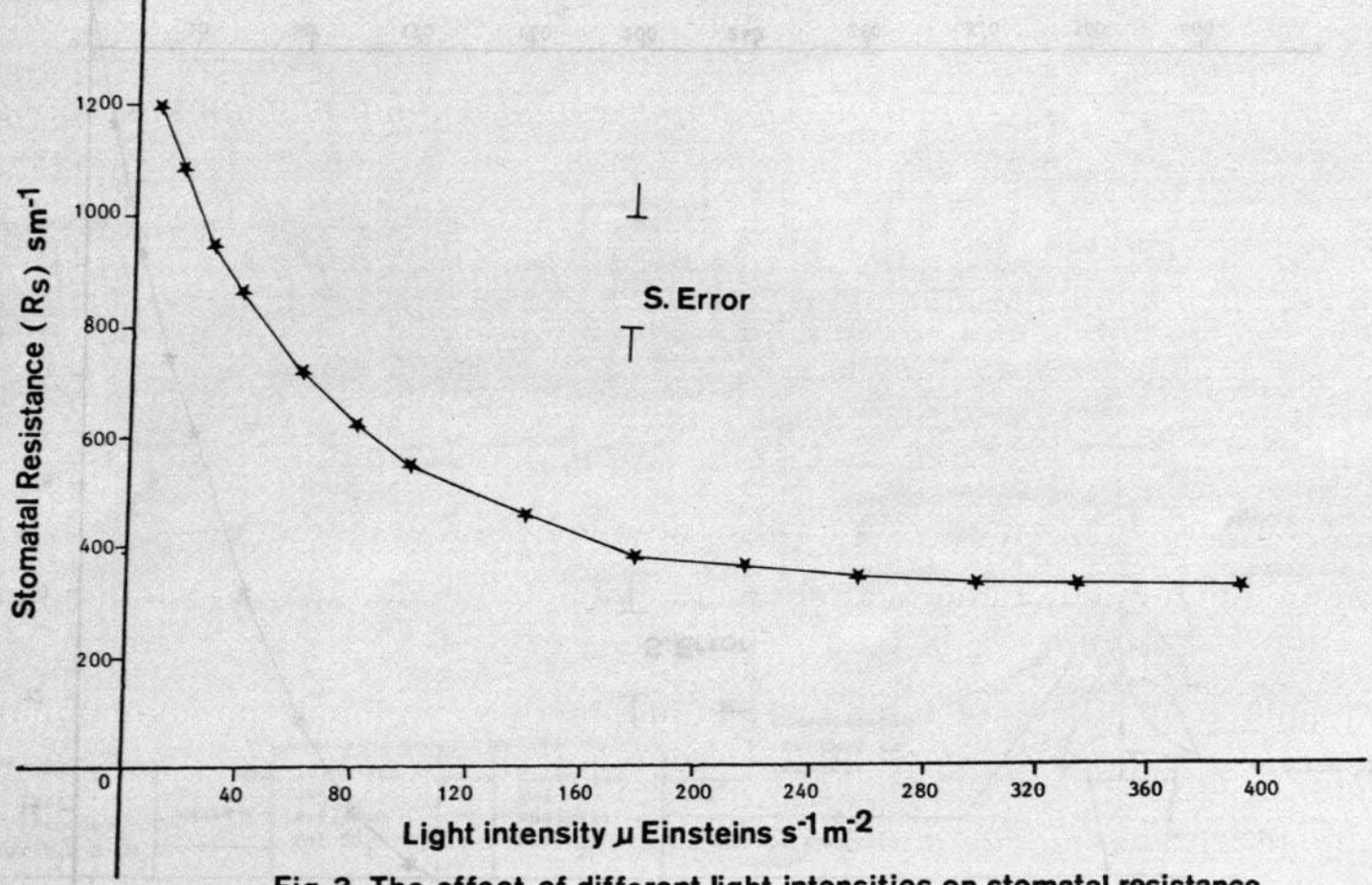


Fig. 3 The effect of different light intensities on stomatal resistance

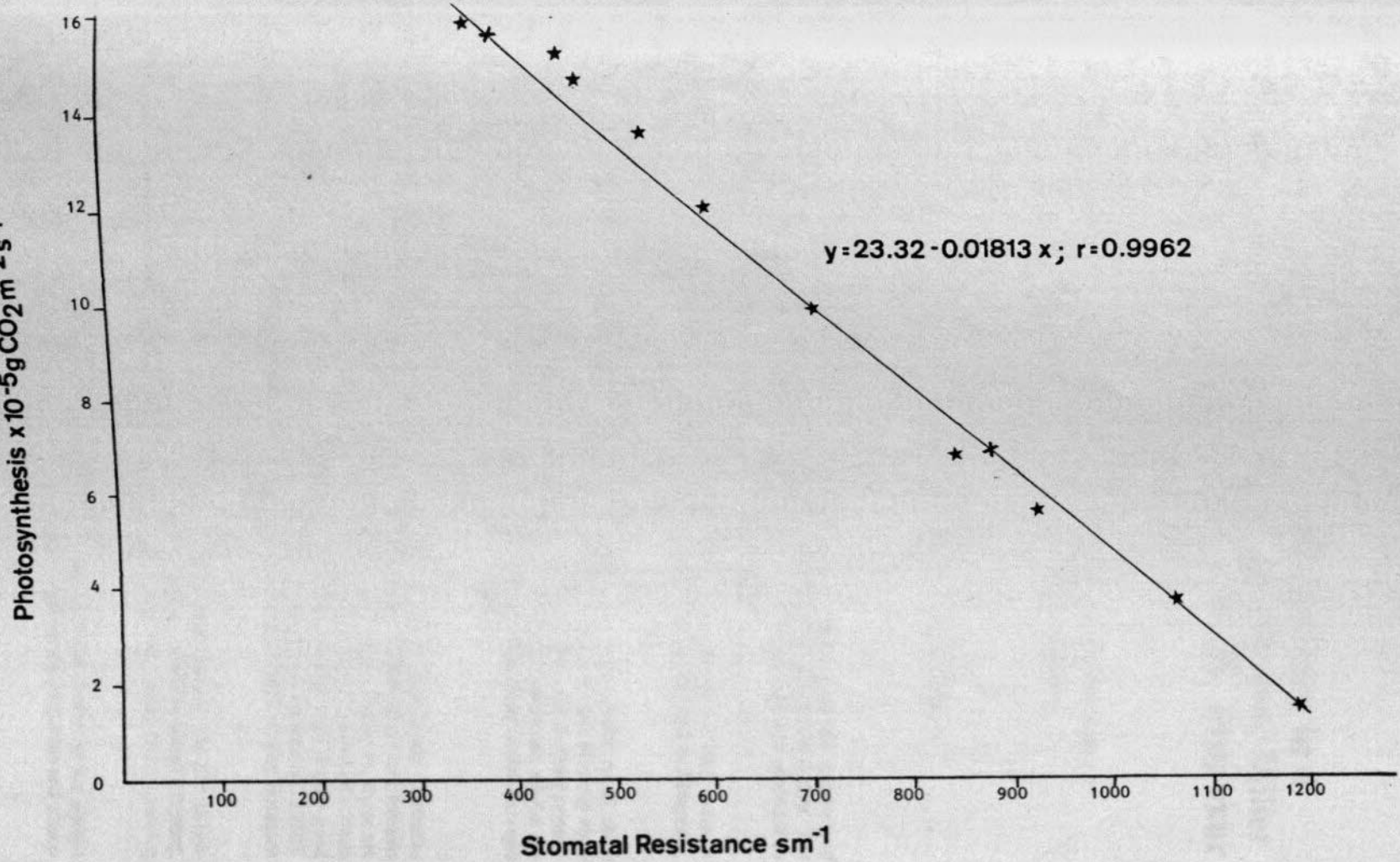


Fig.4 The relationship between photosynthesis and stomatal resistance

P

Preliminary Study of Resistance in 4 Populations of *Helopeltis theobromae* Miller (Hemiptera: Miridae) to γ — HCH, Propoxur and Dioxacarb

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Four populations of Helopeltis theobromae *Miller were investigated for the existence of resistance to γ-HCH, propoxur and dioxacarb by means of time-response assays. The insects were confined on treated filter paper and time to knockdown was recorded to establish lethal exposure time (LT50) and percentage survival.*

The order of sensitivity to γ-HCH was Serdang > Bagan Datoh > Teluk Intan > Kajang; to propoxur, Serdang > Bagan Datoh > Teluk Intan = Kajang; and to dioxacarb, Serdang > Kajang > Bagan Datoh > Teluk Intan.

The Serdang population was consistently most sensitive or susceptible to all three insecticides. The Kajang population could be considered as the only one showing vigor tolerance or resistance, having an LT50 value three times higher than the Serdang population; the survival after 4 h continuous exposure was 36% for the former and nil for the latter. The existence of differential sensitivity to each of the three insecticides between the four populations indicates an impending resistance problem.

The mirid *Helopeltis theobromae* Miller is a major pest of cocoa in Malaysia. It attacks the pods and shoots and can cause severe damage if unchecked. Chemical control remains the most effective and efficient way of controlling mirids in cocoa. However, there are only a few insecticides suitable, the choice of which is governed by a number of criteria (Marchart, 1971; Entwistle, 1972). Trials in West Africa showed that γ-HCH gave good control of cocoa mirids (Mapother, 1955; Donald, 1957; Stapley & Hammond, 1959). The insecticide has several favourable properties which include a quick, strong fumigant action (Raw, 1959) and low persistence (Entwistle, 1972).

The insecticide then came into widespread use in cocoa against mirids. The first indication of mirid resistance occurred in 1961 and was confirmed in 1962 in Ghana (Telford, 1964). Since then resistant strains have been found in the two major cocoa growing countries of Ghana and Nigeria (Omole and Ojo, 1981).

Following the trials in West Africa γ-HCH also became a popular choice for use against *H. theobromae* in Malaysia. Although other insecticides, principally propoxur and dioxa-

carb, are being used, γ-HCH remains the preferred insecticide largely because of its low cost. However, there have been reports that inconsistent results have been obtained when γ-HCH was used. This paper reports our initial investigations into the problem. The insecticides propoxur and dioxacarb were included in our studies for comparison with γ-HCH; the data obtained would also be useful for future resistance studies as these chemicals may replace γ-HCH.

MATERIALS AND METHOD

Test Insects

Four populations were tested for their responses to the insecticides:

Kajang population: The mirids were collected from an area where γ-HCH has been used for a long time. At the time of testing, the mirids had been reared for 21 generations (F21).

Telok Intan and Bagan Datoh populations: There has also been a long history of γ-HCH usage in the localities. The F1 generation was tested.

Serdang population: Unlike the populations above which were originally collected from cocoa, this population was collected from *Acalypha* sp., an ornamental plant commonly grown for its colourful variegated leaves. Insecticides of any kind were rarely used against pests attacking the plant. The F1 generation was tested.

The test insects were obtained using the rearing technique described by Rita and Khoo (1983). The original populations collected from the field consisted of nymphs in their late instars.

In all tests, the fourth and fifth nymphal instars were used.

Insecticides

Technical grade samples of γ-HCH 90%, propoxur 99.2% and dioxacarb 99.2% were used in all experiments.

Measurement of Resistance

The technique used was that recommended by the FAO for detecting cocoa mirid resistance to insecticides (Busvine, 1980) and was originally described by Telford (1964). This method uses time as a dosage variable and knockdown is shown as a function of the time of exposure to the insecticides.

Stock solutions of the insecticides in olive oil were prepared in the following concentrations: 0.5% for γ-HCH, 0.1% for propoxur, and 0.1% for dioxacarb. The stock solutions were kept in the refrigerator at approximately 5°C until required. A volatile solvent consisting of three parts petroleum ether and one part acetone was prepared as required. The mixture used for impregnating the test paper was made up of one part of the insecticide stock solution and three parts of the volatile solvent. For the control the mixture contained the same proportion of olive oil and volatile solvent but without the insecticide.

The test paper was a 12 x 15 cm chromatographic paper (Whatman No. 1) onto which 3 ml of the mixture was evenly applied. The treated paper was hung in a fume hood and allowed to dry for 24 h.

The paper was then used to line a 125 mm height x 51 mm diameter plastic cylinder. (The plastic cylinder was the type supplied by the World Health Organization for testing resistance in mosquitoes.) The bottom end of the cylinder was capped with a lid of wire mesh and the top end with a petri dish instead of a perspex disk as described in the original method. The underside of petri dish was coated with Permatex (R) silicone lubricant to prevent the mirids for alighting on it.

Ten nymphs were introduced into each cylinder. Observations were made after 10, 20, 40, 80 etc. minutes (in geometric progression) until 70–80% knockdown was achieved. Knockdown was considered to have occurred when nymphs failed to cling to the filter paper and were unable to regain their normal posture when gently prodded with a fine soft brush. A test consisted of five replicates of the insecticides cylinders and two with control papers. If knockdown was observed in the control the data in the treatment was corrected by Abbott's formula: however, if knockdown in the control exceeded 10%, the test was repeated.

The tests were carried out in the laboratory which was maintained at 27 ± 2°C and 80 ± 10% relative humidity.

Knockdown figures were plotted against time on logarithmic probability paper and the time response regression lines were obtained. The lethal exposure time (LT50) was determined from this line.

RESULTS

Table 1 shows the responses of the four population of *H. theobromae* to γ-HCH, propoxur and dioxacarb. The resultant regression lines (*Figure 1*) were highly significant ($P < 0.01$) with regression coefficients ranging from 0.96–0.99. The orders of sensitivity, as given by the LT50 values and percentage survival after 4 h continuous exposure were: to γ-HCH, Serdang > Bagan Datoh > Telok Intan > Kajang; to propoxur, Serdang > Bagan Datoh > Telok Intan = Kajang; and to dioxacarb, Serdang > Kajang > Bagan Datoh > Telok Intan. It will be noted that the Serdang population was consistently most sensitive or susceptible to all three insecticides. Resistance ratios were then calculated based on the Serdang population, for the Telok Intan, Bagan Datoh and Kajang populations and are given in *Table 2.*

DISCUSSION

The highest resistance ratio recorded was for the Kajang populations to γ-HCH at a value of approximately 3. A resistance ratio of 3 or less is not sufficiently high to allow one to conclude the existence of a resistant strain. O'Brien (1967) has pointed out that it is difficult to provide explanations for a toxicity difference which is only four-fold, for instance, because differences of this magnitude could be caused by very small differences in any one of a variety of factors. A resistance factor of at least four-fold was arbitrarily chosen by Nyamasyo and Karel (1982) as of practical importance since values above this would be greater than the range of normal variation and could be taken as a warning of the development of resistance. The inconsistent results reported by local cocoa growers

TABLE 1. RESPONSE OF 4 *H. THEOBROMAE* POPULATIONS TO γ-HCH, PROPOXUR AND DIOXACARB

Populations	*γ-HCH*			*Propoxur*			*Dioxacarb*		
	LT50 (min)[a]	*Slope*	*Survival (%)*[b]	*LT50 (min)*[a]	*Slope*	*Survival (%)*[b]	*LT50 (min)*[a]	*Slope*	*Survival (%)*[b]
Serdang	62	4.82	0	74	4.43	0	221	5.06	30
Telok Intan	101	5.07	3	145	5.67	11	349	5.08	68
Kajang	181	4.01	36	148	4.60	16	295	3.94	60
Bagan Datoh	80	4.31	0	105	4.57	0	313	4.26	64

[a] LT50 : Lethal exposure, time corresponding to 50% knockdown of test insects.

[b] After 4 h continuous exposure.

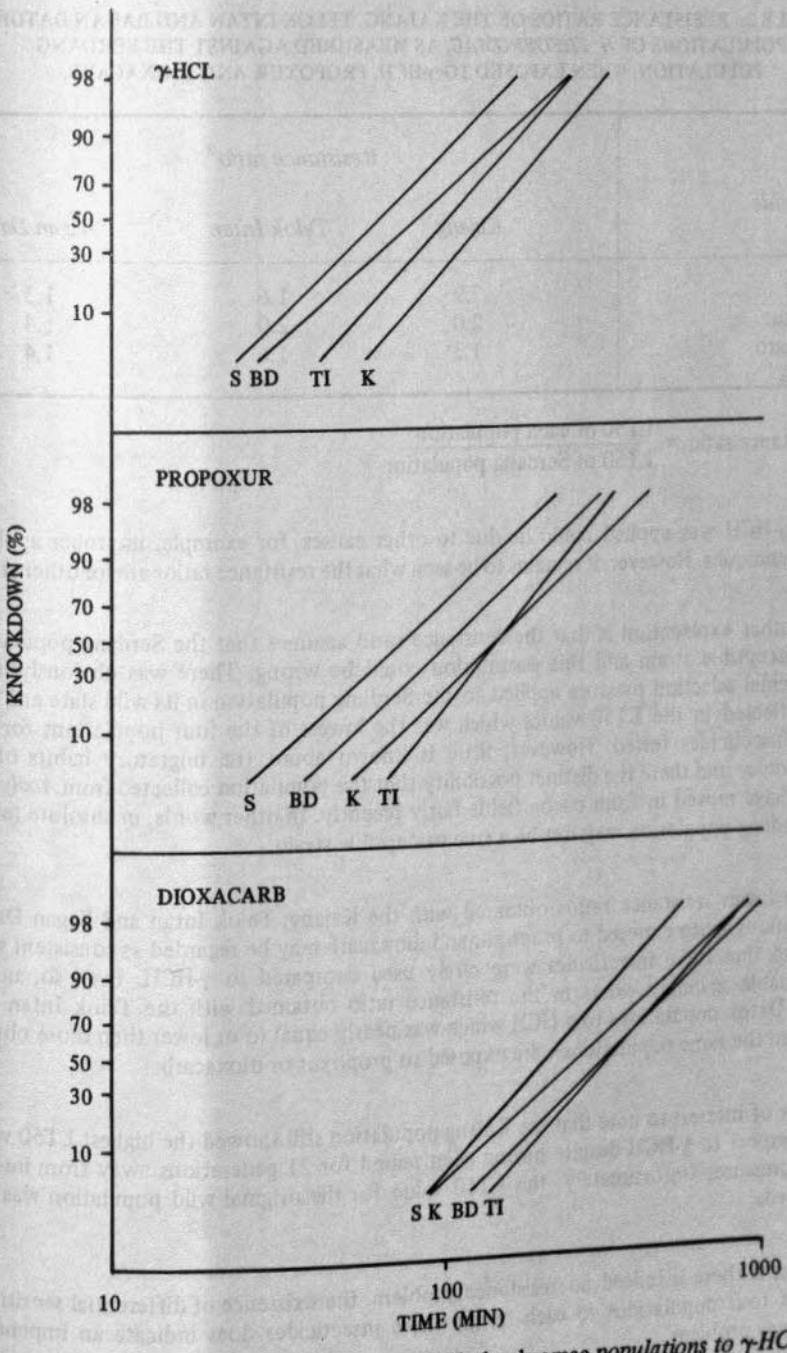


Figure 1: Time-knockdown response of 4 H. theobromae *populations to γ-HCH, propoxur and dioxacarb.*

S – Serdang population
BD – Bagan Datoh population
TI – Teluk Intan population
K – Kajang population

TABLE 2. RESISTANCE RATIOS OF THE KAJANG, TELOK INTAN AND BAGAN DATOH POPULATIONS OF *H. THEOBROMAE*, AS MEASURED AGAINST THE SERDANG POPULATION, WHEN EXPOSED TO γ-HCH, PROPOXUR AND DIOXACARB.

Insecticide	*Resistance ratio*[a]		
	Kajang	*Telok Intan*	*Bagan Datoh*
γ-HCH	2.9	1.6	1.3
Propoxur	2.0	2.0	1.4
Dioxacarb	1.3	1.6	1.4

[a] Resistance ratio = $\frac{\text{LT50 of each population}}{\text{LT50 of Serdang population}}$

when γ-HCH was applied could be due to other causes, for example, improper application techniques. However, it remains to be seen what the resistance ratios are for other areas.

Another explanation is that the resistance ratio assumes that the Serdang population is a susceptible strain and this assumption could be wrong. There was obviously little insecticidal selection pressure applied to the Serdang population in its wild state and this was reflected in the LT50 values which was the lowest of the four populations for the three insecticides tested. However, little is known about the migratory habits of *H. theobromae* and there is a distinct possibility that the population collected from *Acalypha* could have moved in from cocoa fields fairly recently. In other words, in absolute terms, the Serdang population may not be a true susceptible strain.

The lower resistance ratios obtained with the Kajang, Telok Intan and Bagan Datoh populations when exposed to propoxur and dioxacarb may be regarded as consistent with the fact that these insecticides were rarely used compared to γ-HCH. Even so, an unexplainable anomaly exists in the resistance ratio obtained with the Telok Intan and Bagan Datoh populations to γ-HCH which was nearly equal to or lower than those obtained when the same populations were exposed to propoxur or dioxacarb.

It is of interest to note that the Kajang population still showed the highest LT50 value with respect to γ-HCH despite having been reared for 21 generations away from insecticidal pressure. Unfortunately, the LT50 value for the original wild population was not obtained.

Even if there is indeed no resistance problem, the existence of differential sensitivity by the four populations to each of the three insecticides does indicate an impending resistance problem.

Further work will reveal more about the extent of resistance by *H. theobromae* to insecticides, in particular γ-HCH, and the data obtained in this study will provide a basis for comparison in future experiments.

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P

Interrelationship of Daily Movements and Home Range Sizes to Cocoa Rat Population Densities and Their Implications on Control Strategies

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The daily movements and home range sizes of the dominant pest rat species of cocoa, Rattus tiomanicus *(Miller), and their interrelationship with population density was studied. The rats were trapped, marked, and released in three 0.74 ha trapping grid for three trap-rights at 17– 19 day intervals. Male rats tended to be more mobile than females, and older animals moved further and had larger home ranges than younger ones. A linear negative relationship between the mean distance moved by adults and subadults to population density was observed. Home range sizes, however, did not show any relationship to fluctuations in population density. This paper discusses the implications of these factors in rat control strategies.*

Controlling rat pests of cocoa with chemicals has been the common practice among cocoa-growers. Fields are baited when the damaged pods exceed 5% of the total yield (Williams, 1973) and stopped when bait-uptake falls below 20–30% (adapted from oil palm control recommendation; from Wood & Liau, 1978). Baitings have become quite routine and mechanical so that they sometimes become inefficient and economically unsound. Luckman & Metcalf (1975) pointed out that modern pest management must rely on sound ecological principles. Sanderson (1966) singled out that an adequate knowledge of the pest movements was necessary for control success.

This paper examines the daily movements and home range sizes of the dominant rat species of cocoa, *Rattus tiomanicus* (Miller). Their interrelationship with pest population densities was also investigated, and the implication of these factors on the chemical control are discussed.

METHODS

The movements, home ranges and population densities data were obtained from studies carried out between March 1980 to November 1981 at Kuala Bernam Estate, near Teluk Intan, Perak. The rats were trapped in three field areas (Fields 1, 35 and 36), in a trapping grid each approximately 0.74 ha in size. The cocoa trees in these fields were about seven years old and were interplanted with MAWA coconut variety.

200 traps were used in a 10 x 10 trapping grid in each field. Two traps were placed at each trap-point; one on the ground and the other tied to a branch spaced about 6.1 m (20 ft) apart. Animals were trapped live for three trap-nights at 17 – 19 day intervals.

Rats caught were categorised to species, sex, weight, trap location and position and reproductive conditions (male: testis scrotal or abdominal; female: vagina perforated or unperforated, pregnant or lactating). Animals were ear-tagged with numbered Monel metal No. 1 fingerling tags and released at their points of capture.

The population was estimated using the direct enumeration of population size (Krebs, 1966) (*i.e.* the minimum number of rats alive at any one time was obtained by summing (i) the actual number of individuals caught at that time, and (ii) the number of previously marked individuals caught at future sampling periods but not at the current trapping). Movement was measured by the average length moved between the two consecutive capture points at which the animal was trapped during the three trap-nights. Home range was estimated by a computer programme written by Dunsworth (1976) which was based on a model by Koeppl *et al.* (1975). The programme computes from a bivariate normal model an elliptical home range as well as calculates the centre of activity. Results were based on 10 or more captures. The A1 formulae proposed by Jennrich & Turner (1969) and Mazurkiewicz (1969) was adopted in this study when making comparisons on the animal's home range sizes. The preference for this method has been discussed by Madden & Marcus (1978).

To facilitate comparisons, the animals were grouped into three classes based on their weights: adults $\geqslant$ 90 g, subadults 60–89 g, and juveniles $\leqslant$ 59 g. These weights were chosen based on an earlier study (Kamarudin, 1983).

RESULTS

The order of relative abundance of rats trapped at Kuala Bernam Estate were *Rattus tiomanicus* (Miller) 98.2% (1532 rats), *Chiropodemys gliroides* Blyth 1.2% (19 rats) and *R. exulans* (Pearle) 0.6% (9 rats). The minimum number of *R. tiomanicus* known to be alive in the 0.74 ha trapping grids of Fields 1, 35 and 36 tended to vary between 34 and 135, 7 and 54 and 7 and 99 rats, respectively. Although there appeared to be more males than females in the population, the ratio was not significantly different. About 79% and 93% of *R. tiomanicus* and *C. gliroides*, respectively, were caught in traps above ground as compared to only 11% for *R. exulans*.

Though trapped rats weighing 16–178 g were captured throughout the study period, a large proportion of the animals was adults ($\geqslant$90 g – male 64.5% and female 53.9%); the rest comprised subadults (60–89 g – male 20.4% and female 28.3%) and juveniles ($\leqslant$59 g – male 15.1% and female 17.8%).

Movement

Distance moved within a three trap-night period showed significant differences ($P \leqslant 0.05$) between the three age-weight classes. Adults travelled furthest, and subadults moved further than juveniles. Males also travelled significantly further than females ($P \leqslant 0.05$), although subadult females in Fields 35 and 36 showed greater length of movements than males (*Table 1*).

The farthest distance travelled was 79.5 m recorded for adult and subadult males. The extent of movements by the three age-weight classes showed that 37% and 48% adult males and females, respectively, travelled less than 6.1 m. For subadults, 57% males and 49% females moved within this distance, while in the juveniles, 57% males and 74% females exhibited similar length of movements. As the distance of travel increased, the proportion of animals which moved that distance decreased *(Table 2)*.

TABLE 1. MOVEMENTS OF *RATTUS TIOMANICUS* (MILLER) IN FIELDS 1, 35 & 36 – DURING A THREE TRAP-NIGHTS PERIOD

Category	Mean Distance travelled (m ± se)			Maximum Distance travelled (m)		
	Field 1	Field 35	Field 36	Field 1	Field 35	Field 36
Adults:						
Male	14.54 ± 3.30 (366)	16.33 ± 1.39 (18)	10.84 ± 1.02 (18)	79.51	36.58	43.10
Female	10.13 ± 2.17 (326)	11.39 ± 1.05 (10)	7.92 ± 0.52 (16)	60.06	36.58	36.58
Subadults:						
Male	8.78 ± 2.83 (100)	8.92 ± 1.57 (11)	8.73 ± 1.38 (14)	79.51	31.09	24.34
Female	8.69 ± 2.73 (104)	16.89 ± 2.77 (11)	9.19 ± 1.89 (14)	54.54	42.67	27.25
Juveniles:						
Male	7.35 ± 3.18 (46)	10.34 ± 1.72 (9)	5.76 ± 0.94 (7)	32.84	8.63	6.10
Female	6.41 ± 3.19 (50)	5.77 ± 1.09 (5)	3.76 ± 0.36 (6)	14.30	12.19	6.10

Figures within brackets indicate sample sign

TABLE 2. NUMBERS AND PERCENTAGE DISTRIBUTION OF RATS FOR VARIOUS LENGTH OF MOVEMENTS DURING ONE THREE-NIGHT TRAP PERIOD*

Distance moved (m)	Adults		Subadults		Juveniles	
	Males	Females	Males	Females	Males	Females
0 – 6.1	229 (36.9)	282 (47.5)	96 (56.5)	97 (48.5)	51 (57.3)	69 (74.2)
6.2 – 12.2	122 (19.7)	163 (27.4)	39 (22.9)	55 (27.5)	19 (21.3)	14 (15.1)
12.3 – 18.3	84 (13.5)	82 (13.8)	22 (12.9)	24 (12.0)	16 (18.0)	5 (5.4)
18.4 – 30.5	85 (13.7)	48 (8.1)	9 (5.3)	16 (8.0)	2 (2.2)	2 (2.2)
30.6 – 48.8	75 (12.1)	16 (2.7)	2 (1.2)	7 (3.5)	1 (1.1)	3 (3.2)
48.9 – 73.2	23 (3.7)	3 (0.5)	0	1 (0.5)	0	0
73.3 – 109.8	2 (0.3)	0	2 (1.2)	0	0	0

* data pooled for three fields.

The mean distances travelled by rats from the various age-weight classes during a three trap-night period to total minimum number of rats alive showed highly significant relationship for adults of Field 1 ($r = -0.6379$, $p = 0.003$) and subadults for Field 1 ($r = -0.6675$, $p = 0.003$) and 35 ($r = -0.6399$, $p = 0.008$). When the data was pooled, the interrelationship was also significant for both fields *(Table 3)*. Juveniles and the animals in Field 36, however, did not show any of these relationships.

TABLE 3. SUMMARY ON THE CORRELATION ANALYSIS BETWEEN THE MEAN DISTANCE TRAVELLED BY RATS OF VARYING AGE-GROUPS WITHIN A THREE TRAP–NIGHTS PERIOD AND POPULATION DENSITY FOR FIELDS 1, 35 & 36.

Age-weight classes	Field 1	Field 35	Field 36
Adults			
r	-0.6379	-0.0353	-0.2405
p	0.0033 **	0.1502	0.2005
n	19	18	30
Subadults			
r	-0.6675	-0.6399	-0.1265
p	0.0034 **	0.0076 **	0.5214
n	17	16	28
Juveniles			
r	0.0703	-0.4007	-0.0881
p	0.8372	0.2220	0.6756
n	11	11	25
Pooled			
r	-0.7931	-0.5443	-0.2458
p	0.0001 **	0.0160 *	0.1904
n	20	19	30

r correlation coefficient
p probability
n sample size
*,** significant different at P = 0.05 and P = 0.01, respectively

Home Range

The size of the rats' home range was calculated based on 10 or more captures (*Table 4*). The results mainly, therefore, were from data collected over an extended period of time so that individuals often matured from one age-class to another. To allow for changes in age, home ranges were computed and grouped under adults, subadults, juveniles-subadults, and juveniles-adults depending on their weight at first and last capture. Only Field 1, with a large sample size, was statistically tested and there were significant differences in the mean home range areas for males at the various age groups ($p \leqslant 0.01$). Least significant difference (LSD) test showed only the adults and the juveniles-subadults age-groupings to differ significantly in their home range areas. Neither male or female home ranges differed when the two sexes were compared statistically. A plot of the rats' bivariate normal home range contained within the 0.74 ha trapping grid showed that overlapping of home ranges was common (*Figure 1*).

TABLE 4. MEAN HOME RANGE SIZES BASED ON BIVARIATE HOME RANGE MODEL IN HA (± SE) FOR *RATTUS TIOMANICUS* (MILLER) FOR FIELDS 1, 35 & 36 BETWEEN MARCH 1980–NOVEMBER 1981.

Classes	*Field 1*	*Field 35*	*Field 36*
Adults			
o	0.43 ± 0.06 (22)	0.38 ± 0.90 (2)	0.11 ± 0.10 (8)
o	0.12 ± 0.02 (13)	0.14 ± 0.11 (3)	0.05 ± 0.02 (8)
Subadults-Adults			
o	0.17 ± 0.05 (10)	0.03 (1)	0.08 ± 0.07 (3)
o	0.13 ± 0.02 (18)	0.04 (1)	0.03 ± 0.02 (5)
Juveniles-Subadults			
o	0.07 ± 0.02 (5)	-	-
o	0.18 ± 0.09 (4)	-	-
Juveniles-Adults			
o	0.20 ± 0.04 (18)	0.06 (1)	0.01 (1)
o	0.11 ± 0.02 (15)	-	0.04 ± 0.02 (2)

Figures within brackets indicate sample size.

The interrelationship between home range sizes and the population densities was determined by correlating the average home range size computed for a certain time period (*e.g.* weeks 1–10) to the mean and median number of animals alive during the same period. There was no relationship between the home ranges and the population densities.

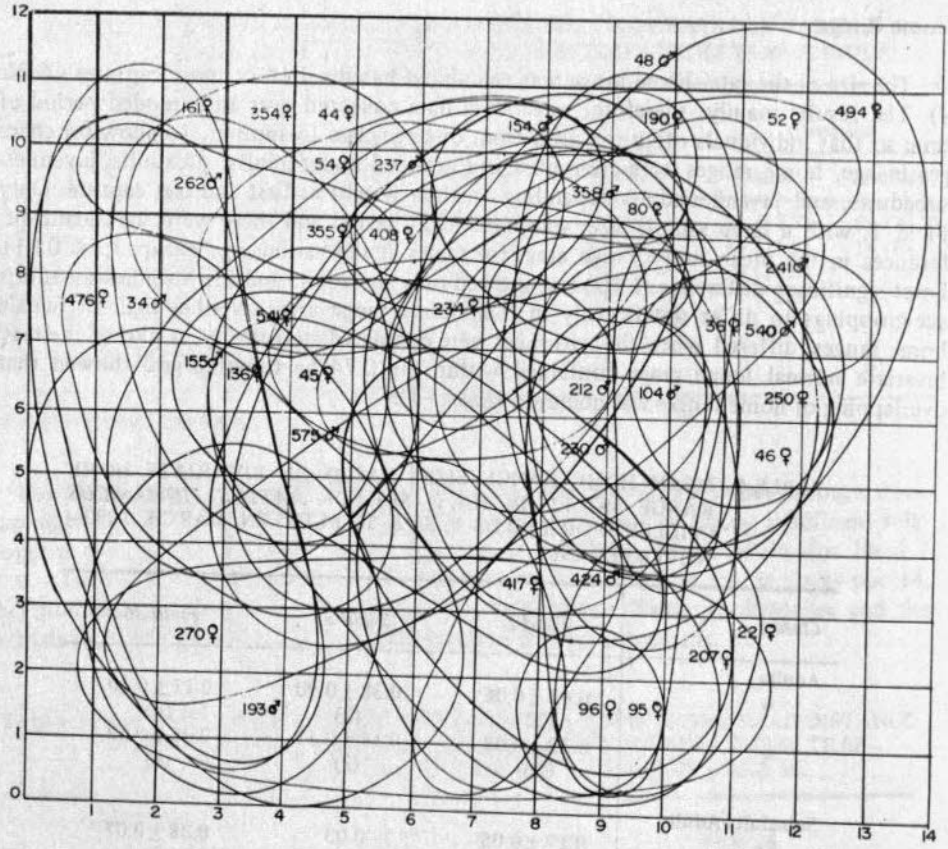


Figure 1. Bivariate normal distribution home ranges contained within a 95% confidence ellipse for 39 Rattus tiomanicus *(Miller) Home range estimate uses A1 formula for rats with 10 or more captures between Match 1980.*

DISCUSSION

As in many mammalian species, male rats tended to be more mobile than females, and the older animals moved further than the younger ones. Such behaviour has also been reported by Spenser & Davis (1950) with roof rats and Nass (1977) with Polynesian rats. The mean distance traversed by the male *Rattus tiomanicus* adult in the cocoa study area was 15 m and the maximum distance was 90 m. Harrison (1958), using the standard diameter method, found the same species to move 90 m in shrubs and 102 m in grassland habitats. In his study, however, he observed no sexual differentiation in the distance moved.

Home range in the rats was also observed to vary between the sexes and age-groups. The differences in the home range between sexes within the same age-group, however, was not statistically significant. Stroud (1982) also reported that although males exhibited larger mean home range sizes than females for *R. rattus* and *R. norvegicus*, statistically they were insignificant.

There are a number of studies reporting changes in the distance moved and the size of home range to be associated to fluctuations in population density. The inverse relationship has been shown in *Microtus pennsylvanicus* by Blair (1940), Getz (1961), Van Vleck (1969), in *M. californicus* by Krebs (1970) and *M. ochrogaster* by Abramsky & Tracy (1980). Batzli (1968), however, reported finding home range size of *M. californicus* to be relatively constant and independent of population density. And Myllymaki (1977) reported the changes of home size in *M. agrosti* to be a function of some seasonal recurring events rather than a function of population size *per se.*

In this study, a linear negative correlation between the distance moved and the population density was observed for adults (Field 1) and subadults (Fields 1 and 35). Juveniles, however, did not show the relationship in all fields. The interrelationship of home range too, was not significant with the mean of median population densities. From this, it can be inferred that adults and subadults moved further distances when population density was low but their overall home range size did not change with the fluctuation in the population number. A number of reasons probably accounted for such phenomena. Since food is available throughout the year, other factors probably influenced the movements and home range sizes. Mating requirement could probably result in the longer movement in adults and subadults, and not the juveniles during periods of low population density. The tendency to maintain a constant level of contact between individuals has been suggested by Mazurkiewicz (1981).

Chitty (1967) has hypothesized that as the population increases, mutual interference causes differential emigration and reduced reproductive rate for certain genotypes. Krebs (1970) noted that the level of aggression apparently increases as population density increases. Thus, the mutual interference suggested by Chitty (1967) might be reflected in the size and the overlap of home ranges. The causative factor of non-overlap of home ranges is typically behaviour and is classified as territoriality. In *R. tiomanicus,* however, overlapping of home ranges were common, thus this probably explained the absence of any relationship between home range and population density. Eisenberg (1966) has reported that most mammalian species are not territorial. Although they may show mutual avoidance and hostility whenever they meet, the benefits of attempting to defend the entire foraging range are probably not sufficient to counteract the very high cost of defending the exclusive use of the area.

Implication on Control Strategy

Proper bait placement is critical to ensure maximum exposure to the pest species. Normally, bait is placed at the base of the cocoa tree. However, having determined that 79% of *Rattus tiomanicus* is arboreal, it is suggested that exposure will be improved where baits are placed on the trees themselves. In areas where cocoa are interplanted with dwarf coconut variety, placing bait directly in the coconut crown would be most beneficial. This has been done successfully in Colombia for black rats (Valencia, 1980).

The rat poison for use in rat control should take into account the bait efficacy and toxicity levels since more than half of the population are adults. Soh *et al.,* (1982), working with varied active ingredient levels of bromethalin baits, reported that the efficacy depended both on the active ingredient in the bait and the size (age-weight class) of the target species.

Sublethal dose has also been attributed to insufficient number of baits made available in the fields. The amount of bait to be broadcast should take into account the range

of movements and home range of the pest population. Although the movements in adults and subadults vary with the population size, the home range size, however, remained constant with frequent overlapping. The common practice of placing one bait per station needs to be examined. Replacement rounds, too, should be increased.

In conclusion, the present findings have been gathered for *R. tiomanicus*, the dominant rat species of cocoa; whether control strategies which follow are area-specific (confined to Kuala Bernam Estate) or not is uncertain. It is hoped that they can be applied generally to other cocoa-growing areas but caution is advocated until local evaluations have been made.

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Chemical Control of Cocoa Stem *Cerosterna* sp. nr. *Pollinosa* Buquet (Coleoptera: Cerambycidae)

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Cerosterna *sp. nr.* pollinosa *Buquet is a serious pest of cocoa in Tawau region, Sabah, Malaysia. The pest is especially serious in plantations started from or under jungle shade.*

Larvae of the beetle bore into cocoa tree trunk and occasionally into the branches. If untreated,the larva continues feeding for over a year and the tree dies.

Nine chemicals, viz. *Chlorpyrifos, DDT, 'Perthane', Naled, Primiphos – Methyl, Permethrin, Decamethrin, Carbosulfan and dieldrin were tested in the field conditions against the larvae. Chlorpyrifos and Naled were found to be the most suitable. Continued use of Chlorpyrifos reduced overall infestation from Ca 116 infested trees per hectare to Ca 10 infested trees per hectare over a period of three years. Death of cocoa trees from this pest is rare now.*

The paper also includes references to the classification and habits of this undescribed species.

The cocoa stem borer *Cerosterna* sp. nr. *pollinosa* Buquet and the damage caused by it were first brought to light by Shah (1976, 1978). A large number of trees in several fields were seen dying due to its attack in late 1970s. Method of treatment with dieldrin in practice at that time gave only Ca 15% control which was clearly insufficient. Testing of new chemicals and methods of application were, therefore, undertaken. This paper reports the description of the work and the results achieved.

Description of Pest and Type of Injury

The genus *Cerosterna* (*Celosterna*) has been classified by Duffy (1968) under the tribe Monochamini (Agniini) of sub-family Lamiinae, Family Cerambycidae. The beetles belonging to this genus have been recorded in Sri Lanka, India, Pakistan and Borneo island in the Oriental Region; Mauritius in the Madagascan Region and Congo in the Ethiopian Region, as pests of cultivated and forest trees. *Cerosterna* sp. nr. *pollinosa,* however, is an undescribed species (Cox, 1980) and differs from the only other *Cerosterna* sp. (*variegata* Aurivillius?) recorded from Borneo on *Ochroma lagopus.*

Larva of the beetle, when fully grown measures about 80 mm long and 10 mm broad at the prothorax. It is of creamy white in colour.

The adults range from 38 mm to 45 mm in length. They have a pubescent beige body with truncated elytra dark brown at the anterior end gradually getting lighter in colour

toward the posterior extremity. Antennae are much shorter than the body in both sexes. Thorax, with a strong pair of lateral spines, has a light coloured patch extending to the median anterior end of the elytra. The patch is medially divided in the prothoracic region by a dark line.

No eggs were found during the studies, however it appears that an egg is laid generally at jorquette level.

At the pest stage, larvae start boring into the stem as indicated by the size of larval galleries, which are narrow at the top and gradually widen towards the ground. The main larval galleries are interrupted at several points along the stem by secondary galleries opening to the outside as circular frass exit holes. The secondary galleries point downwards – a possible adaptation to keep rain water from entering the main galleries. Once the larva has developed fully which takes 315 days to 525 days (based on 12 observations), it starts to make the pupal chamber. Small perforations are made few centimetres above the ground level and higher; a secondary tunnel is made pointing upwards. However, this secondary tunnel ends just short of the bark from inside – another possible adaptation against penetration by water, parasites or predators like ants from the outside. Both ends of the pupal chamber are then plugged with corase wood chippings and the chamber itself is lined with finer sawdust. The pupal stage lasts from 105 days to 216 days as noted in 16 observations. The adult cuts off the intact bark after emergence leaving an oval hole in the stem. In captivity the adults when fed on cocoa shoots and sections of hollowed out stem lived upto a maximum of 110 days in 11 cases observed. The adult caused minor damage to the bark of young shoots in the field.

Although up to three living larvae were found in a single tree, occasionally a single larva generally inhabits one stem. During its development the larva riddles the stem with vertical parallel galleries and by the time the adult emerges the cocoa tree generally dies (*Figure 1*).

Chemical Control

On the atracked trees two types of frass-exit holes could be seen; (a) where the larva was feeding in the vicinity and hence fresh frass was being ejected through the hole (fresh holes) and (b) where the larva had fed earlier and used the frass-exit hole to throw out frass at that time (old hole).

A series of preliminary tests was run with various chemicals by injecting them into, (a) freshly made holes (recognised from the fresh frass), (b) old and new holes and (c) by injecting into fresh holes and plugging all holes with 'plasticine'. No significant difference was found in any of the techniques used. Subsequently, only fresh holes were treated using a plastic oiling can 'jet oiler', which squirted about 20 cc of the formulation with one squeeze.

The treated trees were observed for cessation in frass-ejection. When the frass ejection ceased, it was considered that the larva inside had died. However, all trees were kept under observation for over a year for any evidence of pupation and adults' emergence.

The chemicals tested in three experiments are listed in *Table 1*.

The control achieved is given in *Table 2*.

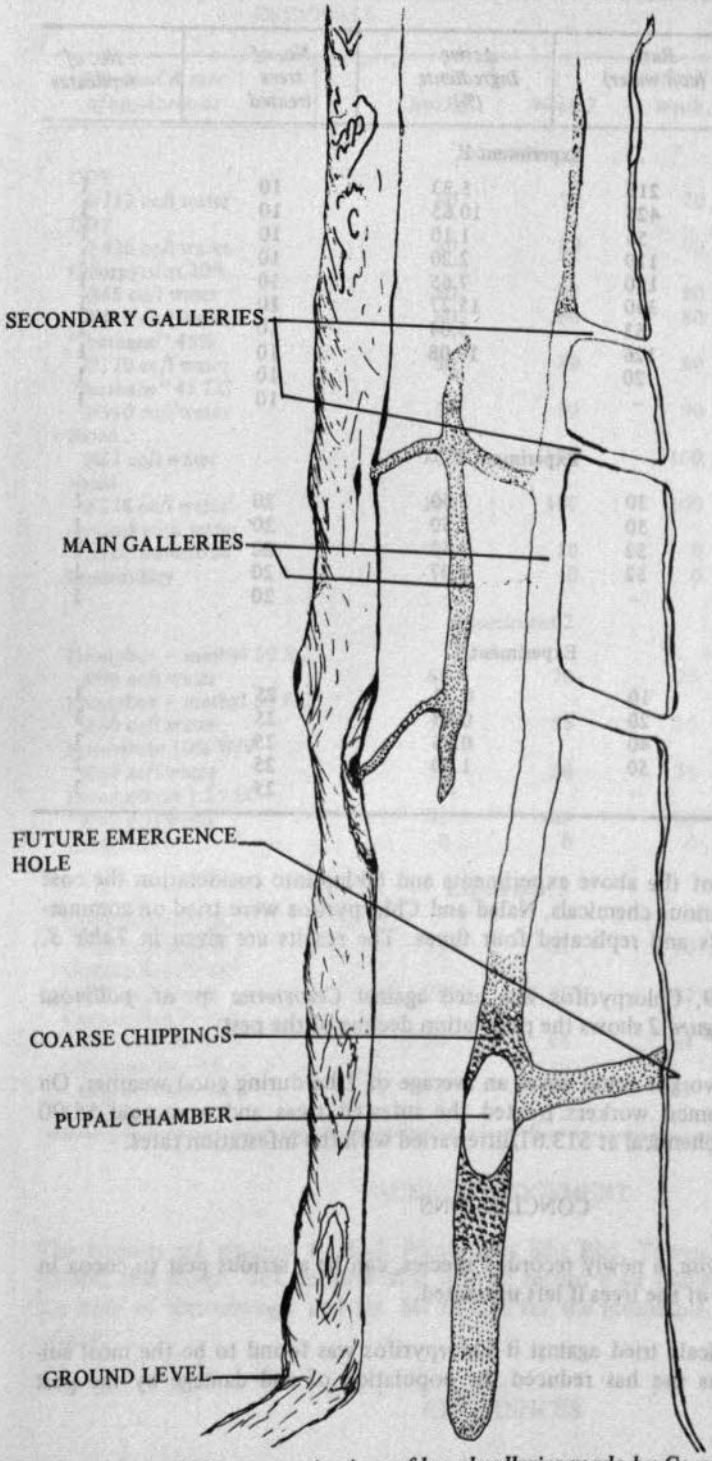


Figure 1: Diagrammatic view of larval galleries made by Cerosterna *sp. nr.* pollinos *in cocoa stem.*

TABLE 1. CHEMICALS TESTED AGAINST *FEROSTERNA* SP. NR. *POLLINOSA*.

Common Name of Chemical	*Rate (cc/l water)*	*Active Ingredients (%)*	*No. of trees treated*	*No. of replicates*
		Experiment 1.		
DDT 25%	213	5.33	10	1
DDT 25%	426	10.65	10	1
Chlorpyrifos	55	1.10	10	1
Chlorpyrifos	110	2.20	10	1
"Perthane" 45%	170	7.65	10	1
"Perthane" 45%	340	15.27	10	1
Naled	63	5.04	10	1
Naled	126	10.08	10	1
Control with water	20	–	10	1
Control Dry	–	–	10	1
		Experiment 2.		
Primiphos – methyl	30	1.50	20	1
Primiphos – methyl	50	2.50	20	1
Permethrin	52	0.52	20	1
Decamethrin	52	0.07	20	1
Control Dry	–	–	20	1
		Experiment 3.		
Carbosulfan	10	0.22	25	3
Carbosulfan	20	0.43	25	3
Carbosulfan	40	0.86	25	3
Chlorpyfifos	50	1.00	25	2
Control water	–	–	25	3

Based on the results of the above experiments and taking into cosideration the cost and availability of the various chemicals, Naled and Chlorpyrifos were tried on commercial scale over 2-ha plots and replicated four times. The results are given in *Table 3.*

Since December 1979, Chlorpyrifos was used against *Cerosterna* sp. nr. *pollinosa* throughout the estate. *Figure 2* shows the population decline of the pest.

It was found that a worker could cover an average of 2 ha during good weather. On the particular estate women workers treated the infested trees and were paid $5.90 per day. The cost of the chemical at $13.61/litre varied with the infestation rates.

CONCLUSIONS

Cerosterna sp. nr. *pollinosa,* a newly recorded species, can be a serious pest to cocoa in Sabah, causing the death of the trees if left untreated.

Of the various chemicals tried against it Chlorpyrifos was found to be the most suitable and its continuous use has reduced the population of and damage by the pest considerably.

TABLE 2. CONTROL OF *CEROSTERNA* SP. NR. *POLLINOSA* WITH VARIOUS CHEMICALS.

Chemical & rate of applications	*Control (%)*				
	Week 1	*Week 2*	*Week 3*	*Week 4*	*Month 3*
	Experiment 1				
DDT @213 cc/l water	80	70	70	70	80
DDT @426 cc/l water	80	80	90	100	100
Chlorpyrifos 20% @55 cc/l water	80	80	80	80	80
@110 cc/l water	80	80	80	80	80
"Perthane" 45% @170 cc/l water	80	80	80	80	80
"Perthane" 45 EC @340 cc/l water	90	90	90	90	90
Naled @63 cc/l water	100	100	100	100	100
Naled @126 cc/l water	100	100	100	100	100
Control with water 20 cc water/tree	10	10	0	10	10
Control Dry	0	0	0	10	20
	Experiment 2				
Primiphos – methyl 50 EC' @30 cc/l water	65	70	70	70	70
Primiphos – methyl 50 EC @50 cc/l water	55	55	55	55	50
Permethrin 10% W/V @52 cc/l water	25	30	35	35	40
Decamethrin 1.25 EC @52 cc/l water	75	85	85	85	85
Control Dry	0	0	0	0	5
	Experiment 3				
Carbosulfan 20 EC @10 cc/l water	75	81	80	80	84
Carbosulfan 20 EC @20 cc/l water	79	85	87	87	84
Carbosulfan 20 EC @40 cc/l water	80	84	84	81	84
Chlorpyrifos 20% @50 cc/l water	77	87	87	84	85
Control water	7	7	7	7	7

ACKNOWLEDGEMENT

The authors are grateful to BAL Plantations Sdn Bhd, Tawau, for their permission to publish this paper. The authors also wish to record their thanks to the Commonwealth Institute of Entomology and Dr. M. L. Cox for the invaluable information on identification.

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COX, M.L. (1980) Personal communications. Comm. Inst. Ent. London.

TABLE 3. CONTROL OF *CEROSTERNA* SP. NR. *POLLINOSA* ACHIEVED IN COMMERCIAL APPLICATIONS OF CHLORPYRIFOS AND NALED.

Plot No.	*Chemical & rate of applications*	*Control achieved in Replicate (%)*			
		1	*2*	*3*	*4*
1	Chlorpyrifos 20% @50 cc/l	71.43	87.04	84.09	94.00
2	Naled 80% @65 cc/l	66.13	80.43	79.24	94.00

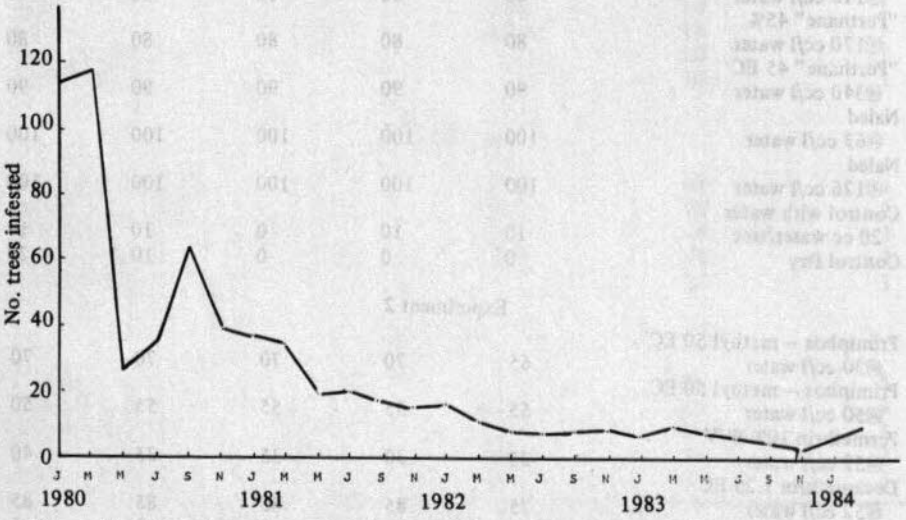


Figure 2: Number of trees infested with Cerosterna *sp. nr.* pollinosa *per hectare on an Estate (1029 ha).*

DUFFY, E.A.J. (1968) *A Monograph of the Immature Stages of Oriental Timber Beetles* (Cerambycidae) pp. 218–223. London: Trustees of the British Museum (Natural History).

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Field Evaluation of Cypermethrin (RIPCORD) on the Control of Some Major Cocoa Insect Pests

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This paper presents the results of a series of field trials on the control of major insect pests in cocoa using several insecticides. The synthetic pyrethroids, cypermethrin (RIPCORD) and alphamethrin as well as gamma BHC afforded effective control at 0.002 to 0.004% ai spray solutions for the synthetic pyrethroids and 0.05% ai for gamma BHC. These compounds gave fast knockdown and good residual control of* Helopeltis *in mature cocoa. The carbamates MTMC and MPMC were not effective.*

*With young cocoa where the main leaf defoliators were grasshoppers (*Valanga *sp) and cockchaefers (*Apogonia *and* Adoretus *sp), cypermethrin at 0.004% and monocrotophos (AZODRIN) at 0.05% ai solutions provided excellent foliar protection. Gamma BHC and alphamethrin were less effective.*

A series of field trials was carried out to evaluate cypermethrin, along with the other insecticides, for the control of the major cocoa pest – *Helopeltis*, cockchaefers and *Valanga*.

Two sets of field trials were conducted. The first was in small-holdings in Kapar, Selangor. The objective was to evaluate cypermethrin against *Helopeltis* in mature cocoa. The second was on an estate in Negeri Sembilan where the target pests were cockchaefer beetles and *Valanga* grasshoppers in one-year old cocoa.

MATERIALS AND METHODS

Field Trial 1 – Helopeltis/Cocoa in Kapar, SELANGOR

Four trials were carried out in Kapar.

The insecticides tested were cypermethrin (synthetic pyrethroid), alphamethrin (synthetic pyrethroid), BPMC (carbamate), MPMC (carbamate), MTMC (carbamate) and gamma BHC (chlorinated hydrocarbon) which is the standard insecticide used by many cocoa growers.

The cocoa plants were mature (nine to ten years old) and already fruiting. The plot sizes varied from 10 to 40 plants per plot with two or three replicates. A knapsack sprayer was used to spray the insecticides directly on all the cocoa pods and nearby branches. Insecticide dosages were given in percentage active ingredient spray solutions. The application rate (spray liquid) was not more than 220 litres per ha.

* A Shell Experimental Insecticide

For assessment, all pods below 2 m high were examined and those with *Helopeltis* nymphs were marked and the count recorded.

Field Trial 2 – Cockchaefers and Valanga/Cocoa in NEGERI SEMBILAN

The second field trial was conducted on an estate where one-year-old mixed hybrid cocoa plants were severely attacked by cockchaefer beetles and *Valanga* grasshopper which devoured the soft young leaves. Prior to this experiment, gamma BHC at 0.05% ai spray solution was used, but did not give adequate control. Cypermethrin, alphamethrin, monocrotophos, and gamma BHC were evaluated.

The trial was laid out in a randomised complete block design, with three replications. Each replicate consisted of 50 cocoa plants (five rows of 10 plants). The plants were about 120 cm high.

The insecticides were applied using a knapsack sprayer with a cone nozzle. The young soft cocoa leaves were sprayed thoroughly until run-off of spray was observed.

For assessment, the new leaf flushes damaged by the insect pests were examined and given a "damage score", defined as follows:-

Damage Score	*New Leaves Damaged (%)*
0	No Damage
1	1 – 10
2	>10 – 30
3	>30 – 50
4	>50 – 80
5	>80

An average damage score was given for each plant. Ten plants from each replicate were marked and assessed.

RESULTS AND DISCUSSION

Field Trial 1

The first experiment showed that all chemicals tested showed good initial activity as evidenced by the complete or almost complete knockdown of the nymphs one day after application (*Table 1*). The nymphs population built up very rapidly in the MPMC-treated plot as shown by their counts at four and 24 days after treatment.

BPMC also appeared to lack the residual activity which would suppress the pest population. An outstanding performance, both in terms of fast knockdown and good residual activities, was evident with the cypermethrin treatment. The control achieved with cypermethrin was comparable to the standard gamma BHC used.

Table 2 shows the total pest counts for 40 trees per plot for the second trial. The results here confirmed the observations made in the earlier trial. BPMC and MPMC possessed good initial knockdown activity but lacked residual control.

Cypermethrin, however, appeared very promising as it was able to reduce the pest

TABLE 1. EFFECTS OF VARIOUS INSECTICIDES ON THE POPULATION OF *HELOPELTIS* NYMPHS, IN 10-TREE PLOTS WITH THREE REPLICATIONS (TRIAL 1, KAPAR, SELANGOR)

Treatments		*Helopeltis* nymphs[a]			
Chemical	*concentration*[b]	*Pretreatment*	*1 DAT*	*4 DAT*	*24 DAT*[c]
	(%)				
BPMC	0.05	381	2	37	51
MPMC	0.05	301	0	45	143
Cypermethrin	0.004	216	0	1	1
Gamma BHC	0.05	193	0	0	0

[a]Total counted on pods up to about 2 m from ground
[b]Active ingredient
[c]DAT = days after treatment
Insecticides were applied in full coverage spray on all pods, the trunk, and the main branches near the jorquette

TABLE 2. EFFECTS OF VARIOUS INSECTICIDES ON THE POPULATION OF *HELOPELTIS* NYMPHS, IN 40-TREE PLOTS WITH TWO REPLICATIONS. (TRIAL 2, KAPAR, SELANGOR)

Treatments		*Helopeltis* nymphs[a]		
Chemical	*concentration*[b]	*Pretreatment*	*1 DAA*	*7 DAA*[c]
BPMC	0.05%	192	9	100
MPMC	0.05%	152	0	159
Cypermethrin	0.004%	116	0	2
Gamma BHC	0.05%	251	1	2
Untreated	–	97	49	40

[a]Total counted on pods up to about 2 m from ground
[b]Active ingredient
[c]DAA = days after application
Insecticides were applied in full coverage spray on all pods, the trunk, and the main brnaches near the jorquette

populations and at the same time it achieved good residual control. Gamma BHC was to all intents and purposes equivalent in effect to cypermethrin.

In the the third trial, three insecticides were compared. Two sprays were applied, one at 0 DAT and one at 12 DAT, after the pest counts were made. *Table 3* shows the results obtained.

Excellent control of the *Helopeltis* population was obtained with alphamethrin (0. 002% ai) and gamma BHC (0.05% ai) as shown by the nymphs count even at 12 days after application. MTMC could effectively reduce the nymphs population but the increase at 12 days after application, indicated lack of satisfactory control. In addition, it was less effective against the adult population than alphamethrin and gamma BHC.

The results of the fourth experiment appear on *Table 4.*

TABLE 3. EFFECTS OF VARIOUS INSECTICIDES ON THE POPULATION OF *HELOPELTIS* NYMPHS, IN 40-TREE PLOTS WITH THREE REPLICATIONS. (TRIAL 3, KAPAR, SELANGOR)

Treatments		*Helopeltis* nymphs[a]				
Chemical	*concentration*[b] *(%)*	*Pretreatment*		*5 DAA*	*12 DAA*	*5 DAA*[c]
alphamethrin	0.002	50	1ST APPLICATION	0	0	0
MTMC	0.005	29		1	17	4
gamma BHC	0.05	18		0	1	0

[a]Total counted on pods up to about 2 m from ground
[b]Active ingredient
[c]DAA = days after application
Insecticide were applied in full coverage spray on all pods, the trunk, and the main branches near the jorquette

TABLE 4. EFFECTS OF VARIOUS INSECTICIDES ON THE POPULATION OF *HELOPELTIS* NYMPHS, IN 30-TREE PLOTS WITH THREE REPLICATIONS (TRIAL 4, KAPAR, SELANGOR)

Treatments		*Helopeltis* nymphs[a]		
Chemical	*concentration*[b] *(%)*	*Pretreatment*	*5 DAA*	*12 DAA*[c]
alphamethrin	0.002	12	0	0
cypermethrin	0.003	13	0	0
MTMC	0.05	10	0	14
Untreated	–	2	17	13

[a]Total counted on pods up to about 2 m from ground
[b]Active ingredient
[c]DAA = days after application
Insecticides were applied in full coverage spray on all pods, the trunk, and the main branches near the jorquette

Fairly low *Helopeltis* population was noted in this trial although the field had been severely attacked previously. Nevertheless, MTMC again proved unsatisfactory as evidenced by a substantial increase in nymphs count 12 days after application. A repeat application is made about 7–10 days after the initial one. This is mainly to control any newly hatched nymphs. It should therefore be noted that MTMC did not appear to be effective. This was in contrast with alphamethrin (0.002% ai) and cypermethrin (0.003% ai) which again, proved to provide good control.

Field Trial 2

The damage scores are shown on *Table 5.* The last column, on the right shows the mean damage score per plant.

TABLE 5. TOTAL AND MEAN DAMAGE OF NEW COCOA LEAVES FOR PLANTS TREATED WITH INSECTICIDES, IN 10-PLANT PLOTS WITH THREE REPLICATIONS

Treatments		Total Damage Score For Three Replicates								*Grand Total*	*Mean Damage Score Per Assessment*	*Mean Damage Score Per Plant*
Chemical	*Dosage Rate (% ai)*		*14 DAA*		*10 DAA*		*17 DAA*		*12 DAA*			
alphamethrin	0.001	1ST INSECTICIDE APPLICATION	67	2ND INSECTICIDE APPLICATION	69	3RD INSECTICIDE APPLICATION	94	4TH INSECTICIDE APPLICATION	91	321	80.25[a]	2.68
alphamethrin	0.002		34		48		84		80	246	61.50[b]	2.05
cypermethrin	0.002		40		50		53		52	195	48.75[b,c]	1.63
cypermethrin	0.004		34		36		47		49	166	41.50[c]	1.38
Monocrotophos	0.05		24		26		27		27	104	26.00	0.87
gamma BHC	0.05		49		82		94		97	322	80.50[a]	2.68
Untreated control	–		112		111		114		113	450	112.50	3.75

DAA = days after application of insecticide
a,b,c = non-significant differences at the 5% level (LSD)

Monocrotophos was noted to be the most effective followed by cypermethrin, alphamethrin (0.002%) and gamma BHC.

All treated plots, except plots treated with alphamethrin at 0.001% and gamma BHC at 0.05% ai gave satisfactory control giving around 10% leaf damage or less.

It was also observed that mealybugs were only absent in plots treated with monocrotophos which strongly indicates that monocrotophos was also effective against this pest.

CONCLUSION

The first set of experiments showed that cypermethrin at the range of 0.003% to 0.004% ai and alphamethrin at 0.002% ai spray solution provided fast knockdown and good residual control of *Helopeltis* in mature cocoa.

These were comparable to gamma BHC and better than the carbamate insecticides. As cypermethrin is a synthetic pyrethroid, hence safer to operators who apply the insecticide than the organochlorine and carbamate insecticides, it is a useful option for use in mature fruiting cocoa.

The results from the second set of experiment showed that monocrotophos and cypermethrin were effective against the leaf defoliators of young cocoa. There is no doubt that either one of these two chemicals could provide the required protection against insect pests in young cocoa.

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P

Preliminary Observations on Incidence of Black Pod Disease in Amelonado Cocoa in Terengganu, Peninsular Malaysia

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Black pod of cocoa caused by Phytophthora palmivora *(Butl.) Butl. is an important disease in Jerangau in the east coast of Peninsular Malaysia. The occurrence of the disease was correlated with weather conditions and fruiting cycle in the area. Heavy infection occurred during the wet season which also coincided with the main fruiting season. Infection can occur at all heights although a large proportion of the diseased pods appeared high up in the crown of the tree. The spread of the disease from pod to pod on the same tree was rapid but from tree to tree was relatively slow. The infection rates decreased with time from December to April, but increased with time from August to December.*

Black pod disease caused by *Phytophthora* spp. is an important disease in all cocoa-growing countries. In Malaysia, the causal pathogen of black pod is *Phytophthora palmivora* (Butl.) Butl. The disease is most rampant in the east coast of Peninsular Malaysia where incidence of 10–30% is commonly encountered (Tey, 1983). In addition to black pod, the pathogen also causes stem canker, cherelle wilt and blight of shoots, chupon, grafts and seedlings.

In recent years, emphasis is placed on research into the epidemiology of black pod to obtain information to help develop more effective control methods of the disease (Gregory & Maddison, 1981). In Malaysia, this aspect of the study is lacking although much is known on the biology and ecology of the pathogen (Lee & Varghese, 1974 a and b).

This paper reports the preliminary results of studies on the influence of weather conditions on the development and progress of the disease.

MATERIALS AND METHODS

The study was conducted in Jerangau in the east coast of Peninsular Malaysia. This is an area with high incidence of black pod disease.

Three plots of fully matured (21–30 years old) Amelonado cocoa, planted at 2.44 m x 2.44 m under thinned jungle shades (with supplementary *Gliricidia* shades), were chosen and marked as C_1, C_2 and C_3. The Amelonado cocoa instead of hybrid plantings were chosen for the study in order to avoid complications due to varietal susceptibility.

Each plot consisted of 10 trees in 10 rows. The trees were 5 – 7 m high and covered with dense canopy which were mostly at heights greater than 2 m above the ground. Diseased pods in the plot were first removed before starting the experiment. Five days

later, and subsequently at weekly intervals, fruits on the trees were examined and black pods at various heights above ground level were recorded. All pods, including the infected ones, were left unremoved after recording. After six months, all black pods in the plots were removed the second time and scoring of the disease was repeated. Confirmation of the causal organism was carried out by plating diseased pod tissue on $P_{10}VP$ medium as described by Tsao and Ocana (1969).

Meteorological data on rainfall, temperature, sunshine hours and atmospheric humidity were collected throughout the study period which lasted from November 1982 to December 1983. Rainfall was measured daily using a rain gauge (Negretti Zambra, London) and the duration of sunshine recorded using a sunshine-recorder (Casella, London) in an open area near the experimental plots; temperature readings were taken from a maximum and minimum thermometer. The atmospheric humidity was recorded using thermahydrographs (Casella, London) placed within the experimental plots.

RESULTS

Black pod Incidence and Weather Conditions

Disease incidence varied with weather conditions. The incidence of black pod expressed as newly infected pods per month is shown in *Figure 1*. The general pattern of occurrence of the disease was similar in the 3 plots. High incidence occurred during the period from October to January, with the peak in December and January. Disease incidence was significantly low from February to August.

Low incidence of black pod was observed during the drier months when the duration of sunshine was longer and the maximum daily temperature was marginally higher (of. *Figures 1* and *2*). The highest level of infection was recorded in the months with heavy rainfall and prolonged period of high atmospheric humidity (*Figure 1*).

Black Pod Incidence and Fruit Production

In Jerangau area, there was only a single major fruiting season for cocoa, *viz.* from August to November (*Figure 3*). In other months, pod production was significantly less.

High incidence of black pod occurred only in the main fruiting season (*Figures 1* and *3*). During the off season, the disease was insignificant.

Black Pod Development in Relation to Height of Trees

To study the pattern of initiation of black pod in the plantation, all diseased pods on the trees were first removed prior to scoring black pod in the main fruiting season. The distribution of newly infected pods according to tree height is shown in *Table 1*.

Cocoa pods at various heights along the trunk and branches of the tree can be infected. A large proportion of infection was initiated at heights > 0.9 m above the ground. However, fewer pods were borne at heights < 1.8 m; indeed $> 70\%$ of the fruits were found at heights > 1.8 m above ground level (*Table 1*).

Development of Epidemics

The progress of epidemic in plot C_1 was analysed. The occurrence of disease expressed as cumulative percentage of black pod against time is shown in *Figure 4*.

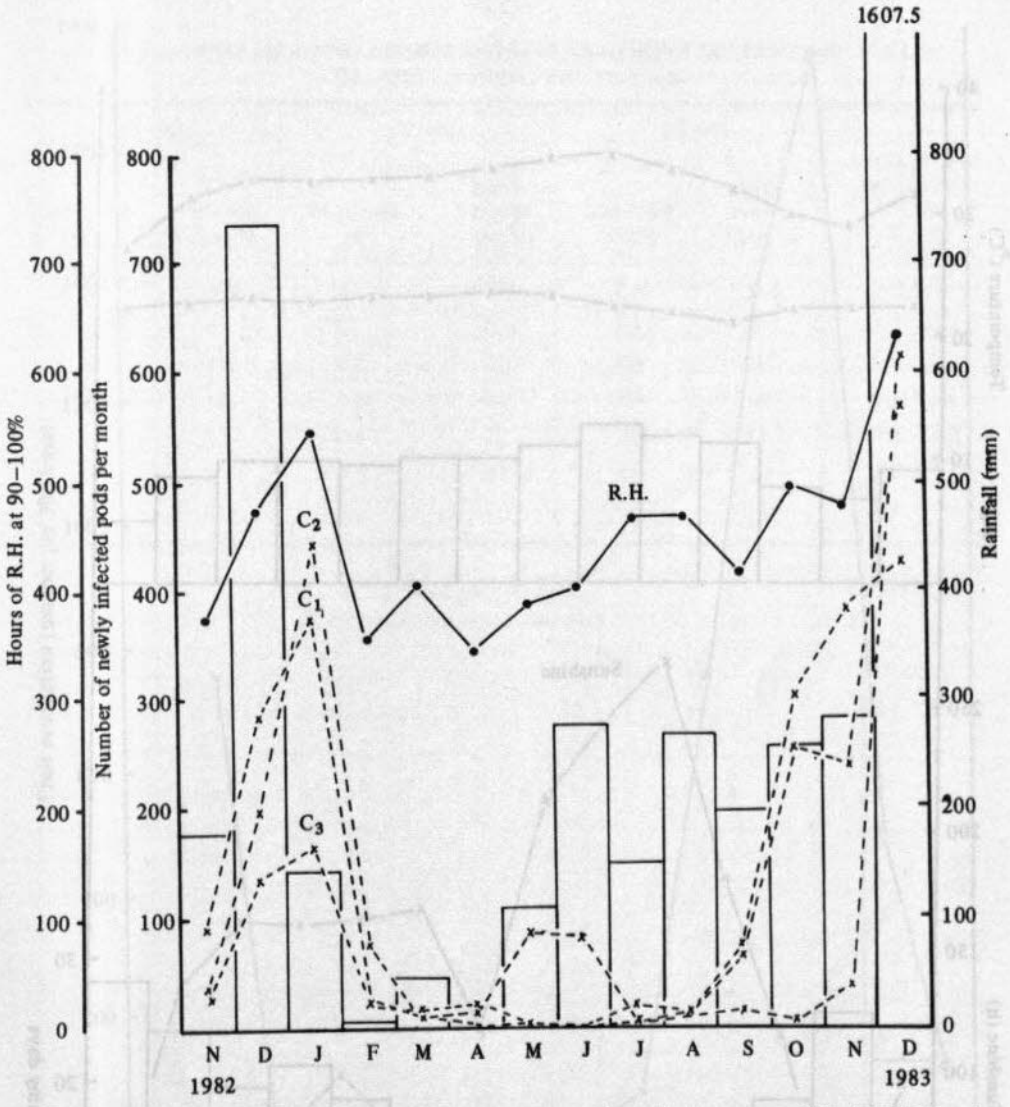


Figure 1. Occurrence of black pod (x---------x) in relation to rainfall (⊓) and atmospheric humidity (•———•)

There are indications that disease progress may develop in three phases. A slow increase of disease incidence at the early stage of infection from July to September, a rapid increase from September to January and a slow progress of the disease after January.

Based on the model of epidemics as described by Van der Plank (1963), the apparent infection and the basis infection rates can be calculated using the equations as stated by Ward (1981) (*Appendix*).

The infection rates, calculated over the periods from November 1982 to April 1983 and July 1983 to December 1983, at 28-day intervals, are shown in *Figure 5*.

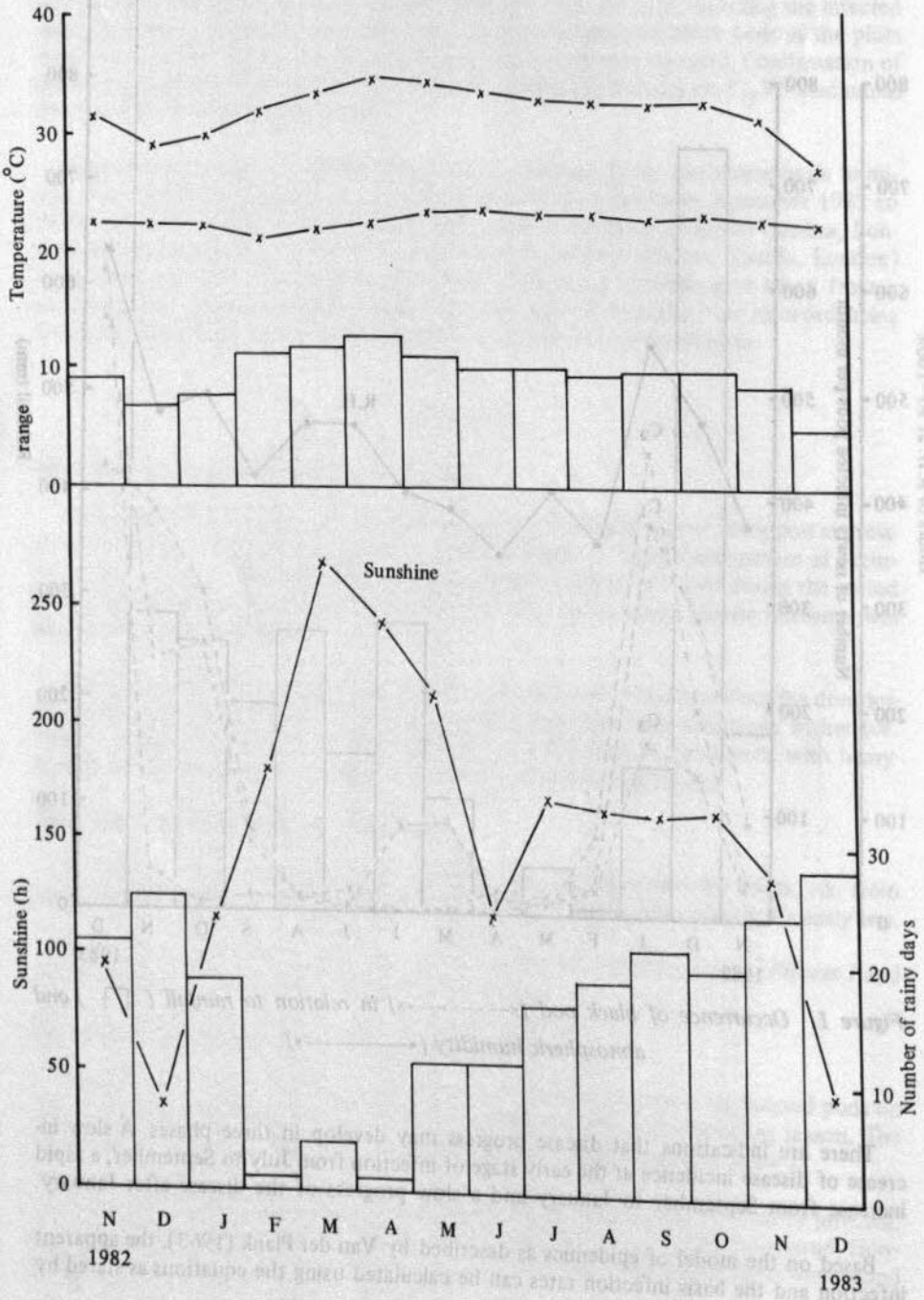


Figure 2. Monthly variation of temperature, sunshine and rainfall in Jerangau.

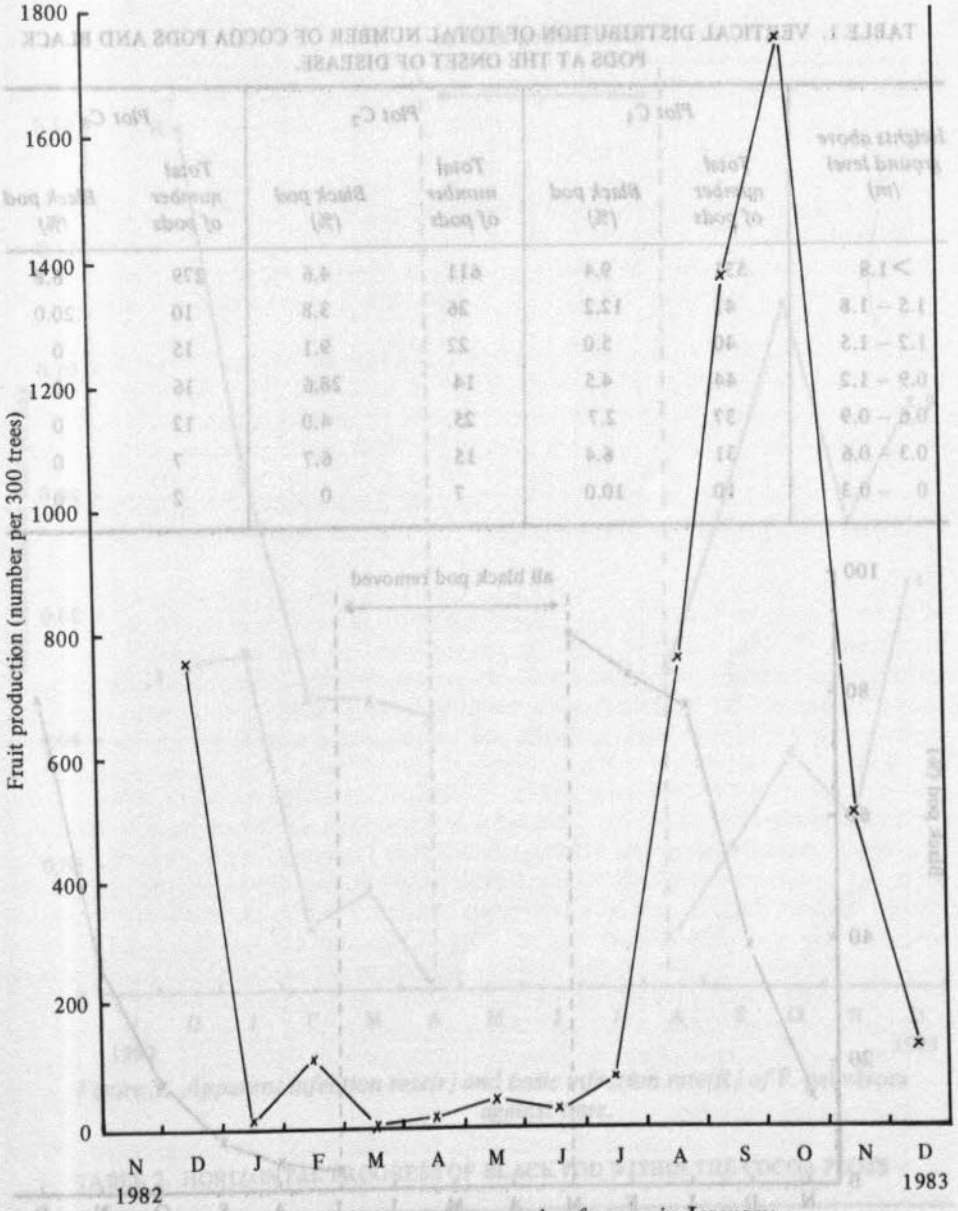


Figure 3. Fruit production cycle of cocoa in Jerangau.

Neither of the infection rates was constant. Whereas both the apparent infection and the basic infection rates decreased with time during the period from December 1982 to April 1983, both tended to increase from August 1983 to December 1983. This indicated that the conditions from multiplication of the disease were favourable from August to December, but not from December to April.

Progress of Black Pod Disease

Infection of black pod started with about 22% of the tree population (*Table 2*). This occurred at random in small groups of trees. The progress of disease from tree to tree

TABLE 1. VERTICAL DISTRIBUTION OF TOTAL NUMBER OF COCOA PODS AND BLACK PODS AT THE ONSET OF DISEASE.

Heights above ground level (m)	*Plot C_1*		*Plot C_2*		*Plot C_3*	
	Total number of pods	*Black pod (%)*	*Total number of pods*	*Black pod (%)*	*Total number of pods*	*Black pod (%)*
>1.8	531	9.4	611	4.6	279	6.8
1.5 – 1.8	41	12.2	26	3.8	10	20.0
1.2 – 1.5	40	5.0	22	9.1	15	0
0.9 – 1.2	44	4.5	14	28.6	16	0
0.6 – 0.9	37	2.7	25	4.0	12	0
0.3 – 0.6	31	6.4	15	6.7	7	0
0 – 0.3	10	10.0	7	0	2	0

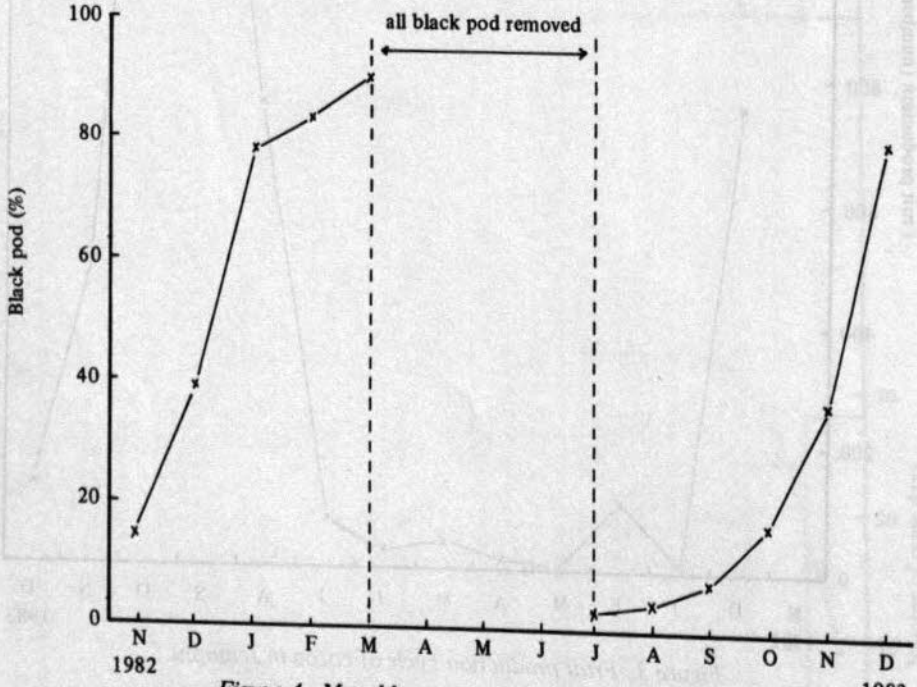


Figure 4. Monthly progress of black pod disease.

remained relatively slow during the first four weeks. This happened mainly through spread of the disease to neighbouring trees. After four weeks, about half of the trees in the plot had black pods (*Table 2*). By the end of the second month, most of the trees had been infected.

The vertical progress of the disease in plot C_1 is given in *Table 3*. Early infection occurred at various heights of the tree. The spread of disease from pod to pod on the same tree was rapid especially for pods near the ground and in the crown. Within two months, 40–80% of the fruit at all heights had been infected.

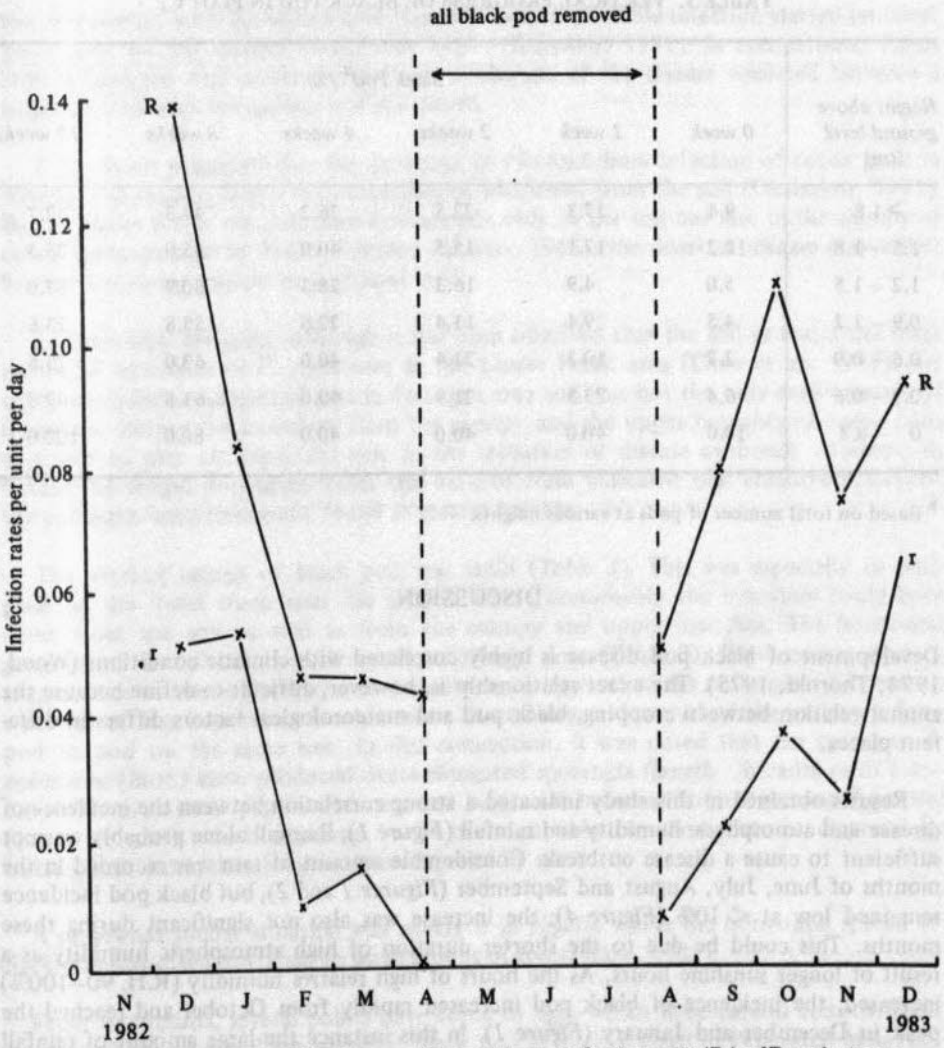


Figure 5. Apparent infection rate(r) and basic infection rate(R) of P. palmivora *against time.*

TABLE 2. HORIZONTAL PROGRESS OF BLACK POD WITHIN THE COCOA PLOTS

Plot Number	*Trees having black pods (%)*					
	0 week	*1 week*	*2 weeks*	*4 weeks*	*8 weeks*	*12 weeks*
Plot C_1	26	39	42	46	56	100
Plot C_2	23	33	35	43	80	87
Plot C_3	17	21	28	51	84	88

TABLE 3. VERTICAL PROGRESS OF BLACK POD IN PLOT C_1

Height above ground level (m)	*Black Pod[a] (%)*					
	0 week	*1 week*	*2 weeks*	*4 weeks*	*8 weeks*	*12 weeks*
>1.8	9.4	17.3	22.5	26.2	44.3	82.7
1.5 – 1.8	12.2	17.1	15.5	40.0	45.0	83.3
1.2 – 1.5	5.0	4.9	16.3	28.3	60.9	87.0
0.9 – 1.2	4.5	9.4	11.4	22.6	55.8	73.6
0.6 – 0.9	2.7	10.3	21.4	40.0	63.0	75.6
0.3 – 0.6	6.4	23.5	21.9	40.0	61.8	67.6
0 – 0.3	10.0	40.0	40.0	40.0	80.0	100.0

[a] Based on total number of pods at various heights.

DISCUSSION

Development of black pod disease is highly correlated with climatic conditions (Wood, 1974; Thorold, 1975). The exact relationship is, however, difficult to define because the annual relation between cropping, black pod and meteorological factors differs in different places.

Results obtained in this study indicated a strong correlation between the incidence of disease and atmospheric humidity and rainfall (*Figure 1*). Rainfall alone probably was not sufficient to cause a disease outbreak. Considerable amount of rain was recorded in the months of June, July, August and September (*Figures 1* and *2*), but black pod incidence remained low at < 10% (*Figure 4*); the increase was also not significant during these months. This could be due to the shorter duration of high atmospheric humidity as a result of longer sunshine hours. As the hours of high relative humidity (R.H. 90–100%) increased, the incidence of black pod increased rapidly from October and reached the peak in December and January (*Figure 1*). In this instance the large amount of rainfall during this period might have provided suitable conditions for infection as well as helped in dispersing the inoculum.

It was evident that fruiting cycle greatly affected the infection by *P. palmivora*. The presence of large amount of host tissue from August to December (*Figure 3*) undoubtedly had constituted a factor which favoured the spread of the disease. There was a decrease in infection rates during the period from December to April (*Figure 5*), and although it was most likely the result of unfavourable climatic conditions, it must also be attributed to the depletion of available uninfected pods for infection.

In Nigeria, it was observed that increase in yield resulted in an increase of black pod (Thorold, 1956). Highly productive trees were also more likely to have more black pods (Ward, 1981), partly because proximity aids spread of the pathogen (Gregory, 1971).

In this study, early infection of *P. palmivora* occurred at all heights above the ground (*Table 1*), but a larger proportion of the disease first appeared at heights > 0.9 m. This

was in contrast with the situation in Nigeria where most of the infection started on trunk pods close to the ground (Maddison, 1981; Okaisabor, 1971). In comparison, Tarjot (1967) reported that in the Ivory Coast outbreaks of the disease occurred between a height of 1 m from the ground and the crown.

It has been suggested that the initiation of *Phytophthora* infection of cocoa pods in Nigeria was mainly caused by rainsplash of inoculum from the soil (Okaisabor, 1971). But in places where the pathogen survives not only in the soil but also in the canopy of cocoa trees, such as in South America (Manco, 1966), the onset of disease may either be initiated in the canopy or at ground level.

In Peninsular Malaysia, although it has been observed that the soil provides the main source of inoculum of *P. palmivora* in the Lower Perak area (Chan *et al.*, 1977), our study nevertheless suggested that in Jerangau area soil was not the only major source of inoculum. Indeed the inoculum from the canopy and the upper branches of cocoa trees appeared to play an important role in the initiation of disease outbreak. Attempts to isolate the fungal propagules from the bark of trees indicated that chlamydospores of the pathogen were commonly found at various heights.

The vertical spread of black pod was rapid (*Table 3*). This was especially so with pods on the lower trunk near the ground where presumably the inoculum could have come from the soil as well as from the canopy and upper branches. The horizontal progress of the disease was, however, relatively slow (*Table 2*). These points tend to suggest that in the early epidemic long-distance dispersal of the pathogen from tree to tree was of less importance compared to short-distance dispersal of the pathogen from pod to pod on the same tree. In this connection, it was noted that the pathogen *P. palmivora* (Butl.) Butl. produced ovate-elongated sporangia (length : breadth ratio 1.4 – 1.6) with prominent papilla and rounded base, and broad and short sporangial pedicel (1.4 – 2.7 μm), which appeared to be more suitable for short-distance dispersal by water splash rather than long-distance dispersal by wind.

A somewhat similar situation was observed in Nigeria where the horizontal spread of black pod was often restricted to small groups of trees (Ward, 1981).

From our results, several points have come to light which need careful consideration when developing control measures for black pod in the east coast of Peninsular Malaysia. These are:

- The development of black pod was correlated with fruit production and rainfall pattern of the area. There was a distinct period when cocoa pods were at the risk of being infected; there was also a peak infection period. Hence, control by regular chemical spray would not only be unsuitable but also uneconomical. The economic threshold level together with the timing and frequency of chemical spray would have to be worked out in accordance with the disease pattern in the area.
- In the early stage of epidemic development, control strategy may be directed to the few heavily infected groups of trees only.
- A large proportion of the fruit and diseased pods appeared in the crown of the tree. The exact sources of this infection needs to be identified. By eliminating these primary sources of inoculum as well as that from the soil, effectiveness of the control programme can be further enhanced.

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Appendix

Calculation of apparent infection rate, r:

$$r = \frac{1}{t_2 - t_1} \ln \frac{X_2 (1 - X_1)}{X_1 (1 - X_2)} \text{ (Ward, 1981)}$$

where r = apparent infection rate, and X_1 and X_2 were the proportions of infected pods on day t_1 and t_2 respectively.

Calculation of basic infection rate, R:

$$R = r \frac{X_t}{X_{t-p}} \text{ (Ward, 1981)}$$

where r = apparent infection rate
X_t = proportion of infected pods on day t
X_{t-p} = proportion of infected pods on day t–p
and p = latent period of *P. palmivora*, which was taken as 5 days based on the findings of Medeiros (1977).

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OBSERVATIONS ON THE SURVIVAL OF MATURE LARVAE AND PUPAE OF COCOA POD BORER ACROCERCOPS CRAMERELLA SNELLEN

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ABSTRACT

The fully mature larvae cocoa pod borer (Acrocercops cramerella) Snellen usually descends to the ground from ripened pods to seek cocooning sites. The wandering larvae were killed by ants (17.8%) and spiders (6.9%) whereas 58.9% of cocooned larvae or pupae were preyed upon by ants and 1.4% were found dead, covered by fungi.

An observation on mortality of pupae was made during the recent drought season. It was found that 23.6 percent of pupae failed to emerge and 0.6 percent was parasitized by two species of pupal parasitoids. However, on two occasions pupation was observed occurring inside the infested pod. Apparently, the larve failed to tunnel out from the pod due to dryness of the pod caused by the drought. This pupa also failed to emerge under laboratory condition.

INTRODUCTION

The cocoa pod borer Acrocercops cramerella Snellen (lepidoptera: Gracillaridae) has become a serious pest in Sabah, Malaysia since 1980. This insect pest has been studied by Lim, et al. (1982). The newly-hatched larva penetrates through the pod immediately. Upon completion of feeding, full-grown larva tunnels out from the green mature pod or ripened pod, then descends to the ground to

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form a cocoon and pupates on a dried leaf or surface of a cocoa pod. This pupa either undergoes continuous development into the adult stage or is attacked by predator or parasitoid. Numerous predatory and parasitic arthropods attack the larvae and pupae (Lim et al., 1982; Lim & Sim, 1982), yet little is known about their contributions to pest suppression and the actual role of these biocontrol agents in the fields have not been investigated.

The objective of this study is to determine (1) the survival rate of the cocoa pod borer from the time of tunneling out from the pod until it forms a pupa; (2) the effects of predators and parasitoids on the wandering larvae or pupae and (3) the effects of the recent drought on the pupal stage.

MATERIALS AND METHODS

A newly-tunneled out larva, particularly one that emerged in the early morning was used for the observation. These larva were then transferred to a plastic specimen tubes (2.0 x 3.0 cm) using a soft brush and were immediately released onto green mature pods in the field.

The fate of the wandering larva in search for the pupation sites were observed and predators collected in killing bottles for identification. The pupation sites were marked and observed daily and the dried leaves where the pupa formed were held in place by a sharp twig.

In order to observe the natural mortality of pupae caused by abiotic factors, particularly in the recent drought, collections of pupae on dried leaves were placed on a heap of harvested pods for four days. These pupae were brought back to the laboratory and kept in a rearing cage (32 x 34 cm) for adult emergence. The pupal parasitoids emerged

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in the rearing cage were collected in killing bottles for identification. Examination of the dead pupae was made when no more adults emerged in the cage.

RESULTS

Out of the 73 larvae observed, 56 larvae successfully pupated. The survival rate were 77%. These wandering larvae were preyed upon by ants (18%) both on the pods and on the ground, while the others were attacked by spiders (7%) on the branches and on the ground. The species of ants that preyed on the larvae were Componotus simillimus Smith and Paratreahina longricornis (Latrille). The predatory spiders recorded were Menemerus bitittatus (Dufour), Myrarechne melanocephala Macleay, Thyene sp. (Family:Tetraynathidae), Argiope versicolor (Doleschall) and Araneus sp. (Family:Argiopidae).

The percentage of pupal predation by ants found on the pods and dried leaves on the ground were 22 and 37 respectively. The species observed was Paratrechina sp.,Tapinoma sp. and Tetraponera sp. A dead pupa (1.4%) covered with fungi was also found. The survival rate of pupae was 15%.

Table 1 shows the percentage of mortality of pupae caused by the recent drought. The results of five replicated observations show the pupal mortality ranges from 15 to 37% with an average percentage of 24. Field parasitism by Ceraphon sp. (Allomicrops group); Ceraphron sp. 2 (Hymenoptera: Ceraphronidae); Goryphus sp., Paraphylax sp. and Paraphylax s. 1. sp. (Hymenoptera: Ichneumonidae) was 0.6%.

In two cases, a pupa was found pupating inside the infested pod but failed to hatch under laboratory condition.

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DISCUSSIONS AND CONCLUSION

The larva of the cocoa pod borer tunnels out from the pod when it is fully mature and descends to the ground or crawls to the branches, trunk or pods to seek out a pupation site. The time when the larva tunnels out of pods and details of the pupation sites of the cocoa pod borer has been investigated (Lim, 1984). Figure 1 shows the fate of the mature larvae from the time of tunnelling out of the pod till the emergence of the adult.

In the tropics, ants are scavengers and they can be found both on the ground or on the trees in the field throughout the growing season. The overall predation of mature larvae and pupae by ants was 75%. The most interesting finding of the present observation is that not more than two species of ants compete for the same prey. Of the total number of 18 larvae that pupated on the pods only one escape predation by ants. The survival rate of the pupae on the pods was very low. Apart from ants the spiders which have nocturnal or diurnal habits also prey on the cocoa pod borer. By comparison with ants, spiders are less important predators but they are far more important than the other predatory carabid beetle or reduviid bugs.

The importance of specific spiders as control agents of the moth of coconut palm in Fiji Islands was also reported (Gertsch, 1979). One of the large, strikingly ornamental jumping spiders, Ascyltus pterygoides was found commonly all the time in the cocoa field. Although the effect of this predator has not been measured directly, it could be of great importance in the suppression of the population of cocoa pod borer. The effect of entomophagous arthropods on the natural population of insect pests on the agroecosystem has been reviewed (Whitcomb, 1974).

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The effects of climatic factors on insects have been reviewed by Messenger (1959; 1972). In general, meteorological factors may influence various metabolic processes of an insect particularly in the drought period. Wilson, et al. (1982) reported that the pupal survival of the Mexican bean beetle Epilachan varivestis Mulsant was poor at 32°C. In this present investigation, the mean annual rainfall and temperature were 3.63 ± 0.79 mm (range: 1.27 - 5.59 mm) and 26.54 ± 0.15°C (range: 21.81 - 21.21°C) respectively. As indicated in Figure 1, the majority of mature larvae was found pupating on the ground and one of the factors associated with the survival of pupal stage may be the moisture. The pupae were further protected from the drought and excessive evaporation by the membrane of cocoon. The cocoa trees and pods were under great water stress during the long period of dry and hot weather. Obviously, the development of the cocoa pod borers in the pods was affected either by prolonging its life cycle or drying inside the pod probably due to the quality of mucilage. Under these conditions, it is difficult for the mature larva to tunnel out from the pod and so there was pupation inside the pods. Even though the adult moth emerged in the pod, it might not be able to fly out. However, assessment of this mortality in the field is difficult. A rise in temperature accelerates the physiological changes associated with the advance in the age-cum-starvation of the insects supplied waters. A rise in temperature and decline in humidity increased the desiccation of the water-deprived insect (Saxena, 1978). This would explain the result of recent drought, that survival decreased with increasing temperature.

Considering all conditions encountered results of these observations suggest that the abiotic and biotic factors play a major role in determining the population of the cocoa pod borer.

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TABLE 1. THE PERCENTAGE OF MORTALITY OF COCOA POD BORER CAUSED BY PARASITOID AND DROUGHT

Replicate	Total no. of pupae collected	Total no. of pupae parasitized	Parasitization (%)	Total no. of dead pupae observed	Mean mortality (%)	Range (%)
5	5,034	31	0.6	1,118	23.6	15.4 - 36.8

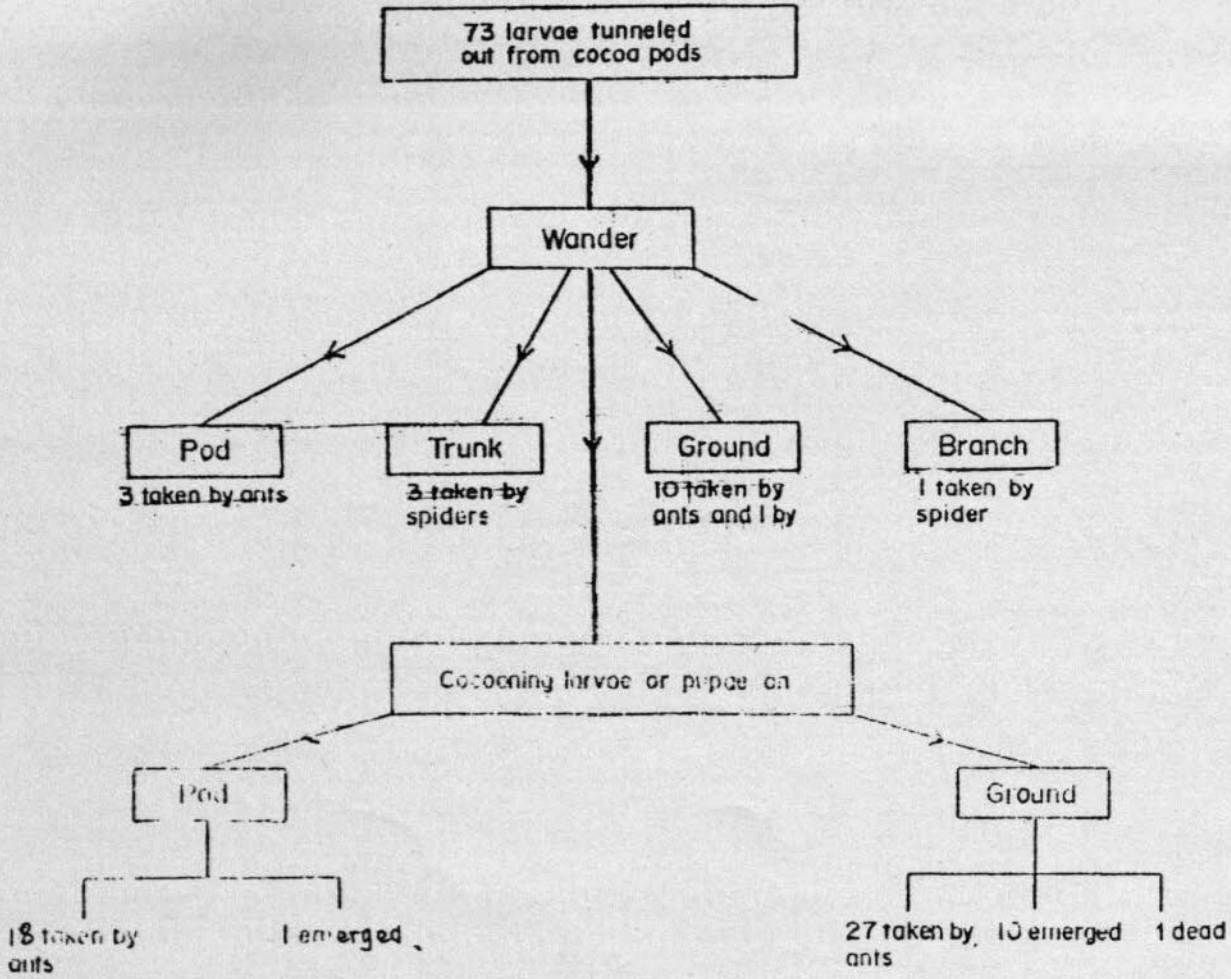


Fig 1. The fate of mature larvae of cocoa pod borer Acrocercops cramerella Snellen

Preliminary Studies on Cacao Ovules in Relation to Bean Number and Bean Size

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The number of ovules per ovary is a very stable character which is controlled by genetic factors and it is possible to estimate the potential number of beans per pod and hence the potential yield of a tree.

Preliminary data indicate that the ovules number does not strongly indicate the actual number of beans per pod. Correlation coefficient of the number of ovules to the number of beans per pod is low. The actual number of beans per pod indicates the number of ovules fertilized. This phenomena is influenced strongly by the compatibility system, frequency and abundancy of flowering, and the population of pollinating insects. However, bean size could be predicted directly from the ovule size.

Potential yield of cocoa trees have been based mainly on the number of pods produced, mean dry bean weight and number of beans per pod (pod index). Potential number of pods produced depends on the variety (genetic potential) (Soria & Esquivel, 1970; Soria *et al.*, 1974), cultural practices (Ampofo & Bonaparte, 1981) and environmental factors (Ruinard, 1963; Atanda, 1972; Are & Atanda, 1972; Alvim, 1981; Ahenkorah, 1981). The potential number of beans in a pod depends on the number of ovules in the ovary. Enriquez and Soria (1967) found that the ovule number in clonal selections ranged between 38.8 and 63.4 per ovary. The number of ovules per ovary is a very stable character which is controlled by genetic factors (Lucas & Reffye, 1981) and it is possible to estimate the potential number of beans per pod (Reffye, Parvais, Mossu & Lucas, 1981) and hence the potential yield of the tree. Variation in the number of beans per pod is due mainly to environmental effects (Toxopeus & Wessel, 1970; Atanda, 1972) and to the pollen source (Toxopeus & Jacob, 1970) and to the available pollinating insect population (Soria, 1981).

Incompatibility (the degree of incompatibility between pollen and ovules) is also one of the major barriers to realizing the potential yield of cocoa. It affects the number of flower set and the number of beans formed per pod (Enriquez & Soria, 1967). Flower setting is positively correlated to the number of pods formed, and the potential number of beans per pod is seldom realized for self-incompatible cocoa cultivar under natural pollination (Toxopeus & Jacob, 1970).

This paper presents the early result of a study on ovules *i.e.* ovule number, ovule size and compatibility. From the number of flower set the number of ovules per ovary and the ovules size and their correlation to the degree of incompatibility, the number of beans per pod, and to the bean size (thickness breadth, and bean weight), assessment of the potential yield of the various cocoa cultivar can be made at an early stage in the laboratory.

MATERIAL AND METHODS

The clones used in this trial were divided into three groups. Each group was made up of two clones which were 'representative' of the type of pods and bean size of cocoa

population. Group 1 was large-pod, large bean and long Angoleta-Cundeamor type clones UIT 1 and WA 159. Group 2 was Amelonado-Calabacillo pod type with standard to average bean size clones I–466 and I–230. Group 3 was small pod, small beaned SCA 6 and SCA 19. The trees used were from mature trees in production at MARDI Hilir Perak, planted as intercrop with mature coconuts.

The design of the experiment was the Nested Esperimental Design and data collection was in phases. This paper presents the results of this early phase, *i.e.* the ovule number per flower stage per tree and pod analysis.

Sampling Procedure

The following procedure was adopted.

'Representative' group	*Clone*	*No. of trees/ clones*	*Stage of flower*	*No. of flower sampled per tree/stage*
1. Large pod	UIT 1	5	a. Bud	5
Large bean	WA 159	5	a. Open-pollinated	5
Angoleta–Cundeamor			c. 24 h (hand-pollinated)	5
2. Average bean	I–466	5	d. 48 h	
Average pod	I–230	5	(hand-pollinated)	5
Amelonado-Calabacillo				
3. Small pod	SCA 6	5		
Small bean	SCA 19	5		

Ovule number, length and breadth. At each stage of flowering the sampling for each clone takes at least a week to complete. Five flower samples from each stage were taken from each tree. Hand pollination was carried out at 48 and 72 h, samples and pollen source were from SCA 6. The technique used was that as suggested by Patrick Lucas of the IFCC Station in Toga;

i) Clean the ovary

ii) Put on the slide and put a drop of waterman blue black ink.

iii) Put a cover slip and crush the ovary gently.

iv) Under binocular microscope count the number of ovules.

v) Using an eyepiece micrometer, take the measurement of length and breadth of the ovules. (Five samples were taken for these ovules).

Pod analysis. Five pods were taken from each tree (five tree samples). Measurements were on:

i) pod
- length
- breadth (circumference)
- weight of husk
- pericarp thickness

ii) Beans (wet) – Number of beans
– Weight of beans/pod
– Weight of placenta

iii) Beans (dry) – Breadth of beans
– Length of beans
– Weight of beans
– Weight of shell

Studies for the control pollination (cross and selfing) compatibility are not reported here since data collection is still in progress.

RESULTS AND DISCUSSION

Table 1 lists the average ovule count per ovary at four different stages and the average bean number per pod. The average number of ovules per ovary was greater than the actual number of beans per pod for every clone in every stage of flower. This could be due to the inadequate fertilization. This phenomena has been observed by Toxopeus and Jacob (1970) in the mean number of ovules per ovary and mean number of beans per pod of Pa 35 and Na 32. This could be attributed to the difference in seasonal pollination frequencies due to the availability of flowers and self-incompatibility. All the clones used

TABLE 1. MEAN OVULES COUNT PER OVARY AT FOUR DIFFERENT STAGES AND AVERAGE BEAN PER POD.

Group	*Clone*	*Flower stage*	*Average ovule*	*Average bean /pod*
I	WA 159	Bud Stage	41.12 ± 2.04	39.58 ± 6.12
		Open flower	42.14 ± 1.27	
		48-hr hand pollinated	43.85 ± 1.70	
		72-hr hand pollinated	40.2 ± 2.77	
	UIT 1	Bud stage	49.55 ± 1.34	39.84 ± 1.35
		Open flower	46.36 ± 1.53	
		48-hr hand pollinated	46.16 ± 1.26	
		72-hr hand pollinated	44.56 ± 1.45	
II	I 230	Bud stage	36.72 ± 2.32	36.00 ± 0.43
		Open flower	39.52 ± 2.94	
		48-hr hand pollinated	–	
		72-hr hand pollinated	–	
	I 466	Bud stage	38.24 ± 4.46	35.24 ± 0.79
		Open flower	41.80 ± 0.66	
		48-h hand pollinated	40.40 ± 1.69	
		72-hr hand pollinated	42.45 ± 0.50	
III	SCA 6	Bud stage	47.50 ± 1.93	40.85 ± 3.84
		Open flower	44.60 ± 2.31	
		48-hr hand pollinated	43.73 ± 0.73	
		72-hr hand pollinated	47.75 ± 2.08	
	SCA 19	Bud stage	42.08 ± 3.52	29.84 ± 3.04
		Open flower	41.88 ± 2.18	
		48-hr hand pollinated	45.08 ± 1.31	
		72-hr hand pollinated	–	

in the experiment were self-incompatible clone and hence the variability in the result. However, as the variability in the number of ovules per ovary for different stages was quite low the number of ovules could be counted at any stage of the flower development.

Table 2 lists the mean ovule length, breadth, mean bean length, breadth, thickness and mean dry bean weight. The ovule length and breadth were measured in micron (μ) and the bean measurement in centimeters (*Figure 1*). The ovule size increased propotionately with time as indicated. Bud stage samples were too fragile and small to work with and the easiest sample was the 48 h hand-pollinated flower.

Table 3 gives the correlation coefficient of the ovules count per ovary, ovule length and ovule width, with the bean number, bean length, bean thickness, and bean width. The ovule number has a very low positive correlation to the number of beans per pod. This indicates that the number of ovules does not give the actual number of beans per pod since each ovule has to be fertilized by at least a viable pollen. The pollen source depends on the abundancy of flowers during the season and the population of the pollinating insects. Fifteen successfully fertilized ovules were found to be sufficient for a pod to mature at the time of harvesting (Toxopeus & Jacob, 1970).

The ovule length and ovule width have a very significant correlation coefficient with that of the number of beans per pod, mean dry bean weight, mean bean length, width and thickness. This indicates that any of these parameters can be used in predicting the number of beans per pod and its size (length, width, thickness and weight). The number of beans per pod, mean dry bean weight, bean length, width, and thickness are strongly correlated with each other (*Table 4*). Glendinning (1965) described in detail as to the correlation and inheritance of bean number and size (breadth, length and thickness) and its significance in a breeding programme.

CONCLUSION

The overall results of this study show that the number of ovules does not indicate the actual number of beans per pod. The correlation coefficient of the number of ovules to the number of beans is low. The variability in the number of ovules per ovary for different stage was low and this indicates that flower sample does not influence the data taken. However, 48 h hand pollinated samples were the easiest to work on. The number of beans indicate the number of ovules fertilized which is directly influenced by the plant compatibility system, frequency and abundancy of flowering, and the pollinating insect population. Bean size could be predicted by the ovule size. However these conclusions are based on the early data and results; thus a more conclusive evidence and results will be reported later.

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TABLE 2. MEAN OVULE LENGTH, BREADTH, MEAN BEAN LENGTH, BREADTH AND MEAN DRY BEAN WEIGHT.

Group	Clone	Stage	Mean ovule		Mean bean			Mean weight
			Length (μ)	Breadth (μ)	Length (cm)	Breadth (cm)	Thickness (cm)	(g/bean)
I	WA 159	Bud	21.63 ± 2.13	17.31 ± 0.95	2.33 ± 0.15	1.30 ± 0.07	0.90 ± 0.06	1.49 ± 0.20
		Open flower	27.07 ± 1.46	22.04 ± 1.45				
		48-h hand pollination	29.69 ± 0.52	24.17 ± 0.64				
		72-h hand pollination	33.79 ± 1.77	26.58 ± 1.53				
	UIT 1	Bud	21.03 ± 1.34	18.32 ± 1.22	2.48 ± 0.09	1.41 ± 0.10	0.83 ± 1.45	1.69 ± 0.18
		Open flower	26.24 ± 0.42	22.37 ± 0.98				
		48-h hand pollination	29.95 ± 2.87	24.12 ± 2.46				
		72-h hand pollination	32.51 ± 0.74	26.59 ± 0.64				
II	I 230	Bud	21.60 ± 1.76	17.74 ± 0.60	2.02 ± 0.11	1.13 ± 0.07	0.69 ± 0.06	0.88 ± 0.02
II	I 230	Open flower	23.33 ± 2.07	19.12 ± 1.74				
		48-h hand pollination	–	–				
		72-h hand pollination	–	–				

TABLE 2. (Cont'd)

Group	Clone	Stage	Mean ovule Length (μ)	Mean ovule Breadth (μ)	Mean bean Length (cm)	Mean bean Breadth (cm)	Mean bean Thickness cm)	Mean weight (g/bean)
	I 466	Bud	24.25 ± 1.45	19.25 ± 1.50	2.09 ± 0.15	1.19 ± 0.07	0.72 ± 0.05	1.00 ± 0.14
		Open flower	26.62 ± 1.79	21.10 ± 2.05				
		48-h hand pollination	30.87 ± 1.39	25.51 ± 2.24				
		72-h hand pollination	33.77 ± 3.40	27.45 ± 1.91				
III	SCA 6	Bud	24.16 ± 1.57	19.93 ± 1.82	1.71 ± 0.08	0.90 ± 0.50	0.72 ± 0.06	0.58 ± 0.05
		Open flower	24.96 ± 3.14	20.76 ± 3.50				
		48-h hand pollination	30.00 ± 2.09	23.89 ± 1.52				
III	SCA 6	72-h hand pollination	32.69 ± 1.30	25.97 ± 0.99				
	SCA 19	Bud	25.11 ± 2.24	20.56 ± 1.16	1.60 ± 0.17	0.83 ± 0.11	0.68 ± 0.11	0.50 ± 0.09
		Open flower	25.05 ± 1.63	20.88 ± 1.92				
		48-h hand pollination	33.14 ± 0.39	25.11 ± 0.66				
		72-h hand pollination	–	–				



Figure 1. Ovule as seen under the microscope.

TABLE 3. CORRELATION COEFFICIENT OF AVERAGE OVULE COUNT PER OVARY, MEAN OVULE LENGTH, MEAN OVULE WIDTH, MEAN BEAN NUMBER, MEAN BEAN LENGTH, MEAN BEAN WIDTH, MEAN DRY BEAN THICKNESS AND MEAN DRY BEAN WEIGHT

Item	*Mean bean number*	*Mean dry bean weight*	*Mean bean length*	*Mean bean width*	*Mean bean thickness*
Mean ovule number	0.3432^{ns}	0.3676^{ns}	0.2419^{ns}	0.2291^{ns}	0.5085^{*}
Mean ovule length	0.7265^{**}	0.6676^{**}	0.6343^{**}	0.5838^{*}	0.6758^{**}
Mean ovule width	0.7771^{**}	0.8008^{**}	0.7589^{**}	0.7143^{**}	0.7937^{**}

** Significant at the 1% level

* Significant at the 5% level

TABLE 4. CORRELATION COEFFICIENT OF AVERAGE NUMBER OF BEANS PER POD, MEAN DRY BEAN WEIGHT, MEAN DRY BEAN LENGTH, MEAN DRY BEAN BREADTH AND MEAN DRY BEAN THICKNESS, FROM POD ANALYSIS

1. Number of beans/pod	(*1*)	(*2*)	(*3*)	(*4*)	(*5*)
2. Mean dry bean weight	–	0.2579^{***}	0.2734^{***}	0.2659^{***}	0.2049^{***}
3. Mean dry bean length		–	0.9340^{***}	0.9123^{***}	0.6447^{***}
4. Mean dry bean breadth			–	0.960^{***}	0.6084^{***}
5. Mean dry bean thickness				–	0.5779^{***}

*** Significant at 0.1% level of probabilities

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P

Tissue Culture Propagation of *Cacao* by the Use of Axillary Buds

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A successful method of tissue culture propagation of cacao would aid plant breeders to build up stock of clonal selections more rapidly than by the current method. As propagation through callus may not yield true clonal progeny, the project at Wye College is using organised tissues, such as terminal or axillary meristems, which can be maintained in an organised state. Attempts are being made to multiply such meristems in order to yield true clones and experiments on the control of continuous growth and the production of multiple buds in culture are described.

Cacao now has priority crop status and demand is rising for material suitable for planting in many countries. Healthy plants are needed to supply the new growing areas being developed as well as to replace old neglected plantations.

Vegetative propagation by conventional methods such as cuttings and budding is successful (Evans, 1953; Balasimha & Subramonian, 1983), but it is labour-intensive, requiring capital to be tied up for many years in the form of protected nursery areas and specialised equipment and still renders the plants vulnerable to disease and pest attack. It would be an advantage to have a rapid multiplication method using material from elite plants bred for certain desirable characteristics. It would then be possible to replant an ideal cacao growing area devastated by a disease epidemic with disease-resistant plants relatively quickly. Micropropagation using tissue culture techniques offers the potential for producing large numbers of uniform plants in a comparatively short time from selected genomes. It is now a commercially viable method for many herbaceous species and it has great potential for both temperate and tropical woody species where the advantages of rapid multiplication of elite stock would justify any extra cost.

There are two basic methods of propagation using tissue culture, *viz.*

- Callus culture, in which a small piece of tissue from almost any part of the plant is encouraged to dedifferentiate into a mass of cells (callus) which subsequently regenerates into differentiated tissues and finally plantlets, often through a process of embryogenesis;

- Meristematic or axillary bud culture, in which differentiated tissue at active growing points is treated with growth factors under precisely controlled conditions to obtain rapid growth and proliferation.

Propagation through callus may result in variation amongst the plantlets regenerated, but the use of organised tissues should enable true clones to be produced.

There have been some attempts to propagate cacao *in vitro* through callus using hypocotyl, stem or cotyledon segments of 14-day old seedlings (Kong & Rao, 1982) but only roots were obtained. Vestigial leaves and roots have been observed from immature embryos (Esan, 1982) and whilst proliferating cell suspensions can be obtained from callus

on cotyledons, no embryogenesis has been reported (Tsai & Kinsella, 1981). Asexual embryos have been shown to proliferate from immature sexual embryos, but no embryogenesis was observed from leaf, pericarp or ovule tissue (Pence, *et al.*, 1979). Callus produced on whole mature embryos gave rise to adventitious shoots and roots from the meristematic zone only and sub-culture of nodal buds from these shoots produced a basal callus and a short shoot with uncharacteristic serrated leaves (Kong & Rao, 1982).

Few attempts to propagate cacao directly by bud culture have been reported. Terminal buds from young seedlings (Orchard *et al.*, 1979) and nodal buds from fan branches of three-year-old plants (Passey & Jones, 1983) were used as source material, but it has only been possible to elicit a response using material removed from the plant in the few days before the onset of flushing and the cyclical growth pattern has not been obtained in culture beyond one flush. Passey and Jones (1983) are alone in their use of bud explants to achieve some shoot proliferation and rooting *in vitro*. They observed shoot extension and leaf expansion followed by proliferation of two to six shoots per explant with the addition of another one to two axillary shoots after a further period of six months but all cultures were dead after 14 months and no continuous growth was observed. There is no indication that any method of tissue culture propagation so far reported is sufficiently successful for use on a large scale in the near future.

Like all tree species cacao presents problems for *in vitro* culturing such as age, breaking of dormancy, sterility of material and achieving the preferred combination of environmental variables for rooting *in vitro*, but it also has the additional complication of copious secretion of mucilage on cutting, having precise nutrient requirements and a complex growth cycle.

The present project is an attempt to discover the optimum conditions for continuous growth and proliferation of cacao shootlets in culture. This includes precise definition of the culture medium, inorganic and organic constituents, growth factor requirements and environmental conditions as well as requiremants for the maintenance of stock plants as a source of high quality explant material.

MATERIALS AND METHODS

Three to four-year-old stock plants of Amelonado variety were maintained in an environmentally controlled glasshouse at 25°C with 16-h photoperiod obtained by supplementing the natural daylight with tungsten and high pressure mercury vapour lamps in the winter months. The plants were grown in lime-free compost with fertiliser added as required. Watering was exclusively with rain water and the plants were not allowed to dry out.

Nodal explants were taken with 2 cm of stem, with the axillary bud and the petiole (*Figure 1*). They were collected just prior to the onset of a new flush before any leaves were visible in the swelling bud.

Sources of explants were:

a) Nodal buds from 'seedling' type shoots (chupons or suckers near the base of the tree)

b) lateral buds from fan shoots

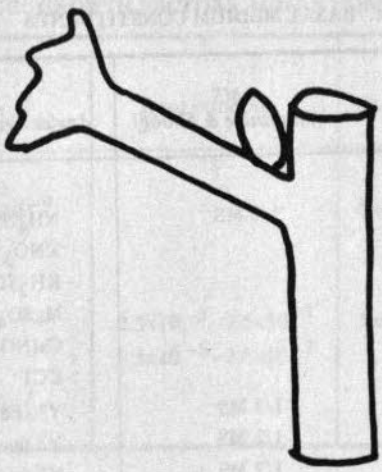


Figure 1. Typical nodal bud explant

c) main stem buds from plants cut back to induce bud break

d) terminal buds (from 'fan' and 'seedling' shoots)

An additional source of explant material was from seed of named clones grown ***in vitro*** to the four leaf stage, when the tips were excised to allow development of the buds at the base of the cotyledons.

Sterilisation

Explants were removed from the mother plants, immersed immediately in 2% sucrose and then placed under running water for 4 h. They were then shaken in a solution of 10% bleach (domestic 'Brobat') plus 0.01% Tween 20 for two periods of 15 min followed by four periods of 15 min in sterile double distilled water.

Culture Medium

Two basic media were used *viz.*, MS foumulated by Murashige and Skoog (1962) as supplied by Flow Laboratories, used at half strength and TC, a formula developed in this laboratory based on nutritional requirements of cacao grown *in vivo*. Full details are shown on *Table 1.* Various concentrations of MS and TC media were tested and full details are set out in *Table 2.* A wide range of growth factor concentrations (*Table 3*) was investigated in order to obtain optimal growth of cultures.

Culture vessels were 7.6 x 2.5 cm glass tubes or 125 ml glass jars which were closed with polypropylene film held in place by a rubber band.

Cuttings were incubated in:

- Growth chambers at a temperature of 29°C, either in the dark or with a 12 h photoperiod from 40 W fluorescent lamps providing ca. 200 μE m^{-2} s^{-1} in the 400–700 nm waveband.

TABLE 1. BASAL MEDIUM CONSTITUENTS

	MS (Murashige & Skoog)	*TC Analar Grade where available*
		(mg l^{-1})
Macro-elements	1/2 MS	NH_4NO_3 200
		KNO_3 2500
		KH_2SO_4 300
		$MgSO_4$ 400
		$Ca(NO_3)_2$ 600
		KCl 100
Micro-elements	1/2 MS	Y3 (Eeuwens, 1976)
Fe EDTA	1/2 MS	Y3 (as above)
Vitamins	1/2 MS	Y3 (as above)
Inositol	1/2 MS	100 mg l^{-1}
Casein hydrolysate	250 mg l^{-1}	250 mg l^{-1}
Scrose (as table sugar)	2–12%	2–12%
Agar[a] (Oxoid No. 3)	0.5%	0.5%

[a]The alternative liquid medium contained a filter paper bridge to support the explant.

TABLE 2. VARIATION IN CONCENTRATION OF MEDIA USED, RELATIVE TO BASAL MEDIA SHOWN IN *TABLE 1.*

Macro-elements	*Micro-elements + organic constituents*	*MS*	*TC*
1/10	1/10	✓	–
1/4	1/4	✓	–
1/2	1/2	✓	✓
1	1	✓	✓
1 1/2	1	✓	✓
1 1/2	1 1/2	–	✓
2	1	–	✓
2	2	✓	✓
2 1/2	1	–	✓
2 1/2	2 1/2	–	✓
3	1	✓	✓
3	3	✓	✓
4	1	–	✓
4	4	–	✓

TABLE 3. GROWTH FACTORS, MOLAR CONCENTRATIONS

	Initial Growth *Shoot initiation*	*Root initiation*	*Transfer* *Shoot growth*	*Root growth*
Cytokinins				
BAP	$5x10^{-5}$–$5x10^{-9}$	–	$5x10^{-5}$–$5x10^{-9}$	–
Kinetin	$5x10^{-5}$–10^{-7}	–	–	–
Auxins				
NAA)	–	$2.5x10^{-5}$–$2.5x10^{-7}$	$5x10^{-6}$–$5x10^{-9}$	$5x10^{-5}$–$5x10^{-9}$
IBA)	–	$2.5x10^{-5}$–$2.5x10^{-7}$	–	–
GA_3	$5x10^{-5}$–10^{-7}	–	–	–

- A growth cabinet within a glasshouse at a temperature of 25°C with a photoperiod of natural light supplemented up to 16 h with 60W tungsten lamps providing ca. 7 μE m^{-2} s^{-1}.

RESULTS

Initial growth responses occurred within two to three weeks and the majority of all clean cultures have produced shoot growth equivalent to a single flush of growth on the plant. The type of growth varied from the production of a good sturdy shoot with leaves and stem elongation of 2.5–5.0 cm with axillary buds clearly visible, to little more than the opening up of the bud (*Figures 2a–g*). Some cultures produced additional axillary bud growth after a further three to eight weeks without further transfer to fresh medium. The red leaf stage was never observed *in vitro*.

Callus was formed at the base of all explants and on the portion of stem above and below the bud. The amount of callus varied but was less in quantity with liquid culture than with agar and generally did not affect the growth of the shoot.

Cultured shootlets were highly sensitive to transfer to fresh medium. Most successful transfers occurred when the explant was left untrimmed and no attempt was made to separate basal buds from the main shootlet. Survival was greater when more leaves were present on the shootlet at transfer and when the time between transfers was 10 days rather than 21–28 days. Cultures which retained their leaves grew best but many had some form of leaf drop (*Figures 3a–d*).

Initial growth showed no positive correlation with the two media used. Concentrations less than basic strength produced slower growth responses but otherwise no observable differences were noted. The explants grown in concentrations of 2 x MS or greater, and 3 x TC or greater dried out within three weeks.

Growth response was unaffected by variation in the sucrose concentration in the medium. The fastest shoot growth and development of the basal buds was obtained with 5 x 10^{-7}M 6-Benzylaminopurine (BAP). Less growth and fewer shoots were obtained with lower levels up to 5 x 10^{-9}-M and with all levels of kinetin. When a combination of 1-Naphthylacetic acid (NAA) and 4-(indol-3-yl)-butyric acid (IBA) was added (each

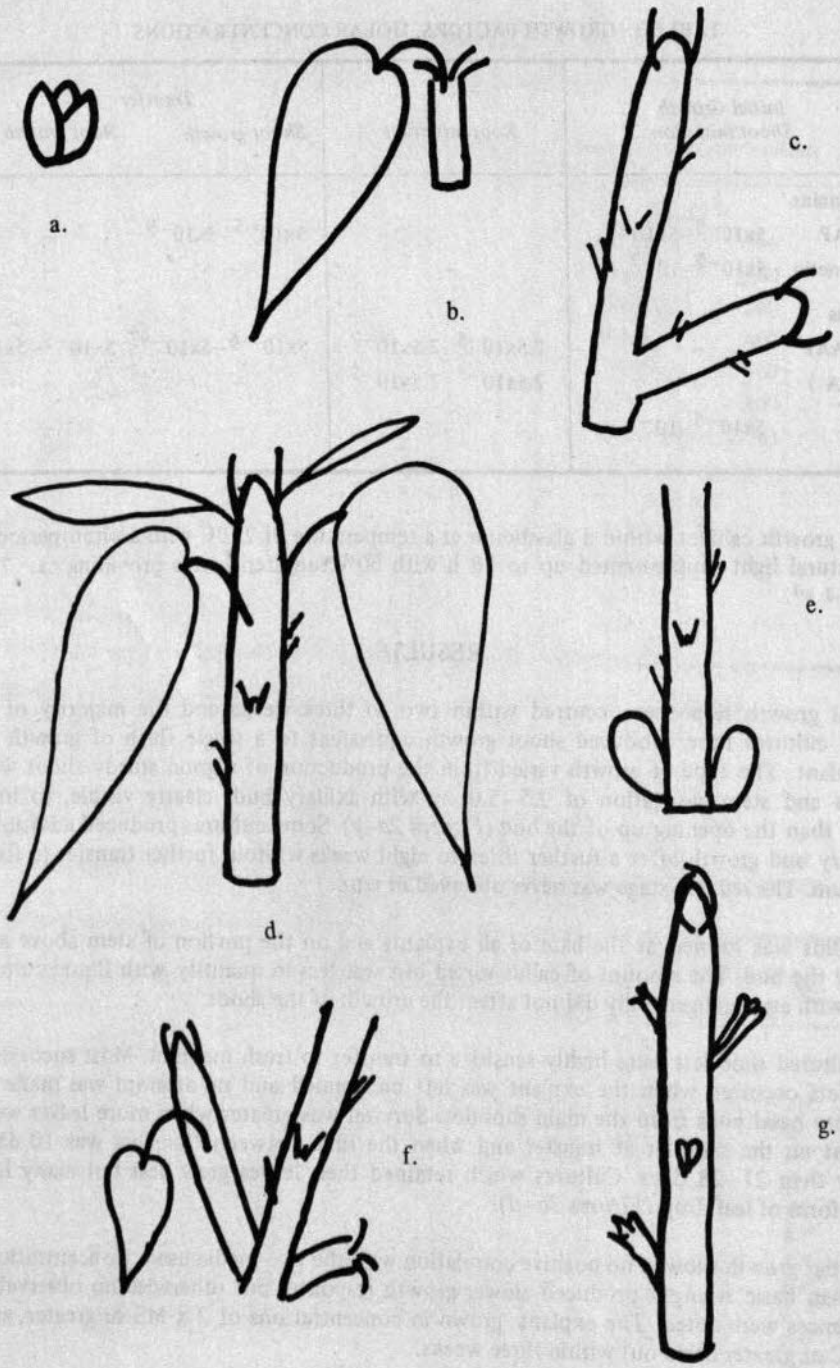


Figure 2. Shoot growth responses on basal medium with 5 x 10^{-7} M BAP

a. bud opened, no further development
b. some shoot growth, only one leaf
c. second shoot development, followed by death of first shoot
d. good shootlet development with leaves
e. basal buds greening
f. basal bud(s) (1–4) development
g. terminal bud dormant, axillary buds on stem developing

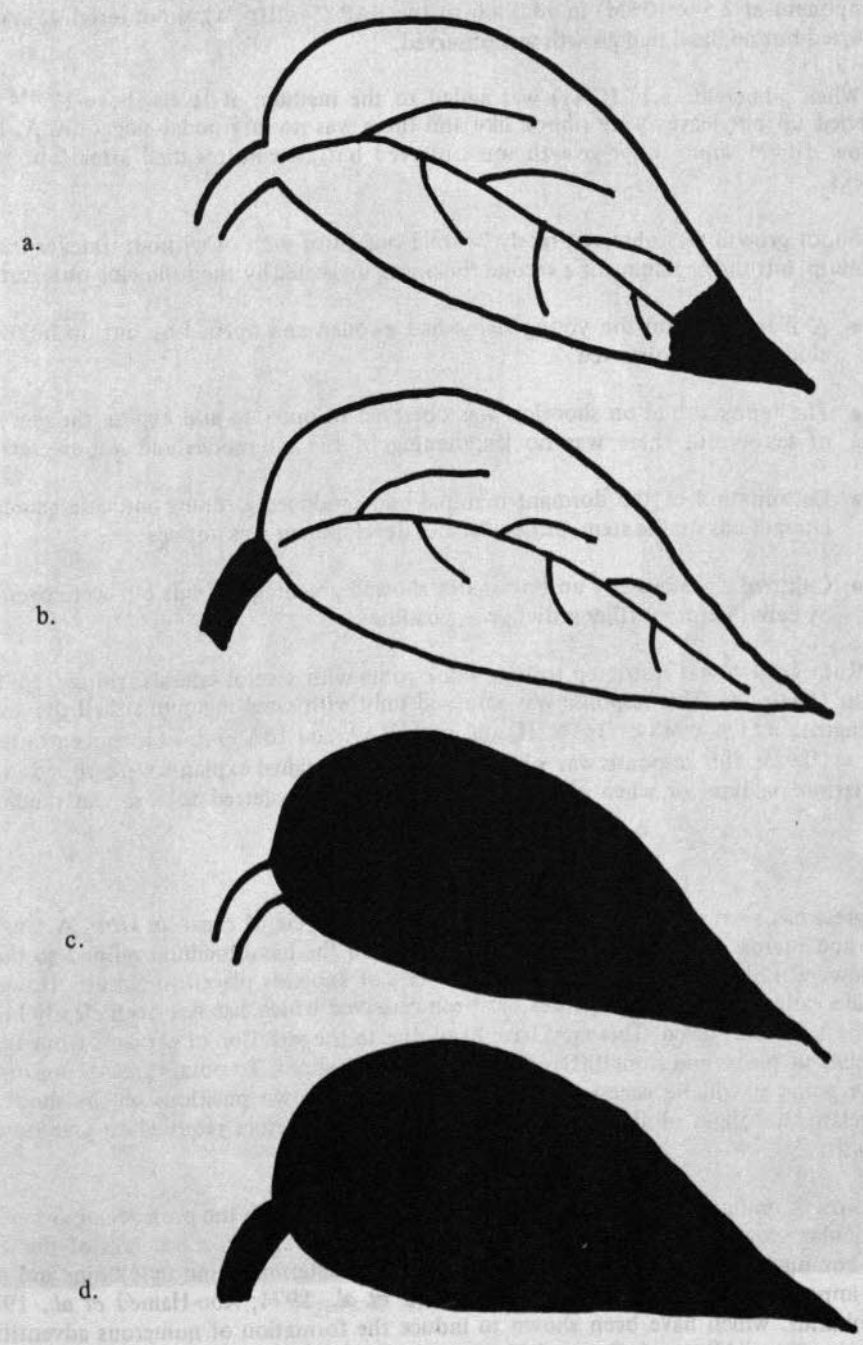


Figure 3. Leaf appearance prior to leaf drop

a. leaf green, tip brown, petiole green
b leaf green, petiole brown
c. leaf brown, petiole green
d. leaf brown, petiole brown

component at 2.5 x 10^{-6}M) in addition to the BAP (5 x 10^{-7}M), shoot response was not affected but no basal bud growth was observed.

When gibberellic acid (GA_3) was added to the medium at levels above 10^{-6}M buds opened up but leaves were ribbon like and there was no internodal elogation. At levels below 10^{-6}M some shoot growth was observed but all cultures died after four to six weeks.

Shoot growth was observed rarely beyond one flush with or without transfer to fresh medium, but the beginning of a second flush was suggested by the following observations:

- Axillary buds on the young stems had swollen and opened up but no internodal elongation was observed;
- The terminal bud on shootlets was observed to open up and expose the new flush of leaves but there was no lengthening of the internodes and leaf enlargement;
- Decapitation of the dormant terminal bud produced greening and enlargement of lateral buds on the stem, but no further development was noticed.
- Cultured shootlets cut up into nodes showed greening of buds but were overcome by callus before further growth was possible.

Root growth was restricted to long thick roots with several laterals arising from basal callus *(Figure 4)*. This response was achieved only with basal medium at half the normal strength, *i.e.* 1/4 x MS or 1/2 x TC and with NAA and IBA each at a concentration of 2.5 x 10^{-6}M. This response was obtained when the original explants were placed in root initiation medium or when cultured shootlets were transferred to a similar medium.

DISCUSSION

Progress has been made in understanding the growth cycle of cacao *in vitro*. A range of salt and sucrose concentrations has been tested and the basal medium refined so that it is now possible to obtain a response from 95% of explants placed in culture. However, a wide variety of growth responses has been observed which has not been clearly linked to the treatment given. This may have been due to the selection of explants from a large number of plants and from different positions on the shoot. To obtain greater uniformity of response it will be necessary to take buds from known positions on the shoot and correlate the origin of the bud with levels of growth factors required to give optimal growth.

Growth limitation is probably most closely associated with the presence or absence of particular growth factors at each stage of the growth cycle. Precise details of the levels and combinations required *in vivo* have not yet been determined but cytokinins and ABA are important factors in bud activity (Alvim *et al.*, 1974; Abo-Hamed *et al.*, 1981). Cytokinins, which have been shown to induce the formation of numerous adventitious buds in citrus (Altman & Goren, 1974), are reported to have had a similar effect in cacao *in vitro* (Passey & Jones, 1983), but this has not been confirmed in our work. We have shown that cytokinins are effective in producing multi-bud growth but the addition of some auxin is also required to obtain continued growth when cultures are transferred. The role of GA_3 has yet to be precisely defined but it is implicated in overcoming the effect of ABA in releasing buds from dormancy (Orchard *et al.*, 1979).

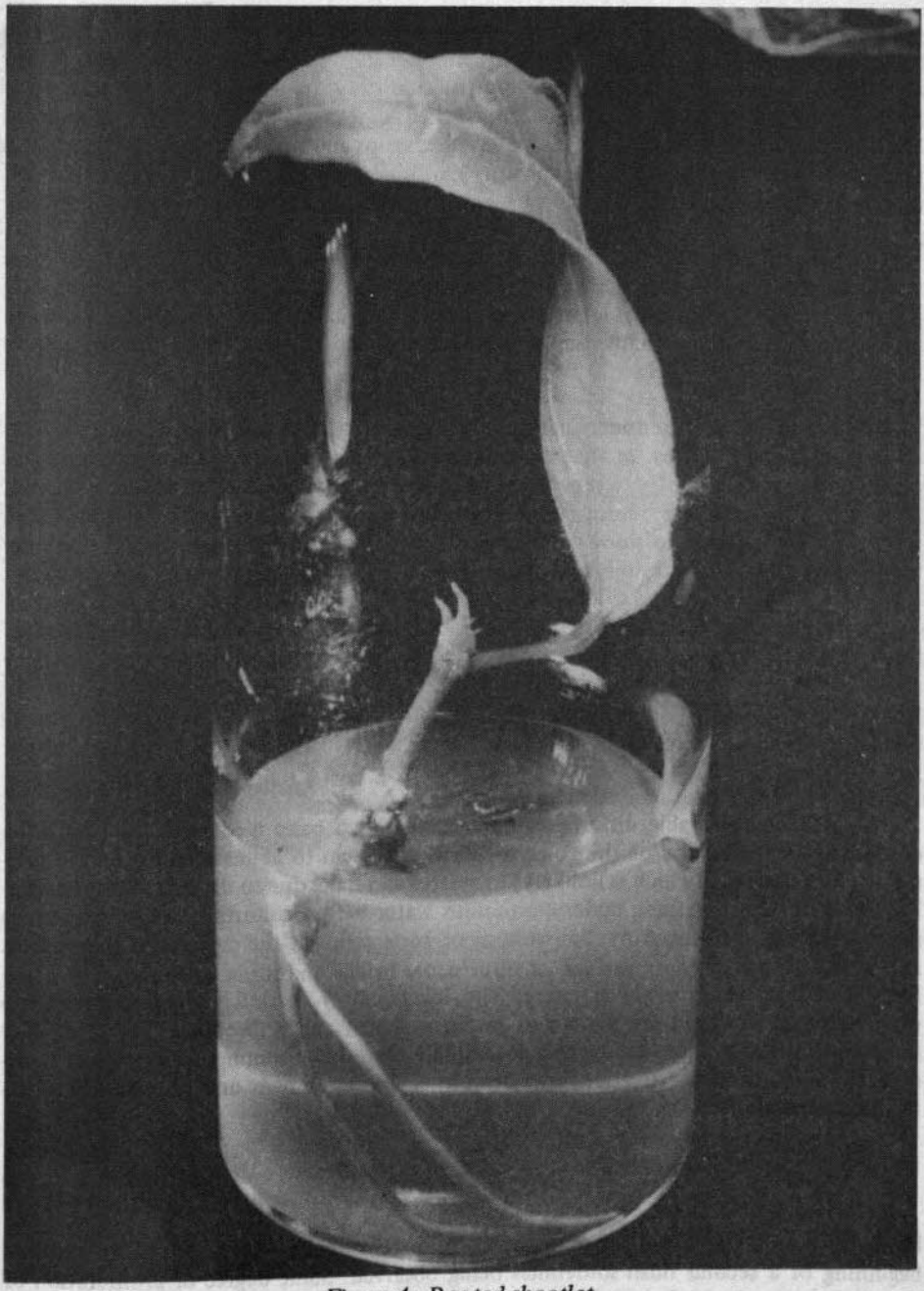


Figure 4. Rooted shootlet

Alternatively the limitation of growth may be linked to inadequate uptake of nutrients due to blockage of vessels by excessive mucilage. Very little growth was observed beyond one flush, which seemed to confirm the inability to utilise stored nutrients or lack of ability to take up and store reserves. It is well known that new flush growth *in vivo* is made possible by the use of reserves of nutrients already stored in the tissues (Wood, 1975; Hutcheon, 1976).

Many cultures dropped most or all of their leaves. This was observed in cultures grown under both natural and artificial light which suggests that the reaction was not due to light levels or quality. This is important because those cultures which retained their leaves grew better than those which dropped their leaves. The tolerance range of nutrient levels is more restricted in cacao than most other crops and small inbalances often lead to premature leaf fall (Murray & Maliphant, 1965). There is also the possibility that leaf drop is due to accumulation of gases such as ethylene within the culture vessel.

The red leaf stage seen *in vivo* was never observed *in vitro*. All leaves of cultures grown totally under artificial lighting were dark green, *i.e.* the colour of mature, fully photosynthetically functional leaves *in vivo*, but those having some natural light showed a paler colouration and thinner texture which may indicate a role for light quality *in vitro*.

Sleigh *et al.*, (1981) consider that there is a rhythm of root and shoot growth in cacao as in other woody species. *In vivo* the sequence of root growth and shoot growth implies a functional equilibrium between roots and shoots. Although such a sequence has not been observed in culture, those cultures which retained their leaves and then produced roots were more likely to show opening of the terminal bud than those where the only response was shoot growth followed by leaf drop.

There is some doubt as to whether the thick roots in culture such as those illustrated by Passey and Jones (1983) and in *Figure 4* are true functional roots of cacao. They appear to arise from basal callus rather than cambial tissue and are unlike the roots on plants grown *in vivo*. It should be possible to obtain normal root growth in culture since typical *in vivo* roots were observed on seeds grown *in vitro* to the four leaf stage *(Figure 5)*.

The lack of observable differences between the two basic media used and both the concentration and ratios of the constituents would seem to indicate either a wide tolerance to excess salts (which is unlikely) or restricted intake due to damage whilst harvesting tissue or whilst washing under continuous water before culturing. Growth responses may have been influenced by the amount of basal callus at the cut end of the explant above and below the agar surface or filter paper bridge and often surrounding the bud itself. Cuttings which are overwatered and inadequately aerated or underwatered and overaerated in the field are known to produce similar callus (Wood, 1975). This may indicate that the culture substrate is inadequate and/or the running water regime detrimental and further investigation into the physical environment and preparation of explants is being undertaken.

CONCLUSION

Media have been developed for shoot growth of axillary buds through one flush, with the beginning of a second flush sometimes being observed. Some degree of proliferation of buds has been obtained, but further multiplication of shootlets should be obtainable, either by cutting up of cultured shootlets into nodal segments to obtain growth of axillary buds, or by inducing the development of axillary buds on the original explant and removing them at a later stage. Further investigation of the growth factors required for maximum proliferation is needed. Although rooting can be obtained *in vitro*, manipulation of the medium may be required to produce a satisfactory root system.

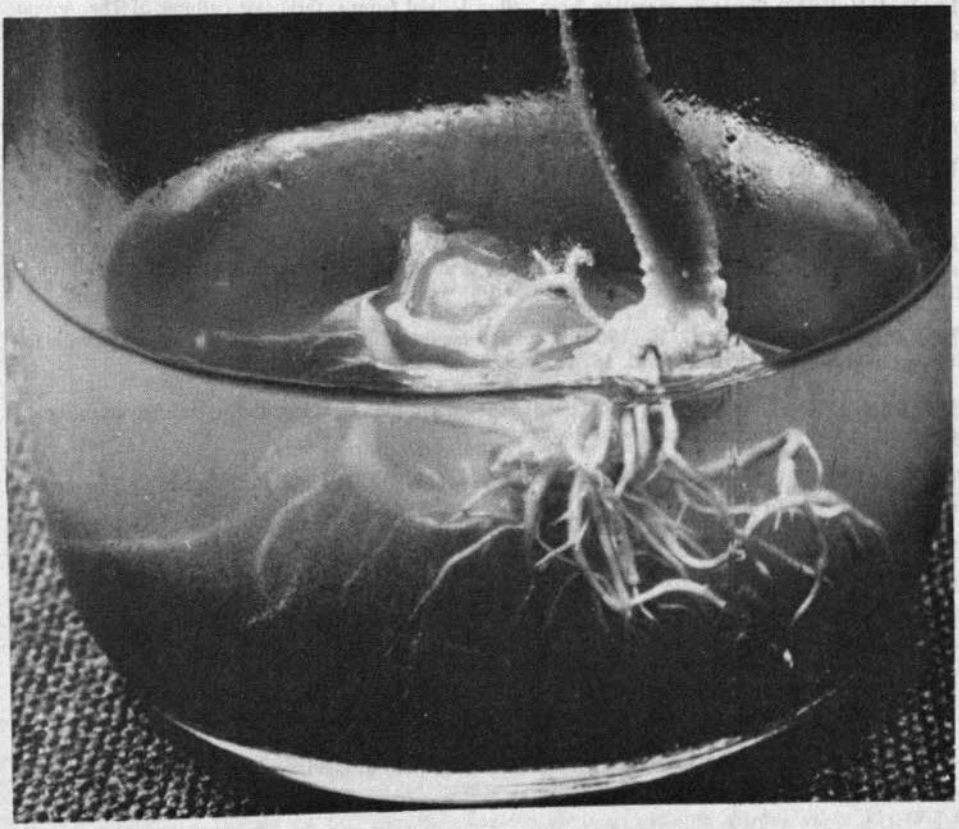


Figure 5. Seedling with roots grown in vitro

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P

Seasonal and Daily Activity Patterns of *Helopeltis theobromae* Mill (Hemiptera : Miridae) and their Implications in Field Control

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Seasonal activity pattern of H. theobromae *was monitored in a cocoa plot at MARDI Hilir Perak. Data on pest density, pod numbers, and rainfall were recorded. The results showed that the time of population build-up varied between years and the population trend seemed to be dictated by the weather and availability of cocoa pods as food source and breeding sites.*

Daily activity pattern of H. theobromae *was studied at various cocoa-growing areas in the Peninsular. It was found that the daily activity increased as light intensity decreased, and remained high throughout the night until the following morning. It was also observed that the increase in activity pattern of* H. theobromae *was also related to the increase in relative humidity and the decrease in dirunal temperature.*

In the development of H. theobromae *management programme, the seasonal population build-up, cropping cycle or pod numbers and weather pattern should be incorporated as important decision making criteria. Insecticide applications during early evening or very early in the morning are suggested.*

Helopeltis theobromae Mill provides the most persistent problems on mature cocoa since its first record of attack on cocoa at Serdang in 1939 (Miller, 1941). Damage is caused by both adults and nymphs feeding on shoots and pods. Severe attacks may result in shoot-dieback and pod loss due to cherelle wilt and secondary infection by pathogens such as *Botryodiplodia theobromae.*

The biology of the pest has been described by Miller (1941), Entwistle (1972), and Tan (1974). Studies on the biology of this pest have also been carried out at MARDI Hilir Perak (Azhar, 1983). Briefly, the eggs are laid in the pod husk and incubation period lasts six to nine days. *H. theobromae* undergoes five nymphal instars. The first instar is pale yellowish brown while the later instars are light to medium green in colour. The nymphs feed on cocoa pods throughout the developmental stages, which last from 10–14 days. The duration from initial egg laying to adult eclosion is about 27 days and longevity of adult caged in the field may reach 63 days.

Proper management of shade level on cocoa has been shown to reduce the severity of attack by mirids such as *Distantiella theobromae* (Dist.) and *Sahbergella singularis* Hagl in West Africa (Williams, 1953; Entwistle 1965; 1972). However, shade level on cocoa seems to have little influence on the *H. theobromae* attack in Peninsular Malaysia as infestation occurs equally severely regardless of shade level. In addition, parasites and predators have not been reported and seem to have very little influence on *H. theobromae* populations, although ants, especially *Dolichoderus* spp. and *Crematogaster* spp, have

been observed to reduce *H. theobromae* attack in isolated cases (Azhar, 1984). Chemical control has so far been the most widely adopted control practice by most cocoa growers.

Chemical control will remain important as a front-line defence against *H. theobromae* attack in the IPM programme on cocoa in Peninsular Malaysia. However, complete reliance on chemicals generally in cocoa has proven to be disadvantageous due to the development of resistance, adverse effect on nontarget organism, chance in pest status and resurgence of treated population, and pollution (Anon, 1969; Conway, 1969; Entwistle *et al.*, 1959; Azhar, 1984). As such, proper timing of insecticide application to coincide with a period of damaging pest densities is absolutely necessary in order to achieve maximum effectiveness with minimum environmental disturbance. Therefore, knowledge of the seasonal and daily activity pattern of *H. theobromae* is very desirable to provide extended and short-term management programmes for the pest.

This paper reports the seasonal and daily activity patterns of *H. theobromae* and discusses their implications in cocoa pest management strategy.

MATERIAL AND METHODS

Seasonal Pattern

The study was carried out in a cocoa plot at MARDI Hilir Perak experimental station. The block contained mature cocoa progenies planted in 1976.

Normal cultural practices, such as weed control and fertilizer application, were carried out when required. However, no insecticides had been applied since 1981, to allow a build up of *H. theobromae* in order to study population patterns. The study was started in April 1982 and is continuing.

Assessment of the *H. theobromae* population was made on 100 tagged trees selected according to a stratified random sampling plan (Southwood, 1976). Adults and nymphs were visually counted without removal on each of the selected trees and recorded. Pods bigger than 5 cm on each sample tree were counted. This was done in the early morning, beginning at about 0800 h at weekly intervals.

Daily Activity Patterns

The study was conducted at four cocoa-growing sites in the Peninsula (*Table 1*). The sample plot at each site consisted of progeny cocoa except the Kg. Api-Api plot, which consisted of clonal cocoa. The cocoa trees at all of the study sites were more than three years old.

At three sites *H. theobromae* populations were monitored on 100 trees and at the Kg. Api-Api site on 77 trees all selected randomly (*Table 1*). The number of nymphs and adults on each tree was visually counted at every hour during the day and every two hours at night. During one of the study occasions at the MARDI Hilir Perak site monitoring was stopped at mid-night.

Weather

For the seasonal activity pattern, the air temperature and rainfall were monitored by the meteorological station located at the MARDI Hilir Perak experimental station.

TABLE 1. COCOA AREAS USED AS SITES TO STUDY DAILY ACTIVITY PATTERNS OF *H. THEOBROMAE*

Site	*Type of planting material*	*Date of study*	*No. of trees sampled*	*Total no. of pods.*
Kg. Api-api, Kuala Selangor, Selangor.	Clonal	16 – 17 Dec. 1982	77	1804
Kg. Kuala Sanggang, Temerloh, Pahang.	Progeny	30 Sept 1982	100	1819
Kg. Sri Menanti, Muar, Johore.	Progeny	12 – 13 Oct. 1982	100	1482
MARDI Hilir Perak.	Progeny	21 – 22 Sept. 1983	100	1587

Weather parameters were collected at each site during the study period. The temperature and relative humidity of the microhabitat was measured with a thermohygrograph, positioned underneath the cocoa trees. The air temperature of the microhabitat were also measured using on ordinary thermometer. Light intensity within the cocoa canopy was measured using a light meter, at five different locations within each site.

RESULTS

The seasonal pattern of *H. theobromae* during the study period is shown in *Figure 1*. The seasonal trend indicated that there were three distinct periods of population build-up. Nymphs were always more abundant than adults.

The population dynamics appeared to be closely associated with weather pattern, especially the number of rainy days per month (*Figures 1* and *2*) and the availability of food in the form of cocoa pods. Although rainfall occurred throughout the year, February and March are usually the driest months of the year (*Figure 2*). A sharp increase in monthly precipitation occurs within the first few months following the dry period, usually in April of each year. The wettest months usually occur towards the end of each year, usually from October-December, and may extend into January. The three population peaks of *H. theobromae* coincided with those moths with heavy rainfall and number of rainy days exceeding 10 days (*Figures 1* and *2*). Cocoa pods were available throughout the year and the period of heavy fruiting occurred a short dry spell after the onset of main rainy season. In 1982 the peak occurred in December while in 1983 it occurred in August (*Figure 1*). The relationship of seasonal trend with average daily temperature was less pronounced, although the *H. theobromae* population was low during the dry period in March 1983.

The population trend (*Figure 1*) showed that in 1982, the nymphal population decreased from April to July and then increased considerably from September, reaching its highest peak in December. Subsequently, the population declined towards March 1983, before a small increase in June. After a slight decline in July the population increased sharply, reaching another high peak in August, followed by a sharp decline towards October. The two highest peaks, in December 1982 and August 1983 reached an average population level of about 200 nymphs per 100 trees.

The adult population showed a somewhat similar but delayed trend to that of the nymph. A lower peak in May 1982 declined towards July and increased steadily after

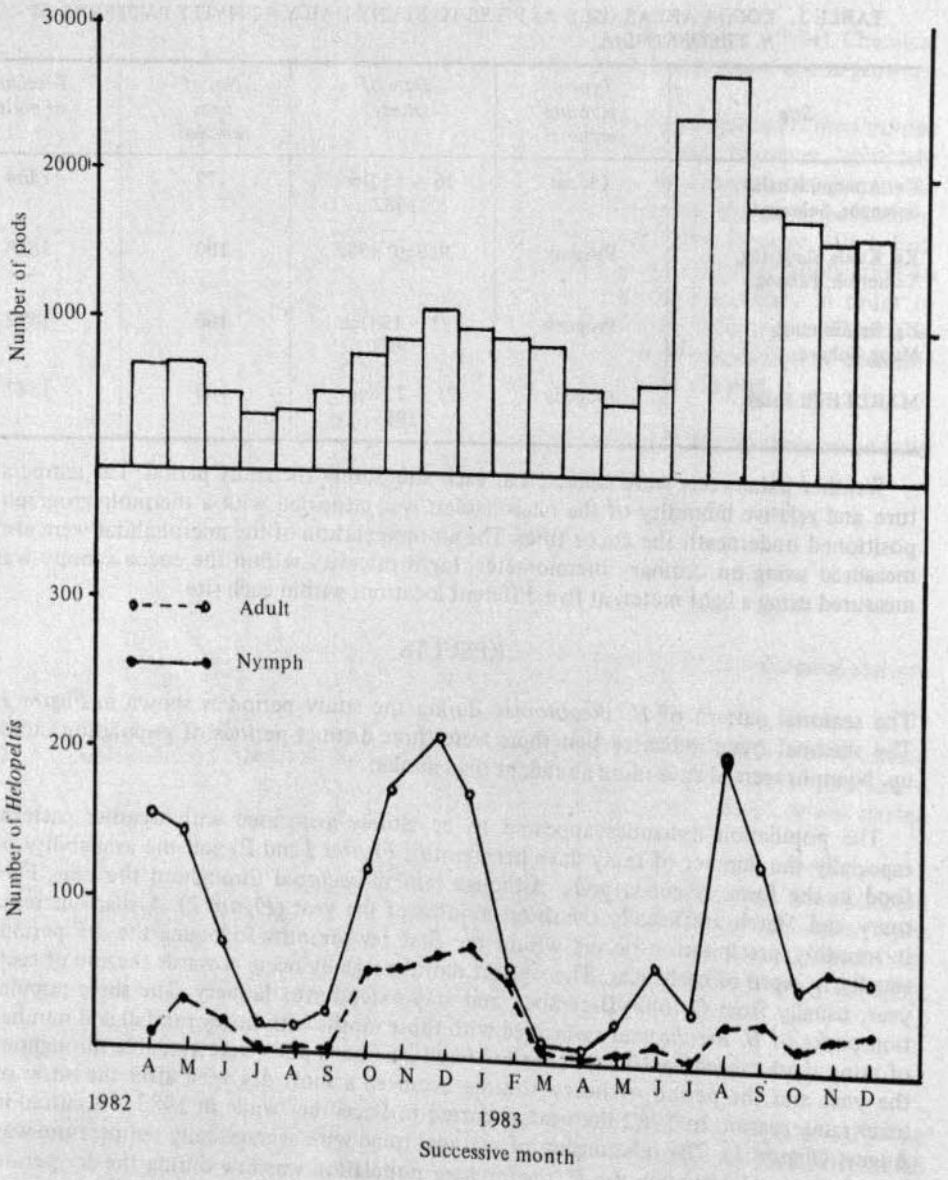


Figure 1. Monthly pattern of variation in H. theobromae *populations indicated by visual observation, and the number of cocoa pods per 100 trees in MARDI Hilir Perak.*

September reaching the highest peak in January 1983, with the population averaging more than 70 adults per 100 trees. There was another peak in September 1983 but the average population level was lower than that of the previous peak in 1983. The adult population peaks were achieved at least a month later than the nymphal population peaks (*Figure 1*). The decline in the nymphal population during these periods of adult peaks was probably because at that time many of the fifth instar nymphs had become adults.

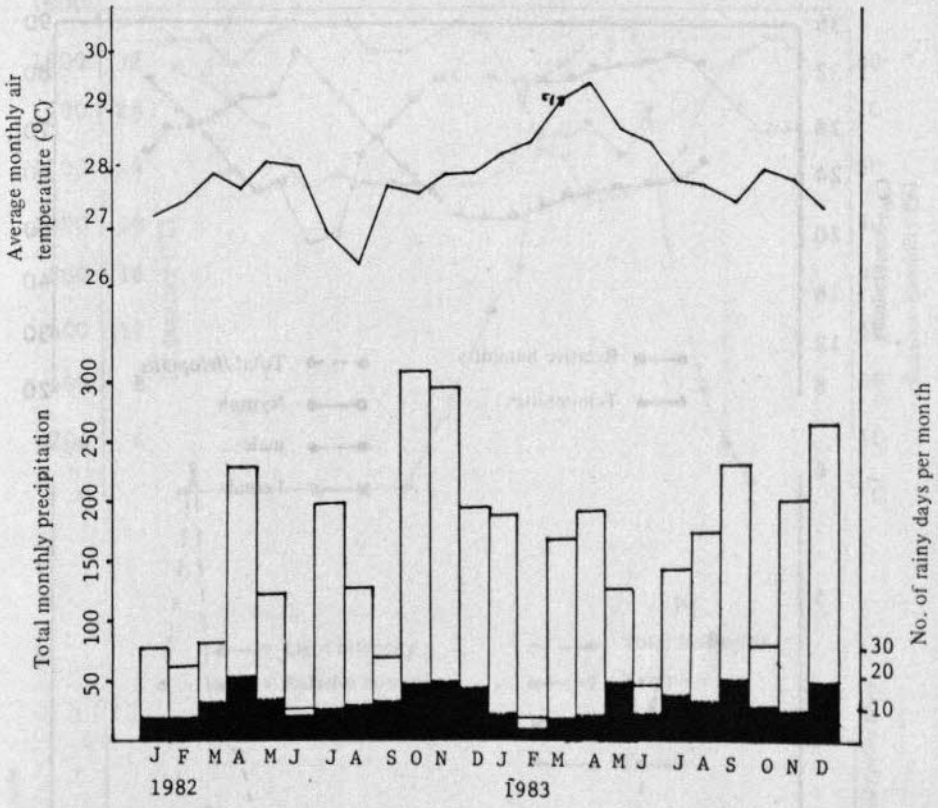


Figure 2. The monthly precipitation pattern, average temperature and number of rainy days at MARDI Hilir Perak.

Daily Activity Pattern

The daily activity pattern of *H. theobromae* found at various locations is presented in *Figures 3–6*.

Both females and males were abundant in the early morning (until about 0800 h), decreased towards the afternoon, and increased in the early evening (beginning at about 1800 h) at all the localities. The adults remained active throughout the night until the following morning. The adult activity appeared to have inverse relationship with temperature and light intensity but positive relationship with relative humidity at all study locations.

No general pattern could be generalized for the nymphs as they fluctuated irregularly regardless of time of the day. Hence any influence of environmental factors such as temperature, relative humidity and light intensity, could not be evaluated.

DISCUSSION

The result of these studies indicate that *H. theobromae* population build-up varies at different time of the year with its population trend being dictated by the weather and

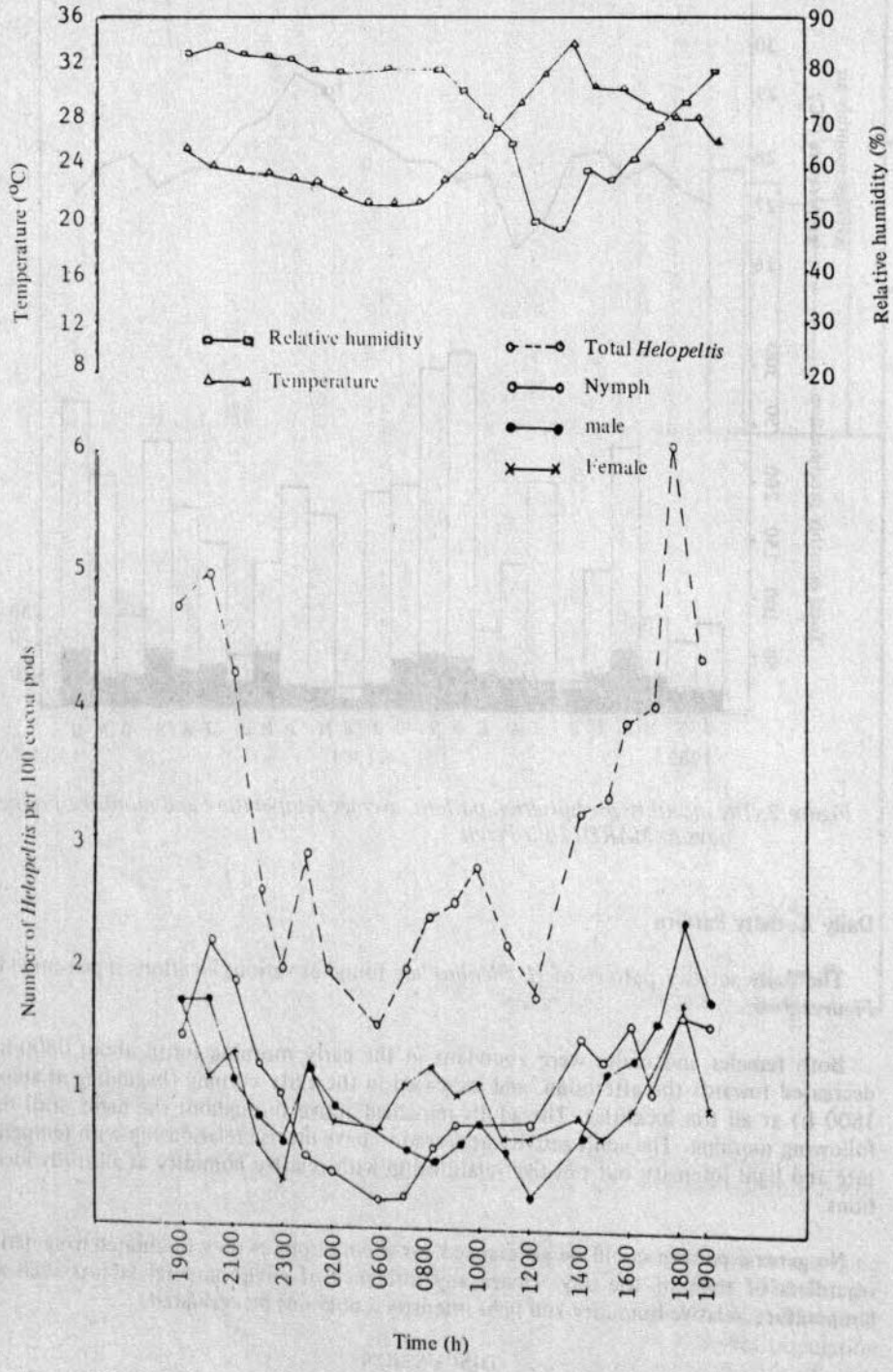


Figure 3. Daily activity patterns of H. theobromae *monitored by visual observation on 77 clonal cocoa trees at Kg. Api-Api, Kuala Selangor, Selangor on 16–17 December 1982.*

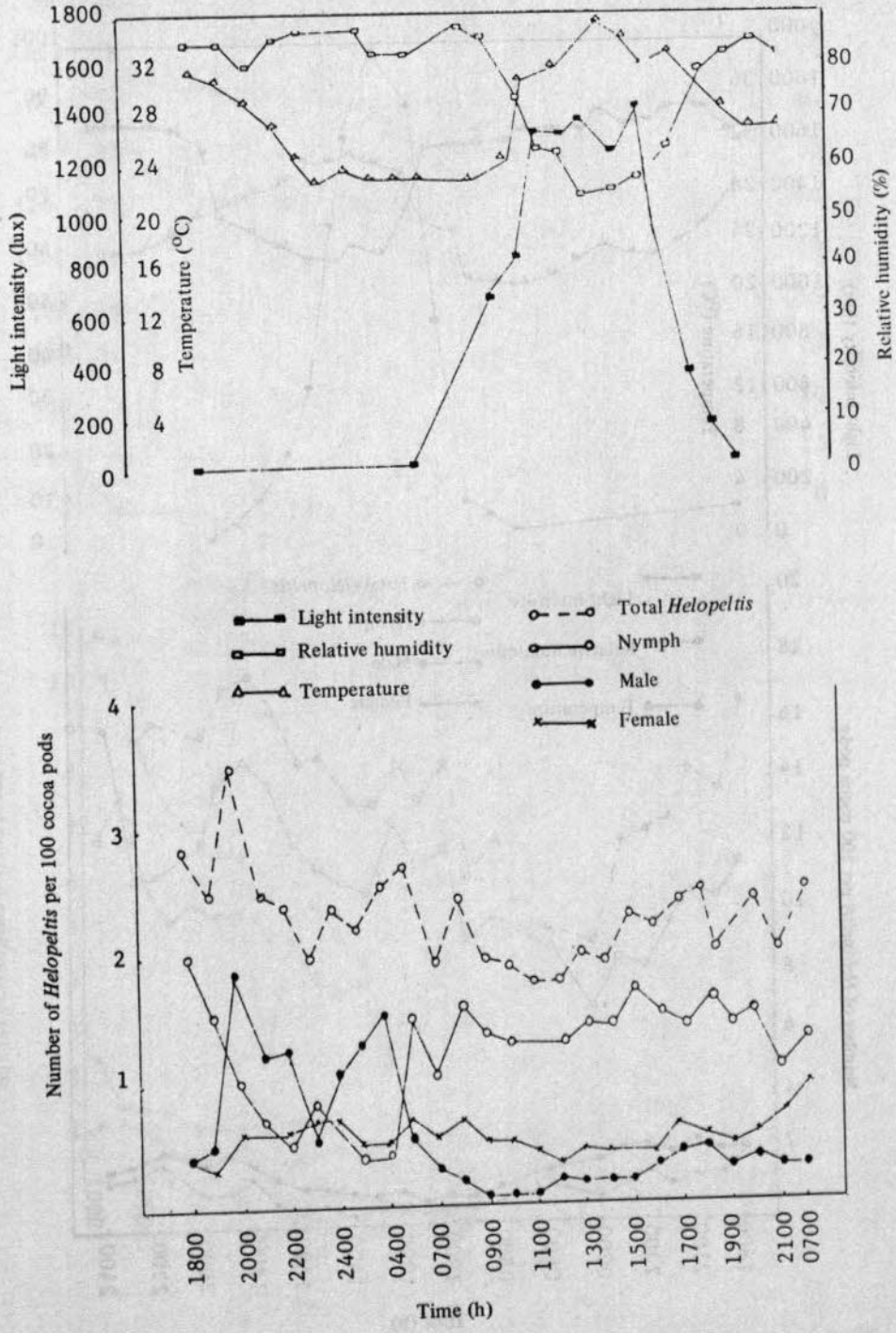


Figure 4. Daily activity patterns of H. theobromae *monitored by visual observation on 100 cocoa progenies at Kg. Kuala Sanggang, Temerloh, Pahang on 30 September, 1982.*

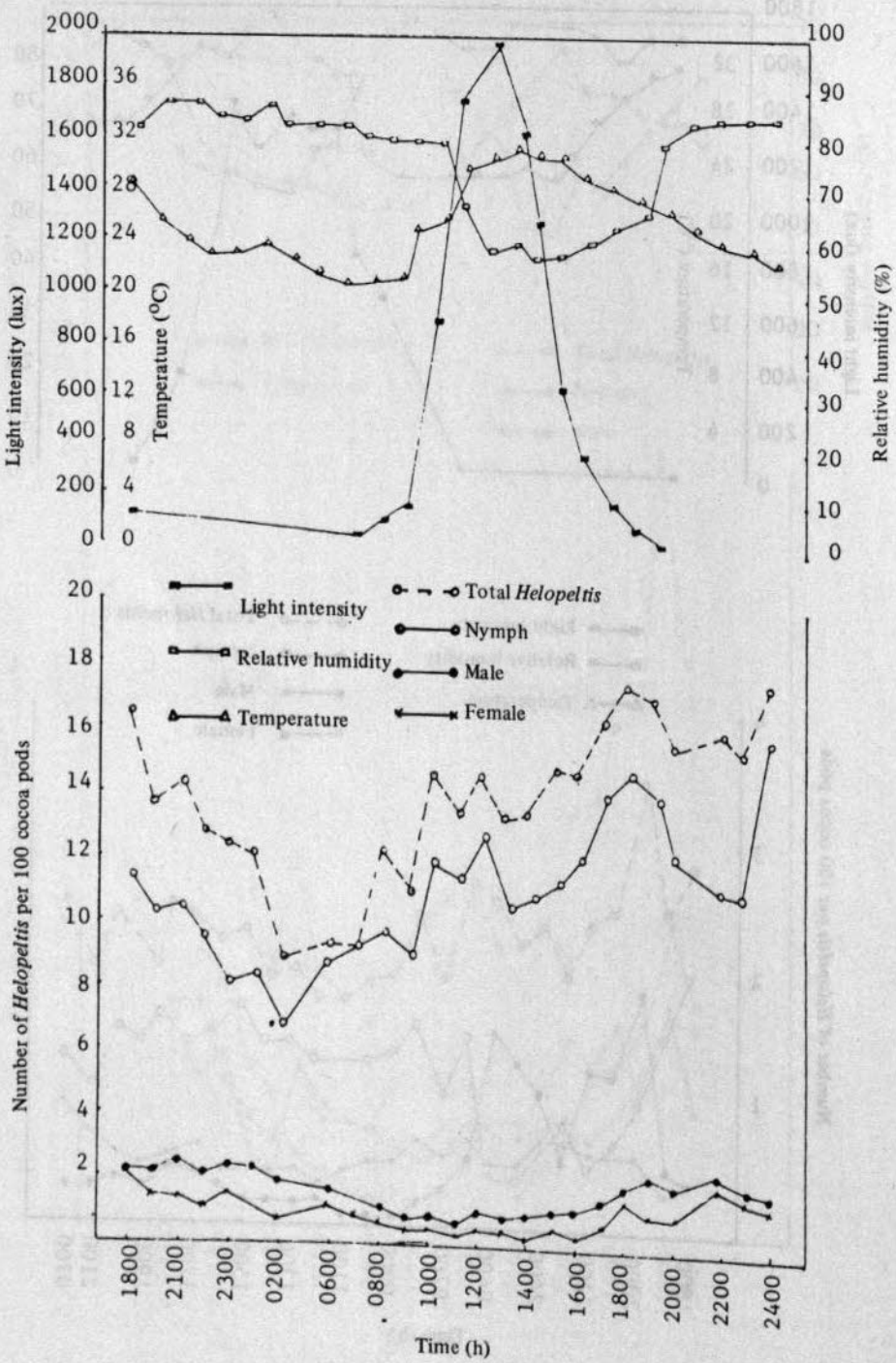


Figure 5. Daily activity patterns of H. theobromae *monitored by visual observation on 100 cocoa progenies at Kg. Sri Menanti, Muar, Johore on 12–13 October, 1982.*

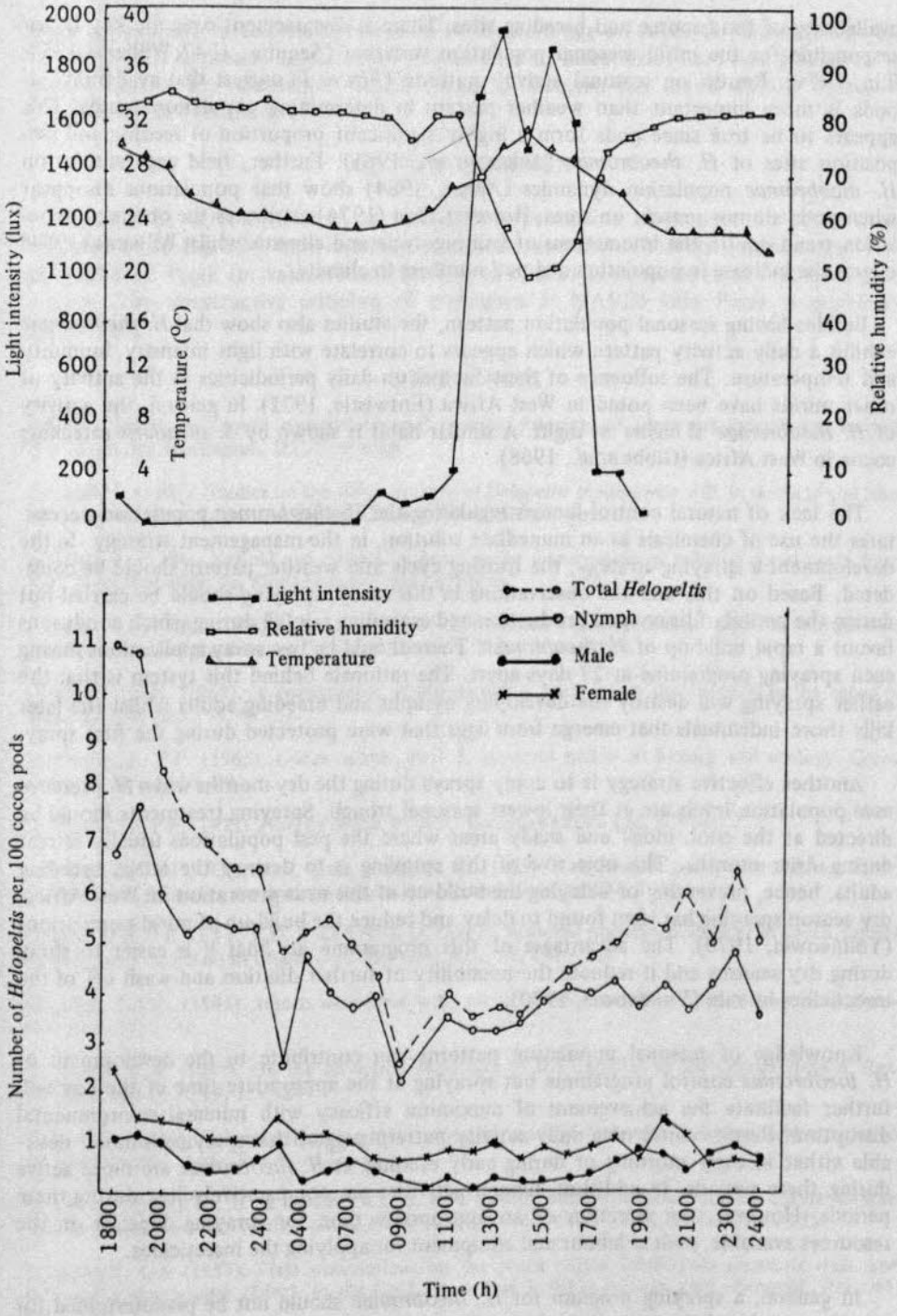


Figure 6. Daily activity patterns of H. theobromae *monitored by visual observation on 100 cocoa progenies at MARDI Hilir Perak on 21–22 September, 1983.*

availability of food source and breeding sites. There is disagreement over the key factor responsible for the mirid seasonal population variation (Sequire, 1947; Williams, 1954; Tan, 1974). Results on seasonal activity patterns (*Figure 1*) suggest that availability of pods is more important than weather pattern in determining population trends. This appears to be true since pods form a highly significant proportion of feeding and oviposition sites of *H. theobromae* (Azhar *et al.*, 1981). Further, field cage studies on *H. theobromae* population dynamics (Azhar, 1984) show that populations disappear when pods are not present on trees. However, Tan (1974) attributes the observed population trend due to the interactions of fruiting cycle and climate, whilst Williams (1954) relates the increase in population and pod numbers to climate.

Besides having seasonal population pattern, the studies also show that *H. theobromae* exhibit a daily activity pattern which appears to correlate with light intensity, humidity and temperature. The influence of these factors on daily periodicities in the activity of other mirids have been noted in West Africa (Entwistle, 1972). In general, the activity of *H. theobromae* is higher at night. A similar habit is shown by *S. singularis* attacking cocoa in West Africa (Gibbs *et al.*, 1968).

The lack of natural control factors regulating the *H. theobromae* population necessitates the use of chemicals as an immediate solution, in the management strategy. In the development a spraying strategy, the fruiting cycle and weather pattern should be considered. Based on this and the observations in this study, spraying should be carried out during the period of heavy pod production and ascending rainfall during which conditions favour a rapid build-up of *H. theobromae*. There should be two spray applications during each spraying programme at 27 days apart. The rationale behind this system is that the earlier spraying will destroy the developing nymphs and breeding adults whilst the later kills those individuals that emerge from eggs that were protected during the first spray.

Another effective strategy is to apply sprays during the dry months when *H. theobromae* population levels are at their lowest seasonal trough. Spraying treatments should be directed at the cool, moist and shady areas where the pest populations usually retreat during drier months. The objective of this spraying is to destroy the initial breeding adults, hence, preventing or delaying the build-up of this next generation. In West Africa, dry season spraying has been found to delay and reduce the build-up of mirid populations (Youdeowei, 1970). The advantages of this programme are that it is easier to spray during dry seasons and it reduces the possibility of further dilution and wash off of the insecticides by rain (Youdeowei, 1970).

Knowledge of seasonal population patterns can contribute to the development of *H. theobromae* control programme but spraying at the appropriate time of the day will further facilitate the achievement of maximum efficacy with minimal environmental disruption. Results concerning daily activity pattern suggest that spraying is more desirable either in early morning or during early evening, as *H. theobromae* are more active during these periods. In addition, human activities are comparatively less during these periods. However, the selection of an appropriate time for spraying depends on the resources available, such as labour and equipment for applying the insecticides.

In general, a spraying program for *H. theobromae* should not be predetermined for specific months of the year, since the results presented here demonstrate that the time of population build-up varies from year to year. Perhaps the adoption of the Early Warning System (EWS) approach (Wignyosoemarto & Soebiyakto, 1980), incorporating fruiting cycle or pod numbers and weather pattern as some of the decision making criteria, is

more appropriate in the management of *H. theobromae* on cocoa in Malaysia. The objective of this approach is to reduce the amount of insecticides used and a decrease in the *Helopeltis* sp. infestation, whilst cocoa production has drammatically increased (Youdeowei & Toxopeus, 1983).

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P

RELATIONSHIP BETWEEN CALCIUM LEVELS AND COCOA STEM CANKER CAUSED BY TWO MORPHOLOGICAL FORMS OF PHYTOPHTHORA PALMIVORA

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SUMMARY

The effect of calcium on stem canker development in cocoa as caused by three isolates of Phytophthora palmivora were examined using seedlings grown in sand and water culture as well as in a nutrient film. At leaf calcium concentration varying from 0.12 to 0.26%, increase in calcium level resulted in increase in resistance of stems to infection by P795, an MF4 isolate from Cameroun ($r = 0.71$). However, at calcium concentration varying from 0.39 to 1.20%, there was a significant increase in susceptibility of seedlings to infection by the same isolate ($r = 0.89$).

There was no significant difference in seedling reactions at calcium concentration varying from 0.12 to 0.26% and 0.1-1.4% when inoculated with P255 and P40 respectively (MF1 isolates from Costa Rica and Malaysia).

A macerating enzyme was produced by P795 but not by P255. Although enzyme activity was significantly inhibited at 10mM Ca^{++}, studies with other Phytophthora isolates suggested that this macerating enzyme appeared only to have localized significance, if any, in the pathogenesis of stem canker and pod rot of cocoa.

INTRODUCTION

Phytophthora palmivora is responsible for causing black pod, stem canker and leaf blight on cocoa (Theobroma cacao L.).Under favourable weather conditions, it also attacks the cherelles. As a group, the pathogen is highly variable physiologically, morphologically and cytologically. Based primarily on work done by Kaosiri (1978) and Waterhouse (1974), the pathogen may be divided into 4 morphological forms (Griffin, 1977; Zentmyer et al., 1977). Kaosiri (1978) suggested MF1 be retained as P. palmivora and MF 4 be referred to as P. capsici.

Although reports on the relationship between host nutrition and disease development have been published for some plant diseases (eg. Forster & Echandi, 1975; Mohr & Watkins, 1959; Robbin & Ogle, 1965; Rowan & Steinbeck, 1977), information is still lacking especially with regards to the relationship between nutritional status of cocoa and diseases caused by P. palmivora. Tarjot (1971) reported that susceptibility to black pod was associated with low calcium and magnesium and high potassium content of pod cortical tissues.

In the present study, the affects of calcium on stem canker development caused by MF1 and MF4 isolates was investigated. The role of a macerating enzyme produced in cultures in the pathogenesis of black pod was also examined.

MATERIALS AND METHODS

For stem inoculation studies, the isolates used were P255 (MF1, ATCC 26200, A^2 mating type from Costa Rica), P795 (MF4, A^1 mating type from Cameroun) and P40 (MF1, A^2 mating type from Malaysia). The first two cultures were maintained on V-8 agar at the Department of Plant Pathology, University of California, Riverside, USA while P40 was maintained in corn-meal agar at MARDI in Serdang, Selangor, Malaysia.

A. Influence of Calcium on Stem Canker Development

1. Sand culture - Cocoa seedlings (a UCLA selection of unknown clonal origin) were grown in sand in the greenhouse for 6 weeks and transplanted to 10-cm pots containing silica sand (No. 20, Crystal Silica Company). For 4 consecutive days per week , each seedling received 100 ml Hoagland's solution (Hoagland & Arnon, 1938) supplemented with 0.1 ml solution of $Ca(No_3)_2.4H_2O$ at 0.1, 5.0, 10.0 and 100.0 mM. Nitrogen concentration was maintained at the same level in all treatments by adding appropriate amounts of 1 M NH_4NO_3. For the following 3 consecutive days, each seedling received 100 ml of distilled water. There were 15 seedlings in each treatment. At the end of 3 months, 5 seedlings from each treatment were stem-inoculated with either P 255 or P 795. The remaining 5 uninoculated seedlings acted as controls. Mycelial discs (5-mm diameter) of the fungus, obtained from the advancing margins of 5-days old V-8 agar cultures, were used as inocula. Stems were first surface-sterilized with 95 percent ethyl alcohol, and a puncture was made with a sterilized needle at a point

0.5 cm below the first internode. The inoculum was held in place by a piece of transparent tape. In the control, seedlings were similarly wounded and a 5-mm diameter piece of sterile V-8 agar disc placed at the wound and held in position with a transparent tape. Length of stem lesions were recorded 7 days after inoculation.

Prior to inoculation, levels of macro-nutrients (Ca, Mg, K, P, and Na) and micro-nutrients (Zn, Mn, Cu, Fe, and B) of seedlings in various treatments were determined through foliar analyses. The youngest fully matured leaf (designated as leaf number 1) and the fourth leaf from each seedling were collected, washed in mild detergent, and dried for 24h at 60°C. Dried and finely ground tissue (1 g) was then placed in a 50-ml silica crucible and ashed for 15 h at 550°C. The levels of Ca, Mg, K and Na (expressed as percent dry weight) and Zn, Mn, Cu and Fe (expressed as ppm) were determined using the atomic absorption spectrophotometer (Perkin-Elmer 460) (Lab$_a$nauskas, 1966). Boron (expressed as ppm) and phosphorus (expressed as percent dry weight) were determined colorimetrically (Jackson & Brown, 1956; Kitson & Mellon, 1944) using a Beckman B spectrophotometer.

2. Water culture - Six-week old cocoa seedlings, established previously in sand, were raised hydroponically in Hoagland's solution (Hoagland & Arnon, 1938) in 14-liter crocks. The solution contained $Ca(NO_3)_2.4H_2O$ at the following concentrations in mM: 0, 0.5, 5.0, 10.0 or 25.0. Nitrogen concentrations were maintained at the same level in all treatments by adding appropriate amounts of 1 M NH_4NO_3. Each crock held 5 seedlings. Nutrient solutions were replenished every 2 weeks with deionized water.

There was a total of 10 seedlings per calcium treatment. At the end of 10 weeks, 5 seedlings from each treatment were stem inoculated with P 795 as described in (1). Prior to inoculation, leaves from the 5 seedlings were sampled and macro-and micro-nutrient concentrations analysed following the procedures as described in (1). In the control, seedlings were wounded and a 5-mm diameter sterile V-8 agar disc placed at the wound and held in position with transparent tape. Length of stem lesions was recorded 14 days after inoculation.

Nutrient film technique - Four uniform one-month old cocoa seedlings (Amelonado variety), grown in Jiffy^{R}-7 peat pellets, were transplanted into 1.3 m long plastic channels. Twenty liters of nutrient solutions in plastic containers were lifted in a continuous stream by air and circulated through the channels in a closed system. The solutions was changed every 10 days. Concentrations of nutrients in the nutrient solutions were as follow: Ca^{++}, 6.0; Mg^{++}, 4.0; K^{+}, 3.5; N (both NH_4^{+} and NO_3^{-}, 7.5; PO_4^{---}, 3.0 and SO_4^{--}, 4.0) (all expressed as meq/liter) and Fe, 4.0; Mn, 0.5; Cu, 0.02; Zn, 0.5; B, 0.4 and Mo, 0.02 (all expressed as ppm). The levels used were based on the average of nutrient concentrations used in previous cocoa nutrition experiments (Greenwood and Djokoto, 1952; Lockard et al., 1959; Lockard and Asomaning, 1963; Hurd, 1966). Five calcium levels (added as $CaCl_2.2H_2O$) tested were 0.094, 0.375, 1.500, 6.000 and 24.000 meq/liter. Each treatment was replicated 4 times. The 5 treatments were arranged in a complete randomized block design. The second and third fully opened leaves were taken from 4-month old seedlings

and the level of calcium analysed using the atomic absorption spectrophotometer (Perkin-Elmer 5000). The seedlings were inoculated with P40, using the method as described in (1). Area of lesions in cm^2 were determined at the end of 14 days.

At the termination of the above 3 experiments, representative pieces of necrotic stems were plated on PVP-hymexazol selective medium (Tsao & Guy, 1977) to reconfirm that the lesions were caused by the isolates used.

B. Enzyme Activity

1. Effect of Calcium on Activity of Macerating Enzyme

For the production of the macerating enzyme, 1 ml mycelial suspension of P 795 was introduced into a 500-ml Erlenmyer flask containing 100 ml liquid medium of the following compositions in g (Yoshikawa et al., 1977): Sucrose, 15; peptone, 5.0; $MgSO_4 \cdot 7H_2O$, KH_2PO_4, 2.0; thiamine HCl, 1 mg; and cucumber extract, 250 ml. The final suspension was made up to 1 liter with DD water. Cucumber extract was prepared by blending 250 g fresh cucumber in 200 ml DD H_2O and boiling the cucumber macerate for 15 minutes. After cooling, the mixture was passed through four layers of cheesecloth. The filtrate collected was centrifuged with the clinical centrifuge at 4,500 rpm for 10 minutes. The supernatant was made up to a final volume of 250 ml. The pH of the medium after autoclaving was 5.8.

Macerating activity of 7-day old sterile culture filtrates (sterilized by passing through 0.2 micron Nalgene^R millipore filters) was assayed by determining the loss in fresh weight of 5-mm diameter cucumber pericarp discs after 6 h of incubation at 33°C. Prior to the assay, the

cucumber discs were soaked in sterile DD water for 1 h and blotted dry. In groups of three, the discs were weighed to the nearest mg and incubated in the reaction mixture for 6 h at 33°C. The reaction mixture consisted of 2 ml culture filtrate, 2 ml citrate-phosphate buffer pH 6.5 (0.1 M citric acid and 0.2 M Na_2HPO_4), 0.5 ml DD H_2O, and 0.5 ml of either 1.0, 10.0 and 100.0 mM $CaCl_2$ or 10 mM EDTA-disodium salt. After incubation the discs were placed on a Buchner funnel, and the loosened cells were removed by spraying distilled water on the discs for 15-20 seconds (rate of water flow was 4-5 litres/min.). After soaking for 15-30 minutes in DD water, the discs were again blotted dry and weighed to the nearest mg to determine the weight loss. Net weight loss was determined by correcting for weight changes of discs incubated in identically prepared solutions that had been autoclaved to inactivate the enzyme. Each treatment had three replicates.

2. Relationship between Ability to Produce Enzyme and Pathogenicity

The following MF 4 isolates were used in studies on the ability of various isolates to produce macerating enzyme: P 252, mating type A^2 from Mexico; P 623, mating type A^2 from Brazil; P 780, mating type A^1 from Brazil; P 795 and P 817, both mating type A^1 from Cameroun; P 836, mating type A^1 from Trinidad; and P 897, mating type A^1 from Venezuela. P 255 (MF 1, ATCC 26200 Costa Rica), mating type A^2 was also included in the study. Methods of producing the enzyme and the bioassay for enzyme activity were as described in (1). Unripe cocoa pods (UCLA selection) were inoculated with the above isolates.

RESULTS

A. Influence of Calcium on Stem Canker Development

Nutrient levels of cocoa seedlings grown in silica sand, water culture and in the nutrient film technique are given in Tables 1, 2 and 3 respectively. Calcium levels (expressed as percent of leaf dry weight) grown in sand ranged from 0.12 to 0.26%, those in water tanks ranged from 0.05 to 1.20% and those in the nutrient film ranged from 0.10 to 1.40%. Seedlings with 0.05% calcium were killed within 5 days when inoculated with P 795.

The relationship between severity of stem canker caused by P 255 and P 795 and calcium in leaves (0.12 to 0.26 percent) is shown in Fig. 1. The two isolates responded differently. With 795, increase in calcium in the host resulted in a decrease in stem canker severity ($r = 0.71$). There was no correlation between calcium in the host and stem canker severity with P 255 ($r = 0.41$). When the percentage of leaf calcium was increased from 0.39 to 1.20, an increase in susceptibility of stems to P 795 ($r = 0.89$) was observed (Fig. 2). There was no significant difference in the lesion size in seedlings of different calcium levels when inoculated with P 40 (Table 4).

B. Enzyme Activity

1. Effect of Calcium on Activity of Macerating Enzyme

A macerating enzyme of unknown substrate was found to be produced in abundance by P 795 (MF 4), but not by P255 (MF 1). The effect of calcium on this enzyme is shown in Fig. 3. Calcium at 10 mM significantly suppressed the activity of this enzyme ($P = 0.05$).

2. Relationship between Ability to Produce Enzyme and Pathogenecity

Attempts to correlate the ability to produce the macerating enzyme in culture filtrates and the degree of pathogenicity of various MF 1 and MF 4 isolates showed that there was no correlation between the two factors ($r = -0.22$) (Table 5). Although P 780 and P 255 were among the most virulent isolates tested, as indicated by the pod inoculation experiment, these two isolates possessed little or no ability to produce the macerating enzyme. Culture filtrates of P 252 and P 623 exhibited high to moderate macerating activity. These two isolates were the least virulent of all the isolates tested.

DISCUSSION

Attempts to correlate calcium levels in cocoa seedlings and resistance of stems to P. palmivora showed that at lower levels of calcium (0.12 to 0.26 percent of leaf dry weight) an increase in calcium resulted in an increase in resistance of stems to infection by P 795 ($r = 0.71$). There was no significant difference in resistance of stems to P 255 under identical conditions. Difference in response could be due to the slower rate of colonization of host tissues by P 795 as compared to P 255 when the calcium level was increased from 0.12 to 0.26%. Our earlier studies showed that P 795 grew best in synthetic liquid medium without added calcium. On the other hand, addition of calcium to the growth medium stimulated growth of P 255. Calcium content of leaves higher than 0.39% predisposed stems to infection by P 795, the only isolate tested ($r = 0.89$).

The predisposition effect was probably due to the imbalance of micronutrient uptake associated with high calcium in the growth medium. Uptake of Zn was reduced from 35 ppm with 0.5% calcium to 3 ppm with 1.20% calcium of total leaf dry weight. Fe uptake was also reduced from 10 ppm with 0.05% calcium to 5 ppm with 1.20% calcium. Reports of interference of micronutrient uptake by excess calcium are numerou (Chapman, 1966; Lohnis, 1960; Thompson & Troch, 1978).

The ability to produce various types of macerating enzymes is widely reported in different organisms ranging from insects to yeasts (Adams & McAllan, 1958; Agate et al., 1962; Bilimoria & Bhat, 1962; Smart et al., 1964). With P. palmivora from cocoa, Spence (1961) found that pectolytic enzymes were important in the initial penetration of cocoa pods and that excess enzymes were deactivated by the products of the action of the polyphenol oxidase system of the host. Yoshikawa et al. (1977) reported the production of a non-pectolytic macerating enzyme by P. capsici. Using a similar growth medium, six of the eight MF 1 and MF 4 isolates investigated in the present study were also found to produce varying amounts of the macerating enzyme, as assayed by the cucumber pericarp technique. Linear regression analysis showed that there was no correlation between ability to produce this enzyme and virulence of the isolates towards pod infection ($r = -0.22$). Activity of this macerating enzyme (as produced by P 795) was suppressed by Ca^{++} at 10 mM. Stem

inoculation studies with P 795 showed that seedlings with high calcium content (1.20% of total leaf dry weight) were more susceptible than seedlings with lower leaf calcium (0.39% calcium). From the above observations, it is concluded that the macerating enzyme produced by the various MF 4 isolates appears to have only localized significance, if any, in the pathogenesis of pod rot and stem canker of cocoa.

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Table 1. Influence of calcium on macro- and micro-nutrient levels in leaves of *Theobroma cacao* grown for three months in silica sand

Concentration of $Ca(NO_3)_2$ (mM)[a]	Leaf nutrient level[b]									
	Ca	Mg	K	Na	P	Zn	Mn	Cu	Fe	B
	(percentage of leaf dry weight)					(ppm)				
0	0.12	0.19	1.62	0.05	0.11	35	246	10	61	42
0.1	0.16	0.30	1.17	0.07	0.11	30	244	5	54	58
5.0	0.17	0.30	1.58	0.07	0.14	24	239	5	35	46
10.0	0.26	0.32	1.67	0.07	0.14	23	243	5	40	50
100.0	0.25	0.27	1.73	0.06	0.14	25	243	5	66	39

a Cocoa seedlings grown in silica sand. Each seedling received 100 ml of full strength Hoagland's solution supplemented with 0.1 ml of 0, 0.1, 5.0, 10.0 and 100.0 mM $Ca(NO_3)$ for 4 consecutive days per week followed by 100 ml of deionized water per day for the rest of the week.

b Average of twenty leaves per treatment.

Table 2. Influence of calcium on macro- and micro-nutrient levels in leaves of Theobroma cacao seedlings grown in Hoagland's solution a in water tank

$Ca(HO_3)_2$ (mM) in Hoagland's solution	Leaf nutrient level[b]									
	Ca	Mg	K	Na	P	Zn	Mn	Cu	Fe	B
	(percentage of leaf dry weight)							(ppm)		
0	0.05	0.41	3.75	0.02	0.21	35	20	1	10	3
0.5	0.39	0.47	3.25	0.01	0.15	21	33	2	4	3
5.0	0.62	0.47	2.58	0.04	0.24	12	38	1	4	4
10.0	0.97	0.34	2.42	0.02	0.14	3	33	1	4	2
25.0	1.20	0.25	2.52	0.03	0.16	3	23	3	5	4

a Cacao seedlings grown for 10 weeks in full strength Hoagland's solution supplemented with 0, 0.5, 5.0, 10.0, and 25.0 mM $Ca(NO_3)_2$.

b Average of ten leaves per treatment.

Table 3. Concentration of calcium, magnesium and potassium in the leaves of cocoa seedlings grown under 5 levels of calcium in the nutrient film system

Treatment (Ca^{++} in meq/liter)	Leaf nutrient level (% dry wt.)		
	Ca^{++}	Mg^{++}	K^{+}
0.094	0.1	0.7	3.1
0.375	0.2	0.7	3.1
1.500	0.5	0.5	2.5
6.000	1.4	0.4	2.8
24.000	1.2	0.4	3.0

Table 4. Effect of calcium on the severity of stem canker of 1-year old cocoa seedlings inoculated with *P. palmivora* (P40) isolated from black-pod collected from Telok Intan, Malaysia

Calcium in plants (%)	Stem canker (cm^2)
0.1	8.3 A
0.2	3.2 A
0.5	12.9 A
1.2	6.2 A
1.4	3.4 A

Means with the same letter are not significantly different, P = 0.05

Table 5. Comparative ability of Phytophthora palmivora (MF 1 and MF 4) to produce the macerating enzyme and to infect unripe cocoa pods[a]

Isolate	Country and mating type	Macerating activity (Loss in cucumber pericarp wt (mg) in 6 hours)	Cocoa pod lesion (cm^2)[b]
P 252 (MF 4)	Mexico A^2	170.5	2.9
P 255 (MF 1)	Costa Rica A^2	18.7	14.4
P 623 (MF 4)	Brazil A^2	63.5	2.2
P 780 (MF 4)	Brazil A^1	0	15.1
P 795 (MF 4)	Cameroon A^1	159.0	12.7
P 817 (MF 4)	Cameroon A^1	91.6	-[c]
P 836 (MF 4)	Trinidad A^1	89.5	18.7
P 897 (MF 4)	Venezuela A^1	73.4	-

a Correlation coefficient (r) = 0.22

b Pods were inoculated with 5-mm diameter culture discs of the fungus and incubated in humid chambers at room temperature (25 ± 2C). Average of three replicates.

c Values not determined

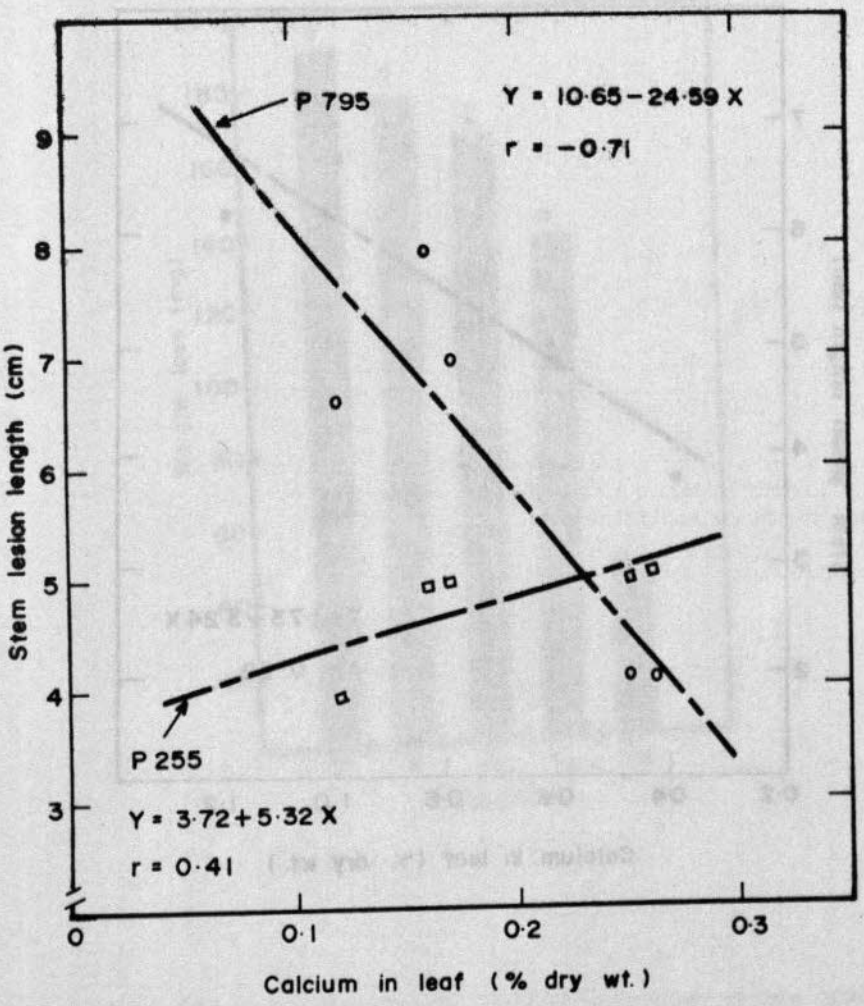


Fig 1. Relationship between leaf calcium (%) of Theobroma cacao and lesion length (cm) of stems inoculated with Phytophthora palmivora (P255, MF1; and P795, MF4).

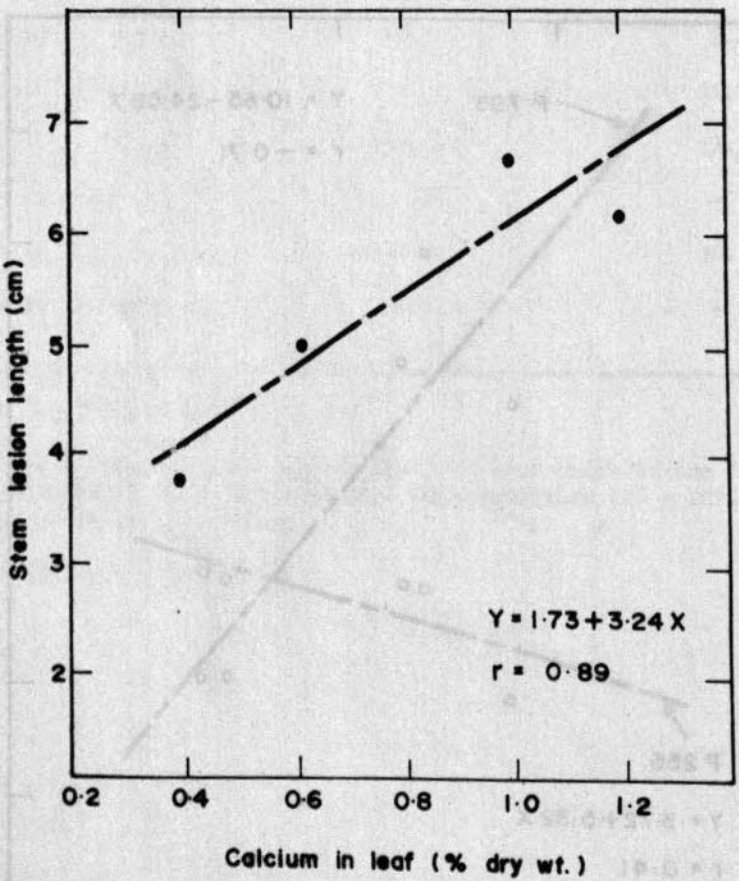


Fig.2. Relationship between leaf calcium (%) of Theobroma caçao and lesion length (cm) of stems inoculated with Phytophthora palmivora (P795,MF4).

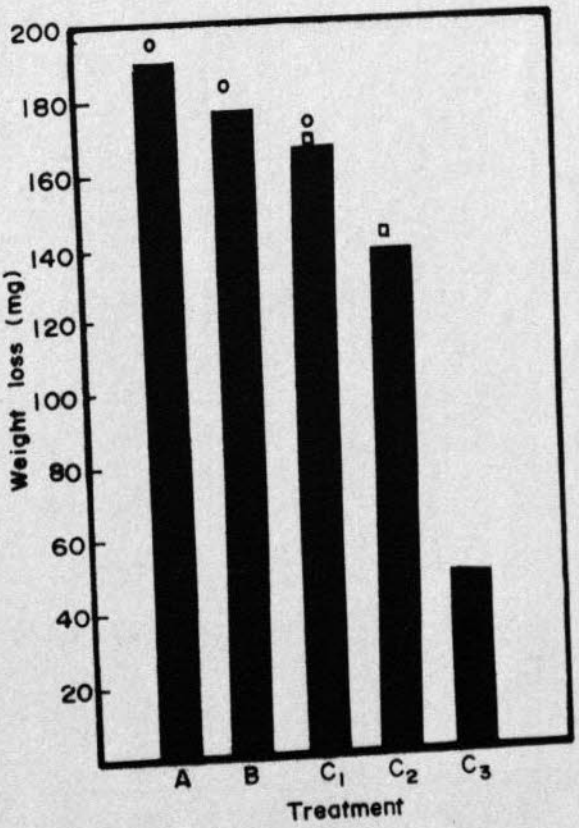


Fig.3. Effect of calcium on the activity of the macerating enzyme produced by P795. A = 1.0 mM EDTA, B = DDH_2 0, C_1 = 0.1 mM $CaCl_2$, C_2 = 1.0 mM $CaCl_2$, C_3 = 10 mM $CaCl_2$. Bars with the same symbols are not significantly different from one another, P = 0.05 by Duncan's multiple range test.

Promising Prang Besar Cocoa Clones

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In 1965 Prang Besar Research Station embarked on an ambitious breeding and selection programme to produce improved cocoa planting materials. Todate, 715 progenies and over 4,000 clones (including 1,222 clones in a joint trial with MARDI) have been established in field trials.

Clones, derived mainly from outstanding seedlings in F1 hybrid trials and commercial plantings on Harrisons Malaysian Plantations Berhad estates, are evaluated initially in preliminary proof clone trials. Outstanding clones in these are subsequently tested in further proof trials from which the most promising clones are selected from commercial polyclone planting. Critical selection standards are applied at all stages of evaluation. Besides high yield potential, considerable emphasis has been placed on secondary characteristics, especially bean size, pod conversion ratio, nib fat content, tolerance of diseases, tree vigour, growth form, etc.

This paper reports the results of five preliminary proof clone trials established before 1976 and four further proof clone trials set up between 1975 and 1980. Of the 837 clones evaluated, twelve clones have been selected for commercial planting. The paper also considers the characteristics and yield perfomances of these clones.

Hybrid seedlings have been traditionally used in commercial cocoa plantings in Malaysia. However, as considerable progress had been made in recent years in the development of high-yielding clones with favourable secondary characteristics (*e.g.* larger, more uniform bean size, higher nib cocoa butter yield, superior diseases tolerance, etc.), it is envisaged that clones will feature more prominently in future cocoa planting programmes.

Prang Besar Research Station (PBRS) has been actively involved in the development of improved cocoa planting materials, both hybrid seedlings and clones, since 1965 when large-scale cocoa planting was undertaken under tall coconuts in coastal estates in Lower Perak. The scale of breeding and selection investigations undertaken todate is indicated in *Table 1*.

The PBRS approach to cocoa improvement by breeding and selection has been broadly similar to that applied since 1921 for production of improved rubber planting materials (Shepherd 1969). The *modus operandi* and results of the first 10 years of progeny trials investigations were presented in the last conference (Ang & Shepherd 1978). This paper considers results of five preliminary proof clone trials established before 1976 and four further proof trials set up between 1975 and 1980, particulars of which are outlined in *Table 2*.

TABLE 1. SCALE OF BREEDING AND SELECTION INVESTIGATIONS (AS AT DECEMBER, 1983)

Nature of trials	*Progeny*	*Preliminary Proof Clone*	*Rehabilitation-cum Preliminary Proof Clone*	*Further Proof Clone*	*Polyclone*
No. of trials	21	11	8	9	4
Year initiated	1968	1972	1972	1975	1977
Hectarage	174	87	36	48	45
Progenies/clones	714	2886[a]	1126	136	40

[a] Includes 1222 clones in a joint trial with MARDI

METHOD

Preliminary Proof Clone Trials

Preliminary proof trials are designed to permit the screening of very large numbers of new clones in plots of adequate size for reasonable evaluation of their merits. Clones were planted in 25-tree plots replicated at least twice. Most of the clones were derived from outstanding seedlings selected in progeny trials and commercial plantings within Harrisons Malaysian Plantations Berhad (HMPB) estates. The ortets were selected on the basis of desirable characteristics such as high pod yield, low pod value (pods required to produce 1 kg dry beans), large bean size, good tree vigour and balanced growth-form, significant tolerance of major diseases, etc.

Further Proof Clone Trials

The most promising preliminary proof clones are allocated PBC (denoting Prang Besar cocoa cultivar); numbers and are then evaluated in further proof trials in environments representative of major cocoa-growing areas. A randomised complete block design has been adopted in all trials, each clone being planted in at least three replicates of 50–80 tree plots.

More exacting selection standards are applied in further proof trials to identify clones for polyclone planting on a commercial scale over a range of environments in company estates. Particular emphasis is placed on the following features:–

- Sustained high yields
- Limited seasonal variation in cropping pattern
- Low pod value
- Good bean size/uniformity
- High nib fat content
- Satisfactory tree vigour and growth form
- Acceptable levels of disease tolerance, especially in respect of *Oncobasidium theobromae* and *Phytophthora palmivora*.

Cured beans from promising clones are processed into chocolates in order to confirm flavour acceptability.

TABLE 2. PARTICULARS OF PRELIMINARY PROOF AND FURTHER PROOF TRIALS

Trial	*Location*	*No. Clones*	*Area (ha)*	*Source of Clones*	*Soil Type*	*Year Budded*	*Design*	*Plot Size (No. trees)*	*SPH*[a]	*Replication*	*Permanent Shade*
P.P. 1	Flemington	119	5	Bagan Datoh & Flemington	Marine clay	1972	RCBD	8–20	750	3	Tall coconuts
P.P. 2	Flemington	44	4	Flemington	Marine clay	1974	RCBD	35	750	2	Tall coconuts
P.P. 3	Bagan Datoh	88	5	Landas	Marine clay	1975	CRD	55	750	1	Tall coconuts
P.P. 4	Flemington	493	25	Bagan Datoh, Flemington, Jerangau & Landas	Marine clay	1975	RCBD	25	900	2	Tall coconuts
P.P. 5	Flemington	105	5	Keravat polycross & Jerangau/Landas	Marine clay	1976	RCBD	20	900	2	Tall coconuts
F.P. 1	Prang Besar	14	2	P.P. 1	Inland soil (Munchong series)	1974	RCBD	50	1075	3	Parkia, durian
F.P. 2	Flemington	14	3	P.P. 1	Marine clay	1975	RCBD	50	900	3	Tall coconuts
F.P. 3	Flemington	26	8	P.P. 1, 2 & 3	Marine clay	1979	RCBD	80	900	3	Tall coconuts
F.P. 4	Sg. Wangi	28	8	P.P. 1, 2, 3 & 4	Sub-recent riverine (Sitiawan series)	1980	RCBD	80	1100	2[b]	Hybrid coconuts

[a] Within coconut area.

[b] Treatments were duplicated in Further Proof Trial No. 5 in Prang Besar Estate.

Clone performances in commercial polyclone plantings are also monitored closely and the best performers continue to be propagated in subsequent plantings.

Trial Upkeep and Recording

Field budding was undertaken in all the trials. Budwood was predominantly of fan branch origin as few ortets bore suitable chupon budwood. Subsequent routine upkeep and maintenance (*viz.* pruning, manuring, weeding, pest and disease control, etc.) were carried out in accordance with estate practices.

The actual numbers of pods harvested in all the plots were recorded at 10–15-day intervals. Separate records were maintained of healthy ripe, diseased ripe and mammalian damaged mature pods at each harvest.

Detailed analyses of pods of each clone were performed twice annually, normally in March and September, to enable definition of pod value, wet to dry bean conversion rate, number of beans per pod, bean weight/size variation and nib yield. Incidences of vascular streak dieback and stem canker on trees within clones were recorded in alternate months.

RESULTS

Preliminary Proof Clone Trial No. 1

This trial compares 118 clones derived from mass selection of outstanding seedlings in commercial plantings on Bagan Datoh and Flemington estates, Na 33 serving as control. Budding was protracted due to initial poor budding success ascribed to inexperience of budders and root-stocks being over-sized. Performances of the eleven best yielding clones are listed in *Table 3* and compared with the trial average and control Na 33 yields.

Yields. Accurate yield assessment in the first two years was difficult, due to variation in ages of the buddings. However, distinct yield differences among clones were clearly evident from the third year of bearing and some clones maintained exceptionally high yield levels in subsequent years. PBC 130 and PBC 112 were the highest yielding clones, producing respectively 1970 and 1679 kg dry beans/ha/year during the first eight years of bearing. PBC 148, PBC 122 and PBC 128 also yielded very well. Although PBC 120 and PBC 122 produce undersized beans, they have been used extensively in breeding programme and commercial hybrid seed production because of their good general and specific combining abilities.

Pod value. The number of pods required to produce 1 kg dry beans ranged from 19.8 to 46.5 and averaged 29.1 in the trial. With the exception of PBC 120, all the high-yielding clones listed have below average pod values.

Bean weight. Wide variations in average bean weights of clones were recorded in the trial. Most of the clones selected for further proof trials produced beans exceeding 1 g.

Vascular streak dieback. The disease incidence, as indicated by the proportion of trees with evidence of infection, was generally high, due to the close proximity of the trial to seedling plantings which were badly affected. However, despite the relatively high disease incidences, most of the selected clones exhibited a degree of tolerance to the disease and their growth and yield performances were acceptable in the circumstances.

TABLE 3. PERFORMANCES OF 11 BEST CLONES IN PRELIMINARY PROOF CLONE TRIAL NO. 1

Clone	Parentage	Yield dry beans (kg/ha/year)									Pod Value	Bean wt. (g)	Vascular streak dieback	
		1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year	1–8th year			Incidence (%)	Tolerance Rating[a]
PBC 130	Na 31 x Pa 35	214	1186	1255	1866	2692	2958	3112	2474	1970	22.7	1.28	36	4
PBC 112	Mix hybrid	514	689	900	1336	2363	2145	2790	2692	1679	25.5	1.01	41	3
PBC 120	Mix hybrid	499	998	1175	1442	1996	1666	1979	2631	1548	29.4	0.83	31	4
PBC 122	Mix hybrid	558	931	1097	1385	1723	1517	2250	2377	1480	28.9	0.86	22	4
PBC 148	Mix hybrid	359	922	1160	1377	1999	1640	2189	1996	1455	24.5	1.00	51	3
PBC 128	Mix hybrid	482	1137	1151	1241	2108	1820	1907	1726	1447	24.6	1.15	40	3
PBC 199	Mix hybrid	182	876	699	1071	1569	1838	3042	2204	1435	23.9	1.01	19	4
PBC 129	Mix hybrid	385	749	770	1254	1735	1732	2263	2120	1376	27.3	0.91	55	3
PBC 149	Mix hybrid	323	887	844	1011	1989	1901	1910	1630	1312	25.0	1.03	54	3
PBC 113	ICS 16 x Na 33	396	584	839	920	1767	1422	1904	2547	1297	20.7	1.07	45	3
PBC 121	ICS 16 x Sca 6	529	761	866	1123	1453	1094	1797	2105	1216	22.5	1.05	19	4
Na 33		230	495	638	801	1094	1294	1106	1157	852	38.8	0.71	21	3
Trial Av.	(119 clones)	288	506	585	742	1297	1246	1593	1319	954	29.1	0.94	36	—

[a] Susceptibility

1 = very high
2 = high
3 = moderate
4 = low
5 = very low

Preliminary Proof Trials No. 2 and 3

Preliminary Proof Trials No. 2 and 3 evaluate 44 and 88 clones rehabilitation trials in Flemington and Bagan Datoh estates respectively. Clones were budded on eight-year-old trees debilitated by vascular-streak dieback. The performances of the best clones in the trials are shown in *Tables 4* and *5*.

Yields. Owing to the advanced age of the rootstocks, initial growth and yields in both trials were impressive. Very good yields were recorded in the fourth and fifth years but production declined slightly in the next two years (1982 and 1983) mainly due to the adverse weather conditions experienced in these years. Nevertheless, the following clones yielded very well over the seven years of bearing: PBC 140 (1656 kg/ha/year), PBC 139 (1492 kg), PBC 202 (1454 kg), PBC 137 (1453 kg) and PBC 123 (1452 kg) in Preliminary Proof Trial No. 2 and PBC 170 (1562 kg), PBC 144 (1423 kg) and PBC 181 (1366 kg) in Preliminary Proof Trial No. 3.

Pod value. The best clones in both trials had relatively low pod values, requiring fewer than 26 pods to produce 1 kg of dry beans.

Bean weight. Clones in Preliminary Proof Trial No. 2 generally produced larger beans than clones in Preliminary Proof Trial No. 3. However, the average bean weights of the most promising clones in both trials were generally above 1 g and ranged up 1.31 g.

Vascular streak dieback. The lower cumulative incidence of vascular-streak dieback in Preliminary Proof Trial No. 3 was ascribed to the fact that the ortets were selected in an environment where the disease was very troublesome. Although significant proportions of trees displayed evidence of infection, most of the high-yielding clones showed a degree of tolerance to the disease as infections were generally mild and did not appear to effect either growth or yield performances to significant extents. Clone PBC 123 displayed appreciable resistance to the disease.

Preliminary Proof Trial No. 4

This trial compares 487 clones derived from outstanding seedlings in commercial plantings on Bagan Datoh (123 clones), Flemington (38 clones), Jerangau (174 clones) and Landas (152 clones) estates in 1974. Six Fo clones, *viz.* ICS 45, ICS 60, UIT 1, GS 29, Na 33 and UA 13, served as controls. The performances of fifteen promising clone selections and the control clones are compared in *Table 6* with the trial averages.

Yields. Very variable yields were recorded among clones within the trial in the first two years of bearing, due in part to the fact that field budding of this large trial extended over almost six months. The most promising clones over seven years of recording were: PBC 154 (1848 kg/ha/year), PBC 137 (1473 kg), PBC 179 (1398 kg), PBC 178 (1357 kg) and PBC 131 (1329 kg). These clones yielded at least 60% and 80% more than the Fo controls and the trial average respectively over the first seven years of bearing. It is of interest to note that results of this trial confirmed the high yield capacities of clones PBC 113 and PBC 137 which were amongst the best yielders in Preliminary Proof Trials No. 1 and 2 respectively.

Pod value. The pod values of clones in this trial ranged fom 17.3 to 55.7. Most of the clones derived from Landas/Jerangau ortets gave undesirably high pod value. However, the outstanding clone selections had acceptable pod values.

TABLE 4. PERFORMANCES OF BEST TEN CLONES IN PRELIMINARY PROOF TRIAL NO. 2

Clone	Yield dry beans (kg/ha/year)								Pod Value	Bean wt. (g)	Vascular streak dieback	
	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	1–7th year			Incidence (%)	Tolerance ratings
PBC 140	665	784	1677	2424	2179	1868	1996	1656	25.2	1.24	47	3
PBC 139	630	874	1540	2100	2246	1584	1469	1492	21.0	1.09	50	4
PBC 202	460	576	1181	2138	1879	2127	1820	1454	25.8	0.97	65	3
PBC 137	764	1132	1453	1716	1762	1810	1534	1453	22.0	1.12	32	4
PBC 123	606	808	1552	1842	1833	1513	2007	1452	23.4	1.03	11	5
PBC 203	685	866	1414	1786	1799	1954	1622	1447	25.6	1.00	46	3
PBC 201	583	708	1064	1769	1964	2142	1684	1415	23.1	0.98	27	4
PBC 167	404	442	1022	1618	2036	1755	2039	1331	21.8	1.18	62	3
PBC 169	467	613	1296	1917	1660	1524	1551	1287	22.7	1.07	54	3
PBC 164	315	525	964	1959	1983	1856	1384	1284	23.1	1.11	42	4
GS 29	339	884	1182	1363	1587	1645	1475	1211	25.6	1.16	38	3
Na 33	403	447	1053	1215	1225	1391	1427	1023	38.9	0.71	42	3
ICS 60	344	816	1052	1193	1282	1276	1309	1039	18.6	1.39	42	3
Trial Average (44 clones)	476	549	1044	1310	1335	1263	1218	1028	27.2	1.03	45	–

TABLE 5. PERFORMANCES OF FIVE PROMISING CLONES IN PRELIMINARY PROOF TRIAL NO. 3

Clone	Yield dry beans (kg/ha/year)								Pod Value	Bean wt. (g)	Vascular streak dieback	
	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	1–7th year			Incidence (%)	Tolerance ratings
PBC 170	513	1176	1470	2280	1825	1800	1869	1562	19.9	1.31	46	4
PBC 144	520	1241	1461	1862	2005	1045	1828	1423	22.9	1.05	47	3
PBC 171	331	1115	1498	1812	1999	1244	1561	1366	24.3	1.11	30	4
PBC 204	904	1172	1079	1666	1637	1320	1017	1256	31.6	1.09	20	4
PBC 205	263	927	1188	1526	1482	1360	1578	1189	26.4	0.97	43	3
Trial Average (88 clones)	372	783	845	1121	1168	878	907	868	31.4	0.91	32	–

TABLE 6. PERFORMANCES OF BEST CLONES IN PRELIMINARY PROOF CLONES TRIAL NO. 4

Clone	Yield dry beans (kg/ha/year)								Pod Value	Bean wt. (g)	Vascular streak dieback	
	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	1–7th year			Incidence (%)	Tolerance ratings
PBC 154	–	997	1933	2049	2777	2973	2217	1848	24.7	1.13	45	4
PBC 137	394	1066	1042	1694	1971	2173	1972	1473	24.0	1.03	26	4
PBC 200	296	1217	1365	1741	1765	2187	1700	1467	32.2	0.91	40	3
PBC 179	226	840	1042	1683	1817	2075	2106	1398	23.9	1.09	10	5
PBC 178	204	512	858	1604	1579	2170	2570	1357	24.0	1.04	20	5
PBC 131	460	1086	1354	1448	1984	1481	1490	1329	18.4	1.30	68	4
PBC 162	102	753	1317	1781	1509	1730	1632	1261	23.9	1.07	18	5
PBC 159	227	773	1138	1274	1957	1550	1653	1225	19.3	1.22	20	4
PBC 132	212	1000	994	1553	1586	1679	1371	1199	28.9	0.97	10	5
PBC 206	58	704	894	1636	1639	1686	1650	1181	29.6	0.97	40	3
PBC 158	272	579	877	1546	1608	1655	1469	1140	19.5	1.29	4	5
PBC 155	198	783	1201	1550	1669	1520	1031	1136	25.5	1.03	50	3
PBC 113	165	877	1023	1495	1706	1291	1080	1091	21.3	1.05	47	4
PBC 175	–	297	592	1311	2067	1943	1374	1083	23.1	1.16	4	5
PBC 157	287	693	897	1355	1296	1706	1320	1079	24.7	1.03	5	5
ICS 45	20	205	422	760	735	752	533	490	32.2	1.02	15	4
ICS 60	71	581	765	1212	1208	1254	1195	898	20.7	1.26	20	3
UIT 1	128	570	847	1445	1422	1549	1264	1032	19.1	1.32	41	3
GS 29	177	677	879	1002	1310	1067	1176	898	25.3	1.14	40	3
Na 33	154	581	681	1110	1026	1271	1192	859	38.1	0.73	45	3
UA 13	178	616	760	1233	1157	1165	1070	883	32.0	0.78	41	3
Average of 6 Fo clones	121	538	726	1127	1143	1176	1072	843	27.9	1.04	34	3
Trial Average (493 clones)	100	516	667	936	971	1045	959	742	32.7	0.83	36	–

Bean weight. Clones derived from Jerangau and Landas ortets also produced generally smaller beans than clones from Bagan Datoh and Flemington ortets. Nevertheless, most of the best yielding clones provided satisfactory average bean weights.

Vascular streak dieback. A severe outbreak of the disease in the trial and surrounding plantings in 1981 enabled more accurate assessment of the comparative susceptibility of clones to the disease. Clones selected from Jerangau and Landas estates in the East Coast where VSD was troublesome, exhibited greater degree of VSD tolerance than clones of Bagan Datoh and Flemington origins. On the basis of the numbers of affected trees and disease severity, PBC 132, PBC 157, PBC 158, PBC 162, PBC 175 and PBC 179 are deemed reasonably VSD-tolerant. With the exception of PBC 175, all these clones originated from ortets selected on Jerangau and Landas estates.

Preliminary Proof Trial No. 5

This trial compares 105 clones of which 69 clones were derived from 43 illegitimate progenies of Keravat Trinitario clones which had been subjected to selection pressure in an environment where VSD was troublesome and 34 clones were obtained from F1 hybrid seedlings from Jerangau and Landas estates, Na 33 and ICS 60 serving as controls. The performances of the best yielding selections are shown in *Table 7.*

Yields. Only six clones yielded more than the ICS 60 control (954 kg/ha/year) over the first five years of bearing. Most of the clones derived from the illegitimate Keravat Trinitario progenies yielded rather unsatisfactorily, but two clones (PBC 183 and PBC 184) outyielded ICS 60 by narrow margins. The best two clones, derived from the F1 hybrid seedlings, produced 1212 and 1117 kg dry beans/ha/year over the first five years.

Pod value. The highest yielding clones had comparatively low pod values.

Bean weight. The average bean weight varied considerably among clones, the trial average being just below 1 g.

Vascular streak dieback. The average cumulative VSD incidence in the trial was only 14% despite an outbreak of the disease in 1981. The low disease incidences were understandable as most of the ortets were selected in environments where VSD was troublesome.

Further Proof Trial No. 1

This trial compares fourteen promising clones selected from Preliminary Proof Trial No. 1 (see *Table 8*). Unlike other trials, the cocoa was planted as a monoculture crop spaced at 3.05 x 3.05 m in inland soil (Munchong series) on Prang Besar Estate. *Albizzia falcata* and *Parkia specioss* were planted as overhead shades. *Sesbania punctata, Cajanus cajan* etc. were established as temporary lateral shades during the initial stages of cocoa establishment. The *Albizzia* and bush covers were removed three years after planting. Recording in the trial was terminated four years after harvesting.

Yield. The trial provides clear proof of the yield superiority of PBC 112 and PBC 113 which produced about 28% more crop than the trial average (1213 kg/ha/year) over the first four years of bearing. Both clones yielded more than 2000 kg/ha/year from the third year of harvesting. Clones PBC 107 and PBC 111 which yielded 1531 and 1413 kg/ha/year respectively over the four years also proved outstanding.

TABLE 7. PERFORMANCES OF BEST CLONES IN PRELIMINARY PROOF CLONES TRIAL NO. 5

Clone	Yield dry beans (kg/ha/year)						Pod Value	Bean Wt. (g)	Vascular streak dieback	
	1st year	2nd year	3rd year	4th year	5th year	1–5th year			Incidence (%)	Tolerance ratings
PBC 207	637	1133	1224	1358	1707	1212	26.5	1.10	7	4
PBC 208	291	1000	1124	1398	1771	1117	29.4	0.95	10	4
PBC 209	573	955	966	1117	1518	1026	24.0	1.05	13	4
PBC 210	721	1053	904	1059	1284	1004	31.2	0.93	21	3
PBC 184	600	862	872	1312	1262	982	25.5	1.08	17	3
PBC 183	442	977	1123	1013	1251	961	30.9	0.92	14	3
ICS 60	712	901	749	1111	1295	954	19.3	1.35	23	3
Na 33	318	454	552	740	752	563	46.5	0.64	7	3
Trial Average (105 clones)	237	463	487	655	736	516	32.9	0.98	14	–

TABLE 8. PERFORMANCES OF PBC CLONES IN FURTHER PROOF TRIAL NO. 1

Clone	Yield dry beans (kg/ha/year)					Pod Value	Bean Wt. (g)	Vascular streak dieback		Canker tree (%)
	1st year	2nd year	3rd year	4th year	1–4th year			Incidence (%)	Tolerance ratings	
PBC 101	229	911	1542	1354	1009	27.2	1.08	0	5	0
PBC 102	189	1541	1541	1737	1252	27.1	1.04	2	5	2
PBC 103	388	950	1722	1735	1199	27.6	0.95	0	5	2
PBC 104	290	1595	1700	1761	1337	27.1	1.01	0	5	4
PBC 105	197	1213	1488	1344	1061	22.3	1.32	0	5	2
PBC 106	154	1211	1521	1270	1039	26.2	1.16	4	4	1
PBC 107	283	1936	2092	1812	1531	28.7	0.90	1	4	1
PBC 108	313	1060	1143	1169	921	25.1	1.05	0	5	0
PBC 109	188	1195	1455	1284	1031	31.6	0.89	0	5	0
PBC 110	213	1439	1990	1567	1302	26.9	0.98	28	3	1
PBC 111	245	1663	1883	1859	1413	29.9	0.95	1	4	2
PBC 112	353	1536	2201	2124	1554	23.8	1.05	0	4	2
PBC 113	314	1657	2245	2016	1558	20.9	1.19	1	4	12
PBC 114	161	707	1000	1242	778	31.8	0.96	0	4	8
Trial Average (14 clones)	251	1330	1680	1591	1213	26.7	1.04	3	–	3

Susceptibility

1 = very high
2 = high
3 = moderate
4 = low
5 = very low

Pod value. With the exception of clones PBC 109, PBC 111 and PBC 114, all clones had a relatively low pod value.

Bean weight. The average dry bean weight in this trial was satisfactory. Both the highest yielding clones produced fairly large beans.

Vascular streak dieback. VSD incidence within the trial was very low, except in clone PBC 110.

Stem canker. PBC 113 and PBC 114 expressed a degree of susceptibility to stem canker during an outbreak in 1980.

Further Proof Trial No. 2

This trial compares 13 PBC clones selected from Preliminary Proof Trial No. 1 in the coastal soil environment on Flemington Estate, Na 33 serving as a control. Six clones evaluated in Further Proof Trial No. 1 are repeated in this trial. Performances of the clones are summarised in *Table 9*.

Yields. Yield and growth within the trial were badly depressed by adverse soil conditions – the low lying, highly acidic soils are poorly structured and subject to waterlogging in wet weather and dry out to depth in dry weather. Clones PBC 116, PBC 113, PBC 102, and PBC 112 yielded reasonably well in the circumstances.

Pod value and bean weight. High pod values and undersized beans were recorded in this trial. Only clones with inherently large beans were able to produce beans of reasonable size in the adverse soil environment.

Vascular streak dieback. The disease incidence within the trial has been very high since the major outbreak in 1981. Differences in clone susceptibility are apparent. Clones PBC 105, PBC 109 and PBC 120 were relatively tolerant of the disease.

Further Proof Trials No. 3 and 4

Twenty-six and twenty-eight promising clones selected from preliminary proof trials are compared in Further Proof Trials No. 3 and 4 respectively. Whereas Further Proof Clone Trial No. 3 was established in 1979 under tall coconuts marine soil on Flemington Estate, Further Proof Clone Trial No. 4 was field budded on Sg. Wangi Estate in August 1980 in subrecent riverine alluvium soils under young rubber, which was subsequently replaced with hybrid coconuts.

Performances of some promising clones over the limited periods of trial recording are listed in *Tables 10* and *11*.

Yields. Results of the two trials clearly demonstrate the influence of soil environment on cocoa performances. During the first two years of bearing, Further Proof Trial No. 3, which was established one year earlier in highly acidic heavy-textured soils with high water table, yielded significantly less than Further Proof Trial No. 4 where the soils are more suitable for cocoa growth. Nonetheless, the yield superiority of some clones, notably PBC 130, PBC 139, and PBC 131 in the Further Proof Trial No. 3 and PBC 153, PBC 156 and PBC 140 in Further Proof Trial No. 4, was obvious. However, recording must be continued to assess long-term yield response of the clones.

TABLE 9. PERFORMANCES OF PBC CLONES IN FURTHER PROOF TRIAL NO. 2

Clone	Yield dry beans (kg/ha/year)							Pod Value	Bean wt. (g)	Vascular streak dieback	
	1st year	2nd year	3rd year	4th year	5th year	6th year	1–6th year			Incidence (%)	Tolerance rating
PBC 102	302	557	630	1092	1283	1010	812	31.0	0.87	33	4
PBC 105	179	332	558	765	873	991	616	26.6	1.12	26	4
PBC 106	159	320	481	502	510	429	400	34.6	0.88	75	3
PBC 109	228	374	686	662	696	826	579	37.5	0.77	30	4
PBC 110	366	544	916	932	1006	637	734	33.9	0.83	79	2
PBC 112	307	494	982	871	1154	973	797	30.8	0.86	43	4
PBC 113	302	722	829	1028	1027	1077	831	25.3	0.96	50	4
PBC 115	155	328	585	775	704	666	536	35.4	0.82	61	2
PBC 116	207	437	808	1278	1084	1222	839	27.4	1.07	56	3
PBC 117	315	382	529	702	764	620	552	31.8	0.88	34	4
PBC 118	325	394	725	1012	1139	1091	781	35.4	0.75	43	3
PBC 119	244	417	661	943	1048	935	708	35.8	0.75	41	3
PBC 120	288	421	586	699	862	650	584	38.1	0.64	28	4
Na 33	289	333	635	615	729	654	543	44.2	0.63	45	3
Trial Average (14 clones)	262	433	687	848	920	842	665	33.4	0.85	46	–

TABLE 10. PERFORMANCES OF THE PROMISING CLONES IN FURTHER PROOF TRIAL NO. 3

Clone	*Yield dry beans (kg/ha/year)*			*Pod Value*	*Bean Wt. (g)*
	1st year	*2nd year*	*1–2nd year*		
PBC 128	226	536	381	25.6	1.06
PBC 130	247	669	458	24.7	1.19
PBC 131	179	695	437	19.6	1.28
PBC 137	201	606	404	25.1	1.01
PBC 139	209	623	456	22.0	1.09
Na 33	194	433	314	39.5	0.68
Trial Average (26 clones)	193	459	326	32.0	1.00

TABLE 11. PERFORMANCES OF THE PROMISING CLONES IN FURTHER PROOF TRIAL NO. 4

Clone	*Yield dry beans (kg/ha/year)*			*Pod Value*	*Bean Wt. (g)*
	1st year	*2nd year*	*1–2nd year*		
PBC 140	536	1110	825	25.1	1.31
PBC 153	786	1231	1009	24.6	1.03
PBC 156	610	1075	843	23.1	1.35
PBC 158	715	921	818	17.3	1.64
PBC 159	416	1053	735	16.4	1.54
PBC 163	466	947	707	22.8	1.33
PBC 167	662	931	797	21.4	1.20
PBC 170	626	998	812	18.3	1.45
Trial Average (28 clones)	455	746	601	24.5	1.22

Pod value. The pod values of the selected clones were relatively low in both trials. Clones PBC 131, PBC 158, PBC 159 and PBC 170 required fewer than 20 pods to produce one kg of dry beans.

Bean weight. Average bean size varied considerably among clones. The most promising clones in both trials had average bean weights well above 1 g.

DISCUSSION

The approach whereby large numbers of clones are screened in Preliminary Proof Trial and the most promising selections are thereafter subjected to more stringent evaluation in the further proof trials has given encouraging results.

Although ortets selected in seedling plantings for cloning were reasonably vigorous and yielded two to five times more than the seedlings growing in close proximity, in apparently similar circumstances, considerable variation in the growth vigour, disease tolerance and yield capacities of derived clones was apparent in Preliminary Proof Trials. In the five such trials in which 837 clones derived from outstanding seedlings identified in progeny trials and commercial plantings of hybrid materials have been yield-recorded for five to eight years, the best clones yielded two to three times more than the lowest yielding clones and 40%–100% more than the trial averages. As expected, less yield variation was apparent in further proof trials where the best clones usually yielded between 20% and 35% more than the trial averages.

As cocoa is very sensitive to variations in environmental circumstances, which differed in the fields in which the preliminary and Further Proof Trials were located, the yield data obtained in individual trials are not strictly comparable. Nevertheless, it was encouraging to note a close concordance in the yield rankings of clones represented in both the oldest further proof trials which were located in inland and highly acidic low-lying coastal soils.

Despite unfavourable weather conditions (both protracted severe droughts and localised flooding) which adversely affected yields in the last two cropping years, yield trends of the best clone selections have been encouraging. With due regard to yield performances of commercial hybrid plantings in proximity to the clone trials, it is expected that the first generation of clones selected for polyclone planting in commercial practice will outyield mixed hybrid seedlings by at least 30% and, in favourable circumstances in Peninsular Malaysia, should yield in the order of 1800–2200 kg dry beans per hectare at full bearing. As only a fraction of the clones already established in trials has been yield-recorded for a sufficient time to enable identification of candidates for commercial planting, it is likely that other clones in the pipeline will have yield capacities in excess of those already selected for polyclone planting.

Considerable variation was also apparent in the average bean weights of clones evaluated in the trials. Generally, a minimum dry bean weight of 1 g has been applied when selecting preliminary proof clones for further proof trials; however, lower bean weights have been accepted for a few outstanding yielders with other favourable secondary characteristics. Such clones merit consideration as parents in breeding programmes and possibly also for commercial planting in environments where satisfactory bean sizes can be assured.

Although bean weight is genetically determined, it can be influenced markedly by environmental circumstances. Further Proof Clone Trial No. 2 provides clear evidence of

the extent to which adverse soil environment can depress bean weight. In that trial the average bean weights of clones PBC 105, PBC 106, PBC 109, PBC 110, PBC 112 and PBC 113 were about 20% lower than the respective clone bean weights recorded in Further Proof Clone Trial No. 1 which is located on more favourable soils. Accordingly, due emphasis must be placed on the selection of clones with above-average bean sizes for planting in environments where soil and environment conditions are sub-optimal.

Vascular-streak dieback (VSD) caused by the fungus *Oncobasidium theobromae* (Keane & Turner, 1972) can be very troublesome in certain cocoa growing environments in Malaysia. Ang & Shepherd (1980) suggested that cloning of outstanding individuals selected in environments where severe VSD outbreaks occur may present a rapid means of developing disease-tolerant cultivars for planting. Records and observations in the trials under consideration have shown that the incidence and severity of the disease vary considerably among clones, even though tolerance was taken into account when ortets were selected for cloning. Nevertheless, clones derived from ortets selected in environments where VSD is troublesome (*e.g.* Jerangau/Landas estates) or bred from Trinitario parents selected in Papua New Guinea on the basis of their VSD tolerance have proved less susceptible to the disease than clones developed from ortets growing in environments where the disease is of limited consequence.

Field observations have also indicated that the impact of VSD on clone yield is influenced by tree vigour. Thus vigorous clones of above-average susceptibility to the disease may continue to sustain high yields whereas less susceptible clones that produce less vigorous leaf flushes become debilitated and are unable to sustain high productivity.

Based on their performances in trials and small-scale polyclone plantings, twelve clones have been recommended since 1982 for polyclone planting on company estates in Peninsular Malaysia. The ten best selections are available to growers in Malaysia for evaluation and, subject to their performances being sufficiently encouraging in specific environments, for commercial planting. The main characteristics of these clones are compared in *Table 12.*

Besides their high yield potentials, the clones also possess desirable secondary characteristics, such as reasonably large and uniform beans, some VSD tolerance, above-average nib fat content, etc. Subject to environmental circumstances and management inputs, it is confidently expected that polyclone plantings of these clones will provide higher economic returns than might be obtained from hybrid seedlings.

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TABLE 12. COMPARATIVE CHARACTERISTICS OF SELECTED PBC CLONES

Characteristics	*PBC 112*	*PBC 113*	*PBC 123*	*PBC 128*	*PBC 130*	*PBC 131*	*PBC 137*	*PBC 139*	*PBC 140*	*PBC 154*	*PBC 158*	*PBC 159*
A. General												
1. Origin	UA x UA	ICS 16 x Na 33	UA x Trin.	UA x Trin.	Na 31 x Pa 35	UA x Trin.	UA x Trin.	UA x UA	UA x UA	UA x UA	UA x Trin.	UA x Trin.
2. Evaluation	PP1, FP1 & 2.	PP1 & 4, FP1 & 2.	PP2 & FP3.	PP1 & FP3.	PP1 & FP3.	PP4 & FP3.	PP2 & 4 & FP3.	PP2 & FP3.	PP2 & FP3 & 4.	PP4 & FP4.	PP4 & FP4.	PP4 & FP4.
3. Yield Potential	2000–2500	2000	2000–2500	2000	>2500	2000	2000–2500	2000–2500	>2500	2000–2500	2000	2000
4. Vigour	mod. vig.	v. vig.	mod. vig.	mod. vig.	v. vig.	v. vig.	vig.	vig.	mod. vig.	v. vig.	mod. vig.	mod. vig.
5. *Disease susceptibility*												
V.S.D.	3	4	5	3	3	3	3	3	3	3	4	4
Stem Canker	4	2	3	4	3	5	3	4	4	4	4	4
Black pod	3	3	3	4	3	4	4	4	5	4	3	4
6. Compatibility	self-compatible	self-compatible	self-compatible	self-compatible	self-compatible	self-compatible	self-incompatible	self-compatible	self-compatible	self-incompatible	self-compatible	self-compatible
B. Pod and bean characteristics (based on 7 determinations)												
1. Pod colour	green	red	red	red	green	green	red	green	green	green	green	green
2. Pod wt. (g)	539	575	549	635	510	562	520	455	551	466	403	544
3. Husk wt. (g)	375	414	411	450	357	384	375	294	425	320	241	334
4. Wet bean wt/pod (g)	164.0	160.6	138.3	134.6	143.3	178.7	144.7	162.0	127.1	132.0	155.5	209.8
5. Dry bean wt/pod (g)	43.1	50.9	45.4	41.7	41.6	56.7	45.9	52.0	46.0	48.8	57.9	56.9
6. No. of beans/pod	37.8	44.3	41.4	34.9	33.5	39.9	38.8	44.2	33.3	37.3	40.9	42.6
7. Av. wet bean wt. (g)	4.34	3.63	3.34	3.86	4.28	4.48	3.73	3.67	3.82	3.54	3.80	4.92
8. Av. wet cleaned bean (g)	1.96	2.08	1.96	2.04	2.18	2.39	2.08	2.10	2.43	2.37	2.27	2.27
9. Av. dry bean wt. (g)	1.10	1.15	1.10	1.19	1.24	1.41	1.18	1.18	1.38	1.31	1.41	1.34
10. Wt. of wet pulp/bean (g)	2.38	1.55	1.39	1.81	2.29	2.09	1.62	1.56	1.38	1.17	1.46	2.67
11. Pulp as % cleaned bean	117.9	74.5	70.9	88.2	105.0	87.5	77.9	74.3	56.8	49.4	64.3	118.6
12. Pulp as % dry bean	200.0	134.8	126.4	152.1	184.7	148.2	137.3	132.2	100.0	89.3	103.5	199.3
13. Butter content of nib	54.9	55.0	53.3	56.3	56.6	57.4	57.0	57.0	57.6	55.2	60.6	60.0

Disease susceptibility: 1 – Most susceptible
5 – Least susceptible

mod. vig. – moderately vigorous
v. vig. – very vigorous

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Performance of Control Pollinated Brazilian Progenies Under Hilir Perak Conditions

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The importation of hand and open-pollinated seeds from Brazil and Costa Rica in 1974 is part of MARDI's strategies in widening the cacao genetic base. Thirty-three crosses were imported and 28 crosses were used in the progeny trial. They were field-planted at Hilir Perak Station in 1975. The trial is laid out in a randomized block design, four replications, 20 plants/plot, spaced at 2.19 m x 3.10 m rectangular under mature coconut stands.

The date obtained from this trial indicates that progenies of Scavina produced the highest number of pods per tree per year, high bean number per pod, smallest bean size, early flowering, high jorquette height and high dry bean yield.

IMC 67 progenies produced average number per tree per year, high bean number per pod, medium size beans, early flowering, high jorquette height, and high dry bean yield.

ICS progenies varied not only in pod production per tree per year, but also on dry bean yield and size, had medium bean number and produced late flowering and low jorquette height.

From this trial, 819 individual trees were identified and selected. Some of them were transfered to observation blocks as well as to further clonal trials. Some were also used in further crossing programmes to produce F_1 progenies of advanced generations of clonal crosses.

The majority of the cocoa population in Malaysia are of mixed-hybrid in origin with narrow/limited genetic base. Thus, cocoa breeding programmes has restricted potential, resulting in a slow progress in obtaining high-yielding and good quality planting materials. As a result, Malaysian cocoa beans (especially Peninsular Malaysia) are generally small and vary in size (an average of 0.85 g to a slightly more than 1.0 g per bean), high percentage of shell, high acidity and a weak or lack of chocolate flavor. Malaysian cacao therefore suffers a discount of 6–10% under the Standard Ghanaian cacao in the world market.

The Malaysian Agricultural Research and Development Institute (MARDI) started the cocoa breeding and selection programmes in 1972 to continue the Department of Agriculture's efforts in formulating means and ways to ensure better planting materials for the future needs of the cocoa industry in Malaysia.

The importation of hand-and open-pollinated seeds from Brazil and Costa Rica is part of the strategies to widen the cocoa genetic base. These progeny seeds have been recommended by Dr. J. Soria based on the results of their breeding and selection efforts (*Appendix 1*) in CEPEC, Itabuna, Brazil. Thus, through these progenies, our objectives are multi-fold, *i.e.*

- To evaluate the adaptibility and performance of these F_1 progenies under Malaysian coastal soil conditions (MARDI Hilir Perak).

- To achieve genetic improvement through individual tree selection of superior trees and cloning these individuals to perpetuate the genotype.

- To produce F_1 and advanced generations of clonal crosses.

MATERIALS AND METHODS

Out of the 33 crosses imported, 28 crosses were used in the progeny trial and the remaining five planted as progeny rows. The seedlings were field-planted in April 1975, when they were six-month old at MARDI Hilir Perak Station under mature coconut stands.

MARDI Hilir Perak Station is situated at longitude E 100°M 52' 01", latitude N 3° 53' 42", at a latitude of 9.14 m above sea-level. The average rainfall of the area is 136.3 mm and the average temperature is 27.78°C with an average maximum of 32.31°C and average minimum of 23.25°C. The soil is predominantly of coastal clay, deep, and moderately well-drained Selangor-Kangkong series. The topography of the area is of flat, low, coastal land.

The progeny trial is laid out in a randomized block design replicated four times with 28 treatments, 20 plants (10 plants/row x two rows) plots. Coconut rows were established at 9.4 m within rows and 8.0 m between in triangular pattern. Two rows of cocoa were planted within the coconut evenue at 2.19 m x 3.10 m rectangular pattern, thus giving a density of 1141 plants per hectare. The total experimental area is 2.40 ha. The management of the area is of the standard cultural-practices adopted by MARDI in cocoa growing (Shaharuddin *et al.*, 1981).

The data collected for each plant were girth measurement at 30 cm above the ground level at six-monthly intervals starting from six months after planting till the third year; precocity which was indicated by the first date of flowering using a scoring method of one point for the first seven days of the month and one point for each additional seven days, the height of the first jorquette, the number of mature pods harvested monthly, the pod analyses on five samples per tree. Pod analyses data on each pod were the wet weight of beans (with and without mucilage, with and without shell), number of beans per pod, weight of peeled oven-dried beans and weight of oven-dried shell.

The data collected were analysed from time to time. Correlation studies on girth measurement and increment, jorquette height, and precocity were reported by Shaharuddin *et al.*, (1981). This paper discusses the overall performance of the progeny trial. Statistical analyses were the analysis of variance and Duncan's Multiple Range Test.

RESULTS AND DISCUSSIONS

Pod Production.

The analysis of the data is given in *Table 1(a)*. The analyses indicate that there are very significant differences in replication, progeny and year in pod production. High variability in pod production of each progeny is very significant and these differences enable the ranking and grouping (Duncan's Multiple Range Test) of these progenies into categories of high, average and low yielder (*Table 2*). It was observed that the progenies of Scavinas were the most productive. On the average each tree could produce 30–80 pods per year which gives an average of 1.00 – 1.40 kg of dry beans (*Table 2*). The pro-

TABLE 1. ANALYSIS OF VARIANCE FOR POD PRODUCTION, NUMBER OF BEANS PER POD AND MEAN DRY BEAN WEIGHT.

a. *Pod production*

Source		*df*	*MS*
Model		195	143.57***
	Replication	3	601.05***
	Progeny	27	512.61***
	Rep x progeny	81	34.88***
	Year	3	2300.50***
	Progeny x Year	81	32.42***
Error		248	9.42

***PR > F = 0.0001 s.d = 3.06 C.V = 11.14 $\bar{x}$ = 27.54

b. *Number of beans per pod*

Source		*df*	*MS*
Model		30	41.37***
	Replication	3	2.73***
	Progeny	27	45.66***
Error		81	0.74

**PR > F = 0.01 ***PR > F = 0.0001 s.d. = 0.86

C.V. = 1.91 $\bar{x}$ = 44.95

c. *Mean dry bean weight*

Source		*df*	*MS*
Model		30	0.04***
	Replication	3	0.005ns
	Progeny	27	0.045***
Error		81	0.003

n.s – non significant ***PR > F = 0.0001 sd = 0.05

C.V = 5.77 $\bar{x}$ = 0.95

TABLE 2a. RANKING FOR CLASSIFYING PROGENIES INTO CATEGORIES

Parameter	*Category*	*Ratings*	*Ranking*
Mean dry bean weight (g)	standard	1.00 g & above	1
	medium	0.90 – 0.99	2
	small	0.80 – 0.89	3
	very small	less than 0.79	4
Average number of pods per tree per year	high yielder	29.00 and above	1
	average yielder	24 – 28.9	2
	Low yielder	less than 23.9	3
Average number of beans per pod	High	45.00 and above	1
	Medium	41.0 – 44.9	2
	Low	less than 40	3

TABLE 2b. RANKING OF PROGENIES

Progeny	*Mean dry bean wt (g/bean)*	*Number of pods per tree/year*	*Number of beans/pod*	*Mean dry yield kg/tree/year*
SIC 962 x ICS 8	1	3	2	1.04
ICS 8 x SIAL CB	1	3	2	1.03
SIC 864 x UF 613	1	3	2	0.77
SIC 5 x ICS 1	1	2	2	1.19
SCA 20 x ICS 1	1	3	2	1.04
SIC 23 x ICS 1	1	3	2	1.02
SIC 2 x DR 2	1	1	3	1.34
SIC 22 x ICS 1	1	3	2	1.03
IMC 67 x CAS 1	1	3	1	1.03
SIC 972 x IMC 67	2	3	1	1.16
SIAL 88 x SIAL 70	2	2	1	1.11
SIC 831 x IMC 67	2	2	1	1.40
SIC 4 x ICS 1	2	1	2	1.26
SIC 4 x DR 2	2	1	3	1.23
IMC 67 x EEG 48	2	2	1	1.27
SIC 971 x IMC 67	2	2	1	1.18
SIC 17 x DR 2	2	3	3	0.87
SIAL 70 x SIAL 325	2	1	2	1.18
SIC 864 x SIC 328	3	3	1	1.06
SIC 812 x SIC 433	3	2	1	1.02
SIC 812 x SIC 250	3	2	1	1.12
SIC 815 x CEPEC 8	3	3	2	0.84
SCA 6 x ICS 1	3	1	2	1.37
SIC 644 x SIAL 542	3	2	1	0.99
SIAL 325 x SIAL 407	3	2	2	1.03
SIC 864 x SCA 12	3	1	1	1.31
SIC 948 x SCA 6	4	1	1	1.30
SIC 831 x SCA 6	4	1	1	1.38

genies of ICS fall into low yielding category (in pod production) but on a tree basis, dry bean yield averages between 1.00 – 1.40 kg (*Table 2*).

Pod production for each progeny varied very significantly year to year (*Table 1*). This could be due to the environmental factors as well as the agronomic factors that affect growth and the performance of the progenies. In the first two fruiting years, pod

production was very high, but reduced in the subsequent years (*Appendix 2*). This trend indicates that growth and potential fruiting capacity was expressed to its optimum capacity but in the subsequent years, competition between plants for light and space limited the potential since the planting distant was quite close.

In Hilir Perak there are two fruiting seasons – *i.e.* the major one is in October – December and the second one is in March – May. Flowering would commence in February for the major fruiting season and some time in September for the second season. The two critical periods for cherrelle formation coincide with rainy season. Moses and Enriquez (1982) had suggested that the amount of rainfall played an important role in the early developmental stages of the pod with regard to the final amount of dry yield produced. The number of pods produced by each progeny would depend on the severity of the rainy season which would affect the flowering formation, pollination activities by the pollinating insects and fruit set, as well as the spread of the *Phytopthora* pathogens to the forming cherrelle.

The number of pods harvested was taken as an indication of the relative yielding capacity of these progenies. Field recording was on individual tree basis since the commencement of first fruiting. To nullified the changing effects of the environment, our analyses were based on the average pod production per tree per year over a five-year period. This is the best in predicting the yield potential of cocoa progenies as has been suggested by Atanda (1972).

Number of Beans per Pod.

Pod analysis was carried out for all the individual trees in all the replicates over the five-year period. Due to the large number of trees, seasonal variations were not taken into considerations.

The analysis of the data is given in *Table 1 (b)*. Analysis indicates that there is a very significant difference in the bean number between replications and between progenies. High variability is observed within and between progenies which enable the ranking and grouping of these progenies into categories (*Table 2*). Variability is due to varietal variation as well as to seasonal variation. As to the varietal variations, progenies with the IMC and SCA genes have high number of beans per pod, and those of DR genes low bean numbers (*Table 2*). The number of beans formed is also determined by the number of ovules fertilized, which in turn depends on the number of pollen received. The number of pollen received depends on the activity of the pollinating insects as well as the compatibility system of the flower and pollen. Even though the number of pollen received is enough to have a complete fertilization of all of the ovules, incompatibility would interfere with the fruit setting.

Mean Dry Bean Weight

The analysed data on the dry bean weight is shown in *Table 1(c)*. Variation between progenies is significantly high and grouping of these progenies showed that only nine progenies attained the standard bean size of 1.10 g and most of them were of the ICS 1 progenies (*Table 2*). Scavina origins had the smallest bean size of 0.77 g to 0.80 g per bean. On the basis of the average bean size, only about 30% of the total population of the 28 progenies produced the acceptable bean size that would be economical to the planter. The variation of bean size between these progenies proves the high variability of bean size in a mixed hybrid population which forces the planter to market about

30% standard bean, 30% of the average bean and 40% of small beans if the beans are really selected and standardized (*Table 2*).

It has been suggested (Atanda, 1972) that bean development is very sensitive to the mean maximum day temperature as well as the relative humidity. However, in Hilir Perak conditions, these factors are negligible compared to that of Bahia (16°S). This is indicated by the non-significant different in bean size within a progeny (*Table 1*). Further more these populations are of controlled pollinated F_1 generation whereby variation within progeny is expected to be low. Seasonal variation within progeny in a year's production could be observed when there is marked drought period in that year. The bean size would be smaller than average, due to the stress imposed on the crop.

Dry Bean Yield.

The average dry yield is calculated on the basis of monoculture planting density of 1220 trees per hectare. *Table 3*, lists the yearly fluctuation in the average dry bean yield, the cumulative total and the average yield. SIC 831 x IMC 67 has the highest average of dry bean yield *i.e.* 1712 kg/ha/year and SIC 864 x UF 613 produced the lowest *i.e.* 985 kg/ha/year. The eventual yield is positively determined by the number of pod produced per tree per year, the number of beans per pod and the bean size. Even though the bean size of Scavina is very small, the tree has the capacity to produce high number of pods per tree and the average dry yield is ranked in the top ten progenies. High numbers of small pods would increase the cost of management (harvesting and pod cracking) but the average bean weight per pod is still lower than in other crosses. There is also an indication that Scavina progenies show very high initial production of pod in the first five years and then decline in the sixth year onward (Bartley, *et al.*, 1982). In the case of our trial, we are yet to prove this.

Overall Average Performance

The overall performance of these progenies are generally average and comparable to others planted in Brazil. Progenies planted in Hilir Perak had high initial dry bean yield compared to the Brazilians (*Appendix 1*). This indicates that plant growth in Hilir Perak is more vigorous and more precocious. Competition between plants for space and light as well as with the coconut roots for nutrients might have imposed a constraint to the crop potential and thus the decline in dry bean yield (*Figure 1*). *Appendix 1* shows that Brazilian yield data are very low initially which might indicate a very slow establishment growth as well as slow to full bearing. However, from their third bearing year onwards, the yield increased tremendously (*Figure 1*).

Table 4 summarizes the average performance of the individual progeny. High variability is due to the genetic potential of the hybrids and this wide variability presents an opportunity to have individual tree selection for cloning purposes and further crossings.

Early flowering progenies (56–63 weeks) of IMC 67 x EEG 48, SIC 864 x SIC 328, SIC 971 x IMC 67, SIC 948 x SCA 6, SIC 831 x IMC 67, SIC 831 x SCA 6, and SIC 971 x IMC 67 generally have high jorquette height (the mean range between 96–130 cm), high dry bean weight/tree/year (ranges between 1.0 – 1.4 kg/tree/year) but have medium to small bean size (ranges between 0.77 – 0.98 g/bean). This confirmed the results obtained by Bartley *et al.*, (1970) whereby the progeny of Scavina 6, SCA 12 and IMC 67 have the greatest precocity values, accumulated production and largest trunk diameter. In

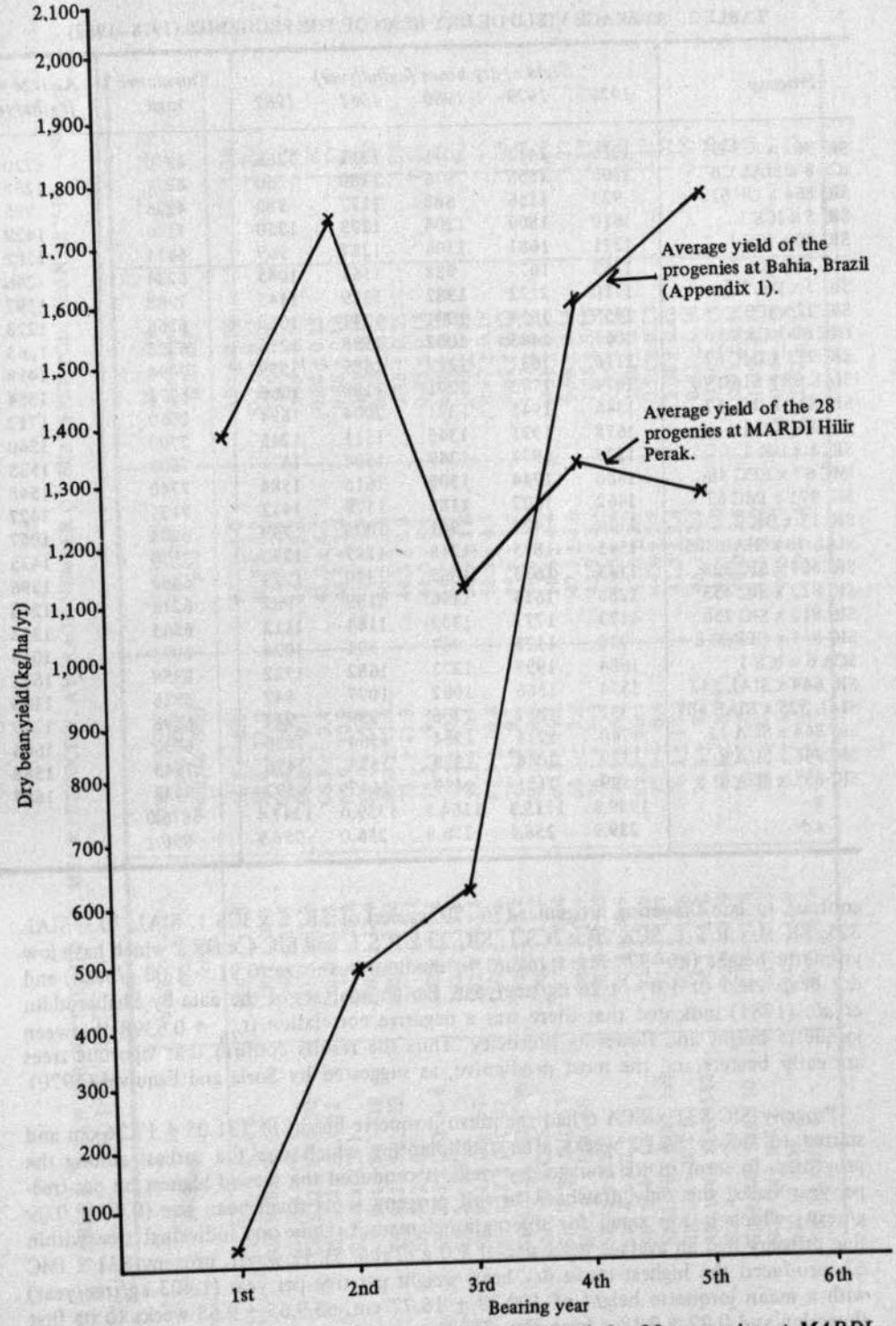


Figure 1. Production Pattern. Average dry bean yield of the 28 progenies at MARDI Hilir Perak compared to the progenies at Bahia, Brazil (Appendix 1).

TABLE 3. AVERAGE YIELD OF DRY BEAN OF THE PROGENIES (1978–1982)

Progeny	*Yield of dry beans (kg/ha/year)*					*Cumulative total*	*Average yield (kg/ha/year)*
	1978	*1979*	*1980*	*1981*	*1982*		
SIC 962 x ICS 8	1316	1412	1045	1311	1266	6350	1270
ICS 8 x SIAL CB	1306	1555	976	1180	1260	6277	1255
SIC 864 x UF 613	923	1156	688	1177	982	4926	985
SIC 5 x ICS 1	1610	1809	1204	1273	1250	7146	1429
SIC 20 x ICS 1	1371	1681	1106	1287	969	6414	1282
SIC 23 x ICS 1	1363	1677	988	1161	1045	6234	1246
SIC 2 x DR 2	1710	2122	1382	1329	1445	7988	1597
SIC 22 x ICS 1	1455	1614	1001	1241	1055	6366	1273
IMC 67 x CAS 1	1067	1445	1002	1598	1216	6328	1265
SIC 972 x IMC 67	1116	1631	1119	1689	1539	7094	1418
SIAL 88 x SIAL 70	1474	1773	1271	1188	1066	6772	1354
SIC 831 x IMC 67	1546	1945	1371	2004	1694	8560	1712
SIC 4 x ICS 1	1678	1921	1345	1511	1245	7700	1540
SIC 4 x DR 2	1575	1977	1249	1507	1371	7679	1535
IMC 67 x EEG 48	1488	1744	1309	1615	1584	7740	1548
SIC 971 x IMC 67	1462	1503	1180	1579	1412	7136	1427
SIC 17 x DR 2	1116	1424	941	1008	799	5288	1057
SIAL 70 x SIAL 325	1545	1895	1218	1289	1232	7179	1435
SIC 864 x SIC 328	1143	1633	1065	1370	1273	6484	1296
SIC 812 x SIC 433	1283	1616	1196	1139	982	6216	1243
SIC 812 x SIC 250	1173	1777	1339	1164	1112	6565	1313
SIC 815 x CEPEC 8	938	1173	967	991	1024	5093	1018
SCA 6 x ICS 1	1684	1997	1273	1682	1722	8358	1671
SIC 644 x SIAL 542	1374	1566	1062	1077	847	5926	1185
SIAL 325 x SIAL 407	1331	1881	1206	939	941	6298	1259
SIC 864 x SCA 12	1740	1915	1284	1564	1529	8032	1606
SIC 948 x SCA 6	1539	2066	1329	1533	1476	7943	1588
SIC 831 x SCA 6	1589	2121	1489	1647	1592	8438	1687
$\bar{x}$	1389.8	1715.3	1164.5	1359.0	1247.4	6876.0	
s.d	229.9	258.1	175.8	256.0	258.9	996.1	

contrast to late flowering progenies (76–79 weeks) of SIC 5 x ICS 1, SIAL 70 x SIAL 325, SIC 4 x ICS 1, SCA 20 x ICS 1, SIC 23 x ICS 1, and SIC 4 x DR 2 which have low jorquette height (86–97 cm), standard to medium bean size (0.91 – 1.08 g/bean) and dry bean yield of 1.0 – 1.26 kg/tree/year. Earlier analyses of the data by Shaharuddin *et al.*, (1981) indicated that there was a negative correlation (r_{26} = 0.6398) between jorquette height and flowering precocity. Thus the results confirm that vigorous trees are early bearers and the most productive, as suggested by Soria and Esquivel (1970).

Progeny SIC 831 x SCA 6 had the mean jorquette height of 131.05 ± 17.26 cm and started to flower 56.72 weeks after field-planting which was the earliest among the progenies. In term of its average dry yield, it produced the second highest on per-tree-per-year basis; the only drawback to this progeny is its small bean size (0.77 ± 0.09 g/bean) which is too small for international market. Only one individual tree within this progeny had an average bean size of 1.0 g (*Table 5*). However, progeny 831 x IMC 67, produced the highest mean dry bean weight per tree per year (1.403 kg/tree/year) with a mean jorquette height of 100.38 ± 16.77 cm, 65.9.65 ± 9.65 weeks to its first flowering and 0.97 + 0.18 g bean size. Thirty-two individuals were selected from within the progeny on the basis of mean dry bean weight (1.0 g – 1.38 m).

TABLE 4. MEAN JORQUETTE HEIGHT, MEAN PRECOCITY, AVERAGE NUMBER OF BEANS PER POD, MEAN DRY BEAN WEIGHT AND DRY YIELD

Progeny	*Mean jorquette height (cm)*	*Mean precocity (weeks after transplanting)*	*Average no. of beans/ pod*	*Mean dry bean weight (g/bean)*	*Dry yield (kg/tree/year)*
SIC 831 x SCA 6	131.1 ± 17.3	56.7 ± 8.1	47.2 ± 4.0	0.77 ± 0.09	1.38
SIC 948 x SCA 6	129.1 ± 26.7	58.6 ± 11.0	46.9 ± 3.7	0.77 ± 0.11	1.30
ICS 8 x SIAL CB	124.4 ± 23.7	67.5 ± 8.60	44.5 ± 2.3	1.15 ± 0.20	1.03
SIC 812 x SIC 250	121.3 ± 21.8	69.0 ± 9.7	45.3 ± 2.6	0.89 ± 0.13	1.12
SIC 864 x SCA 12	116.0 ± 19.1	66.3 ± 9.4	46.3 ± 4.1	0.80 ± 0.15	1.32
SCA 6 x ICS 1	111.4 ± 20.8	69.9 ± 10.9	44.5 ± 3.4	0.86 ± 0.18	1.37
SIC 864 x SIC 328	109.5 ± 13.9	64.0 ± 12.9	49.3 ± 3.9	0.91 ± 0.17	1.06
SIC 812 x SIC 433	108.9 ± 17.3	66.5 ± 11.4	46.5 ± 3.4	0.89 ± 0.15	1.02
SIC 962 x ICS 8	107.8 ± 23.2	73.2 ± 11.3	44.5 ± 3.3	1.15 ± 0.21	1.02
SIC 815 x CEPEC 8	102.9 ± 19.6	75.2 ± 9.9	44.0 ± 3.1	0.88 ± 0.14	0.84
SIC 2 x DR 2	102.7 ± 19.9	73.5 ± 10.8	38.1 ± 4.1	1.05 ± 0.18	1.34
SIC 971 x IMC 67	102.4 ± 21.8	57.1 ± 9.7	50.9 ± 4.6	0.95 ± 0.13	1.18
SIC 831 x IMC 67	100.4 ± 16.8	63.9 ± 16.8	51.5 ± 4.7	0.97 ± 0.18	1.46
SIAL 325 x SIAL 407	99.0 ± 16.1	75.0 ± 9.1	44.6 ± 3.5	0.82 ± 0.13	1.03
IMC 67 x CAS 1	98.5 ± 17.9	67.0 ± 8.7	48.6 ± 5.3	1.02 ± 0.19	1.03
SIC 972 x IMC 67	97.4 ± 23.4	60.8 ± 11.1	50.6 ± 4.4	0.98 ± 0.15	1.16
IMC 67 x EEG 48	96.9 ± 15.4	63.3 ± 7.7	47.3 ± 5.6	0.94 ± 0.14	1.27
SIC 5 x ICS 1	96.6 ± 15.3	76.1 ± 9.3	42.9 ± 3.2	1.08 ± 0.15	1.19
SIC 4 x DR 2	96.4 ± 20.9	79.5 ± 8.1	39.5 ± 3.6	0.95 ± 0.17	1.26
SIC 864 x UF 613	91.7 ± 11.6	61.2 ± 10.1	43.0 ± 3.7	1.08 ± 0.17	0.77
SIAL 70 x SIAL 325	91.0 ± 15.7	77.9 ± 8.5	44.0 ± 2.8	0.91 ± 0.13	1.18
SIC 23 x ICS 1	90.5 ± 15.6	76.3 ± 10.2	41.5 ± 3.4	1.06 ± 0.16	1.02
SIC 644 x SIAL 542	90.1 ± 15.6	74.8 ± 9.2	45.2 ± 2.1	0.82 ± 0.10	0.99
SIC 4 x ICS 1	90.2 ± 21.9	77.8 ± 8.9	41.4 ± 4.0	0.96 ± 9.15	1.26
SIAL 88 x SIAL 70	87.5 ± 15.3	75.1 ± 9.1	46.0 ± 2.8	0.97 ± 0.13	1.11
SCA 20 x ICS 1	86.8 ± 15.3	76.1 ± 9.5	41.6 ± 4.2	1.05 ± 0.18	1.04
SIC 17 x DR 2	84.5 ± 16.9	75.2 ± 8.9	40.5 ± 5.3	0.94 ± 0.19	0.87
SIC 22 x ICS 1	83.8 ± 19.5	74.7 ± 9.9	42.7 ± 3.4	1.02 ± 0.15	1.03

TABLE 5. NUMBER OF INDIVIDUALS IDENTIFIED FROM EACH PROGENY FOR CLONAL OBSERVATION AND PROPAGATION

Progeny	*No. of individual identified*	*Range of mean dry bean weight*
1. SIC 962 x ICS 8	56	1.0 – 1.56
2. ICS 8 x SIAL CB	57	1.0 – 1.72
3. SIC 864 x UF 613	48	1.0 – 1.60
4. SIC 5 x ICS 1	51	1.0 – 1.41
5. SCA 20 x ICS 1	46	1.0 – 1.44
6. SIC 23 x ICS 1	47	1.0 – 1.45
7. SIC 2 x DR 2	52	1.0 – 1.89
8. SIC 22 x ICS 1	58	1.0 – 1.60
9. IMC 67 x CAS 1	42	1.0 – 1.51
10. SIC 972 x IMC 67	33	1.0 – 1.39
11. SIAL 88 x SIAL 70	31	1.0 – 1.26
12. SIC 831 x IMC 67	32	1.0 – 1.38
13. SIC 4 x ICS 1	28	1.0 – 1.44
14. SIC 4 x DR 2	28	1.0 – 1.35
15. IMC 67 x EEG 48	26	1.0 – 1.30
16. SIC 971 x IMC 67	24	1.0 – 1.20
17. SIC 17 x DR 2	25	1.0 – 1.37
18. SIAL 70 x SIAL 325	14	1.0 – 1.28
19. SIC 864 x SIC 328	21	1.0 – 1.46
20. SIC 812 x SIC 433	17	1.0 – 1.23
21. SIC 812 x SIC 250	11	1.0 – 1.15
22. SIC 815 x CEPEC 8	19	1.0 – 1.20
23. SCA 6 x ICS 1	13	1.0 – 1.42
24. SIC 644 x SIAL 407	23	1.0 – 1.05
25. SIAL 325 x SIAL 407	7	1.0 – 1.15
26. SIC 864 x SCA 12	7	1.0 – 1.34
27. SIC 948 x SCA 6	2	1.0 – 1.12
28. SIC 831 x SCA 6	1	1.0
Total	819	

Table 5 indicates the number of individuals indentified from each progeny for clonal observations and further evaluations. ICS 8 and ICS 1 contributed the most number of individuals for direct clonal propagation. SCA 6 and SCA 12 progenitors showed high production of pods and some individuals from progenies SIC 831 x SCA 6, SIC 948 x SCA 6, SCA 6 x ICS 1 and SIC 864 x SCA 12 produced a range of 80–100 pods/tree/year. However, out of these progenies only 23 individuals are with a mean dry bean weight of 1.0 g. These individuals can be used in further crossing programmes.

CONCLUSIONS

The performance of these progenies under Hilir Perak conditions compared to some progenies in Brazil in term of their dry bean yield are generally average except that those at Hilir Perak had high bean yield from the first bearing year. This is an indication that at Hilir Perak conditions, these progenies are very vigorous, early bearers and the most productive. However, due to competition for space, light and nutrient as well as environmental factors the dry bean yield declined in the third bearing year onward.

Progenies of Scavinas fall into the most productive category for pod production with high number of beans per pod, the smallest bean size, early flowering, high jorquette

height and high average dry bean yield. The greatest drawback to these progenies are the small pod and the small bean size. Some individuals with the standard bean size and high pod production will be selected for further crossing programmes.

IMC 67 progenies are average pod yielders with high bean number per pod and medium size bean. They are early flowering with high jorquette and high dry bean yield. Individual tree have been identified for direct clonal propagation as well as for crossing programmes.

ICS progenies are late flowering with low jorquette height, vary in pod production and with standard to medium size beans. However, they contributed the most number of individuals for direct clonal observation and propagation.

From the above progeny trial, 819 individual trees have been identified and selected. They will be transferred to observation blocks. Some of the individuals have been selected and transferred for clonal trials in the station as well as in farmer's areas. Those that have been used in clonal trials in the station will be transferredto new clonal trials in different environment. Some of the selected clones have been used as progenitors in a three-way crosses and their progeny is already in the field for evaluation.

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Appendix 1. Available yield data on imported progenies as recorded in Bahia, Brazil.

Progeny	Production (kg/ha/year)					
	1966	*1967*	*1968*	*1969*	*1970*	*1971*
SIC 962 x ICS 8	–	–	–	197	1128	1968
SIC 864 x UF 613	–	–	–	22	534	1026
SIC 5 x ICS 1	–	0	76	819	1841	2312
SIC 23 x ICS 1	–	2	54	885	2041	2475
SIC 2 x DR 2	–	0	60	610	1211	1956
SIC 22 x ICS 1	–	0	25	704	1637	2164
IMC 67 x CAS 1	–	–	–	–	529	1201
SIC 831 x IMC 67	–	–	–	365	1547	2007
SIC 4 x ICS 1	–	0	48	767	1897	2273
SIC 4 x DR 2	–	1	34	626	1233	2027
IMC 67 x EEG 48	–	–	–	–	356	901
SIC 971 x IMC 67	–	–	–	623	1966	1963
SIC 17 x DR 2	–	0	81	682	1441	2212
SIAL 70 x SIAL 325	–	11	136	838	2213	2613
SIC 864 x SIC 328	–	5	124	1263	2242	2323
SIC 812 x SIC 433	–	0	26	575	1180	1708
SIC 812 x SIC 250	36	542	566	1667	1711	2267
SIC 815 x CEPEC 8	–	0	81	952	2184	2467
SCA 6 x ICS 1	–	–	–	–	334	2074
SIC 644 x SIAL 542	60	421	688	1496	1774	1644
SIC 864 x SCA 12	–	–	–	585	2387	2957
SIC 948 x SCA 6	–	–	–	678	2326	2819
SIC 831 x SCA 6	–	–	–	716	2362	2449
	48	481.5	627	1581.5	1742	2170.5

From: Pruducao de selecao de cacaueiros hibridos na Bahia. F. Vello, Garcia, J.R. & Magalhaes W.B. (1972)

Planted at 3 m x 3 m monoculture planting

Appendix 2. Average annual pod number per tree, number of beans per pod, mean dry bean weight and yield of dry bean weight

Progeny	Average number of pods/tree/year					No. of beans/pod				Mean dry bean weight (g)				Dry bean weight (kg/tree/year)
	Year	df	$\bar{x}$	sd	cv	df	$\bar{x}$	sd	cv	df	$\bar{x}$	sd	cv	
SIC 22 x ICS 1	78	75	27.41	17.36	63.34	71	42.68	3.43	8.04	71	1.02	0.15	15.13	1.193
	79	76	30.41	16.46	54.13									1.323
	80	76	18.86	12.62	66.90									0.821
	81	79	23.39	14.86	63.55									1.018
	82	65	19.89	14.00	70.38									0.865
IMC 67 x EEG 48	78	75	27.47	14.21	51.75	66	47.26	5.61	11.86	66	0.94	0.14	15.31	1.220
	79	76	32.20	15.80	49.06									1.430
	80	76	24.16	17.35	71.82									1.073
	81	72	29.82	17.14	57.50									1.324
	82	72	29.25	13.53	46.25									1.299
SIC 2 x DR 2	78	76	35.05	16.88	48.16	74	38.10	4.12	10.82	74	1.05	0.18	17.19	1.402
	79	76	43.51	22.23	51.08									1.740
	80	76	28.34	17.30	61.06									1.133
	81	73	27.25	16.05	58.89									1.090
	82	77	29.63	16.53	55.78									1.185
SIAL 325 x SIAL 407	78	76	29.84	14.31	47.97	70	44.61	3.54	7.54	70	0.82	0.13	15.33	1.091
	79	76	42.18	21.64	51.31									1.542
	80	75	27.06	18.06	66.74									0.989
	81	74	21.06	12.20	57.92									0.770
	82	74	21.13	13.39	63.36									0.772
SIC 5 x ICS 1	78	76	28.53	13.69	48.00	69	42.85	3.22	7.51	69	1.08	0.15	13.46	1.320
	79	76	32.98	14.84	32.98									1.483
	80	76	21.95	11.56	52.66									0.987
	81	72	22.58	13.39	59.32									1.044
	82	69	22.17	15.29	68.96									1.025
SIC 17 x DR 2	78	73	24.05	13.08	54.38	70	40.51	5.33	13.15	70	0.94	0.19	20.17	0.915
	79	76	30.69	17.31	56.40									1.168
	80	76	20.29	12.47	61.45									0.772
	81	73	21.74	14.20	65.33									0.827

Appendix 2. (Cont'd)

Progeny	Average number of pods/tree/year					No. of beans/pod				Mean dry bean weight (g)				Dry bean weight (kg/tree/year)
	Year	df	$\bar{x}$	sd	cv	df	$\bar{x}$	sd	cv	df	$\bar{x}$	sd	cv	
SIAL 70 x SIAL 325	78	75	31.59	16.24	51.43	64	44.09	2.79	6.32	64	0.91	0.13	14.16	1.267
	79	76	38.74	17.97	46.38									1.554
	80	75	24.82	13.39	53.74									0.999
	81	73	26.36	13.82	52.41									1.057
	82	77	25.19	13.93	55.52									1.010
SIC 864 x UF 613	78	76	16.31	9.55	58.55	67	43.01	3.68	8.55	67	1.08	0.17	15.46	0.757
	79	76	20.41	10.96	53.70									0.948
	80	76	12.16	8.60	70.72									0.564
	81	74	20.78	14.55	70.03									0.965
	82	75	17.34	10.99	63.37									0.805
SIC 864 x SIC 328	78	75	20.91	12.22	58.46	62	49.27	3.90	7.91	62	0.91	0.17	18.64	0.937
	79	76	29.88	17.40	50.24									1.339
	80	76	19.48	12.03	61.76									0.873
	81	71	25.05	16.08	64.19									1.123
	82	76	23.30	13.14	56.39									1.044
SIC 864 x SCA 12	78	75	38.77	22.62	58.33	72	46.03	4.09	8.88	72	0.80	0.15	18.29	1.427
	79	76	42.64	20.50	48.08									1.570
	80	76	28.60	15.32	53.58									1.053
	81	76	34.83	18.46	53.01									1.282
	82	80	34.07	17.75	52.09									1.254
SIC 962 x ICS 8	78	72	21.11	11.29	53.47	69	44.48	3.28	7.38	69	1.15	0.21	18.30	1.079
	79	76	22.64	11.41	50.39									1.158
	80	75	16.77	10.74	64.05									0.857
	81	74	21.03	10.29	48.94									1.075
	82	77	20.31	10.90	53.66									1.038
SIAL 88 x SIAL 70	78	75	27.10	12.52	46.21	61	46.03	2.83	6.16	61	0.97	0.13	13.13	1.209
	79	75	32.57	15.07	46.26									1.454
	80	76	23.34	13.43	57.54									1.042
	81	72	21.83	10.15	46.48									0.974
	82	72	19.59	10.69	54.56									0.874

Appendix 2. (Cont'd)

Progeny	Average number of pods/tree/year					No. of beans/pod				Mean dry bean weight (g)				Dry bean weight (kg/tree/year)
	Year	df	$\bar{x}$	sd	cv	df	$\bar{x}$	sd	cv	df	$\bar{x}$	sd	cv	
SCA 6 x ICS 1	78	74	36.10	16.93	46.89	70	44.50	3.37	7.58	70	0.86	0.18	21.19	1.381
	79	74	42.78	19.12	44.70									1.637
	80	75	27.29	14.01	51.33									1.044
	81	74	36.05	17.43	48.36									1.379
	82	78	36.92	18.45	49.97									1.412
SIC 4 x ICS 1	78	74	34.63	17.66	51.01	69	41.40	4.03	10.62	69	0.96	0.15	15.98	1.376
	79	75	39.65	22.03	55.56									1.575
	80	77	27.77	17.86	64.31									1.103
	81	73	31.18	17.47	56.04									1.239
	82	73	25.71	14.53	56.51									1.021
SCA 20 x ICS 1	78	95	25.78	11.78	45.69	69	41.56	4.17	10.03	69	1.05	0.18	17.06	1.124
	79	96	31.60	15.44	48.85									1.378
	80	76	20.79	13.18	63.43									0.907
	81	66	24.19	14.19	58.66									1.055
	82	69	18.23	11.36	62.31									0.795
SIC 971 x IMC 67	78	73	24.91	12.12	48.65	69	50.68	4.56	9.00	69	0.95	0.13	13.42	1.199
	79	76	25.60	13.82	54.00									1.232
	80	76	20.11	12.49	62.09									0.968
	81	73	26.90	14.99	55.75									1.295
	82	76	24.07	14.43	59.95									1.158
SIC 812 x SIC 250	78	55	26.16	10.83	41.40	65	45.25	2.61	5.76	65	0.89	0.13	14.25	1.053
	79	56	37.00	14.24	38.47									1.490
	80	76	27.89	13.01	46.65									1.123
	81	57	24.25	11.10	45.77									0.976
	82	74	23.16	12.43	53.67									0.932
SIC 948 x SCA 6	78	75	34.96	21.58	61.72	72	46.91	3.65	7.78	72	0.77	0.11	14.96	1.262
	79	76	46.91	25.22	53.76									1.694
	80	76	30.20	15.06	49.86									1.090
	81	76	34.80	18.65	53.59									1.257
	82	79	33.50	19.26	57.49									1.210

Appendix 2. (Cont'd)

Progeny	Average number of pods/tree/year					No. of beans/pod				Mean dry bean weight (g)				Dry bean weight (kg/tree/year)
	Year	df	$\bar{x}$	sd	cv	df	$\bar{x}$	sd	cv	df	$\bar{x}$	sd	cv	
SIC 831 x IMC 67	78	75	25.41	11.71	46.08	72	51.47	4.71	9.14	72	0.79	0.18	18.18	1.268
	79	76	31.96	14.99	46.89									1.595
	80	76	22.53	12.11	53.77									1.124
	81	74	32.91	17.96	54.58									1.643
	82	78	27.83	13.47	48.40									1.389
SIC 831 x SCA 6	78	76	35.85	19.14	53.40	72	47.21	4.00	8.47	72	0.77	0.09	12.17	1.303
	79	76	47.86	21.75	45.44									1.739
	80	75	33.59	21.05	62.66									1.221
	81	76	37.14	20.80	56.00									1.350
	82	80	35.92	17.82	49.61									1.305
SIC 23 x ICS 1	78	74	25.44	14.68	57.70	67	41.46	3.37	8.05	67	1.06	0.16	15.31	1.118
	79	75	31.29	15.33	48.98									1.375
	80	76	18.44	10.27	55.70									0.810
	81	74	21.68	12.99	59.92									0.952
	82	72	19.52	16.35	83.76									0.857
SIC 812 x SIC 433	78	75	25.41	11.28	44.41	70	46.53	3.43	7.37	70	0.89	0.15	17.42	1.052
	79	76	32.01	13.78	43.06									1.325
	80	76	23.69	11.79	49.79									0.981
	81	75	22.57	10.92	48.37									0.934
	82	77	19.44	11.58	59.56									0.805
IMC 67 x CAS 1	78	73	17.66	9.51	53.85	67	48.62	5.30	10.89	67	1.02	0.19	18.72	0.875
	79	76	23.90	11.08	46.35									1.185
	80	76	16.59	10.65	64.21									0.822
	81	73	26.43	14.19	53.71									1.310
	80	75	20.12	11.44	56.85									0.997

Appendix 2. (Cont'd)

Progeny	Average number of pods/tree/year					No. of beans/pod				Mean dry bean weight (g)				Dry bean weight (kg/tree/year)
	Year	df	$\bar{x}$	sd	cv	df	$\bar{x}$	sd	cv	df	$\bar{x}$	sd	cv	
SIC 972 x IMC 67	78	73	18.45	11.02	59.73	70	50.64	4.42	8.73	70	0.98	0.15	15.56	0.915
	79	76	26.96	13.55	50.25									1.337
	80	76	18.50	10.60	57.31									0.918
	81	72	27.92	15.05	53.91									1.385
	82	76	25.44	13.80	54.42									
SIC 815 x CEPEC 8	78	69	19.90	12.36	62.12	60	43.95	3.05	6.95	60	0.88	0.14	16.08	0.769
	79	76	24.88	16.00	64.33									0.962
	80	75	20.51	12.12	59.11									0.793
	81	74	21.04	10.49	49.85									0.813
	82	77	21.74	12.13	55.79									0.840
SIC 644 x SIAL 542	78	72	30.42	14.13	46.44	69	45.19	2.09	4.58	69	0.82	0.10	12.24	1.127
	79	75	34.67	17.66	48.16									1.284
	80	76	23.51	12.59	53.55									0.871
	81	54	23.84	11.21	47.02									0.883
	82	71	18.76	11.18	59.59									0.695
ICS 8 x SIAL CB	78	73	20.96	10.53	50.21	70	44.45	2.72	6.13	70	1.15	0.20	17.61	1.071
	79	76	24.96	12.61	50.52									1.275
	80	76	15.66	10.31	65.80									0.800
	81	76	18.94	11.33	59.84									0.968
	82	76	20.22	11.30	55.88									1.033
SIC 4 x DR 2	78	73	34.43	15.08	43.80	70	39.49	3.54	9.05	70	0.95	0.17	18.17	1.291
	79	76	43.21	20.52	47.48									1.621
	80	76	27.31	16.21	59.36									1.024
	81	74	32.97	18.47	56.02									1.236
	82	79	29.97	17.77	59.29									1.124

Evaluation of Early Vigour of Wild Cocoa from the Amazon Region of Ecuador

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To evaluate the vigour of wild cocoa genotypes collected by the London Cocoa Trade Amazon Project (LCTAP) in the Amazon Region of Ecuador, stem diameters of 405 trees from 52 collections were measured at 90-day intervals over a period of 2 years. An average growth rate for each collection was calculated by fitting an exponential growth function to the data for the first year. During the second year, there was a reduction in growth rate for which the exponential model was unsatisfactory.

Growth rates for the collections showed a continuous, approximately normal distribution in the range 0.0018 to 0.0032 mm/mm/day. There were statistically significant differences among the collections and also between trees within collections.

The calculated growth rates were used to rank the collections in order of vigour. This ranking is intended to aid breeders in the selection of material from the LCTAP collection.

It is widely accepted that measurements of vegetative growth of cocoa may be used both to assess the effects of experimental treatments (for example, Legg *et al.*, 1980) and also to evaluate the performance of clones and progenies (Lockwood, 1976 and Batista, 1982). Stem diameter or circumference can be measured easily and precisely, and data may be collected from trees too young to produce pods. For agronomic evaluation, the correlation between early vegetative growth and later yield is not completely reliable (Legg 1981), but it is acceptable in the absence of other information, particularly when screening a series of genotypes showing marked variation in vigour.

Data were available on stem diameter growth in progenies from seeds collected among wild cocoa populations in the Amazon Region of Ecuador during the London Cocoa Trade Amazon Project (LCTAP) (Allen & Lass, 1983). These progenies (here referred to as collections) have been planted out as a field gene bank, from which material is available to breeders anywhere in the world. The object of the analysis was to rank the collections in order of vigour, based on vegetative growth within the period up to 32 months from field planting. Since the stem diameters of the collectons are recorded at regular intervals, it was decided to try to calculate an overall growth rate for each collection by fitting a simple growth function to all the data from each collection.

MATERIALS AND METHODS

The LCTAP gene bank is located in the INIAP (National Agricultural Research Institute,

Ecuador) Napo-Payamino Experimental Station, at San Carlos (0°20's, 76°50'W), near Coca, in the Amazon Region of Ecuador. The station is at an altitude of 265 m, with an average annual rainfall of 3100 mm, evenly distributed throughout the year. The environment of the region is described in detail in Allen & Lass (1983); which also lists the origins and characteristics of the collections in the LCTAP gene bank.

In the gene bank, each collection is planted out as a single row of up to 10 seedlings (some rows are incomplete), spaced at 3 m within the rows and 4 m between the rows. For each collection, the seedlings originated from 1–3 pods, obtained from a single wild tree. Towards the end of the period of data collection there was some overlap of canopies within the rows, but none between the rows. Fairly heavy shade was provided by large tress remaining from the original forest on the site.

The first group of 25 collections was planted out in February 1981 and a second group, of 27 collections, was planted out in July 1981. The trees, which were grown from seed collected in the wild, were 7–11 months old when planted out. The girth data used here were calculated from stem diameters, which were measured with a caliper at 15 cm above soil level, at 90-day intervals from October 1981 (Day 0) to October 1983 (Day 730). More recently, girths have been measured directly.

Data Analysis

The data were fitted to the simple exponential growth function:

$dG(t)/dt = rG(t)$ $\quad G(t)$ = girth at t day
r = growth rate (mm/mm/day)

equivalent to:

$$lnG(t) = lnG(0) + rt$$

by calculating the regression of ln(girth) against time (in days) for each tree. The growth rate is then equal to the slope of the regression line. Regressions were also calculated from pooled data for each collection and for all collections together. Analysis of variance was used to check the significance of differences of slope between trees and between collections. All calculations were made at San Carlos using an Osborne 1 microcomputer and a specially written programme.

The fit of the data to the model was checked visually, by plotting the data and the fitted line for a representative selection of collections (*Figure 1*). On inspection, it was obvious that the growth of the trees was slowing down during the second year of data collection. It was therefore decided to fit the growth model only to the first year's data, up to 20 months from field planting, giving five data points for each of 405 trees.

RESULTS AND DISCUSSION

The analysis of variance (*Table 1*) indicates that there are differences in growth rate between collections (using a variance-ratio test, $F[51, 1568\ df] = 8.09, P<0.01$). There is evidence of smaller differences between individual trees within collections ($F[353, 1215\ df] = 2.41, P<0.01$).

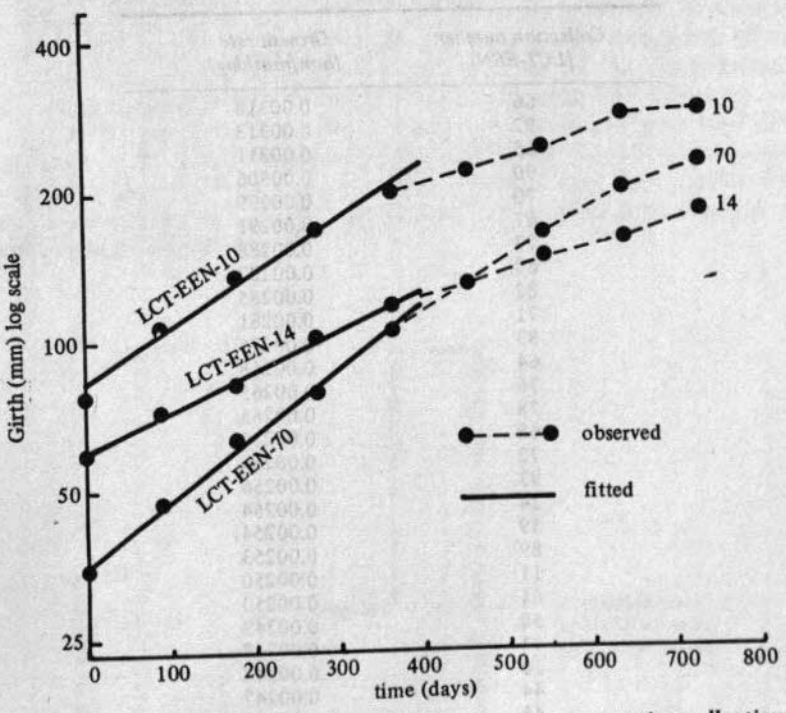


Figure 1. Girth plotted against time for three representative collections.

TABLE 1. ANALYSIS OF VARIANCE FOR REGRESSION OF IN(STEM-DIAMETERS) AGAINST TIME

Factor	*df*	*ss*	*ms*
Overal regression	1	204.3755	204.375539
Residuals	1619	18.4871	0.011419
(Difference)	51	3.8509	0.075509
Within collections			
Residuals	1568	14.6361	0.009334
(Difference)	360	6.0274	0.017075
Within trees			
Residuals	1215	8.6087	0.007985
Total	1620	222.8626	

The calculated growth rates were used to rank the 52 collections in order of vigour (*Table 2*). The top 10% of collections (LCT-EEN-65, 66, 70, 90 and 92), with a mean growth rate of 0.0031 mm/mm/day, are growing about 60% faster than the bottom 10% (mean growth rate 0.0019 mm/mm/day).

These results should be interpreted cautiously. The variability within collections means that there are statistically significant differences only between those collections near the top of the list and those near the bottom. Furthermore, the layout of the gene bank was determined by the need to store the collections with minimum maintenance and minimum risk of confusion between material of different origins. As a result, the plantings of

TABLE 2. COLLECTIONS RANKED IN ORDER OR GROWTH RATE

Collection number (LCT-EEN)	*Growth rate (mm/mm/day)*
66	0.00318
92	0.00313
65	0.00311
90	0.00306
70	0.00299
67	0.00291
77	0.00288
69	0.00287
82	0.00285
71	0.00281
83	0.00276
64	0.00268
76	0.00265
78	0.00265
68	0.00264
72	0.00264
93	0.00256
24	0.00254
59	0.00254
89	0.00253
11	0.00250
61	0.00250
58	0.00249
74	0.00248
10	0.00247
44	0.00247
48	0.00247
62	0.00245
84	0.00243
86	0.00241
26	0.00240
79	0.00236
25	0.00235
23	0.00231
29	0.00231
20	0.00230
87	0.00227
88	0.00223
22	0.00221
19	0.00220
15	0.00216
21	0.00215
27	0.00215
85	0.00212
18	0.00210
5	0.00209
1	0.00208
6	0.00201
8	0.00198
28	0.00194
4	0.00184
14	0.00180

the collections are not replicated within the gene bank, and differences between collections may result from environmental differences within the site, although the site is fairly uniform. In general, the collections from Zamora-Chinchipe Province (LCT-EEN-66 to

LCT-EEN-93), planted in the eastern half of the block, are faster-growing than those from Napo Province (LCT-EEN-1 to LCT-EEN-57), which occupy the western half of the block. However, the distribution of growth rates within each group of collecitons does not suggest any overall environmental gradient across the site. The calculated growth rates do seem to reflect the genetic variation present in the LCTAP collections, which also show marked differences in growth habit. The size of the LCTAP gene bank (245 collections at the end of 1983) makes full-scale trials of all the colections impractical, in these circumstances, the assessment of vigour presented here does provide the breeder with an objective basis for selecting vigorous genotypes, which form one end of a continuous distribution (*Figure 2*).

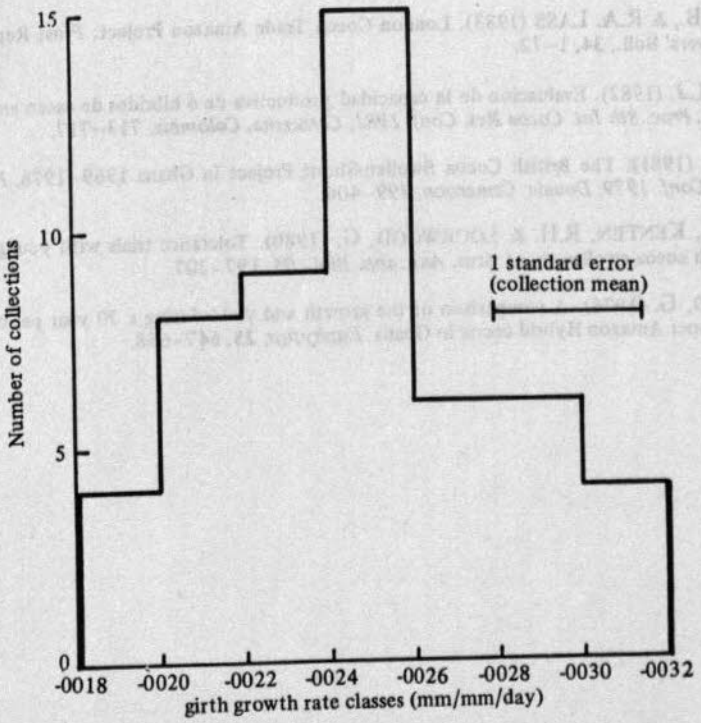


Figure 2. Frequency distribution of collection mean growth rates.

Evaluation of vigour using a series of measurements offers several advantages over comparisons at a single date, or calculation of growth rate between two dates. The growth rate parameter in the exponential growth function should not be affected by differences of several months in the age of the trees, so long as growth still follows the exponential model (which can and should be checked, easily by visual comparison of the observed values with those calculated from the model). There is less risk of evaluation results being confused by the occasional bad measurement. Finally, standard regression statistics can be used to measure the precision of the estimated growth rates.

It may be possible to use a longer series of measurements by fitting a more complex model to the data. However, a model with several growth rate parameters would not

lead to a straightforward ranking of collecitons in order of vigour. A more complex model might also be needed to cope with seasonal differences in growth rates. At San Carlos, with continuous rainfall through the year, there is apparently no seasonal change in the rate of vegetative growth.

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4 Clonal Cocoa Work on BAL Plantations

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Two aspects of clonal cocoa work were carried out by BAL. The first concerned the choice of vegetative propagation methods while the second dealt with the selection and evaluation of elite clones.

Yields of fan-rooted cuttings were shown to be better than those of fan buddings but the difference was insignificant. Because of the traditional familiarity with budding as a propagation method in the Malaysian plantations and its relatively lower cost and higher efficiency in propagation, budding was preferred to rooting of cuttings.

Different cocoa clones were also shown to vary in yield performance as chupon and fan buddings. However, the erratic and low production of chupon material posed a serious limitation on budding with chupon material. Hence, budding with fan material is considered as the currently most practicable vegetative propagation method for large-scale commercial plantings. In addition, rootstock influence on the yields of buddings was shown to be insignificant.

Five of the selected clones evaluated appeared to be promising in yields and pot/bean characteristics. However, because of defect in trial design the results were somewhat imprecise and should only be accepted as indicative. Further work with better trial design, new selection criteria and wider range of selection base have been initiated.

BAL Plantations Sdn Bhd (BAL) commenced its work on clonal cocoa after hybrid cocoa was introduced at BAL in the late 1960s'.

The first move was to obtain basic information regarding the choice of vegetative propagation method and the use of fan or chupon material for propagation. This was thought relevant because cocoa readily lent itself to vegetative propagation by both rooted cutting and budding. For both the methods, either fan or chupon material may be used, but they result in different tree forms and growth habits which require different approaches in crop husbandry.

Secondly, trials were initiated to clone high-yielding individual cocoa plants with reasonable pod and bean qualities for evaluation.

This paper describes the progress made on these two aspects of clonal cocoa work carried out by BAL.

MATERIALS AND METHODS

Propagation Method Trial (Trial A)

Trial A was set up in 1970 in which buddings of chupon and fan material, and rooted cuttings of fan material were compared with open-pollinated seedlings. Both the vegetative and seed materials were derived from four high-yielding trees selected from two hybrid cocoa progeny trials. Thus, the chupon buddings, fan buddings and fan-rooted cuttings would have identical genetic material while the seedlings would have genetic material very closely related to the clones.

The trial was laid down in randomised block design with six replicates. Plot size was 16 trees comprising four trees each of the four clones or progenies. All plants were produced in a polybag nursery, with seedlings and cuttings planted out in the field when 12-months-old, and the buddings three months after budding onto 14-months-old seedlings. Planting distance was 3 m x 3 m. Four different rootstocks were used for the budding treatments to allow observation on the influence of rootstock on yield.

Standard estate field practices were maintained uniformly for all treatments with regard to weeding, fertilizing, pest and disease control. Regular rounds of cocoa training and pruning for proper shape development were implemented for the clonal cocoa especially fan buddings. For the seedlings, a single stem with single jorquette was maintained. Uniform *Gliricidia* shade of 3 m x 3 m was initially planted, which was thinned to 6 m x 3 m about one year after field planting of cocoa, and further thinned to stand along the plot boundary, *i.e.* 12 m x 12 m at five-years-old.

Yields were recorded as pod number on individual tree basis beginning April 1973 until June 1981 when the trial was terminated.

Clonal Selection Trial (Trial B)

Trial B was set up in 1971 to evaluate 15 high-yielding cocoa clones selected from two hybrid cocoa progeny trials as fan and chupon buddings. Three common commercial hybrid seedlings were used as control. Two primary cocoa clones, UIT1 and Na32, were also included for general comparison.

Trial B was laid down in two randomised blocks with single-row plots of 30 trees consisting of 10 trees each of UIT1 x Na33, Aml x Pa7 and Aml x Pa35 as rootstocks. Half of each rootstock in a plot was budded with chupon material while the other half received fan material. Budding was done on 14-months-old seedlings planted at 3.96 m x 3.66 m.

Standard estate field practices, similar to those described for Trial A, were maintained uniformly for all the treatments in this trial. Uniform *Gliricidia* shade of 3.96 m x 1.83 m was initially planted, which was thinned to 3.96 m x 3.66 m in May 1972, and further thinned to 7.92 m x 3.66 m in September 1972. In October 1976, the *Gliricidia* shade was further thinned, leaving shade only along the boundaries of each rootstock, thus creating three rectangular boxes each of about 0.55 ha in size.

Yields were recorded as pod number on individual tree basis beginning February 1973 until August 1981.

Observation Trials on Budded Cocoa (Trials C & D)

Partly with the objective of establishing a large source of propagation material for the selected clones and partly to allow evaluation of them on small commercial scale, two commercial blocks of budded cocoa using chupon material were established.

Trial C, sited on older basaltic soil of the Table Series, was field-budded in mid 1974 using six-months old seedlings planted commercially at 3.66 m x 3.05 m. Plot sizes varied, according to the rootstocks, from 0.2 to 0.3 ha per plot. Thirteen clones were included, majority of which were tested in Trials A and B described earlier.

It must be mentioned that it took about a year to achieve a 90% stand of chupon budding, largely due to shortage of chupon budwood. Complete budding required another six months. A certain degree of variability was thus introduced as far as tree age was concerned and early yields must be regarded as atypical.

Trial D was located on younger basaltic soil of the Tiger Series. Ten-months old commercial seedlings planted at 3.66 m x 2.44 m were used for budding. Plot sizes were slightly larger, varying from 0.3 to 0.4 ha per plot. A total of 12 clones were entered.

Field budding commenced in early 1976 and had experienced similar delay in achieving a full stand of budding due to shortage of chupon budwood.

Both Trials C and D were maintained through standard estate field practices. Low jorquettings were common for chupon buddings and these low jorquettes were pollarded to induce new chupons which gave rise to higher jorquettes.

Yields were recorded as pod number on plot basis. Recording of wet to dry conversion rate and other bean qualities commenced only in 1983.

RESULTS

Trial A

Nursery establishment. Table 1 gives the success rates of nursery establishment by the four propagation methods. Seedlings topped the list, showing 99% rate of success compared with 84%, 79% and 75% for fan buddings, chupon buddings and fan-rooted cuttings respectively.

It should be noted that the smallscale of the trial made it rather easy to achieve reasonably satisfactory success rates for the three vegetative propagation methods. The success rates, therefore, should not be regarded as representative of what can be achieved in large scale commercial propagation.

Yields. Results showing the effect of the four propagation methods on yields are summarised in *Table 2* and illustrated in *Figure 1.*

Since the seedlings received less tree-form-pruning, they produced the highest yields in the first cropping year. This was followed by fan-rooted cuttings, chupon buddings and fan buddings. All the first three propagation methods, however, outyielded fan buddings significantly.

In the second and third cropping years, fan-rooted cuttings and chupon buddings yielded more than seedlings while fan buddings yielded fairly close to seedlings. During

TABLE 1. SUMMARY OF NURSERY DATA ON ESTABLISHMENT BY VARIOUS METHODS OF PROPAGATION

Methods of propagation			*Chupon buddings*			*Fan buddings*			*Fan-rooted cuttings*			*Open pollinated seedlings*		
Treatment	*Tree no.*	*Varieties*	*Total points budded*	*No. of failures*	*Success (%)*	*Total points budded*	*No. of failures*	*Success (%)*	*Total cuttings budded*	*No. of failures*	*Success (%)*	*Total points planted*	*No. of failures*	*Success (%)*
A	63A	UIT1 x Na32	24	2	91.7	24	1	95.8	40	9	77.5	24	0	100
B	817B	Am1 x Pa7	24	6	75.0	24	9	62.5	40	14	65.0	24	0	100
C	246A	Pa35 x Na32	24	4	83.3	24	3	87.5	40	6	85.0	24	0	100
D	151B	Am1 x UIT2	24	8	66.7	24	2	91.7	40	10	75.0	24	1	95.8
	Overall		96	20	79.2	96	15	84.4	160	39	75.6	96	1	99.0

All failures were replaced before the end of June 1972.
Casualties observed in the field were as follows:

63A – 1 Chupon budding
151B – 1 Chupon budding
63A – 1 Fan budding
246A – 1 Fan budding

TABLE 2. THE EFFECTS OF PROPAGATION METHODS ON THE YIELDS OF DRY BEANS[a] FOR THE CROPPING YEARS 1973/74 TO 1980/81

Propagation method	*Yield (kg dry bean/ha)*								*Mean annual yield 9/73–8/77*	*Mean annual yield 9/77–6/81*	*Mean annual yield 9/73–8/81*
	9/73–8/74	*9/74–8/75*	*9/75–8/76*	*9/76–8/77*	*9/77–8/78*	*9/78–8/79*	*9/79–8/80*	*9/80–6/81*			
Chupon buddings	1052*	1452	2544	3627	3031**	3303*	4185***	3611***	2169*	3532***	2850**
Fan buddings	643	1170	2262	2823	2274	2773	3193	2584	1725	2707	2215
Fan-rooted cuttings	1086*	1622*	2577	2763	2874*	3017	3538	3065	2012	3124	2568
Open-pollinated seedling	1278**	1258	2243	3444	2710	3263	3930**	3672***	2056	3394**	2725**
Mean	1015	1376	2407	3164	2722	3089	3712	3233	1990	3189	2590
S.E.	±172	±180	±295	±461	±213	±240	±233	±226	±206	±194	±171
LSD (P = 0.05)	366	383	628	983	453	512	496	482	439	413	365
LSD (P = 0.01)	506	530	868	1359	627	708	686	666	607	571	505
LSD (P = 0.001)	700	733	1200	1879	866	978	948	921	839	789	698
C.V. (%)	29.33	22.66	21.20	25.25	13.53	13.46	10.86	12.11	17.93	10.53	11.46

[a] Kg dry bean/ha based on a pod value of 20.99 pods to 1 kg dry bean, being average value for the four clones: 20.58 (63A), 23.15 (817B), 18.98 (246A) and 21.23 (151B) recorded in 1983.

* Significant at P = 0.05)
** Significant at P = 0.01) When compared with fan buddings.
*** Significant at P = 0.001)

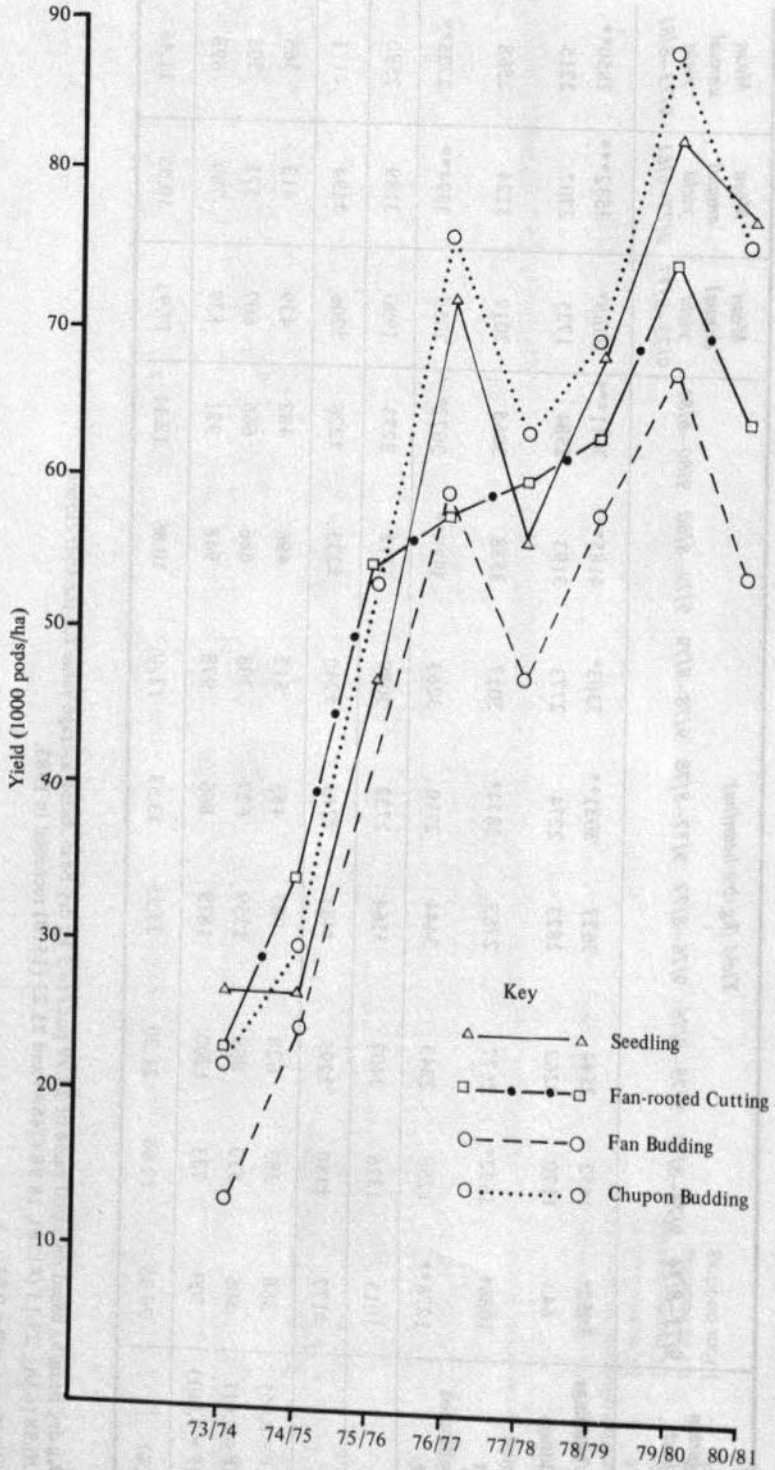


Figure 1. Effects of propagation methods on yields of total pods

the next two cropping years, there were yield fluctuations between the four treatments. From the sixth cropping year onwards, the trend was clear; chupon buddings gave the highest yield followed by seedlings, fan-rooted cuttings and fan buddings. Chupon buddings and seedlings outyielded fan buddings significantly during the last two cropping years.

Because of the small plot size, it was noted in later years that the larger size chupon buddings and seedlings competed with the smaller size fan-rooted cuttings' and fan buddings for light assimilation. Such interplot competition has introduced a certain degree of bias and reduced the accuracy of the trial. Hence, the yield results at the later stage should be viewed with reservation while the early yields should be considered more reliable.

Based on the early yields, *i.e.* the mean annual yield of the first four cropping years (*Table 2*), chupon buddings appeared to be highest yielding, followed by seedlings, fan-rooted cuttings and fan buddings. While chupon buddings showed an edge over seedlings and fan-rooted cuttings, the yield differences were not significant. Fan buddings showed a wider yield gap when compared with others and were significantly outyielded by chupon buddings – by as much as 26%.

Trials B, C and D

Yields. Unfortunately, Trial B sufferred even greater design defect than Trial A. With its single-row plots, interplot competition set in at the later stage of the trial resulting in the less vigorous clones being shaded out by the more vigorous ones. Serious bias was thus introduced rendering the yield data of the later cropping years doubtful. The marked changes in their yield ranks (*Table 3*) between the early yields (mean annual yields of 9/73–8/77) and the later yields (mean annual yields of 9/77–8/81) of some of the clones may lend support to this assumption. In view of this, only the early yields are of value for yield comparison.

Based on the early yields, five of the 17 clones tested yielded significantly more than the hybrid seedlings which comprised of UIT1 x Na33, Am1 x Pa7 and Am1 x Pa35. These are, in decreasing order: 82A (UIT1 x Na33), 369A (Pa7 x Na32), 481A (Pa35 x Na32), 102B (Am1 x Pa7) and 470A (UIT1 x Na32) (*Table 3*). They produced mean annual yields of 3,717, 2,743, 2,616, 2,611 and 2,596 kg dry beans per ha respectively for the first four cropping years compared with 1,964 kg dry beans per ha for the hybrid seedlings. In the fourth cropping year (9/76–8/77), which was the best yielding cropping year because of favourable weather, the highest yielding clone, 82A recorded 6,693 kg dry beans per ha against 3,876 kg dry beans per ha for the hybrid seedlings.

Trials C and D are unreplicated observation trials. The budding establishment took a long time to complete due to the scarcity of chupon budwood. This resulted in a great deal of variability in the successful buddings. It follows therefore, that the yield data generated from these two trials (*Tables 4 and 5*) would not be of much value as far as comparison between individual clones is concerned. However, they did give some indication of the yield potential of these selected clones when planted as polyclonal blocks under different planting densities and on different soil types. With a higher planting density and better soil, Trial D produced a mean yield of 3,417 kg dry bean per ha against 2,359 kg dry bean per ha in Trial C during their early cropping years.

Pod and bean characteristics. Based on the mean data of two recordings done in 1983, seven of the 20 clones showed interesting pod and bean characteristics. (*Table 6*).

TABLE 3. YIELD[a] PERFORMANCE OF SELECTED CLONES *VS* HYBRID SEEDLING

Treatment	Yield (Kg dry bean/ha)								Mean annual yield			
	9/73–8/74	9/74–8/75	9/75–8/76	9/76–8/77	9/77–8/78	9/78–8/79	9/79–8/80	9/80–8/81	9/73–8/77	Rank	9/77–8/81	Rank
82A (UIT1 x Na33)	2,783***	1,150	4,244***	6,693***	6,026***	5,808***	5,740***	4,336	3,717	1	5,468	1
369A (Pa7 x Na32)	1,955***	1,254	3,071*	4,692	4,784*	4,278	3,588	3,887	2,743*	2	3,646	3
481A (Pa35 x Na32)	1,702**	1,334	3,255*	4,175	3,795	3,485	3,427	3,289	2,616*	3	3,499	6
102B (Am1 x Pa7)	1,898***	725	2,979	4,842	4,347	4,106	3,933	3,864	2,611*	4	4,062	2
470A (UIT1 x Na32)	1,978***	1,449*	2,910	4,048	3,968	3,611	2,979	3,646	2,596*	5	3,551	5
63A (UIT1 x Na32)	1,599*	1,288	2,726	3,956	3,669	3,554	2,772	2,680	2,392	6	3,168	8
Hybrid Seedling[b]	702	1,012	2,266	3,876	3,531	3,381	2,979	3,393	1,964	7	3,321	7
Na32	1,495	– [c]	1,426	2,634	2,358	2,231	2,093	2,220	1,852	8	2,225	13
566A (UIT2 x Pa7)	1,495*	863	1,875	2,990	2,956	2,680	2,680	2,473	1,806	9	2,697	11
743A (Pa 7 x Na32)	955	449	1,898	3,899	3,634	3,807	3,565	3,490	1,800	10	3,625	4
1016B (Am1 x UIT2)	943	633	1,909	3,381	2,806	2,691	2,749	2,887	1,716	11	2,783	10
518B (Am1 x UIT2)	759	702	1,771	2,438	2,392	2,887	2,519	2,415	1,417	12	2,553	12
549B (Am1 x Pa7)	1,288	725	1,093	2,174	2,404	1,840	2,024	2,323	1,320	13	2,148	15
810B (Am1 x Pa7)	748	345	1,231	2,714	2,875	2,645	3,094	3,036	1,259	14	2,912	9
647B (Am1 x Pa7)	1,012	299	874	2,519	2,703	1,921	2,312	2,151	1,176	15	2,271	14
685B (Am1 x UIT2)	725	426	1,139	2,289	2,083	2,243	1,702	1,840	1,144	16	1,967	16
UIT1	771	– [c]	621	2,036	2,151	1,829	1,507	1,495	1,142	17	1,745	17
638B (Am1 x Pa7)	840	230	748	1,886	1,967	1,288	1,967	1,380	926	18	1,650	18
Mean	1,314	805	2,002	3,402	3,256	2,986	2,874	2,830	1,900		2,959	
S.E.	±287	±164	±359	±523	±470	±463	±558	±466	±288		±448	
L.S.D. P = 0.05	606	350	758	1,104	992	976	1,177	984	608		946	
P = 0.001	823	484	1,041	1,516	1,363	1,341	1,616	1,351	835		1,299	
P = 0.001	1,139	669	1,424	2,074	1,865	1,835	2,211	1,849	1,143		1,777	
C.V.(%)	21.87	20.40	17.95	15.37	14.45	15.50	19.41	16.48	15.17		15.15	

When compared with hybrid seedling:

* Significant at P = 0.05

** Significant at P = 0.01

*** Significant at P = 0.001

[a] Kg dry bean/ha figures were calculated from pod values given in *Table 6.*

[b] Hybrid seedling comprising equal proportions of UIT1 x Na33, Am1 x Pa7, and Am1 x Pa35.

[c] Flowers were removed from the UIT1 and Na32 trees for hand-pollination with Am1 for commercial seed production.

TABLE 4. YIELD[a] OF TRIAL C

Clones	Yield (kg dry bean/ha) 2/77–8/77	9/77–8/78	9/78–8/79	9/79–8/80	9/80–8/81	9/81–8/82	9/82–8/83	Mean annual yield[b] 9/78–8/83	%[c]	Rank
470A (UIT1 x Na32)	52	196	501	2,420	5,738	6,710	2,404	3,555	151	1
743A (Pa7 x Na32)	182	610	2,163	2,132	3,331	3,598	2,973	2,839	120	2
354A (UIT1 x Na33)	61	548	1,599	1,933	3,224	3,282	2,556	2,519	107	3
369A (Pa7 x Na32)	180	1,050	1,995	2,072	3,010	2,794	2,531	2,481	105	4
151B (Am1 x UIT2)	24	622	1,447	2,165	3,236	3,240	2,317	2,480	105	5
63A (UIT1 x Na32)	16	1,054	1,718	1,899	2,602	3,011	2,363	2,318	98	6
82A (UIT1 x Na33)	138	929	1,554	1,346	3,133	3,327	2,071	2,286	97	7
102B (Am1 x Pa7)	192	1,142	1,424	1,498	2,662	3,315	2,134	2,207	94	8
246A (Pa35 x Na32)	140	748	1,393	1,453	3,254	2,821	2,046	2,193	93	9
817B (Am1 x Pa7)	117	509	1,126	1,363	3,517	2,915	1,974	2,179	92	10
549B (Am1 x Pa7)	3	86	556	1,458	3,270	3,097	1,560	1,988	84	11
566A (UIT2 x Pa7)	49	618	1,357	1,552	2,560	2,296	1,316	1,816	77	12
481A (Pa35 x Na32)	15	317	1,246	957	2,671	2,623	1,544	1,808	77	13
Mean	90	648	1,391	1,711	3,247	3,310	2,138	2,359	100	

[a] Kg dry bean/ha figures were calculated from pod values given in *Table 6*.

[b] Yield of the first 18 months was not included because of vast differences, obviously due to delayed budding success of some of the clones.

[c] Percentage of mean yield of the 13 clones.

TABLE 5. YIELD[a] OF TRIAL D

Clone	Yield (kg dry bean/ha) 9/78–8/79	9/79–8/80	9/80–8/81	9/81–8/82	9/82–8/83	Mean annual yield[b] 9/79–8/83	%[c]	Rank
246A (Pa35 x Na32)	1,057	3,021	5,103	4,135	4,241	4,125	121	1
82A (UIT1 x Na33)	518	2,481	5,311	4,729	3,049	3,892	114	2
481A (Pa35 x Na32)	655	2,663	4,413	4,376	3,925	3,844	112	3
63A (UIT1 x Na32)	1,138	1,622	4,898	4,736	3,848	3,776	111	4
102B (Am1 x Pa7)	1,266	2,369	3,834	4,048	3,461	3,428	100	5
354A (UIT1 x Na33)	716	2,128	4,361	4,291	2,730	3,378	99	6
369A (Pa7 x Na32)	1,163	2,579	4,028	3,722	3,135	3,366	99	7
817B (Am1 x Pa7)	877	1,728	4,382	4,116	3,192	3,355	98	8
151B (Am1 x UIT2)	407	1,833	4,195	4,063	2,920	3,253	95	9
549B (Am1 x Pa7)	927	1,654	3,994	3,337	2,895	2,970	87	10
623B (Am1 x Pa7)	1,005	1,630	3,844	3,347	2,902	2,931	86	11
638B (Am1 x Pa7)	780	1,187	2,772	3,877	2,893	2,682	78	12
Mean	876	2,075	4,261	4,065	3,266	3,417	100	

[a] Kg dry bean/ha figures were calculated from pod values given in *Table 6.*

[b] Yield of the first year was not included because of vast differences obviously due to delayed budding success of some of the clones.

[c] Percentage of mean yield of the 12 clones.

TABLE 6. POD VALUE[a], BEAN SIZE, BEAN UNIFORMITY AND SHELL CONTENT OF 20 BAL P1 COCOA CLONES

Location of clone	*Clone no.*	*Parentage*	*Pod value (kg dry bean)*	*Bean Size*		*Bean Uniformity*		*Range of bean size (g)*	*Shell content (%)*
				Average bean weight (g)	*Bean count per 100 g*	*Bean below 1/3 of average bean weight (%)*	*Beans above 1/3 of average bean weight (%)*		
	Am1 x UA								
P5	102B	Am1 x Pa7	20.00	1.15	87	7.5	0.0	0.5–1.4	10.20
P5	549B	Am1 x Pa7	24.63	1.20	83	2.5	5.0	0.5–2.0	11.06
Q4	623B	Am1 x Pa7	22.90	0.98	102	10.5	2.0	0.5–1.8	10.32
CA28	638B	Am1 x Pa7	23.92	1.02	98	8.0	9.0	0.5–1.7	7.70
CA28	647B	Am1 x Pa7	26.15	1.04	96	5.5	1.0	0.5–1.5	9.80
CA28	810B	Am1 x Pa7	21.92	1.20	83	3.5	0.5	0.6–1.6	8.68
P5	817B	Am1 x Pa7	23.15	1.01	99	5.5	1.5	0.5–1.7	9.09
	Am1 x TRIN								
P5	151B	Am1 x UIT2	21.23	1.15	87	7.0	3.0	0.5–1.9	8.32
CA28	518B	Am1 x UIT2	23.93	1.29	78	4.5	0.5	0.7–1.8	9.21
CA28	685B	Am1 x UIT2	23.38	1.18	85	6.0	5.0	0.6–1.9	9.84
CA28	1016B	Am1 x UIT2	23.58	1.25	80	6.0	1.0	0.6–1.9	9.78
	UA x UA								
P5	369A	Pa7 x Na32	24.42	0.96	104	10.5	2.0	0.5–1.6	10.60
P5	743A	Pa7 x Na32	21.45	0.95	105	2.5	0.5	0.5–1.5	10.30
P5	246A	Pa35 x Na32	18.98	1.40	71	5.0	0.5	0.7–2.0	7.56
P5	481A	Pa35 x Na32	23.91	1.13	88	10.0	1.5	0.5–1.7	7.83
	TRIN x UA								
P5	63A	UIT1 x Na32	20.58	1.14	88	10.0	2.0	0.6–1.8	8.31
P5	470A	UIT1 x Na32	17.73	1.46	68	13.0	1.5	0.6–2.1	8.71
P5	82A	UIT1 x Na33	21.63	1.22	82	4.5	0.5	0.6–1.7	11.02
P5	354A	UIT1 x Na33	21.82	0.99	101	9.0	0.5	0.5–1.3	10.98
P5	566A	UIT2 x Pa7	29.47	1.01	99	3.5	0.0	0.5–1.3	8.82

[a] Data on pod value, bean size, bean uniformity and shell content are means of two samplings recorded in 1983.

Clones 470A and 246A showed very good pod values and large bean size. They recorded pod values of 17.73 and 18.93 and average bean size of 1.46 g and 1.40 g respectively. However, the beans of 246A are more uniform.

Five other clones with reasonably good pod values and average bean size are 102B, 810B, 151B, 63 and 82A. They have pod values ranging from 20.00 to 22.00 and bean size ranging from 1.14 g to 1.22 g. In addition, their beans are also very uniform.

In comparison, clone 566A recorded the largest pod value of 29.47 and clones 369A and 743A showed the smaller bean size of 0.96 g and 0.95 g respectively.

Influence of rootstocks on yields. No significant yield difference was detected for the four rootstocks *viz.* (Na32 x UIT1) x Sca12, Am1, (UIT1 x Na32) x Sca12, and (UIT1 x Na33) x Pa35 used for budding in Trial A (*Table 7*). This was true for both chupon and fan buddings during the early and later period of cropping years.

In Trial B where three rootstocks were tested *viz.* UIT1 x Na33, Am1 x Pa7, Am1 x Pa35, rootstock effect on yields was also found to be insignificant (*Table 8*).

DISCUSSION

Choice of Vegetative Propagation Methods

Two important factors which would strongly determine whether a vegetative propagation method could be popularly accepted by the plantation industry are the yields of the clonal plants produced and its practicability under the plantation conditions. Therefore, a good vegetative propagation method should be one which could maximise the yielding capacity of the selected clones. It should be cheap, requiring little initial capital expenditure, simple and fairly efficient in terms of success rate. The tree form and habit of the clonal plants produced are also important from field management point of view.

Propagation by rooting of cuttings is a more intricate operation than budding. It requires a higher level of manipulative skill which may not be readily available in the Malaysian plantations. Different cocoa clones may vary considerably in their rooting ability (Ramadasan, 1980) and the less responsive clones would therefore be more difficult to propagate.

Although Ramadasan (1980) estimated that in large-scale propagation, rooted cuttings could be produced as cheaply as fan buddings in the long term, considerable initial capital expenditure would still be required.

With respect to yields, while there are indications from the results of Trial A that fan-rooted cuttings can give better yield than fan buddings (chupon rooted cuttings were not tested in Trial A and thus could not be compared with chupon buddings), the yield differences is not significantly large to favour the former. It is doubtful that rooting of cuttings can gain acceptance in the Malaysian plantation industry.

On the other hand, budding has been extensively used in the Malaysian plantations for propagation of rubber and skilled labour is readily available. It is a much more simple and efficient operation. Cost of propagation is low and requiring little expensive initial capital expenditure. In terms of practicability under the plantation conditions, budding is no doubt preferred to rooting of cuttings.

TABLE 7. EFFECTS OF ROOTSTOCK ON YIELD IN TRIAL A

Rootstock	*Mean Annual Yield (pods/ha)*					
	Chupon Buddings			*Fan Buddings*		
	9/73–8/77	*9/77–6/81*	*9/73–6/81*	*9/73–8/77*	*9/77–6/81*	*9/73–6/81*
(Na32 x UIT1) x Sca12	45,242	74,867	60,061	35,138	58,414	48,779
Amelonado	47,271	74,832	61,052	36,933	55,971	46,453
(UIT1 x Na32) x Sca12	45,625	72,453	59,033	37,156	51,779	44,467
(UIT1 x Na33) x Pa35	43,951	74,436	59,198	35,555	61,017	48,286
Mean	45,522	74,147	59,836	36,196	56,795	46,496
S.E.	±4,725	±8,880	±5,697	±3,216	±4,828	±3,498
L.S.D. (P = 0.05)	10,069	18,923	12,139	6,854	10,287	7,454
(P = 0.01)	13,926	26,169	16,789	9,477	14,227	10,309
(P = 0.001)	19,245	36,169	23,204	13,097	19,663	14,248
Coefficient of Variation (%)	17.98	20.74	16.49	15.39	14.72	13.04

TABLE 8. EFFECTS OF ROOTSTOCK ON YIELD IN TRIAL B

Rootstock	*Mean Annual Yield (pods/ha)*					
	Chupon Buddings			*Fan Buddings*		
	9/73/8/77	*9/77–8/81*	*9/73–8/81*	*9/73–7/88*	*9/77–8/81*	*9/73–8/81*
UIT1 x Na33	46,083	72,947	59,514	44,588	66,804	55,696
Am1 x Pa7	41,032	79,079	60,055	43,111	68,488	55,800
Am1 x Pa35	43,249	71,852	57,549	46,511	61,522	54,016
Mean	43,455	74,626	59,039	44,737	65,604	55,171
S.E.	±3,495	±6,154	±4,281	±3,659	±1,404	±2,532
L.S.D. (P = 0.05)	15,039	26,480	18,421	15,750	6,044	10,892
(P = 0.01)	34,688	61,077	42,488	36,322	13,929	25,123
(P = 0.001)	110,435	194,450	135,269	115,635	44,362	79,984
C.V.	8.04	8.25	7.25	8.18	2.14	4.59

The results of Trial A showed that of the four clones tested, *viz.* 63A (UIT1 x Na32), 817B (Am1 x Pa7), 246A (Pa35 x Na32), 151B (Am1 x UIT2), chupon buddings could yield significantly higher than fan buddings. On the other hand, the data in Trial B when analysed separately for the effects of chupon and fan buddings gave a different results. Clones 470A (UIT1 x Na32), 481A (Pa35 x Na32), 638B (Am1 x Pa7) have yielded more as fan buddings (*Table 9*).

TABLE 9. COMPARISON OF THE EARLY YIELDS OF SOME CLONES IN TRIAL B AS CHUPON AND FAN BUDDINGS

Clones	*Yield (pods/ha)*			
	1973/74	*1974/75*	*1975/76*	*1976/77*
Clones yielded higher as chupon buddings				
Chupon buddings				
82A	64,187	28,519	99,932	153,727
63A	37,901	33,234	69,274	95,838
810B	22,538	10,902	39,697	73,483
Fan buddings				
82A	56,000	21,642	83,349	135,995
63A	28,218	19,779	42,723	66,859
810B	10,487	3,795	14,030	45,792
Clones yielded higher as fan buddings				
Chupon buddings				
470A	22,193	18,376	41,008	58,924
481A	27,850	26,725	70,194	92,273
638B	15,823	3,795	14,191	42,549
Fan buddings				
470A	48,250	32,958	62,443	84,890
481A	53,585	37,029	85,442	107,614
638B	24,263	7,544	21,297	47,563
Mean (for whole trial)	30,670	18,110	46,203	78,136
S.E.	±9,052	±4,339	±9,326	±12,690
L.S.D. (P = 0.05)	18,485	8,860	19,044	25,913
(P = 0.01)	24,894	11,933	25,647	34,898
(P = 0.001)	33,005	15,820	34,004	46,268
C.V. (%)	29.52	23.95	20.19	16.24

Data for six clones are presented, but the statistical analysis was based on data for the whole trial.

Propagation by chupon buddings has its limitation in that natural production of chupon material is not only low but also very erratic. This makes large-scale commercial plantings by chupon buddings impracticable. Until such time the technique of chupon induction is successfully developed which could increase the production of chupon material, or alternatively, clonal chupon plants can be produced commercially at reason-

able cost by means of tissue culture, commercial clonal cocoa plantings will most likely be established by fan buddings.

Rootstock influence on yields was shown to be insignificant in both Trials A and B. However, in view of the limitated range of rootstocks being evaluated, further investigation into this aspects is necessary.

Clonal Selection of Cocoa

It should be mentioned that the clonal selection and observation trials reported in this paper are BAL's early investigation on the potential of clonal cocoa. Selection was based on a limited number of trees from a narrow range of hybrids and the trials lacked precision as described earlier. However, the shortcomings have now been rectified.

Selection criteria and priorities have also been reviewed. Further trials are now at hand to verify some of the more promising clones indicated in Trial B. New selection work has also been initiated to cover a wider range of prospective elite clones and to evaluate them under a wider range of environments. New cocoa germplasm have also been imported for producing new hybrids which will further enlarge the clonal selection base.

It is hoped that our current work on clonal selection of cocoa could mature sometime in the future and contribute towards cocoa improvement for the progress and advances of the cocoa industry.

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Evaluation of Clonal Materials in Mardi Hilir Perak and Mardi Jerangau

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The earliest clonal trials established in 1972 established in 1972 were the clonal trials at Site B and Site C, at MARDI Jerangau. Five clones have been released as new varieties from the two trials. These clones were 1C, 9C, 46B, 49B and 53B and are named as Klon Koko MARDI (KKM) 1, 2, 5, 6 and 7 respectively.

Two clonal trials at MARDI Hilir Perak were established in 1978. Materials used for the trials were selected from progeny trials at MARDI Jerangau, from the Brazilian and Costa Rican progeny trials, Kuala Bernam Estate selections and Felda Sungai Tekam selection. Results indicate that selections from within the progeny trials at MARDI Jerangau were more promising than those selected at Hilir Perak or Kuala Bernam Estate and Felda Sungai Tekam. From within these two clonal trials, a few clones are potentially promising and are recommended for planting in certain parts of the country.

Majority of the clones selected from the Brazilian and Costa Rican populations are good pod producers but the bean size is below 0.90 g/bean. Jerangau selections are more tolerant to vascular streak dieback disease. Promising clones from within the four clonal trials are being transferred to other areas for further clonal trials.

Clonal planting of cocoa is gaining increasing popularity among smallholders and in the private sector planting industry. Among the major methods of vegetative propagation, budgrafting has been the easiest method of cloning cocoa. Theoretically, clonal materials are uniform in growth, precocity and production. Most of the heritable traits are retained by the individual clonal plant and variability within individuals is due to environmental factors, cultural practices and edaphic factors. Hence, yield per unit area can be roughly predicted based on the average performance of the mother plant.

The first clonal trials established by the Department of Agriculture at Jerangau Station have been reported by Arasu and Phang (1972). These materials were originally from progeny trials at Jerangau Station and F_0 collections by the Department of Agriculture (DOA) at Serdang. From within nine hybrids type in a series of six progeny trials which were established in 1955 to 1957 and on the basis of their fresh bean weight, compatibility, bean size (more than 1.00 g), percentage shell (less than 14%) and their high yield, individual trees were selected and transferred to the clonal trials (Haddon, 1961). Two advanced clonal trials were established in 1972 (Site B and Site C). These trials were almost neglected for seven years. This is so due to the change of administration from the Department of Agriculture to MARDI in early 1972 which caused a lapse period. As a result, the mortality rate among the budded plant was enumerably high. Dual work involving efforts to rehabilitate and restore the trials and the transfer of materials from Jerangau to MARDI Hilir Perak were in progress in 1978.

It was only in 1979 that the Cocoa Breeding Unit of MARDI Hilir Perak salvaged the two trials, and yield recording commenced in April 1979. These trials are being well maintained and within the trials, five outstanding clones were identified and released as new varieties.

MARDI Hilir Perak established its first clonal trials in 1978 (Clonal Trial 4 and Clonal Trial 5). The materials used in these two trials were selected from within the Brazilian and Costa Rican progeny trials, Felda Sungai Tekam selections, Kuala Bernam selections and transfer materials from MARDI Jerangau.

This paper reports the performance of these trials (two at Jerangau and two at MARDI Hilir Perak). Due to time constraint, only clones with complete data (pod analysis) and with mean dry bean weight of 0.90 to more than 1.00 g are reported here.

MATERIALS AND METHODS

Jerangau Clonal Trials

Clonal Trial Site B. Amelonado rootstocks were used in this experiment and was planted in January 1972 on an area of 0.38 ha. The soil type is of the Jerangau series which are fine sandy clay to clay, friable, deep with an occasional thin band of laterite occurring at depths below 1 m. Drainage is somewhat excessive and permeability is also good.

Rainfall is not evenly distributed with most of it falling of the end of the year and the annual average is 4,000 mm.

The materials used for this trial were those selections from progeny trials C 36, C 37, C 38 and C 45 (*Appendix 5*). There are 53 clones but were planted without any replication in a completely randomized block design with five plants per clone per plot. The planting distance of cocoa was 3.1 m x 3.1 m (square) and the shade tree used was *Gliricidia maculata* (monoculture system).

The first yield data were collected in April 1979, seven years after its establishment. Pod counting was on the individual tree on a monthly basis (four intervals). Clones with less than three plants per plot with small bean size were dropped from the potential list; however they are still being well maintained. Pod analysis was based on a five-sample pods from an individual tree. No data are available as to their precocity and their early pod production. Most of the tree were from chupon budwood and they show the pseudo-characteristics of seedling plantings.

Clonal trial Site C. The trial is on a 0.71 ha area. Budded Amelonado rootstocks were also planted in January 1972. The soil was similar to that of the preceding trial.

The experimental design is of randomized complete block with four replications consisting of five plants per plot. There were two treatments per replication and the clones for this trial were selected from progeny trials C 36, C 37, C 38, C 41 and C 45 (*Appendix 5*). The planting distance was 3.1 m x 3.1 m square planting in a monoculture system with *Gliricidia maculata* as the main shade tree.

Yield recordings were carried out on per-plant basis taken on monthly rounds. Pod analysis was on five pods sample per tree taken during the peak season.

Clonal Trials at Hilir Perak

Clonal Trial 4. Amelonado rootstock were field-planted in July 1978 and field-budding was carried out in November to December 1978. It is under Malayan Talls coconut

planted in a 9.1 m x 9.1 m x 9.1 m triangular and is about 40–50 years old. The soil type is that of the Selangor/Kangkong series.

The clones used were mainly selected from Jerangau Progeny trials C 36, C 37, C 38, C 41 C 45 and C 47 and also from Hilir Perak Brazilian and Costa Rican progeny trials. Four control clones *i.e.* UIT 1, Pa 7, Na 33 and ICS 95, were used in the trial. The trial consisted of a total of 64 clones and the parentage is summarized in *Appendix 5.*

The experimental design was that of randomized complete block with tree replications, 64 clones per replicate and plots of 10 plants each. The planting distance of cocoa was 2.1 m x 3.1 m.

Data collected are the pod yield and pod analysis. Pod yield is collected on the number of mature pods on a four-week intervals. Pod yield is on individuals tree basis and pod analysis is on a five-sample pods taken randomly from each plot. Due to the large number of clones (64 clones x 4 plots per clone), pod analysis have not been completed.

Clonal Trial 5. ICS 60 x Na 33 rootstocks were field-planted in September 1978 and field budding was carried out in November 1978. It is also planted under mature Malayan Talls 9.1 m x 9.1 m x 9.1 m triangular. This experiment is a duplicate of the FELDA Sungai Tekam clonal trial.

The clones used were selections from Jerangau, Kuala Bernam Estate, Costa Rica Progeny Row, Brazilian Progeny Trial and FELDA. There are 49 clones altogether (*Appendix 5*).

A randomized block design with three replicates and plots of 10 plant each were planted at 2.4 m x 3.3 m triangular. Normal cultural practices were adopted in the management of the trials.

Data collection consisted of monitoring mature pods per tree on a monthly rounds. Initial pod analysis was done on three pods per clone and currently still in progress.

RESULTS AND DISCUSSIONS

Clonal Trial Site B

Potential clones selected are summarized in *Table 1.* Out of 53 clones, only 18 clones were selected for further evaluation. The average bean size was 1.04 g/bean, with an average of 39.02 beans/pod and a mean pod number of 43.8 pods per tree. An average of 1.95 tonne per hectare of dry bean yield could be obtained from these potential clones when planted in a monoculture system. Some of these potential clones were transferred to other parts of the country to facilitate location verification trials on farmers areas.

Three outstanding clones were selected on the basis of their vigour, bean size, average pod yield of more than 50 pods per tree per year, fat content, dry bean yield of more than 2.0 tonne per hectare planted in a monoculture system, and their resistance to vascular streak dieback (VSD) disease. They were clone 46 B, 49 B, and 53 B and were released as new varieties in 1983 and known as KKM 5, KKM 6, and KKM 7 respectively. The performance of the above clones under the verification trial is given in *Table 2.*

TABLE 1. CLONAL TRIAL SITE B, MARDI JERANGAU, MEAN DRY BEAN WEIGHT; AVERAGE NUMBER OF BEANS/POD, AND AVERAGE YIELD/HA/YEAR

Clone	*Mean dry bean wt (g)*	*Average no. of pod/tree/year (4-year average)*	*Average no. of bean/pod*	*Average yield (kg/ha/year) (1111 trees/ha)*
1 (A) B	1.30	30.65	38.2	1,691.02
41 B	1.17	25.02	45.3	1,473.28
46 B	1.12	52.07	41.8	2,708.29
7 B	1.11	41.27	38.4	1,954.35
28 B	1.10	48.45	41.4	2,451.32
47 B	1.08	39.20	39.1	1,839.08
18 B	1.07	41.37	42.0	2,065.53
43 B	1.06	48.32	39.9	2,270.49
8 B	1.05	41.80	38.0	1,852.94
6 B	1.02	23.77	35.5	956.25
28 B	1.01	48.45	41.4	2,250.76
49 B	0.99	62.18	36.1	2,468.92
21 (B) B	0.99	38.60	36.7	1,558.12
10 B	0.94	50.84	38.4	2,038.81
53 B	0.94	93.50	38.0	3,710.54
36 B	0.93	25.17	42.2	1,097.47
22 (B) B	0.93	59.42	36.4	2,234.76
52 B	0.91	47.40	37.6	1,801.86
9 B	0.90	33.20	35.3	1,175.37
$\bar{x}$	1.04	43.80	39.20	1,951.68
Δ	0.10	16.01	2.68	642.93

TABLE 2. CLONAL TRIAL SITE C, MARDI JERANGAU. MEAN DRY BEAN WEIGHT, AVERAGE POD/TREE/YEAR, AVERAGE NUMBER OF BEANS/POD, AND AVERAGE YIELD/HA/YEAR

Clone	*Mean dry bean wt (g)*	*Average Pod/tree/year*	*Average No. of bean/pod*	*Average yield (kg/ha/year) (827 trees/ha)*
14 C	1.28	60.73	25.0	2,159.07
1 C	1.19	40.79	42.2	2,275.76
9 C	1.12	53.29	31.8	2,108.65
15 C	1.10	33.25	39.2	1,592.89
3 C	1.07	37.74	36.2	1,624.08
10 C	1.03	24.56	34.1	958.37
11 C	1.00	32.58	44.1	1,592.64
6 C	0.98	38.61	36.7	1,542.79
21 C	0.98	38.12	39.4	1,635.27
4 C	0.97	33.48	39.0	1,407.14
23 C	0.97	25.72	36.7	1,017.24
5 C	0.96	35.13	37.1	1,390.07
8 C	0.95	18.87	37.1	738.89
13 C	0.94	27.10	42.6	1,205.65
12 C	0.93	43.18	43.2	1,927.36
22 C	0.93	49.86	38.8	1,998.85
7 C	0.90	36.33	38.8	1,409.46
$\bar{x}$	1.02	37.02	37.76	1,563.78
Δ	0.10	10.63	4.60	436.10

The overall performance (on the basis of 18 clones) of the clones in this trial is given in *Appendix 1.* The average bean size is 0.92 g with an average dry bean yield of 1.49 kg/tree/year.

Clonal Trial Site C.

Seventeen potential clones were selected from this trial (*Table 2*). The average dry bean yield was 1.56 tonnes/hectare/year with an average bean size of 1.02 g. Overall performance of the clones in this trial is presented in *Appendix 2.*

Two outstanding clones selected on the criteria described in Clonal Trial B were selected and released as new varieties. They are clone 1C and 9C and known as KKM 1 and KKM 2. Their performance in the verification trial is given in *Table 3.*

General to Sites B and C

The results obtained from Site B and Site C were based on limited number of plants and as such the statistical analysis are not presented here. The variability was too great and the sample size was too small. However, these selected potential clones were transferred to smallholders commencing in 1982. Five of the selected clones were released as new varieties (KKM 1, KKM 2, KKM 5, KKM 6, and KKM 7). Detailed information on these varieties are reported in the booklet 'Klon-klon Koko MARDI, Generasi Pertama' (Anon, 1983). Early performance of these varieties is given in *Table 3.*

Clonal Trial 4

Table 4 summarizes the potential clones that were selected on the basis of their mean dry bean weight. Greater emphasis was directed towards the selection of beans of more than 1.0 g so as to conform to the International Standard requirement. However, clones with an average weight of 0.9 g per bean were also included in the selection. From the 64 clones tested twenty were identified as potential clones, and of which some were transferred to other areas for further evaluation. A few of them were identified as potential clones in specific regions in the country; selection for potential clones were made only from one-third of the total pool of clones tested. This was inevitable in view of the fact that some of the plots in Replication 1 were damaged by fire. Plots with less than five plants were not considered in the trial.

The average bean weight for the best 20 clones was 1.02 per bean with an average of 42.7 beans per pod and 31.08 pods/tree/year. Subsequently, dry bean yield was about 1.2 tonne per hectare per year when planted as intercrop under coconut (*Appendix 3*).

Most of the potential clones were materials transferred from MARDI Jerangau, a few from the Brazilian and Costa Rican trials. The selection for materials from within the Brazilian and Costa Rican population was limited to the early yielding capacity of the mother plant in which bean size was not taken into consideration, hence the limited number of clones selected from this trial. Generally, individual plant from the above selections could produce about 1.4 kg of dry bean per year.

Clonal Trial 5

Pertinent yield components of the potential clones from this trial are presented in *Table 5.* Twenty-two clones were selected. The average bean size is 1.02 g with an average

TABLE 3. EARLY PERFORMANCE OF THE KKM 1, KKM 2, KKM 5, KKM 6 AND KKM 7 CLONES AT BATU LAUT, KUALA LANGAT, SELANGOR (CLONAL VERIFICATION TRIAL).

Clone	*Total pods/tree/year*		*Average pods/tree/ year*	*Average number of beans/pod*	*Mean dry bean weight (g/bean)*	*Mean dry yield (kg/ha/year) (717 plants intercropped)*	*Estimated dry yield kg/ha/year (monoculture planting) (1220 plant)*
	Jan–Dec 1983	*Jan–June 1984*					
KKM 1 (I C)	230	275	23.2	52.3	1.18	1,026.6	1,746.8
KKM 2 (9 C)	228	320	22.9	31.8	1.19	621.3	1,081.6
KKM 5 (46 B)	28	71	18.7	41.8	1.03	577.3	982.1
KKM 6 (49 B)	132	278	20.5	38.8	1.10	627.3	1,067.4
KKM 7 (53 B9)	363	588	48.6	36.1	0.93	1,169.9	1,990.6

From: Percubaan penilaian Verifikasi setempat tanaman klon-klon koko terpilih di kawasan petani – satu kajian awal. Abdul Halim Abdul Hamid, 1984. (in press).
Planting distant: 3.1 m x 3.1 m x 3.1 m (triangular); Mean Annual rainfall: 202 mm; Mean temperature: 28.0°C

TABLE 4. CLONAL TRIAL 4, AT MARDI HILIR PERAK. MEAN DRY BEAN WEIGHT, AVERAGE NUMBER OF PODS/TREE/YEAR, AVERAGE NO. OF BEANS/POD, AND THE AVERAGE YIELD/HA/YEAR

Clone (MHP)	*Mean dry bean wt (g)*	*Average no. of pod/tree/year*	*Average no. of bean/pod*	*Average yield (kg/ha/year) (827 trees/ha)*
414	1.48	28.00	33.5	1,148.07
266	1.37	22.43	38.0	965.69
262	1.34	16.05	41.0	729.23
254	1.24	42.46	41.0	1,785.22
21	1.19	36.92	52.5	1,907.54
261	1.16	33.10	39.0	1,238.39
288	1.13	28.23	36.0	949.72
119	1.09	12.22	39.0	429.60
259	1.08	20.84	42.0	781.77
136	1.07	66.64	46.0	2,712.58
264	1.05	13.77	49.0	585.90
265	1.05	29.28	47.0	1,194.98
258	1.04	33.29	40.0	1,145.28
418	1.02	30.69	45.5	1,177.92
362	1.02	50.25	41.0	1,737.90
251	1.01	32.40	44.5	1,204.29
156	0.95	29.38	48.0	1,107.96
248	0.94	46.12	54.0	1,936.05
253	0.91	20.43	40.27	617.61
411	0.90	29.04	37.0	799.74
x	1.02	31.08	42.68	1,207.77
	0.16	13.05	5.41	560.13

TABLE 5. CLONAL TRIAL 5 AT MARDI HILIR PERAK. MEAN DRY BEAN WEIGHT, AVERAGE PODS/TREE/YEAR, AVERAGE NUMBER OF BEANS/POD/PERCENT DRY SHELL, AND AVERAGE YIELD/HA/YEAR

Clone (MHP)	*Mean dry bean wt (g)*	*Average pod/tree/ year*	*Average no. of bean/pod*	*Dry shell (%)*	*Average yield (kg/ha/year) (827 trees/ha)*
79	1.31	24.12	38.0	11.29	992.97
55	1.21	9.04	25.0	12.36	226.15
83	1.16	21.38	25.8	14.71	529.16
70	1.15	13.86	46.0	10.30	606.35
81	1.11	4.47	36.0	7.84	147.72
80	1.10	22.16	35.0	10.67	705.56
52	1.08	25.38	30.0	8.26	680.05
78	1.01	18.46	35.0	10.51	539.67
76	1.00	20.50	33.0	10.49	559.47
77	1.00	17.81	31.0	10.46	456.59
223	1.00	13.92	37.0	10.59	425.94
222	0.98	38.26	33.0	9.80	1023.27
219	0.96	30.23	34.0	10.27	816.01
216	0.95	15.88	39.0	8.96	486.57
74	0.95	31.70	36.0	9.70	896.58
54	0.93	43.50	35.0	11.06	1170.97
68	0.93	28.27	53.0	10.96	1152.37
221	0.93	27.93	42.0	11.45	902.22
217	0.93	14.40	40.0	9.59	443.01
84	0.91	23.81	39.0	9.79	698.83
60	0.91	20.64	43.0	10.75	667.92
218	0.90	34.38	41.0	9.24	1049.15
Mean	1.02	22.00	36.67	10.41	689.80
	0.11	9.41	6.32	1.41	283.69

estimated dry bean yield of 689 kg/ha/year. The overall performance of these clones is shown in *Appendix 4*.

Most of the potential clones were those selections transferred from MARDI Jerangau. Clones from within the progeny trials at Hilir Perak are mostly good pod producer but their bean size is below the required criterion.

General to Trials 4 and 5

On the basis of bean size and pod production per tree per year, some of these clones are being tested on smallholdings. Early results on its performance are very promising. Some of these clones have been currently recommended for wide-scale planting by four states in Malaysia (Anon, 1983). A detailed description and their performance will be reported soon.

CONCLUSIONS

This paper presents the results of the earliest clonal trials by MARDI. The choice of materials was limited to selected plants from Jerangau, early pod results from the Brazilian and Costa Rican progeny trials, and selected clones from Kuala Bernam Estates and Felda Sungai Tekam. All the trials either did not have sufficient number of plants per plot or they were without any replication. The main contributory factor to this situation was the limited supply of budwood available for budding as each clone was from one mother plant (Brazilian and Costa Rican). Further more, Site B and Site C were budded from chupon budwood and a substantial stand was knocked out during the neglected years. Apart from the limited availability of budwood for budding, the budders in the past were not as experienced and skilful as they are at present.

From the four clonal trials, MARDI released five clones as new varieties and sixteen clones as potentially promising and further recommended specific clones for the states of Perak, Selangor, Johore and Pahang. A further evaluation of these clones is being carried out in different parts of the country with the collaboration of the private sectors, semi-government bodies, state governments and individual entrepreneurs. These trials are laid down to assess the adaptability of various clones to specific environments in the country.

An interesting feature of clones selected from MARDI Jerangau is that they are quite tolerant to VSD as compared to clones selected from Brazilian and Costa Rican populations. This selection criteria for diseases-tolerant materials may in fact be attributed to high disease inoculum potential prevalent in Jerangau as compared to in Hilir Perak.

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APPENDIX 1. CLONE, PARENTAGE, YEARLY TOTAL PODS, AVERAGE PODS/TREE/YEAR, MEAN DRY BEAN WEIGHT, NUMBER OF BEANS/POD, AND DRY BEAN YIELD.

Site B. MARDI Jerangau.

Clone	Parentage	Total pods/year 1980	1981	1982	1983	Cumulative Total Pods	Average pods/ tree/year	Mean Dry bean wt. (g/bean)	No. of beans/ pod	dry bean yield (kg/ tree/year)
1 (A)	TMS 15/43 269 x Amel 698	153	46	147	145	491	30.65	1.30	38.2	1.522
41	UAWA 32 x T. TD. A 925	85	89	123	104	401	25.02	1.17	45.3	1.326
46	UAWA 18 x T. INB. 15/4 352	164	152	209	309	834	52.07	1.12	41.8	2.437
7	T. INA 594 x UAWA 31	187	17	177	280	661	41.27	1.11	38.4	1.759
28	UAWA 12 x UAWA 20	141	140	320	369	970	48.45	1.10	41.4	2.206
47	UAWA 13 x T. TD 990	132	133	91	115	471	39.20	1.08	39.1	1.655
18	UAWA 20 x T. IN. D 466	329	152	160	187	828	41.37	1.07	42.0	1.859
43	UAWA 32 x T. TD. A 925	97	117	183	183	580	48.32	1.06	39.9	2.043
8	CMS 1124 x UAWA 31	117	88	131	166	502	41.80	1.05	38.0	1.667
6	T. INA 594 x UAWA 31	115	10	78	83	286	23.77	1.02	35.5	0.860
28	UAWA 12 x UAWA 20	141	140	320	369	970	48.45	1.01	41.4	2.025
21 (B)	UAWA 20 x T. IN. E 269	225	140	164	244	773	38.60	0.99	36.7	1.402
10	CMS 1124 x UAWA 31	199	57	276	359	891	50.80	0.94	38.4	1.833
53	CMS 1124 x UAWA 31	345	209	282	287	1123	93.50	0.94	38.0	3.339
36	UAWA 30 x UAWA 13	122	67	111	103	403	25.17	0.93	42.2	0.987
22 (B)	UAWA 20 x T. IN. E 269	242	115	146	211	714	59.42	0.93	36.4	2.011
52	CMS 1124 x UAWA 31	236	181	202	330	949	47.40	0.91	37.6	1.621
9	CMS 1124 x UAWA 31	187	94	203	181	665	33.20	0.90	35.3	1.054
5	T. MS 15/43 385 x UAWA 31	65	41	128	185	419	20.95	0.89	37.0	0.689
32	UAWA 10 x UAWA 8	98	44	40	71	253	15.75	0.89	43.2	0.605
33	UAWA 13 x T. MS 15/43 305	220	108	309	226	863	43.10	0.86	46.7	1.730
13	UAWA 18 x AMEL 704	149	88	161	223	621	51.72	0.86	43.0	1.912
23 (A)	UAWA 13 x UAWA 10	161	151	150	173	635	31.75	0.85	43.1	1.163
27	UAWA 12 x UAWA 20	118	88	190	173	569	35.55	0.84	43.5	1.298
38	UAWA 8 x UAWA 31	136	67	172	175	550	34.32	0.83	46.5	1.324
3	T. MS 15/43 385 x UAWA 31	87	38	95	96	316	19.72	0.83	42.2	0.690
39	UAWA 8 x UAWA 31	226	119	181	220	746	46.30	0.82	42.2	2.472
22 (A)	UAWA 18 x UAWA 31	222	192	384	374	1172	73.25	0.80	42.2	2.472
42	UAWA 32 x T. TD. A 925	228	177	202	244	851	42.50	0.80	39.9	1.356
34	UAWA 30 x UAWA 13	123	82	56	52	313	17.38	0.78	41.1	0.557
35	UAWA 30 x UAWA 13	213	73	258	187	831	41.00	0.74	37.0	1.122
31	UAWA 13 x UAWA 20	143	97	143	160	543	33.90	0.73	44.6	1.103
20	UAWA 20 x T. IN. D 466	34	61	90	114	299	18.65	0.72	43.2	0.580
18	UAWA 20 x T. IN. D 466	329	152	160	187	828	41.37	0.71	41.9	1.230
2	UAWA 33 x UAWA 9	133	182	184	265	764	47.68	0.68	35.6	1.154
	Total	5902	3807	6226	7150	23085	–	–	–	–
	Average x	168.6	108.7	177.8	204.2	659.5	40.09	0.92	40.56	1.492
	S.D.	73.3	52.7	79.1	89.1	244.3	15.78	0.14	3.18	0.609

APPENDIX 2. CLONE, PARENTAGE, YEARLY TOTAL PODS, AVERAGE PODS/TREE/YEAR, MEAN DRY BEAN WEIGHT, NUMBER OF BEANS/POD, AND DRY BEAN YIELD.

Site C, MARDI Jerangau.

Clone	Parentage	Total pods/year 1980	1981	1982	1983	Cumulative Total Pods	Average pods/ tree/year	Mean dry bean wt. (g/bean)	No. of beans/ pod	Dry bean yield (kg/ tree/year)
14	T. IND 466 x T. MKD 793	875	923	1472	1588	4858	60.73	1.28	25.0	1.943
1	T. INB 173 x UAWA 18	407	199	325	421	1352	40.79	1.19	42.2	2.048
9	CMS 1124 x UAWA 31	683	603	853	1059	3198	53.29	1.12	31.8	1.897
15	UAWA 13 x T. INA 306	357	239	390	352	1331	33.25	1.10	39.2	1.433
3	T. INA 594 x UAWA 31	310	298	491	453	1552	37.74	1.07	36.2	1.461
10	CMS 1124 x UAWA 31	394	270	430	469	1563	24.56	1.03	34.1	0.862
11	T. INA 306 x T. IND 466	448	347	432	432	1564	32.58	1.00	44.1	1.436
6	CMS 1124 x UAWA 31	419	408	631	550	2008	38.61	0.98	36.7	1.388
21	UAWA 32 x T. T. DA 925	472	430	594	639	2134	38.12	0.98	39.0	1.266
4	T. INA 594 x UAWA 31	639	400	544	561	2144	33.48	0.97	39.0	1.266
23	UAWA 13 x CMK. KC 75	94	140	186	198	618	25.72	0.97	36.7	0.915
5	CMS 1124 x UAWA 31	283	127	229	205	844	35.13	0.96	37.1	1.251
8	CMS 1124 x UAWA 31	327	233	355	232	1147	18.87	0.95	37.1	0.665
13	UAWA 18 x AMEL 704	187	129	232	246	790	27.10	0.94	42.6	1.085
12	UAWA 18 x AMEL 704	532	408	673	748	2361	43.18	0.93	43.2	1.734
22	UAWA 18 x TMS 15/43	479	245	491	580	1795	49.86	0.93	38.8	1.799
7	CMS 1124 x UAWA 31	400	257	347	305	1309	36.33	0.90	38.8	1.268
18	UAWA 18 x UAWA 13	561	489	530	491	2071	31.88	0.88	35.4	0.993
19	UAWA 13 x UAWA 20	476	287	394	552	1709	44.66	0.79	42.1	1.485
20	UAWA 30 x UAWA 13	541	401	512	507	1961	28.82	0.78	41.9	0.941
17	UAWA 20 x UAWA 10	284	307	485	353	1428	43.42	0.76	38.4	1.267
16	UAWA 20 x UAWA 10	228	258	290	279	1055	31.99	0.65	44.6	0.927
	Total	9392	7398	10886	11193	38792	–	–	–	–
	Average $\bar{x}$	426.9	336.2	494.8	508.7	1763.2	36.82	0.96	38.3	1.342
	S.D.	174.9	177.3	269.3	313.0	906.5	9.24	0.14	4.46	0.379

APPENDIX 3. CLONE, PARENTAGE, YEARLY TOTAL PODS, AVERAGE PODS/TREE/YEAR, MEAN DRY BEAN WEIGHT, NUMBER OF BEANS/POD, % SHELL AND DRY BEAN YIELD'

Clonal Trial 4 – MARDI Hilir Perak.

Clone	*Parentage*	*Total pods/year* 1981	1982	1983	*Cumulative total pods*	*Average pods/ tree/year*	*Mean dry bean wt. (%)*	*No. of beans/ pod*	*Shell (%)*	*Dry bean yield(kg/ tree/year)*
414	T. MS 27/43 521 x T. INB 173	194	117	289	600	28.00	1.48	33.5	11.46	1.388
266	SIC 23 x ICS 1	17	39	101	157	22.43	1.37	38.0	–	1.167
262	T. IN. C 1148 x T. TD 95	13	115	193	321	16.05	1.34	41.0	9.24	0.881
254	UA 18 x AMEL 704	269	390	530	1189	42.46	1.24	41.0	10.12	2.158
21	SIC 831 x IMC 67	230	375	355	960	36.92	1.19	52.5	–	2.306
261	T. MS 27/43 521 x T. INB 173	84	109	138	331	33.10	1.16	39.0	–	1.497
288	UA 20 x T. IN. E 269	396	164	287	847	28.23	1.13	36.0	8.25	1.148
119	UF 29 O.P.	29	45	146	220	12.22	1.09	39.0	11.99	0.519
259	T. IN. A. 594 x UA 31	73	132	191	396	20.84	1.08	42.0	11.35	0.945
136	SIC 1 O.P.	390	888	628	1906	66.64	1.07	46.0	–	3.280
264	SPA 5 O.P.	32	121	95	248	13.77	1.05	49.0	–	0.708
265	SIC 4 x ICS 1	95	241	396	732	29.28	1,05	47.0	11.86	1.444
258	T. MS. 15/43 385 x UA 31	56	392	451	899	33.29	1.04	40.0	–	1.384
418	UA 13 x UA 10	180	194	424	798	30.69	1.02	45.5	9.14	1.424
362	SCA 6 x ICS 1	339	263	403	1005	50.25	1.02	41.0	–	2.101
251	UA 8 x UA 31	212	310	353	875	32.40	1.01	44.5	9.67	1.456
156	SPA 12 O.P.	343	194	227	764	29.38	0.95	48.0	–	1.339
248	IMC 67 x EEF 48	307	452	394	1153	46.12	0.94	54.0	13.78	2.341
253	UA10 x A. WA 561	39	84	204	327	20.43	0.91	40.1	12.81	0.745
411	UA 18 x T. MS. 15/43 352	48	207	471	726	29.04	0.90	37.0	–	0.967
252	UA 19 x UA 22	168	497	388	1053	39.00	0.84	38.1	9.39	1.248
413	UA 19 x A. WA 708	132	280	413	825	35.87	0.80	40.0	–	1.147
124	CC 42 O.P.	40	228	322	590	42.14	0.79	37.0	–	1.231
341	SIC 948 x SCA 6	300	333	498	1131	45.24	0.79	44.0	13.06	1.572
269	SIC 831 x SCA 6	46	88	179	313	39.12	0.78	46.0	–	1.403
30	CC 9 O.P.	276	413	751	1440	53.33	0.74	32.0	–	1.262
410	UA 19 x UA 22	178	321	317	816	34.00	0.72	45.3	12.44	1.108
	Total	4486	6992	9144	20622	–	–	–	–	–
	Average x	166.1	258.9	338.6	763.7	33.71	1.01	42.09	11.04	1.413
	S.D.	125.3	180.6	160.5	409.3	12.44	0.19	5.37	1.72	0.589

APPENDIX 4. CLONE, PARENTAGE, YEARLY TOTAL PODS, AVERAGE PODS/TREE/YEAR, MEAN DRY BEAN WEIGHT, NUMBER OF BEANS/POD, % SHELL, AND DRY BEAN YIELD.

Clonal Trial 5. MARDI Hilir Perak.

Clone	Parentage	Total pods/tree 1981	1982	1983	Cumulative Total Pods	Average pods/ tree/year	Mean dry bean wt. (g/bean)	No. of beans/ pod	Shell (%)	Dry bean yield (kg/ tree/year)
MHP 79	CMS 1124 x UA 31	31	188	360	579	24.12	1.31	38.0	11.29	1.200
55	UA 19 x T. TD. 39	0	53	173	226	9.04	1.21	25.0	12.36	0.273
83	R 15	6	169	381	556	21.38	1.18	25.0	14.71	0.630
70	SIC 23 x ICS 1	39	132	148	319	13.86	1.15	46.0	10.30	0.733
81	SPA 12	3	24	58	85	4.47	1.11	36.0	7.81	0.178
80	UA 18 x TMS 15/43	15	256	283	554	22.16	1.10	35.0	10.67	0.853
52	CMS 1124 x UA 31	17	359	360	736	25.38	1.08	30.0	8.26	0.838
78	UA 13 x T. IN. B 173	34	236	247	517	18.46	1.01	35.0	10.51	0.652
76	UA 18 x IMC 60	74	178	281	533	20.50	1.00	33.0	10.49	0.676
77	UA 13 x UA 10	39	161	263	463	17.81	1.00	31.0	7.46	0.552
223	IMC 67 x CAS 1	32	112	232	376	13.92	1.00	37.0	10.59	0.515
222	SIC 2 x DR 2	42	223	614	879	38.26	0.98	33.0	9.80	1.237
219	R 311	54	145	466	665	30.23	0.96	34.0	10.27	0.986
216	R 221	9	162	216	387	15.88	0.95	39.0	8.96	0.588
74	Pound 7	86	262	413	761	31.70	0.95	36.0	9.70	1.084
54	UA 13 x T. MS. 15/43. 385	15	722	220	957	43.50	0.93	35.0	11.60	1.415
68	SIC 831 x IMC 67	25	193	404	622	28.27	0.93	53.0	10.96	1.393
221	UNKNOWN	60	308	414	782	27.93	0.93	42.0	11.45	1.090
217	R 118	9	106	173	288	14.40	0.93	40.0	9.59	0.535
84	UA 18 x AMEL 704	47	246	328	621	23.81	0.91	39.0	9.79	0.845
60	AMEL x NA 33	3	186	327	516	20.64	0.91	43.0	10.75	0.807
218	R 318 x P 347	53	316	525	894	34.38	0.90	41.0	9.24	1.268
56	ICS 6 x NA 33	50	161	402	613	23.57	0.88	40.0	9.65	0.829
65	EET 75	8	106	141	255	11.08	0.88	39.0	10.04	0.380
72	UF 677	6	115	215	336	15.27	0.88	39.0	11.59	0.524
51	UA 32 x T. TD. A 925	60	198	256	514	22.35	0.86	43.0	10.71	0.826
85	UA 19 x AMEL 708	18	146	246	410	17.08	0.85	37.0	11.32	0.537
57	AMEL x NA 33	5	129	145	279	10.73	0.85	43.0	10.16	0.392
53	UA 13 x UA 20	10	303	305	618	24.72	0.85	38.0	12.12	0.798
71	R 2	0	120	68	188	9.89	0.83	26.0	10.74	0.213
69	ICS 8 x SIAL CB	2	86	175	263	17.53	0.81	38.0	12.25	0.539
61	R 48	5	42	177	224	13.18	0.81	38.0	10.16	0.405
215	LT 224	61	287	437	785	35.68	0.78	40.0	8.56	1.113
58	UIT 3 x NA 32	6	90	200	296	11.38	0.76	37.0	9.91	0.320
82	EEG 29	26	144	271	444	29.60	0.76	38.0	13.39	0.854
67	SIC 971 x IMC 67	38	287	606	931	37.24	0.75	52.0	8.19	1.452
220	758/5	0	147	352	499	21.69	0.75	36.0	13.52	0.585
64	SC 6	17	111	246	374	15.58	0.73	41.0	10.48	0.466
75	SIC 1	90	522	400	1012	42.16	0.73	44.0	9.41	1.354
63	SPA 5	74	110	171	355	15.43	0.71	45.0	10.55	0.492
66	SIC 948 x SCA 6	38	392	655	1085	41.73	0.71	47.0	12.56	1.392
62	UF 29	0	189	68	257	9.88	0.70	33.0	11.73	0.228
59	ICS 6 x NA 33	189	248	422	859	34.36	0.65	47.0	11.39	1.049
73	CC 9	98	578	804	1480	52.85	0.58	48.0	12.64	1.471
	Total	1497	9248	13649	24392	–	–	–	–	–
	Average x	34.0	210.1	310.1	554.3	23.02	0.89	38.5	10.62	0.785
	S.D.	36.2	138.6	161.5	285.6	10.90	0.15	6.2	1.52	0.374

APPENDIX 5. NUMBER OF TREATMENTS, CODE, PARENTAGE, ORIGIN OF CLONES USED IN CLONAL TRIALS: SITE B, SITE C, 4 AND 5.

Clonal Trial Site B.

Treatment No.	*Code*	*Parentage*	*Origin/Parent Tree*
1.	B 1	TMS 15/43 269 x AMEL 698	C36/V/1/E51/1/901
2.	B 2	UAWA 33 x UAWA 9	C 45/1/8/P504/8/417
3.	B 3	TMS. 15/43 285 x UAWA 31	C36/111/5/H25/5/751
4.	B 4	UNKNOWN	C36/IV/1/H445/10
5.	B 5	TMS. 15/43 385 x UAWA 31	C36/IV/5/H68/5/751
6.	B 6	T.INA. 594 x UAWA 31	C36/1/12/J13/12/752
7.	B 7	T.INA. 594 x UAWA 31	C36/111/8/J34/8/752
8.	B 8	CMS 1124 x UAWA 31	C36/11/3/K42/3/850
9.	B 9	CMS 1124 x UAWA 31	C36/111/12/K18/12/850
10.	B 10	CMS 1124 x UAWA 31	C36/IV/5/K54/5/850
11.	B 11	T.IN.A 306 x T.IN.D. 466	C36/1/7/N3/7/950
12.	B 12	T.IN.A 195 x AMEL 704	C36/1/7/N3/7/950
13.	B 13	UAWA 18 x AMEL 704	C36/111/5/P25/5/700
14.	B 14	T.IN.D. 466 x T.MK.D 793	C37/IV/5/E258/5/182
15.	B 15	I.IN.B 173 x UAWA 18	C36/11/10/G30/10/902
16.	B 16	UAWA 13 x T.MS. 15/43.385	C36/IV/9/G270/9/754A
17.	B 17	UAWA 20 x T.IN.D. 466	C36/IV/8/J253/8/801
18.	B 18	UAWA 20 x T.IN.D 466	C36/111/10/L224/10/400
19.	B 19	UNKNOWN	C36/11/5/L 229/5
20.	B 20	UAWA 20 x T.IN.D. 466	C36/111/10/L224/10/400
21 A	B 21A	UA	C36/IV/7/L257/7
21. B	B 21B	UAWA 20 x T.IN.E 269	C45/1/9/M502/9/762
22. A	B 22A	UAWA 18 x UAWA 31	C45/1/7/M201/1/401
22. B	B 22B	UAWA 20 x T.IN.E. 269	C45/1/9/M502/97762
23.	B 23	UAWA 13 x UAWA 10	C38/IV/2/F356/2/404
24.	B 24	UAWA 13 x UAWA 10	C38/IV/9/F356/9/404
25.	B 25	UAWA 13 x UAWA 10	C38/V/9/F363/9/404
26.	B 26	UAWA 12 x UAWA 20	C38/1/3/G333/3/405
27.	B 27	UAWA 12 x UAWA 20	C38/IV/1/G370/1/405
28.	B 28	UAWA 12 x UAWA 20	C38/IV/10/G370/10/405
29.	B 29	UAWA 13 x UAWA 20	C38/1/3/J313/407
30.	B 30	UAWA 13 x UAWA 20	C38/1/J326/1/407
31.	B 31	UAWA 13 x UAWA 20	C38/11/6/J362/6/407
32.	B 32	UAWA 10 x UAWA 8	C38/111/4/L324/4/409
33.	B 33	UAWA 13 x TMS 15/43.385	C37/IV/9/G270/9/754 A
34.	B 34	UAWA 30 x UAWA 13	C38/11/5/J315/5/412
35.	B 35	UAWA 30 x UAWA 13	C38/11/9/P315/9/412
36.	B 36	UAWA 30 x UAWA 13	C38/IV/8/P244/8/412
37.	B 37	UAWA 30 x UAWA 13	C38/V/9/P367/9/412
38.	B 38	UAWA 8 x UAWA 31	C41/11/2/B/441/2/413
39.	B 39	UAWA 8 x UAWA 31	C41/11/4/B441/4/413
40.	B 40	UAWA 8 x UAWA 31	C41/IV/10/B445/10/413
41.	B 41	UAWA 32 x T.TD.A 925	C41/1/1/G404/1/757
42.	B 42	UAWA 32 x T.TD.A 925	C41/11/10/G403/10/757
43.	B 43	UAWA 32 x T.TD.A 925	C41/IV/1/G470/1/757
44.	B 44	UAWA 32 x T.TD.A. 925	C41/2/G470/2/757
45.	B 45	UAWA x TMS 15/43.352	C41/1/1/H414/1/758
46.	B 46	UAWA 18 x TMS 15/43.352	C41/IV/9/H 468/5/758
47.	B 47	UAWA 13 x T. TD. 990	C41/1/2/J413/2/803
48.	B 48	T.IN.B 474 x T.IN.D 466	C41/1/5/M401/5/149
49.	B 49	T.MS. 15/43. 385 x T.IN.D 466	C45/V/9/D563/9/154
50.	B 50	T.MS. 15/43. 385 x UAWA 31	C36/IV/H68/5/751
51.	B 51	T.MS. 15/43. 269 x AMEL. 698	C36/V/1/M51/1/901
52.	B 52	CMS 1124 x UAWA 31	C36/11/3/42/3/850
53.	B 53	CMS 1124 x UAWA 31	C36/111/12/18/12/850

Clonal Trial Site C

Treatment No.	*Code*	*Parentage*	*Origin/Parent Plant*
1.	C 1	T.IN.B 173 x UAWA 18	C36/11/5G30/5/750
2.	C 2	T.IN.B 173 x UAWA 18	C38/111/12/G33/12/750
3.	C 3	T.IN.A 594 x UAWA 31	C36/111/9/J34/9/752
4.	C 4	T.IN.A 594 x UAWA 31	C36/IV/12/J53/12/752
5.	C 5	CMS 1124 x UAWA 31	C36/1/7/K2/7/850
6.	C 6	CMS 1124 x UAWA 31	C36/1/12/K2/12/850
7.	C 7	CMS 1124 x UAWA 31	C36/11/1/K42/1/850
8.	C 8	CMS 1124 x UAWA 31	C36/11/9/K42/9/850
9.	C 9	CMS 1124 x UAWA 31	C36/IV/1/K54/1/850
10.	C 10	CMS 1124 x UAWA 31	C36/V/12/K66/12/850
11.	C 11	T.IN.A. 306 x T.IN.D 466	C36/IV/11/M43/11/181
12.	C 12	UAWA 18 x AMEL 704	C36/IV/8/P44/8/700
13.	C 13	UAWA 18 x AMEL 704	C36/IV/12/P44/12/700
14.	C 14	T.IN.D. 466 x T.MK.D 793	C37/11/3/E239/3/182
15.	C 15	UAWA 13 x T.IN.A 306	C37/1/10/H214/10/800
16.	C 16	UAWA 20 x UAWA 10	C37/11/12/L229/12/400
17.	C 17	UAWA 20 x UAWA 10	C37/IV/9/L259/9/400
18.	C 18	UAWA 18 x UAWA 13	C38/IV/3/E358/3/403
19.	C 19	UAWA 13 x UAWA 20	C38/V/10/J364/10/407
20.	C 20	UAWA 30 x UAWA 13	C38/V/5/P367/5/412
21.	C 21	UAWA 32 x T.TD.A 925	C41/IV/11/G470/11/757
22.	C 22	UAWA 18 x T.M.S. 15/43. 352	C41/C5/H450/5/758
23.	C 23	UAWA 13 x CMK.KC. 75	C45/11/5/H505/5/853
24.	C 24	UAWA 9 x T.TD. 89	C45/V9/L562/9/761

Clonal Trial 4

Treatment No.	*Code*	*Parentage*	*Origin*
1.	MHP 251	UA 8 x UA 31	MJS C41/409/711
2.	MHP 251	UA 10 x UA 8	MJS C38/307/798
3.	MHP 251	UA 10 x UA 19	MJS C47/611/17
4.	MHP 251	UA 12 x UA 20	MJS C38/349/255
5.	MHP 418	UA 13 x UA 10	MJS C38/332/495
6.	MHP 418	UA 18 x UA 60	MJS C47/646/300
7.	MHP 418	UA 19 x UA 20	MJS C38/316/615
8.	MHP 410	UA 19 x UA 22	MJS C41/461/93
9.	MHP 410	UA 19 x UA 37	MJS C45/537/358
10.	MHP 410	UA 20 x UA 10	MJS C37/229/486
11.	MHP 252	UA 19 x UA 22	MJS C41/459/112
12.	MHP 252	UA 30 x UA 13	MJS C36/344/299
13.	MHP 252	UA 32 x UA 19	MJS C36/343/274
14.	MHP 252	UA 33 x UA 9	MJS C45/503/770
15.	MHP 253	UA 10 x A. WA 561	MJS C41/454/183
16.	MHP 254	UA 18 x AMEL 704	MJS C36/44/321
17.	MHP 413	UA 19 x A. WA 708	MJS C47/633/498
18.	MHP 413	UA 10 x CMS. KC. 54	MJS C37/242/360
19.	MHP 413	UA 13 x CMS. KC. 75	MJS C45/546/224
20.	MHP 413	UA 18 x CMS. KC. 75	MJS C38/340/392
21.	MHP 255	UA 10 x T.MS.S 15	MJS C41/463/129
22.	MHP 256	UA 13 x T.MS 15/43.385	MJS C37/249/293
23.	MHP 411	UA 18 x T.MS. 15/43.352	MJS C41/450/251
24.	MHP 288	UA 20 x T.IN.E 269	MJS C45/505/833
25.	MHP 288	UA 13 x T.IN.A 306	MJS C37/214/699
26.	MHP 257	UA 13 x T.TD.A. 990	MJS C41/453/180
27.	MHP 258	T.MS. 15/43.385 x UA 31	MJS C36/16/605

Clonal Trial 4 (cont'd)

28.	MHP 259	T.IN.A. 594 x UA 31	MJS C36/64/43
29.	MHP 260	T.IN. 8173 x UA 18	MJS C36/70/19
30.	MHP 260	T.IN.A 594 x AMEL 12	MJS C37/220/625
31.	MHP 260	T.MS. 15/43.269 x AMEL 698	MJS C36/51/174
32.	MHP 260	T.IN.A 594 x T.IN.D. 230	MJS C36/45/280
33.	MHP 260	T.IN.E 269 x T.IN.A 306	MJS C36/11/703
34.	MHP 260	T.MS. 15/68.224 x T.IN.A 306	MJS C37/211/683
35.	MHP 260	T.MS. 15/68.224 x T.MK. 1025	MJS C38/311/705
36.	MHP 260	T.MS. 515 x T.IN.D. 466	MJS C41/424/555
37.	MHP 260	T.TD. 60 x T.MK. 144	MJS C45/530/500
38.	MHP 260	T.MS. 15/43.385 x T.IN.D 466	MJS C45/508/649
39.	MHP 414	T.MS. 27/43.521 x T.IN.B 173	MJS C47/602/828
40.	MHP 261	T.MS. 27/43.521 x T.IN.B 173	MJS C47/626/532
41.	MHP 262	T.IN.C 1148 x T.TD. 95	MJS C47/612/724
42.	MHP 262	T.TD 95 x A.WA 708	MJS C47/603/771
43.	MHP 262	T.TD.A 990 x A.WA 708	MJS C45/570/26
44.	MHP 119	UF 29 O.P	CRHP B12/82
45.	MHP 264	SPA 5 O.P	CRHP B12/443
46.	MHP 124	CC 42 O.P	CRHP B12/147
47.	MHP 263	R 15 O.P	CRHP B12/780
48.	MHP 156	SPA 12 O.P	CRHP B12/579
49.	MHP 136	SIC 1 O.P	CRHP B12/290
50.	MHP 30	CC 9 O.P	CRHP B12/246
51.	MHP 265	SIC 4 x ICS 1	BHP R4/112/10
52.	MHP 248	IMC 67 x EEG 48	BHP R4/63/2
53.	MHP 266	SIC 23 x ICS 1	BHP R4/106/20
54.	MHP 269	SIC 831 x SCA 6	BHP R1/34/7
55.	MHP 341	SIC 948 x SCA 6	BHP R1/32/3
56.	MHP 341	IMC 67 x CAS 1	BHP R1/51/3
57.	MHP 341	SIC 4 x DR 2	BHP R1/56/5
58.	MHP 341	SIAL 88 x SIAL 70	BHP R4/83/17
59.	MHP 21	SIC 831 x IMC 67	BHP R4/80/1
60.	MHP 362	SCA 6 x ICS 1	BHP R1/27/1
61.	MHP 362	UIT 1	
62.	MHP 362	PA 7	
63.	MHP 362	NA 33	
64.	MHP 362	ICS 95	

Note:
MHP – MARDI Hilir Perak.
MJS – MARDI Jerangau Selection
CRHP – Costa Rica Family Row Hilir Perak.
BHP – Brazilian Progeny Trial Hilir Perak.

APPENDIX 5. (Cont'd)

Clonal Trial 5

Treatment No.	*Code*	*Parentage*	*Origin*
1.	MHP 74	Pound 7 O.P	CRHP B9/1920
2.	FEL 2		
3.	MHP 73	CC9 O.P	CRHP B12/280
4.	MHP 83	R 15 O.P	CRHP B12/785
5.	MHP 69	ICS 8 x SIAL CB	BHP B10A/77/7
6.	FEL 3		
7.	MHP 63	SPA 5 O.P	CRHP B12/434
8.	MHP 82	EEG 29 O.P	CRHP B12/327
9.	MHP 81	SPA 12 O.P	CRHP B12/572
10.	MHP 218	R 318 – P 347	HP B10/38/285
11.	FEL 1		
12.	MHP 59	ICS 6 x NA 33	KBE T82
13.	MHP 67	SIC 971 x IMC 67	BHP B10/233
14.	NA 33	CONTROL	
15.	MHP 61	R 48 O.P	CRHP B12/54
16.	MHP 58	UIT 3 x NA 32	KBE T823
17.	MHP 56	ICS 6 x NA 33	KBE T790
18.	MHP 222	SIC 2 x DR 2	BHP B9/79
19.	MHP 84	UA 18 x AMEL 704	MJS C36/67/31
20.	MHP 55	UA 19 x T.TD. 39	MJS C47/639/411
21.	MHP 216	R 221	HP B10/39/205
22.	MHP 77	UA 13 x UA 10	MJS C38/306/793
23.	MHP 218	LT 224	HP B10/38/285
24.	MHP 54	UA 13 x T.MS. 15/43.385	MJS C37/204/831
25.	MHP 65	EET 75 O.P	CRHP B9/1701
26.	MHP 68	SIC 831 x IMC 67	BHP B10/440
27.	MHP 78	UA 13 x T.IN.B 173	MJS C37/263/167
28.	MHP 64	SC 6 O.P	CRHP B12/218
29.	MHP 221	UNKNOWN	HP B10/36/361
30.	MHP 220	758/5	HP B10/36/332,334
31.	MHP 51	UA 32 x T.TD. A 925	MJS C41/404/768
32.	MHP 76	UA 18 x IMC 60	MJS C47/640/349
33.	MHP 79	CMS 1124 x UA 31	MJS C36/66/78
34.	MHP 85	UA 19 x AMEL 708	MJS C47/604/789
35.	MHP217	R 118	HP B10/39/227, 228
36.	MHP 57	AMEL x NA 33	KBE T670
37.	MHP 75	SIC 1 O.P	CRHP B12/313
39.	PA 35	CONTROL	
40.	MHP 223	IMC 67 x CAS 1	BHP B9/1375
41.	MHP 219	R 311	BHP B10/37/371
42.	MHP 60	AMEL x NA 33	KBE T661
43.	MHP 66	SIC 948 x SCA 6	BHP B10/99
44.	MHP 52	CMS 1124 x UA 31	MJS C36/54/183
45.	MHP 72	UF 677 O.P	CRHP B12/662
46.	MHP 53	UA 13 x UA 20	MJS C38/364/42
47.	MHP 80	UA 18 x T.MS. 15/43	MJS C41/414/748
48.	MHP 62	UF 29 O.P	CRHP B12/98
49.	MHP 70	SIC 23 x ICS 1	BHP B9/536

Note:
MHP – MARDI Hilir Perak.
MJS – MARDI Jerangau Selection.
CRHP – Costa Rica Family Row Hilir Perak.
BHP – Brazilian Progeny Trial Hilir Perak.
KBE – Kuala Bernam Estate Selection.
HP – Hilir Perak Collection.

Pollination Ecology of Cocoa in Malaysia: Identification of Taxonomic Composition and Breeding Sites, Ecology and Pollinating Activities, and Seasonal Abundance

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Insects have been noted to play a vital role in the pollination of cocoa in many cocoa-growing areas of the world. However, little is known on the pollination ecology of cocoa in Malaysia. For this reason, studies were initiated to determine the taxonomic composition and their breeding sites. Observations on their ecology and pollinating activities were also carried out.

Four species of ceratopogonids were collected and identified. The species comprised Forcipomyia (Euprojoannisia) fuscimana Kieffer, Dasyhelea *sp., Brachypogon sp., and* Atrichopogon *sp. in order of abundance. 1*F. (E.) fuscimana *is more abundant in Hilir Perak and Kuala Selangor cocoa-growing areas while* Dasyhelea *sp. is more prevalent in Kemaman cocoa areas. The other two species are less common in all the areas.*

Screening of various decaying plant materials confirmed that decaying cocoa shells, rotten banana stumps, and decaying leaf litters were the principle breeding sites for F. (E.) fuscimana *and other species. Only cecidomyiids were collected from the damp coconut stumps.*

Ceratopogonids require cool, shaded, and moist habitat for various activities. Clonal or progeny cocoa having closed canopies, with good shade cover, and having abundant leaf-litter, seemed to harbor higher ceratopogonid populations. Population fluctuations varied temporally and were generally higher during the wet season and lower during the dry period.

Pollination takes place more in the morning and in late afternoon. Females frequently visited cocoa flowers more than the males. During the dry and low flowering period only about 13% effective pollination was achieved.

The possibilities of manipulation of pollinators breeding sites to increase natural pollination and cocoa production are recognised and discussed.

Malaysian cocoa industry has experienced rapid growth since its initial commercial planting in the early sixties. Total production increased substantially from 9,000 tonnes in 1972 to 60,000 tonnes in 1982 (Anon., 1983). It appears that the increase in production resulted from an increase in area of production especially as an intercrop under coconut. However, as suitable land for cocoa cultivation is rapidly becoming scarce, our ultimate aim of becoming one the the leading world cocoa producers must be realised through increasing cocoa yield. Although yield increases can be accomplished through planting of high yielding varieties and the employment of proper agronomic practices, effective pollination is considered the ultimate factor in determining fruit setting (Winder, 1978).

In spite of the importance of pollination and the activity of the pollinating agencies in crop production, research efforts in this field are unfortunately lacking in Malaysia.

Cocoa produce thousands of flowers directly on the main stem and older branches at points that originally were leaf axils. However, only a small proportion of the flowers produced (generally less than 5%) are pollinated (Winder, 1977 a and b). The unpollinated flowers drop within two to three days after opening. The self incompatible nature of many cocoa varieties require cross pollinating agents especially insects. The floral structure and the stickiness of the pollen generally precludes the possibility of pollination by wind and water (Free, 1970). In addition, cocoa flowers were reported to bear two types of small nectaries which secrete nectar that attracts insects (Stejskel, 1969). It is generally believed now that cocoa pollination is principally affected by the ceratopogonid midges of the genus *Forcipomyia* in many parts of the world (Billes, 1941; Posnette, 1944; Soria, 1970; Bystrak & Wirth, 1978). At least 75% of pollination in cocoa is brought about by *Forcipomyia* activities (Posnette, 1944).

In Malaysia, research on pollination ecology of cocoa has been initiated at MARDI Hilir Perak. This paper reports the early results on (1) species composition, (2) breeding sites, (3) the ecology and pollinating activities of the cocoa pollinators and (4) population fluctuations in relations to cocoa phenology.

MATERIAL AND METHODS

Midge Collection

Ceratopogonids were collected from cocoa field at MARDI Hilir Perak, MARDI Kemaman, and Johore Barat. Collections were made using aspirator by sucking the insects perching on any part of the cocoa trees as well as those that were in flight. The probability of catching the midges using this method was higher than by trapping them with a vial and stopper used by many of the previous workers (Saunders, 1959; Posnett, 1944; Kaufmann, 1975a, b and c; Young, 1982). The specimens collected were preserved in 80% alcohol and later sent for identification.

Breeding Sites

For evidence of the breeding substrates used by the ceratopogonids, decaying cocoa pods, rotten banana stumps, and decomposing matter from rotting coconut stumps were screened for emergence of ceratopogonids. Any midge that emerged from the substrates were counted and recorded. Observations on the breeding substrates for the ceratopogonids were also made on the decomposing cocoa leaf litter, rotten jackfruits, *Artocarpus heterophyllus* Lam. (Urticaceace), and decomposing skin of durian fruit, *Durio zibethines L.* (Bombacaceae).

Pollinating Activity

Studies were carried out at MARDI Hilir Perak, and Kg. Api-Api, Kuala Selangor, to determine the pollinating activities of the ceratopogonids in relation to time. The plots differed in vegetational structure and composition. The MARDI Hilir Perak plot, block 34A, was a Costa Rican progeny trial plot with cocoa progenies planted in late 1975 intercropped under tall coconut more than 50 years old. The cocoa trees had well developed canopies forming a cool shady condition underneath. On the other hand, the Kg. Api-Api consisted of clonal cocoa planted in 1978. The cocoa clones were interspersed with clumps of banana, *Gliricidia maculata*, and young MAWA coconut.

A total of more than 600 flower buds that were about to open the following morning were caged with clear plastic. The following morning, 50 flowers were exposed at each hour of the day for a duration of 1h. At the end of each hour the flowers were collected, examined and recorded for pollen grains on the styles and stigmas.

On the same day of flower caging study three Malaise traps were set up in the cocoa interrows early in the morning. The insects in the traps were colllected at each hour of the day and analysed for the number of ceratopogonid midges.

During the study period data on the hourly diurnal variation of relative humidity and temperature were recorded using a thermohygrograph.

Cocoa Phenology and Population Fluctuations

Studies were carried out in three cocoa blocks at MARDI Hilir Perak which included block 4A, 34A, and 1C. These three sites differed in varietal composition and shade types. Block 4A consisted of clonal cocoa planted in 1976 whilst Blocks 34A and 1C consisted of progeny cocoa planted in 1976 and 1970, respectively. The cocoa progenies in Block 34A were of the Costa Rican origin whilst those of Block 1C were Sabah hybrids. In all the Blocks, cocoa was intercropped with tall coconut of more than 50 years old. Block 34A had a more uniform overshade while Blocks 4A and 1C were slightly more exposed. *Gliricidia* trees were planted to provide additional shade in Block 4A. Block 1C had a few open patches due to the cocoa trees mortality.

A sample of 50 trees was selected in each block and the number of buds, open flowers, new cherelles (less than 1 cm long) and mature pods were counted and recorded fortnightly. A biweekly monitoring of ceratopogonid populations was also carried out in each block by collecting the insects early in the morning between (0800) to 1030 h by four trained man. Ceratopogonids perching on any part of the tree and in flight were collected by sucking with an aspirator. The number of ceratopogonid midges were counted and recorded. No attempt to identify the species was made.

Weather information such as rainfall and temperature was gathered by the metereological station located at the MARDI Hilir Perak experimental station.

RESULTS

Midge Collection

A total of four genera of ceratopogonid midges was represented in the preliminary collections collected from MARDI Hilir Perak, MARDI Kemaman and Johore Barat. The specimens were identified by Dr. W.W. Wirth of the United States Department of Agriculture, Washington, D.C. and comprised the genera *Forcipomyia* Meigen, *Dasyhelea* Kieffer, *Atrichopogon* Kieffer and *Brachypogon* Kieffer. A species from the genus *Forcipomyia* was identified as *F. (Euprojoannisia) fuscimana* Kieffer and was present in all the samples while *Dasyhelea* sp. was identified from the sample collected from Kemaman. The other two species were less common in all the areas.

In addition to Ceratopogonidae, other Diptera families such as Cecidomyiidae and Drosophillidae were also collected. Cecidomyiidae midges were sent for identification to the Commonwealth Institute of Entomology, London. Three tribes and a possible genus were identified which were Aphidoletini, Clinodiplosisi and Cecidomyiidi, and cf. *Parallelodiplosis,* respectively.

Breeding Sites

Results on the determination of potential breeding substrates of cocoa pollinators showed that both rotten cocoa pod husks and rotten banana stumps collected from various localities yielded high numbers of ceratopogonid midges (*Table 1*). Other dipterans such as cecidomyiids, psychodids, and drosophillids were also recovered from these substrates but their numbers were comparatively lower than those of the ceratopogonids (*Table 1*). Non-dipterans that emerged from these substrates were mainly Hymenoptera and were probably parasitic species parasitizing on other insects such as the larvae of Lepidoptera and Coleoptera which at the same time also occupied these substrates. More than five specimens of cecidomyiids were reared from rotten organic matter of the old coconut stumps collected from Kg. Api-Api, Kuala Selangor. However, no ceratopogonids emerged from this substrate.

Setting up of emergence traps above cocoa leaf litter during April 1984 failed to collect any dipterans and other insects. However, the larvae of ceratopogonids midges were collected twice from the moist decomposing cocoa leaf litter during the course of field works at MARDI Hilir Perak in 1983. Ceratopogonid midges also seemed to use the rotting skin of durian fruit, *D. zibethinus,* and rotting jack-fruit (nangka), *A. heterophyllus,* when a number of adult ceratopogonids were collected using aspirator while hovering above these substrates in a young smallholder cocoa planting at Kg. Gijan, Salak near Seremban.

Pollinating Activity

The results of percentage of pollination in relation to time of the day at Kg. Api-Api, Kuala Selangor, and MARDI Hilir Perak are shown in *Tables 2* and *3*.

In general, the percentage of pollination was comparatively different at each study site and was very variable relative to the hour of the day. Pollination began early in the morning and continued throughout the day. Pollination ranged from 4–6% at Kg. Api-Api (*Table 2*) and 4–48% at MARDI Hilir Perak (*Table 3*). At Kg. Api-Api the percentage of pollination relative to the hour of the day was irregular reaching the maximum peak at about 1800 h. However, the percentage of pollination at MARDI Hilir Perak showed an increasing trend in the morning reaching maximum peak at about 1300 h, after which it declined towards the evening.

The results of the pollination study also showed that little correlation existed between the number of ceratopogonids and percentage of pollination at both locations (*Tables 2* and *3*). Results at Kg. Api-Api (*Table 2*) revealed that diurnal variation of temperature and relative humidity seemed to influence the diurnal trend of ceratopogonid populations. However, no such relationship could be observed at MARDI Hilir Perak (*Table 3*).

Behaviour of Immature and Adult Ceratopogonids

Inspection of decaying cocoa pod husks and rotten banana stumps revealed that larvae of the ceratopogonids were gregarious but the number of individuals within a group was variable. A congregate of more than 50 individuals was often observed on the moist part of breeding substrates. On the other hand, groups of two individuals were also occasionally observed. Within the group, the larvae often aligned themselves towards a particular direction but dispersed upon exposure to light. The pupae also appeared in groups fastening themselves securely to the substratum at the abdominal end and wiggled vigorously when disturbed.

TABLE 1. CERATOPOGONIDAE AND OTHER INSECTS EMERGING FROM TWO DIFFERENT SUBSTRATA COMMONLY AVAILABLE IN MANY COCOA-GROWING AREAS IN PENINSULAR MALAYSIA.

Locations	*Sampling date*	*Substrate*	*Weight (g)*	*Number of ceratopogonids*		*Other dipterans*			*Number of non-dipterans*
				Female	*Male*	*Cecidomyiids*	*Psychodids*	*Others*	
Kg. Kuala Sanggang, Temerloh, Pahang.	28 Nov. '83	Rotten cocoa pods	500	54	82	–	19	7	–
		Rotten banana stumps	2500	19	18	3	1	–	4
Kg. Api-api, Kuala Selangor, Selangor.	24 Nov. '83	Rotten cocoa pods	100	349	100	2	19	9	4
		Rotten banana stumps	1100	578	418	139	8	42	–
Kuala Lipis, Pahang	29 Nov. '83	Rotten cocoa pods	800	191	34	1	16	24	13
MARDI Hilir Perak, Teluk Intan, Perak.	23 May '83	Rotten cocoa pods	–	148	80	–	–	1	–
		Rotten banana stumps	850	589	215	–	–	19	–
	23 Nov. '83	Rotten cocoa pods	600	174	21	–	–	24	10
	7 Jan. '84	Rotten cocoa pods	–	383	38	–	20	8	10

TABLE 2. PERCENTAGE OF POLLINATION, NUMBER OF CERATOPOGONID FEMALES WITH RESPECT TO TIME, TEMPERATURE AND RELATIVE HUMIDITY AT KAMPUNG API-API, KUALA SELANGOR.

Time (h)	*Temperature (°C)*	*Relative humidity (%)*	*Pollination (%)*	*Number of female ceratopogonids*
0700	24.0	89.0	6	17
0800	25.5	86.0	10	33
0900	28.0	70.0	10	19
1000	30.1	56.5	6	14
1100	32.5	44.0	6	4
1200	33.5	45.0	4	6
1300	32.5	46.0	14	8
1400	32.5	52.0	6	8
1500	31.9	56.0	10	5
1600	30.0	62.0	8	10
1700	29.0	66.0	16	11
1800	28.0	67.0	62	2

Female ceratopogonids were collected using aspirator on various parts of cocoa plants such as pods, flowers, dried cherelles, and leaf-tips.

TABLE 3. PERCENTAGE OF POLLINATION, NUMBER OF CERATOPOGONID FEMALES WITH RESPECT TO TIME, TEMPERATURE AND RELATIVE HUMIDITY AT MARDI HILIR PERAK, TELUK INTAN.

Time (h)	*Temperature (°C)*	*Relative humidity (%)*	*Pollination (%)*	*Number of female ceratopogonids*
0700	24.0	78.0	4	
0800	24.7	78.0	16	4
0900	21.5	74.0	36	1
1000	29.0	66,0	30	4
1100	30.0	60.0	44	10
1200	32.0	52.0	38	4
1300	31.5	53.0	48	15
1400	32.0	55.0	44	8
1500	33.5	51.0	18	7
1600	31.0	58.5	44	12
1700	30.5	62.0	24	6
1800	30.5	63.5	20	6
1900	29.5	66.5	16	18
2000	28.5	72.0	6	20

Female ceratopogonids were collected using two Malaise traps set in the cocoa inter-rows.

Throughout the field studies only adult females were observed to actively pollinate cocoa flowers while the males were only observed to perch on flower petals. On several occasions, swarming activities were usually observed during the bright mornings over a small stem or within the broken cocoa canopies. Interestingly, the swarms consisted of only the males. The flight activity of the ceratopogonids was observed to be higher during sunny weather but no outside activity took place during rainy period.

Observations on the pollinating behavior indicated that adult female alighted on the inner part of the staminoid and crawled upward towards the base of the staminoid brushing its thorax bearing pollen grains against the style of the stigma. While crawling, the insect was observed to probe on the surface of the red guideline of the staminoid. The insect crawled back and forth before disappearing into the petal pouch. After a short

while the insect reappeared onto the staminoid (which could be the earlier or the new one) repeating similar activities of crawling and probing. The time spent on a cocoa flower varied from just a few seconds to more than 5 min. The insect flew away when disturbed.

Cocoa Phenology and Population Fluctuations of Ceratopogonid Midges

The results showed that cocoa flowers were produced throughout the year in all study plots and exhibited similar pattern of flowering phenology (*Figures 1–3*). Examination of climatic data (*Figure 4*) showed little variation in daily minimum and maximum temperature range. However, there was a clear variation in monthly rainfall pattern with the period between late January to early March, regarded as the dry period of the year. The rainfall pattern of 1984 was abnormal with the usually drier months of January to March receiving an unusually above normal amount of rainfall (*Figure 4*).

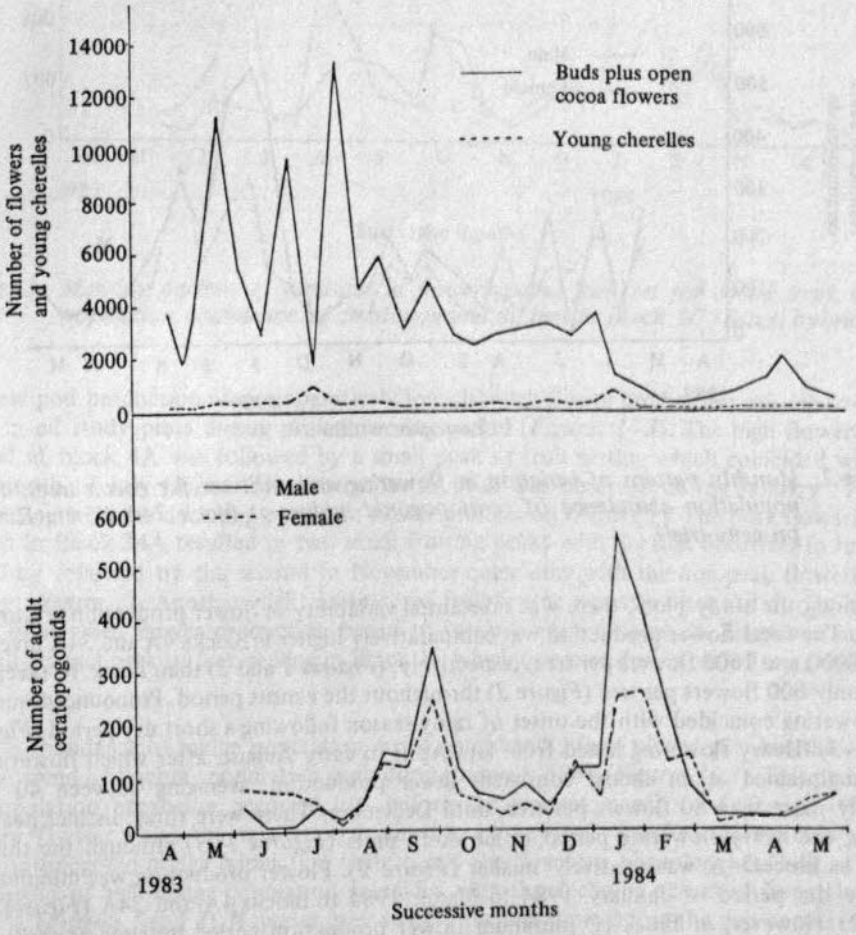


Figure 1. Monthly pattern of variation in flowering and fruit set for cocoa trees, and population abundance of ceratopogonid midges in Block 4A (clonal materials).

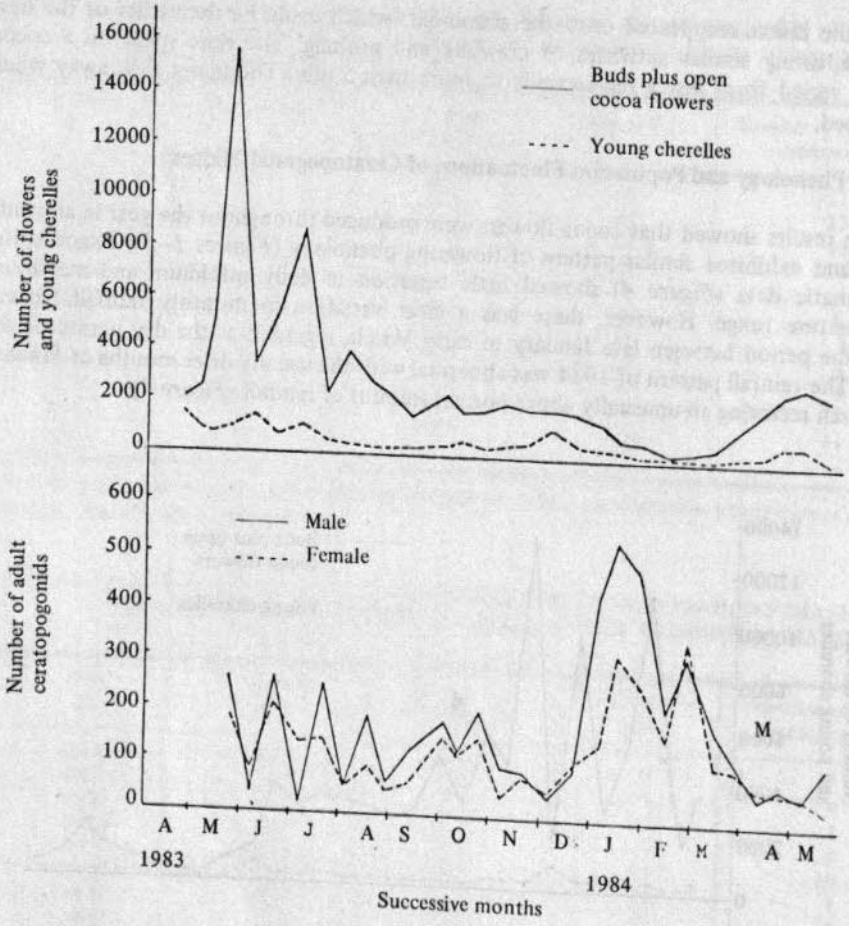


Figure 2. Monthly pattern of variation in flowering and fruit set for cocoa trees, and population abundance of ceratopogonid midges at Block 34A (Costa Rican progeny trial).

Among the study plots, there was substantial variability in flower production (*Figures 1–3*). The total flower production was comparatively higher in Blocks 4A and 34A (averaging 2000 and 1600 flowers per tree, respectively, (*Figures 1* and *2*) than Block 1C (averaging only 600 flowers per tree (*Figure 3*) throughout the census period. Pronounced burst of flowering coincided with the onset of rainy season following a short dry period (*Figures 1–3*). Heavy flowering lasted from late April to early August, after which flowering was maintained at an almost consistent lower production, averaging between 40 to slightly more than 80 flowers per tree, until December. There were three distinct peaks during the heavy flowering period in all study plots (*Figures 1–3*) although the third peak in Block 34A was relatively smaller (*Figure 2*). Flower production was minimum during the period of January 1984 to March 1984 in Blocks 4A and 34A (*Figures 1* and *2*). However, in Block 1C minimum flower production period initiated as early as September. Normal flowering pattern was disrupted in 1984 as a result of excessively wet period during the months of January to March. Although flower production rebounded in April 1984 it never reached the previous year's peak production level (*figures 1–3*).

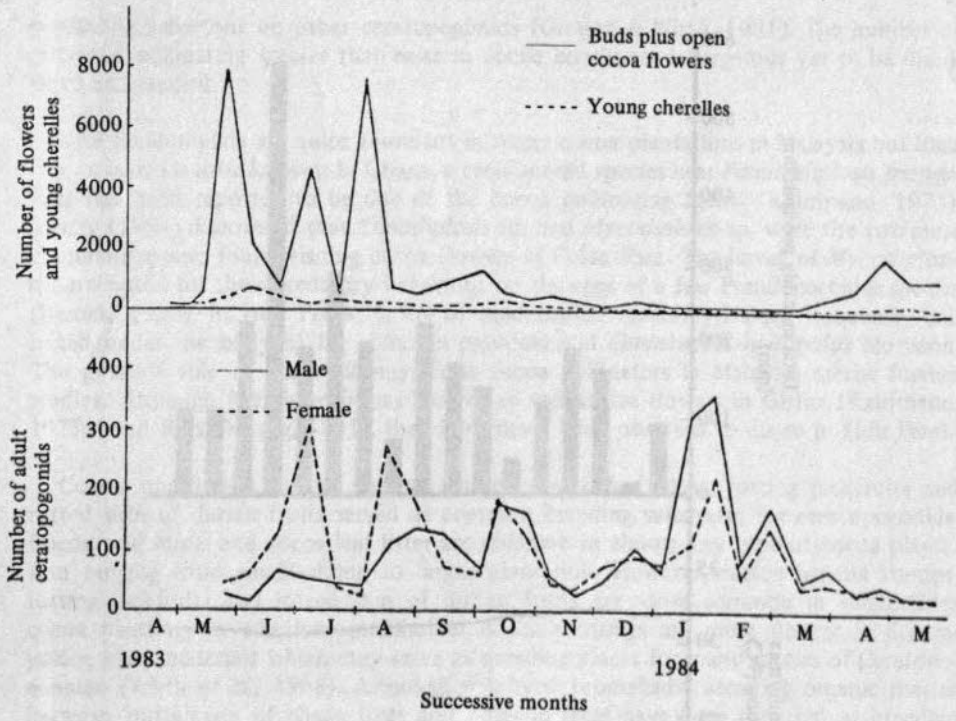


Figure 3. Monthly pattern of variation in flowering and fruit set for cocoa trees, and population abundance of ceratopogonid midges in Block 1C (Sabah hybrids).

New pod production was comparatively low although flower production was relatively high in all study plots during peak flowering period (*Figures 1–3*). The high flowering period at block 4A was followed by a small peak of fruit setting which coincided with the month of July (*Figure 1*). Another small peak was observed during January 1984 coinciding with the declining period of flower production (*Figure 1*). The peak flowering period in Block 34A resulted in two small fruiting peaks with the first occurring in June and July followed by the second in November coinciding with the non-peak flowering season (*Figure 2*). Another slight increase of fruit-setting was also observed during late May 1984 when flower production began to increase again (*Figure 2*). There was only a small distinct peak of fruit-setting in Block 1C which occurred during early June (*Figure 3*).

The abundance of midge population varied considerably from plot to plot but showed similar trend of reaching population peak during January 1984 (*Figures 1–3*). This period of population expansion occurred just before the wettest month of February 1984 (*Figure 4*) after which the population declined to a lower level. Synchronization between the ceratopogonid midge population pattern and the flowering phenology was lacking as the period of high midge population coincided with the declining period of flower production (*Figures 1* and *2*). However, plot-to-plot analysis showed that the two population peaks of female ceratopogonids in Block 1C, during July and August, coincided with the two peaks of main flower production period (*Figure 3*). On the other hand, a distinct smaller burst of midge population in Block 4A occurring during September was delayed by a month following the main flower production period (*Figure 1*).

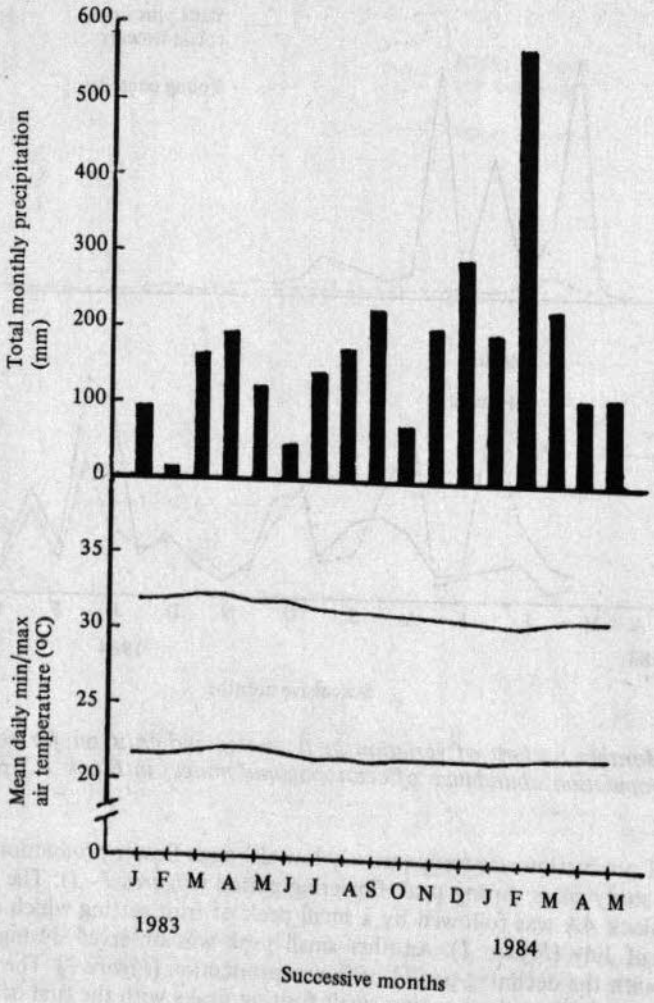


Figure 4. The monthly pattern in absolute rainfall and mean daily minimum and maximum air temperature at the MARDI Hilir Perak research station.

DISCUSSION

The four genera identified in this preliminary study are the first record of ceratopogonidae collected from cocoa ecosystem in Malaysia. *Forcipomyia* (E.) *fuscimana* seems to be an important cocoa pollinator in Peninsular Malaysia judging from its wide distribution and frequent observation in cocoa flowers. Members of this sub-genus have been reported to be important pollinators in many cocoa-growing areas and have been studied by many authors (Soria & Wirth, 1974; Winder, 1978, Bystrak & Wirth, 1978). Although Macfie (1934) reported about 41 different species of ceratopogonidae from Malaysia; *F. (E.) fuscimana* was absent from his list and the collection was not from the cocoa field. Species of the genera *Dasyhelea* and *Atrichopogon* have also been reported as pollinating agents of cocoa (Winder, 1978). Many of the *Brachypogon* species are noted for their

predatory behaviour on other ceratopogonids (Grogon & Wirth, 1981). The number of potential pollinating species that exist in cocoa ecosystem is large but yet to be discovered and studied.

The cecidomyiids are quite abundant in many cocoa plantations in Malaysia but their role in cocoa is little known. In Ghana, a cecidomyiid species near *Paralleldiplosis triangularis* has been reported to be one of the cocoa pollinating agents (Kaufmann, 1973). Young (1984) discovered that *Clinodiplosis* sp. and *Mycodiplosis* sp. were the two most abundant species found visiting cocoa flowers in Costa Rica. The larvae of *Mycodiplosis* sp. are noted for their predatory behaviour on the eggs of a few Pseudococcidae species (Barnes, 1930). In Hilir Perak, larvae of unidentified cecidomyiids are frequently collected under the body of the common pseudococcid *Cataenococcus hispidus* Morisson. The possible role of the cecidomyiids as cocoa pollinators in Malaysia merits further studies. Although bees have been observed to visit cocoa flowers in Ghana (Kaufmann, 1975a) and Rica (Young, 1981), they have never been observed to do so in Hilir Perak.

Cocoa pod husks, rotten banana stumps, cocoa leaf litter, rotting jackfruits and rotted skin of durian fruits served as common breeding substrates for ceratopogonids. Cocoa pod husks and cocoa leaf litter are common in almost any type of cocoa plantation ranging from smallholding to larger plantation. However, rotten banana stumps, rotting jackfruits and rotted skin of durian fruits are more common in smallholder cocoa planting. In addition, smallholder cocoa plantings are more diverse in decomposing plant materials which may serve as breeding places for many species of Ceratopogonidae (Wirth *et al.*, 1968). Although epiphytic bromeliads, decaying organic matter between butteresses of shade trees and holes in trees have been reported as breeding places for cocoa pollinator (Winder, 1977b, 1978) they are less prevalent in the cocoa and coconut ecosystem than in cocoa areas in Trengganu and Sabah.

Pollinating activities by the female ceratopogonid appear to occur throughout the day but vary between the hours of the day, varieties, locations, and also under different weather conditions. Pollination was reported to be high in the morning with another peak in the afternoon in Ghana (Entwistle, 1972) and Brazil (Winder, 1977 a and b). However, results in the present study show that pollination reached maximum peak in the afternoon which comforms to similar findings by Barroga (1965) in the Philippines. The decrease in flight activity of the ceratopogonid midges in the afternoon may be due to the hot afternoon temperature which forces the midges to settle in more protected areas such as in the cocoa canopies and in the flowers. The activity of midges during this time of the day within cocoa flowers may have resulted in increased pollination. Weather conditions also influence the pollinating activity of ceratopogonid midges (Wellensiek, 1932; Soria, 1970; Entwistle, 1972; Kaufmann, 1975b). The rainy and overcast conditions inhibit pollinating activity while clear sunny weather enhances it. Pollinating activity by male ceratopogonids has never been observed in Malaysia although such activity has been reported in Ghana (Kaufmann, 1975c).

The gregarious behaviour of ceratopogonid larvae and pupae seems to be of ecological significance. It is probably a defensive adaptation against predation although larvae move away if attacked. Many of the predators include mites, Collembola, a number of coleopteran species (especially of the family Carabidae) and trombiculids. Higher mortality occurs during immobile pupal stage but they defend themselves by wiggling vigorously (Kaufmann, 1975b). The significance of heterosexual adult swarming in a few species of adult ceratopogonids has been associated with mating (Kaufmann, 1975b). However, the ecological significance of all male swarming as discovered during this study is little known and merits further study.

The cocoa flowering phenology indicates a seasonal response towards rainfall distribution pattern rather than temperature (*Figures 1–4*). This is true as the temperature range in Malaysia is within the optimal range of vegetation growth but the changes in the amount and distribution of rainfall will result in adverse effect (Todorov & David, 1982). Rainfall seems to influence the onset of flowering in cocoa in Hilir Perak and this is generally true for many of the trees and shrubs in the tropics (Opler *et al.*, 1976). However, a short dry period, which normally accurs during January to March, is regarded necessary in the flowering cycle of cocoa (Alvim, 1977). Continuous heavy rainfall will result in delayed and reduced flowering as shown by the 1984 flowering phenology (*Figures 1–3*).

The results of the present study support the proposal by Young (1983) that unevenness in seasonal abundance of the ceratopogonid populations changes in response to the availability of resources. Similarly, rainfall distribution also plays an important role in the population dynamics of the ceratopogonid midges which also conforms with the findings of Soetardi (1950), Entwistle (1972), Winder and Silva (1975), and Soria and Abreu (1976). The low ceratopogonid population during the main flowering period may be due to the drying up of breeding places during the earlier drier months of January to March 1983 (*Figures 1–4*). During this period little harvesting is carried out hence limited amount of decaying cocoa pod husks are available as breeding substrate to the ceratopogonid. The only available substrates are the pod husks from previous main harvesting period (October to early December 1982) which have decomposed and are no more suitable for colonization as breeding site by the ceratopogonids. The availability of decaying cocoa pod husks from the main harvesting period of 1983 (*i.e.* from October to early December) and the favourable moist condition in January 1984 may have resulted in the burst of ceratopogonid population during this month. However, very wet condition deprived the ceratopogonid midges of their breeding places causing a population decline in late February 1984 following a heavy rainfall and flood during the second week of the month.

Site characteristics such as shade and type of planting materials may not only affect the abundance of the ceratopogonid population but also the flowering intensity as shown in this study. The clonal planting in Block 4A and the more uniformly shaded environment of Block 34A produce greater number of flowers as compared to Block 1C, which is slightly exposed and consists of mature progenies. Although it is not demonstrated in this study, ceratopogonid midges are visually attracted towards the dense open cocoa flowers (Downes, 1955) and presumably may increase pollination rate. The shaded environment of Block 34A provides a more uniform condition suitable for the continuous development of ceratopogonid population. The significance of shade in the development of pollinator population has been demonstrated by Young (1982; 1983).

Synchronization between flowering peak and pollinator abundance is necessary to ensure greater pollination (Auspurger, 1980). However, the present study shows that synchronization is lacking between these two components and could have resulted in a great number of loss of open flowers as judged from separation of flower abundance and pod setting at each census date (*Figures 1–3*). The lack of synchronization is probably due to the unavailability of breeding substrates which is an important factor in the continued ceratopogonid population abundance. The results of the present study indicate that pollinators are not limited and are present continuously throughout the year although the limitation of pollinator population has been noted in other cocoa-producing countries such as Ghana and Costa Rica (Soria, 1970; Entwistle, 1972; Mire & Mbondji, 1975). This is probably due to the fact that Hilir Perak and many cocoa areas in the

Peninsular Malaysia experience less marked seasonality as compared to other countries such as Brazil, Costa Rica, and West Africa (Soria 1970; Entwistle, 1972; Winder & Silva, 1975; Young, 1983). The dry season in those regions has a greater negative effect on the ceratopogonid population (Entwistle, 1972; Young 1983).

In Malaysia, pollinators' abundance may be synchronized through environmental manipulation. Knowing that decaying cocoa pod husks, rotten banana stumps and rotting leaf litter are important breeding substrates of the ceratopogonids, they may be supplemented into the cocoa field during the period of maximum flowering period to increase pollinators. Maintenance of proper shade level is important to ensure optimal moist condition suitable for ceratopogonid population build-up and avoiding the drying up of cocoa leaf litter during dry season. The supplement of the breeding materials to increase pollinator abundance was proposed by earlier workers (Saunders, 1959; Winder, 1977). Young (1983) demonstrated that pollination and fruit set was increased by placing discs of freshly cut banana stem under cocoa trees and allowed to rot later to be colonized by the ceratopogonids. This is practical in many of the cocoa smallholdings, which always have banana trees interplanted within the cocoa field to serve as initial shade and also for cash return. On the other hand, larger plantations may increase the pollinator abundance during the main flowering period by supplementing with heaps of cocoa pod husk. These heaps must be placed under cocoa canopy to avoid direct exposure to sunlight which might dry up the heap. In addition, the heaps should be well distributed in cocoa field to ensure a greater distribution of pollinator populations within the cocoa field. Stacking the cocoa pod husk into heaps will allow greater retention of moisture by the husk at the bottem of the heaps. On the other hand, scattering of cocoa pod husk in the cocoa field will enhance the drying up of the pod husk, hence depriving cocoa pollinators from colonizing the husk as their breeding substrate.

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Irrigation of Cocoa on Coastal Soils in Peninsular Malaysia

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The high average annual rainfall (> 2,000 mm) in Peninsular Malaysia is unevenly distributed in most years. Coupled with the high evapotranspiration and loss by surface runoff, this means that moisture deficits, especially in top soil, occur quite often. Since cocoa is essentially a surface feeder, and is highly susceptible to moisture stress, investigations were carried out on some methods of irrigation as potential means for improving cocoa yields, both in quantity and quality.

Drip irrigation with pressure regulating emitters was preferred because of its efficiency in applying water in small quantities near to the consumption requirement of the crop, directly onto the rooting zone.

A drip irrigation trial was set up in March 1981 on 1974 monocultured cocoa (mixed hybrid seedlings) planted on a coastal marine clay soil (Bernam series). Monthly yield records showed that pod number increased by up to 80% with an overall annual increase of 39%. Monthly bean weight improved up to 22% with an annual mean increase of 7%. The variation in yield response was shown to be influenced by the previous rainfall pattern, pod number five to six months and bean weight three to four months prior to harvesting. In general, the quantity yield increases were more pronounced as enhanced peaks, than as flattened troughs. Bean number per pod was not significantly affected by drip irrigation but the nib fat content improved slightly.

Irrigation was shown to increase stomatal dimension, but stomatal density in leaves decreased after treatment started. Irrigation was also found to influence the flushing, leaf nutrient levels, flowering and cherelle wilting of cocoa.

Water quality was shown to be crucial. With adequate liming, cocoa was found to tolerate acidic water of about pH 3 but salinity of more than 2,000 μmhos cm^{-1} was detrimental.

This paper considers some practical implications of drip irrigation of cocoa. Currently the cost of setting up a large scale system on 100 ha, estimated to be in the region of M$6,000/ha, does not justify it for general application. However, at a cocoa price zone of around M$4,500/tonne dry bean, it could become economical, provided a supply of 40,000 litres of water per hectare per day (4 mm/day) were available. In special circumstances, e.g. a seedgarden, drip irrigation is justified and one such system was set up and is described with cost.

Further, other methods of optimising the soil moisture regime for cocoa, e.g. *through land preparations, mulching and control of ground water-table are evidently well justified, and their implementation is discussed.*

Malaysia lies in the humid tropics which experience high annual rainfall, but it can be unevenly distributed, with periods of shortage or excess in relation to the evapotranspiration needs of the plant. In drier months with rainfall of less than 100 mm, moisture deficits, especially in the top soil, can often occur. At other times, heavy rainfall may create accelerated soil erosion and nutrient losses through surface run-off, especially on sloping land.

Fertilization and shade management are usually the main agronomic factors that are manipulated to maximise cocoa yield. Cocoa originated in the Amazon jungle, and it evolved in conditions of good soil moisture. It seems to suggest that even in the high rainfall conditions of Malaysia irrigation can have a beneficial effect on cocoa yield if applied to correct moisture deficits in dry periods. Jadin and Jacquemart (1978) reported that both drip and sprinkler irrigation in Ivory Coast greatly enhanced pod yield of cocoa.

A drip irrigation trial to quantify the yield response of cocoa was conducted in March 1981. Preliminary results were reported by Lim *et al.,* (1983) and indicated benefits in yield and bean size. This paper updates the results of this trial together with the findings todate of some other investigations on irrigation of cocoa.

MATERIALS AND METHODS

Drip Irrigation On Mixed Hybrid Cocoa

The trial is being conducted on 1974 cocoa at a coastal estate in Selangor. *Albizzia* shade trees are spaced at 12m x 12m. The soil type is a Bernam series (Typic Tropaquept) with a topsoil texture containing 50% clay, 33% silt, 15% fine sand and 2% coarse sand.

The mechanical and chemical properties of Bernam series are shown in *Table 1.* The soil water retention characteristics of the soil is given in *Table 2.* The source of water used for the trial was rather acidic (pH3). However, no adverse effects on the irrigated cocoa plants nor on soil pH were observed (*Table 3*). Each tree was limed with 900 g limestone dust per year.

The top 30cm of the soil is very friable and dries out rapidly during short drought periods. Cracking of the soil surface was observed to adversely affect the cocoa feeder roots.

The trial is a simple comparison of two adjacent half-hectare plots, one irrigated and one acting as a control. Water is applied through 1.27cm (0.5 inch) diameter polyethylene laterals laid in every tree row. Pressure compensating emitters (8 litres/h) are located at every cocoa point.

Irrigation commenced in early March 1981. It was only carried out during water-deficit months, *i.e.* when rainfall was lower than the assumed potential evapotranspiration.

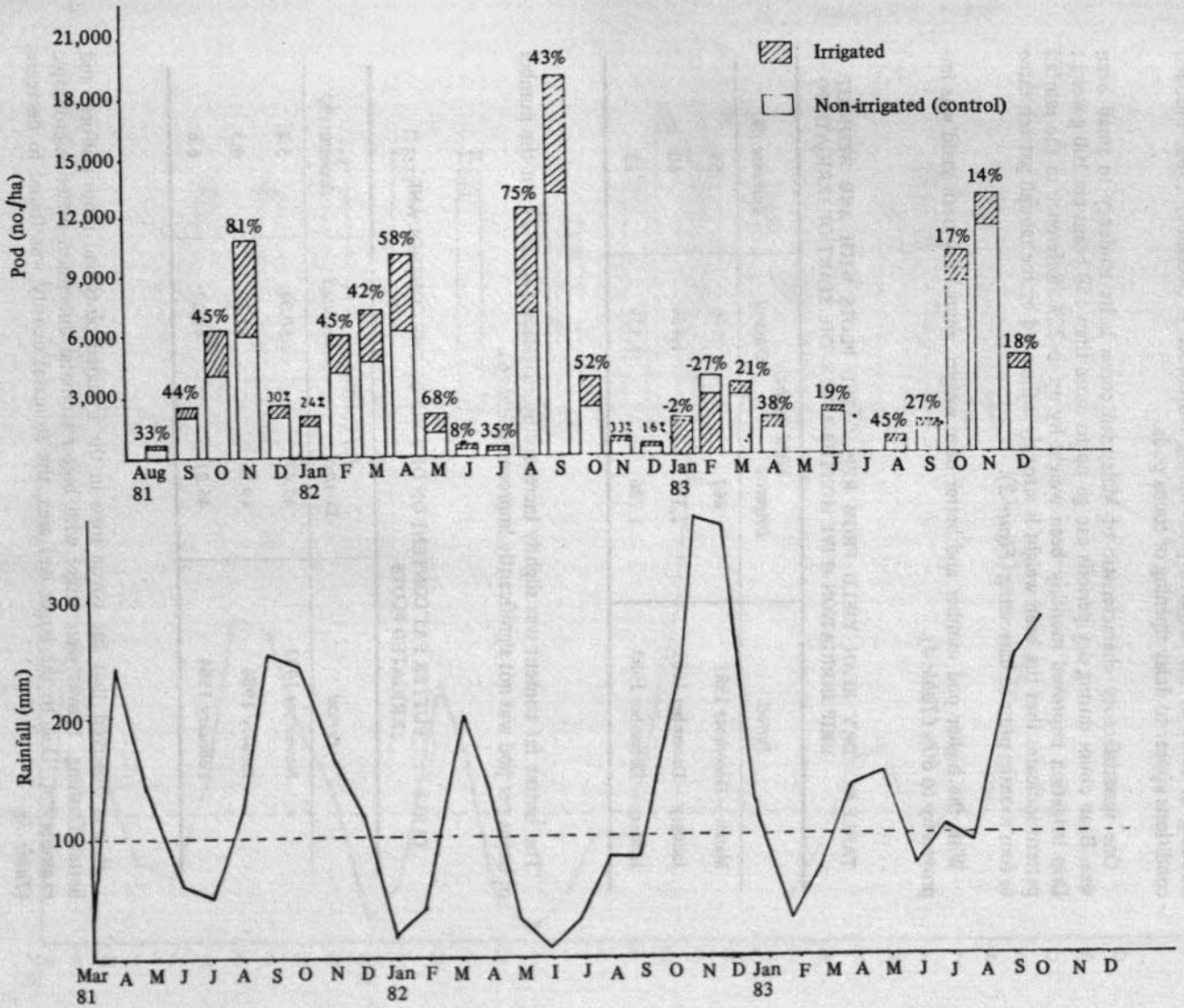


Figure 1. Effects Of Drip Irrigation On Pod Number

In January and February 1983, yield response to irrigation was negative. This may be due to random variation under equal water conditions, or could be explained by the flooding of some of the irrigated plots during November – December 1982. Flooded conditions appear to delay ripening of cocoa pods.

One unsatisfactory characteristic of Malaysian cocoa is its tendency to small bean size. Bean count during dry periods can go up to more than 150 beans per 100 g weight Drip irrigation improved monthly bean weight by up to 22%. Reference to the rainfall pattern indicates that the bean weight is strongly influenced by the rainfall pattern three to four months prior to harvesting (*Figure 2*).

With the higher pod number and better bean weight, annual dry bean yield was improved up to 60% (*Table 4*).

TABLE 4: DRY BEAN YIELD FROM REPLICATED PLOTS WITH AND WITHOUT DRIP IRRIGATION (FIVE MONTHS AFTER THE START OF IRRIGATION)

Period	*Yield (kg/ha)*		*Increase (%)*
	Irrigated	*Control*	
March – December 1981	867	546	59
January – December 1982	2,376	1,486	60
January – December 1983	1,726	1,535	12

The butter fat content was slightly increased by irrigation (*Table 5*) but the number of beans per pod was not significantly improved (*Table 6*).

TABLE 5: BUTTER FAT CONTENT ON DRY NIB OF THE CONTROL AND IRRIGATED PLOTS

Period	*Fat Content (%)*		*Increase (%)*
	Control	*Irrigated*	
November 1983	47.47	50.04	5.4
January 1984	49.86	51.99	4.3
February 1984	46.21	49.27	6.6

It was observed that the cocoa trees in the irrigated plots had more uniform and better flushing. Leaves were larger with bigger stomatal dimension under microscopic examination. Due to the larger leaf area, the stomatal density was found to decrease (*Table 7*).

Leaf analysis showed that irrigation enhanced the leaf N, P and K (*Table 8*). This could be explained by the better nutrient uptake due to the more favourable moisture regime in the irrigated plots.

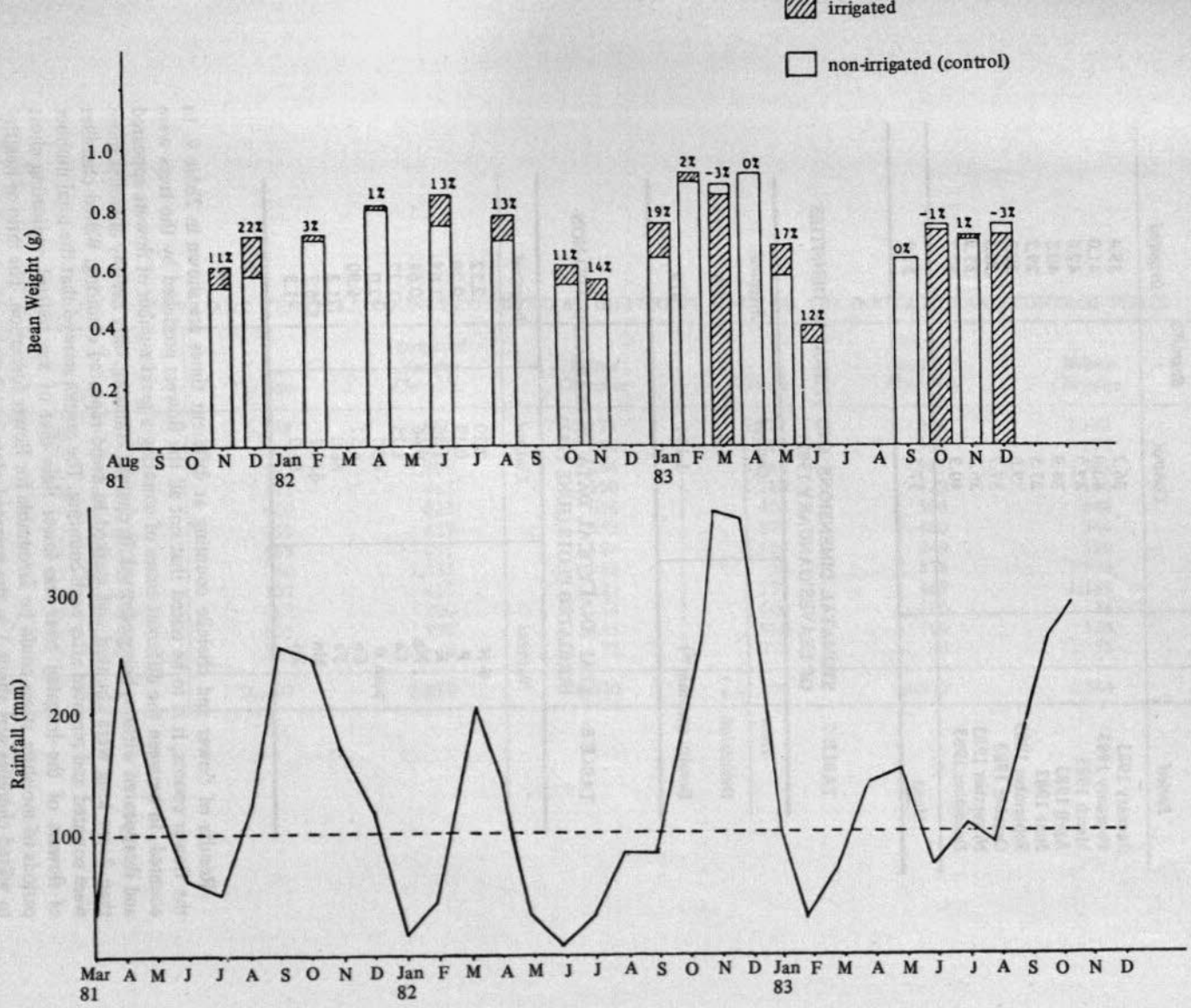


Figure 2. Effects Of Drip Irrigation On Bean Weight

TABLE 6: BEAN NUMBER PER POD OF THE CONTROL AND IRRIGATED PLOTS

Period	*Bean No.*	
	Control	*Irrigated*
January 1983	36.2	39.4
February 1983	40.9	41.0
March 1983	42.7	42.6
April 1983	34.9	40.5
June 1983	27.5	29.2
September 1983	39.0	38.3
October 1983	37.7	36.1
November 1983	36.3	37.1
December 1983	40.3	37.7
Mean	37.3	37.9

TABLE 7: STOMATAL DIMENSIONS AND STOMATAL DENSITIES OF LEAVES (JANUARY 1982)

Item	*Control*	*Irrigated*
Dimension (u)	4.6	5.9
Density (no. mm^{-2})	1,114	819

TABLE 8: LEAF ANALYTICAL DATA OF IRRIGATED AND NON-IRRIGATED PLOTS (JUNE 1983)

Nutrient	*Control*	*Irrigated*
% N	2.20	2.32
P	0.19	0.20
K	1.56	1.65
Mg	0.66	0.64
Ca	1.25	1.22
ppm B	42.7	42.0
Cu	6.57	6.90
Fe	66.0	71.3
Mn	632.7	576.7
Zn	66.0	71.3

Results of flower and cherelle counting at different times are shown in *Table 9*. In the flower counts, it is to be noted that not all the flowers produced by the trees were counted. In between the different times of counting a great number of flowers appeared and disappeared without being counted. In cherelle counting, only healthy cherelles more than 2 cm long were counted and marked to avoid repeated counting. Wilted cherelles were counted and removed after each counting. The results showed that the total number of flowers of the irrigated trees was lower than that of the control, indicating short periods of moisture stress could be favourable for flower formation. The ratio of healthy to wilted cherelles was about 1 in the irrigated plots and 0.72 in the control plots. This indicated that the increase in yield of the irrigated plots was due mainly to the decrease in cherelle wilting.

TABLE 9: FLOWER AND CHERELLE COUNTS (30 TREES) AT DIFFERENT TIMES ON THE IRRIGATED AND CONTROL PLOTS

Date	Irrigated Flowers	Irrigated Healthy Cherelles	Irrigated Wilted Cherelles	Control Flowers	Control Healthy Cherelles	Control Wilted Cherelles
14– 5–83	1,308	830	2,171	2,131	298	2,146
18– 6–83	596	491	160	1,010	300	132
16– 7–83	2,567	1,859	264	2,440	987	394
2– 8–83	1,975	963	390	1,188	429	140
17– 8–83	610	823	616	405	506	546
7– 9–83	859	859	652	879	480	344
24– 9–83	659	291	1,104	1,120	249	580
21–10–83	240	1,083	1,253	50	876	1,123
5– 3–84	102	413	1,123	133	469	1,189
19– 3–84	462	220	74	600	185	36
4– 4–84	635	130	141	910	100	138
18– 4–84	394	48	72	251	43	75
Total:	10,407	8,010	8,020	11,106	4,922	6,844

It should be noted that in this trial, the shade plant was *Albizzia falcata.* This is not currently recommended due to its competitive nature, but it had been thinned down to very wide spacing by the time the trial was carried out, and it is expected that differentials of the same order would occur with other shade trees currently considered more desirable.

Drip Irrigation on Different Primary Cocoa Clones

Preliminary results show that increase in pod number after drip irrigation varies between clones (*Table 10*). Clonal differences in dry bean production after irrigation are given in *Table 11. Table 12* shows the seed production of the different clones in the seedgarden after drip irrigation.

Furrow Irrigation on Cocoa and Effect of Salinity

Irrigation was going on for two months when it had to be terminated due to several trees dying back. The cause of the dieback was the salinity of the water source. Analysis of the water during high tides gave an electrical conductivity of about 2,000 μmbos cm^{-1}.

A disadvantage of using the furrow system was the uneven distribution of water; the front portion of a furrow received more water than the end portion. Further, labour cost involved in removing fallen branches and leaf litters from the furrows was high.

DISCUSSION AND CONCLUSION

Irrigation

Since the ultimate criterion for the commercial application of irrigation on cocoa is the economic benefit, the main objective of the trials described is to quantify the actual yield benefit through irrigation. Without accurate data on this, equations cannot be drawn up for linking input costs to the value of higher yield. We have progressed to defining the yield improvements that can be expected in a locality that is known to experience moderate rain deficit during at least one season in the year. Annual yield improvement of up to 60% was experienced whilst overall bean size was improved by 7%. Nib fat content was also improved by irrigation. The lower yield response in 1983 was mainly due to the exceptionally high rainfall during the later part of 1982 and early 1983 when not much irrigation was carried out.

The beneficial effect of drip irrigation can also be partly attributed to the minimal surface soil cracking, thus minimizing damage to the cocoa feeder roots in the dripped zone. The total dripped area is estimated to be roughly 10% of the ground surface area ($1m^2$/tree).

Preliminary flower counts indicate that the number of flowers/tree is slightly decreased by irrigation, but that the lower incidence of cherelle wilting is able to produce higher pod number. This is in agreement with findings of Hutcheon *et al.*,(1973), who reported that under-canopy sprinkler irrigation of mature amelonado cocoa reduced cherelle wilting particularly at the end of dry seasons.

The cost of setting up a 100-ha drip irrigation system on cocoa is estimated at a total capital of about M$6,000 ha^{-1} with an operating cost of M$60^{-1} $year^{-1}$ (*Appendix 1*). Economic analysis shows that it becomes worthwhile to implement such a system if a

TABLE 10: POD NUMBER OF DIFFERENT CLONES FROM REPLICATED IRRIGATED AND CONTROL PLOTS (FIVE MONTHS AFTER START OF IRRIGATION)

Clone	Pods (no/ha)												Total June – Dec '83		Increase (%)
	June '83		Aug '83		Sept '83		Oct '83		Nov '83		Dec '83				
	I	C	I	C	I	C	I	C	I	C	I	C	I	C	
NA–33	941	699	672	1,908	8,600	3,225	15,345	18,086	5,113	2,150	5,294	2,284	35,965	28,352	26.9
UA–13	2,096	1,908	403	269	4,757	2,311	9,756	10,777	2,499	2,338	4,811	4,434	24,322	22,037	10.4
UIT–1	833	564	134	81	1,828	693	9,110	7,283	6,154	3,601	2,446	2,069	20,505	14,297	43.4
UIT–2	1,129	1,102	–	–	4,757	1,263	6,020	4,542	6,073	4,461	1,371	1,129	19,350	12,497	54.8
SCA–6	7,149	7,578	269	188	4,623	1,666	7,606	6,773	10,239	4,381	5,563	5,375	35,449	25,961	36.7
NA–32	1,505	1,048	779	269	5,294	1,075	6,289	8,278	9,890	2,768	2,688	2,822	26,495	16,260	62.6

I = Irrigated plot

C = Control plot

TABLE 11: DRY BEAN PRODUCTION OF DIFFERENT CLONES FROM REPLICATED IRRIGATED AND CONTROL PLOTS (FIVE MONTHS AFTER START OF IRRIGATION)

Clone	Average Pod Value		Dry Bean Production (kg/ha)												Total June – Dec '83		Increase (%)
			June '83		Aug '83		Sept '83		Oct '83		Nov '83		Dec '83				
	I	C	I	C	I	C	I	C	I	C	I	C	I	C	I	C	
NA–33	26	24	36.2	29.1	25.9	79.5	330.8	134.4	590.2	753.5	196.7	89.6	203.6	95.2	1,383.4	1,181.3	17.1
UA–13	19	18	110.3	106.0	21.2	14.9	250.4	128.4	513.5	598.7	131.5	129.9	253.2	246.3	1,280.1	1,224.2	4.6
UIT–1	13	13	64.1	43.4	10.3	6.2	140.6	53.8	700.8	560.2	473.4	277.0	188.2	159.2	1,577.4	1,099.8	43.4
UIT–2	11	11	102.6	100.2	–	–	432.5	114.8	547.3	412.9	552.1	405.6	124.6	102.6	1,759.1	1,136.1	54.8
SCA–6	32	31	223.4	244.5	8.4	6.1	144.5	53.7	237.7	218.5	320.0	141.3	173.8	173.4	1,107.8	837.5	32.3
NA–32	23	23	65.4	45.6	33.9	11.7	230.2	46.7	273.4	359.9	430.0	120.4	116.9	122.7	1,149.8	707.0	62.6

I = Irrigated plot

C = Control plot

Appendix 1: Capital and Running Costs for Setting up A Drip Irrigation System for 100 Hectare Cocoa

Capital Costs	*M$*
Pump, Mainlines & Laterals	400,000
Emitters	200,000
Installation	12,000
Total Capital Costs:	612,000
Running and Maintenance Cost Per Year	6,000

Appendix 2: Cost/Benefit Analysis for Drip Irrigation of 100 Hectares Cocoa (Over a 10 Year Period)

Assumptions

Average Yield	=	1 tonne dry bean/ha/year
Production Cost	=	M$2,000/tonne dry bean
Expected Yield Increase	=	50%
Depreciation on capital per year	=	10%
Interest on capital/yr	=	10%

Market Price (M$/tonne dry bean)	*Benefit/Loss (10 years (M$)*
3,500	188,023
4,000	34,408
4,500	119,207
5,000	272,822
6,000	580,052

Appendix 3: Costings for Setting up a Drip Irrigation for a 8-ha Cocoa Seedgarden

	CAPITAL ITEMS	*M$*
1)	Pumpset with capacity of 1,500 litres/min	5,500
2)	Installation of pumpset and construction of pumphouse	3,000
3)	Filter	1,000
4)	24,000 m x 1.27 cm diameter polyethylene tubing @ $0.85/m	20,400
5)	8,000 emitters @ $2.00/emitter	16,000
6)	800 m 7.6 cm diameter PVC main pipe @ $6.50/m	5,200
7)	Laying of 800 m main pipeline @ $2.00/m	1,600
8)	Accessories at 10% of capital items	3,000
	TOTAL:	55,700

	RUNNING COST/ANNUM	*M$*
1)	1 man @ $13/day for 150 days	1,950
2)	Pump running for 600 hrs @ $2/hr	1,200
3)	Maintenance	500
		3,650

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Recent Advances in Vegetative Propagation Techniques of *Theobroma cacao* L. Under Malaysian Conditions

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Throughout the world, the cocoa plant has been vegetatively propagated mainly by means of rooted cuttings, bud-grafting and, to a limited extent, by marcots and grafts. Rooted cuttings and buddings are associated with major drawbacks. The production of rooted cuttings involves investment in basic facilities and considerable operational skill; also, there is a clonal variation in rooting success. On the other hand, the traditional or conventional bud-grafting technique entails a lengthy nursery period with the practice of raising relatively old rootstocks (at least five or six months old) and an undesirably long post-budding period. Marcots do not have widespread application due mainly to poor success whilst grafts have not merited more attention consequent upon the availability of relatively effective techniques for production of rooted cuttings and buddings. There is hence a need to screen other available and newly-developed techniques. This paper discusses the practical applicability of promising techniques-cleft-grafting, lateral grafting, nurse-seed grafting and chip-budding. The techniques are considered in relation to rooted cuttings and conventional buddings, with specific reference to production efficiency and costing. Investigations demonstrate that chip-budding is the simplest and cheapest technique which affords an effective means of green budding and also possesses significant potential for reduction of rootstock age.

Consequently, it could have a ready application in the exploitation of clonal cocoa in Malaysia. Nurse-seed grafting, involving the use of rootstocks which are only five to nine days old, also has tremendous potential for practical application.

There has been an upsurge of interest in the vegetative propagation if *Theobroma cacao* L. in Malaysia with growing realisation of its benefits and concurrent with the rapid rate of expansion of the cocoa industry. Hitherto, almost all commercial plantings have been derived from standard planting material comprising selected hybrid progenies with the wide-ranging Upper Amazon type providing most of the parental lines. Unfortunately, these progenies exhibit a high degree of variability with a relatively small proportion of the seedlings in a progeny contributing a major percentage of the yield of that progeny (Ramadasan & Arasu, 1976). The tremendous potential for obtaining greater homogeneity and improving crop yields significantly, coupled with the perpetuation of other desirable genetic characteristics by means of clonal plantings has been well discussed elsewhere (Ramadasan & Arasu, 1976; Byrne, 1976). The recent availability of proven or recommend clones, constituting the first generation of clones from breeding research programmes in Malaysia, heralds a new phase of technological development for the cocoa industry in Malaysia. Henceforth, it can be expected that exploitation of clonal plantings will assume growing importance and, before long, become standard practice in the industry.

The current technology for clonal plantings centres on the use of the conventional budding technique and plants derived from fan shoots which are more readily available than chupon material. The shaping of such plants, which tend to be shrub-like and assymetrical in growth habit, can be successfully undertaken (Ramadasan *et al.*, 1978). The availability of an effective technique for budding mature trees offers a ready means for the conversion of existing seedling plantings to clonal stands as well as the rehabilitation of trees which are ravaged by Vascular Streak Dieback.

There is tremendous scope for further technological improvements. One major area of research is the development of improved techniques for vegetative propagation, resulting in greater production efficiency and reduced costs.

STATUS OF VEGETATIVE PROPAGATION METHODOLOGY IN MALAYSIA

There are two main methods of vegetative propagation for cocoa which have been, or are being, extensively employed for commercial exploitation of clonal cocoa and each has its own inherent advantages and disadvantages.

In the light of successful experiences with the production of rooted cuttings elsewhere, notably the West Indies (Wood, 1975), there has been considerable interest in certain quarters in employing the technique in Malaysia. Results of research investigations have been already reported in detail (Ramadasan *et al.*, 1976; Ramadasan, 1978; Ramadasan, 1979). It has been recommended that two-leaf, semi-hardwood cuttings (from fan shoots and with the leaves trimmed by half) be treated with a rooting hormone (indole-butyric acid) at a suitable concentration (6,000 p.p.m), using the quick-lip method. Subsequently, the cuttings are covered with polythene sheets, supported on a frame or, alternatively, within a mist-humidification chamber containing mist nozzles. Details of operation are given elsewhere (Ramadasan *et al.*, 1976). Although rooted cuttings can be transplanted in the field in five or six months as in the case of seedlings, their production invariably involves a high level of management expertise. More importantly, there is a clonal variation in rooting ability (Ramadasan, 1978; 1979). This is a major drawback with respect to its ready commercial application, as many otherwise highly desirable clones are often poor rooters. Nevertheless, in the light of the need to exploit clonal rootstocks in the long-term and evidence from work elsewhere (Cope, 1953) that good clones do better as cuttings while poor ones may perform better when budded, research interest is still being maintained in the production of rooted cuttings.

Due to the already existing tradition of bud-grafting in the rubber and fruit industries, notably the former, the cocoa industry in Malaysia has been quick to take up the technique for the establishment of clonal plantings. The modified Forkert method is the most commonly used along with semi-hardwood buds. An incision is made in the stock in the form of a normal or inverted letter 'U'. The bark is lifted away in the form of a tongue and the bud shield inserted. The tongue is left to form a protection to the bud when bound over. Budding below the cotyledonary scars on the rootstock prevents shoots developing from the stocks. The standard practice has been comprehensively discussed by Rosenquist (1952). Although bud-grafting requires a measure of skill it possesses many advantages over rooted cuttings in that it entails the use of easy-to-transport budwood, enables more economical use of limited propagation materials and does not involve the use of any specialised propagating facilities. The technique, however, entails an undesirably long period in the nursery, *i.e.* five or six-month-old roostocks and a post-budding period of similar duration. Previous work elsewhere (Giesberger & Coester, 1976; Ramadasan &

Arasu, 1976) with respect to conventional bud-grafting procedures is indicative that, in general, they have been performed on rootstocks which are five months old and older. Since the size, vigour and nutrient status of stock plants are more important than age *per se*, more vigorous genetic materials and superior management practices could enable the use of much younger rootstocks. Such research efforts, however, can be rather long-term and there is also a possibility that there may not be any significant reduction in costs. Hence, it may be preferable and prudent to explore the possibilities for the exploitation of alternative techniques or procedures. In this context, green budding also assumes paramount importance, since it offers considerable scope for more vigorous scion development as well as more economical and efficient production and utilisation of propagation material.

Topper (1958) succeeded in employing four-month-old rootstocks involving inverted T-budding (a form of shield budding) and the use of buds from mature, terminal shoots; this, in fact, constitutes a technique of green budding for cocoa. More recently, Giesberger and Coester (1976) have reported successful trials with green budding and grafting of two to six-week-old seedlings, employing the modified Forkert method and side-grafting method respectively. They have also described a tubular budding knife, allowing for partial mechanization of the budding operation. Other methods of grafting such as cleft-grafting and wedge-grafting have been the subject of experimentation but have had little practical application (Wood, 1975) probably because of the prior existence of effective techniques for the production of rooted cuttings and bud-grafts. Nevertheless, such techniques merit closer examination under Malaysian conditions in the context of possible establishment of any economic advantages over the conventional bud-grafting method.

Marcotting procedures, not involving any grafting, possess little potential for commercial exploitation under Malaysian conditions because of unsatisfactory production efficiency and practical considerations, as evidence by trials in the Malaysian Agricultural Research and Development Institute (MARDI). Nevertheless, the method still merits consideration in certain situations and involves older vegetative material on the mother tree itself.

This paper describes results, observations and experiences with respect to the screening of the above grafting methods, including two newly developed nurse-seed grafting and chip-budding procedures, in both experimental and routine propagation. Consideration is also given to the relative production efficiency of promising methods. Costing for these methods is compared with those for production of seedlings, conventional bud-grafts and recommended methods for production of rooted cuttings.

INVESTIGATIONS ON GRAFTING METHODS

Site of Propagation

Studies were carried out at the MARDI Research Station in Hilir Perak.

Propagation Materials

Scion materials were derived from one or more of the following clones: UIT 1, ICS 95, MHP 363, UA 9 and PA 7. Unless stated otherwise, softwood was used. Rootstocks were obtained from UIT 1 x NA 32 seedlings which have an attractive shoot to root ratio.

Preparation of Polybags

Perforated, black polybags, 15 x 23 cm, were filled with sandy loam top soil.

Sanitary Measures

Seeds were treated with Captan solution (0.1%) during sowing. The soil was drenched with Difolaton (0.2%) two days before actual budding or grafting. Rootstocks and propagation material were wiped with cotton wool dipped in 95% (v/v) alcohol prior to grafting operations in order to minimise the risk of contamination of the graft union.

Provision of Shade

A suitable shade regime of about 5% of full sunlight (measured at midday with a luxmeter) was obtained in sheds, established under the shade of coconuts and *Gliricidia maculata* with the roofing and lateral shade derived from coconut fronds. This shade level is a requirement for the operation of mist-humidification chambers, as described by Ramadasan *et al.* (1976). In the case of techniques which do not involve the use of mist-humidification units, about 30% of full sunlight was provided.

Watering Schedules

This was carried out twice a day, once in the early morning and again in the early afternoon. For chip-budding, it was critical to ensure that this was done in the form of a fine spray from a knapsack sprayer in order to avoid any violent disturbance to the plant. In the case of those techniques which involved the use of mist-humidification chambers, mist nozzles were turned on for 15 min. each time. Essentially, a mist-humidification unit consists of transparent polythene covers supported on a wooden frame, with the incorporation of mist nozzles to provide a high relative humidity close to 100%.

Grafting Tools and Materials

Unless stated otherwise, these consisted of a razor blade and Parafilm*. The latter, normally used in microbiological work, was found to be more suitable and convenient than the normal budding tape because of its elasticity and cohesiveness when subjected to a certain pressure. A further advantage is that there is no necessity to remove it after 'take', as it deterioratres by itself. Moreover, the newly-bursting bud is able to penetrate through it easily. The material is also much cheaper than normal budding tape.

METHODOLOGY, EXPERIMENTAL RESULTS AND OBSERVATIONS

Topper's T-budding Technique

Peliminary trials were performed on four-month-old seedlings more or less as described by Topper (1958). A green bud from a terminal shoot was inserted into a inverted T-shaped cut just below the cotyledonary scars. Much difficulty was experienced in inserting the bud, and the comparatively lower success (about 45%) may have been an indication of cambial damage. Consequently, it was decided not to proceed further with this technique.

*manufactured by American Can Co., Greenwich, Connecticut, U.S.A.

Mechanised Budding

This was performed on four-week-old rootstocks as described by Giesberger and Coester, (1976) except that budding tape was employed instead of raffia and aluminium foil. A tool, similar to a cork borer but containing a spring-loaded plunger, was constructed. By appropriate manipulation, a circular disc of about 0.3 mm in diameter could be removed from the rootstock and a corresponding patch, containing a bud, from the scion. By pressing on the plunger, the disc of bark can be discarded or inserted. In practice, this was not an easy and smooth operation. The presence of thick, slimy mucilage aggravated the situation; the green bud often failed to be released for insertion. No success was obtained with any of the buddings.

Top-grafting and Side-grafting

There were performed more or less according to Giesberger and Coester (1976).

Top-graftings. Two to four-week-old seedlings which had just started to unfold their first pair of leaves, were decapitated just above the cotyledon. Subsequently, a 2 to 3 cm longitudinal incision was made between the cotyledons through the stem for wedge-grafting with a 2 cm piece of defoliated green scion wood containing one or two buds. Cotton yarn was used to bind the stock and scion. A transparent polythene bag was placed over the grafted plant to protect it from dehydration. Very poor success (about 2%) was obtained. Binding was very difficult as the wedge tended to slip out due to the presence of the slimy mucilaginous fluid. Callus development along the slit tended to squeeze out the graft. A major drawback was the tendency for the axillary buds from the cotyledons to develop, despite regular excision. These observations were in line with those made by Giesberger and Coester (1976).

It was decided not to pursue any further work on this technique.

Side-grafting. Two to four-week-old rootstocks were employed. The hypocotyl, just below the cotyledons, was split downwards through the centre for a distance of 2 to 3 cm. The base of the graft, prepared from green defoliated branches and possessing a single axillary bud, was subjected to two slanting cuts, one slightly longer than the other in order to form a gradually tapering wedge. Budding tape was used to secure the graft firmly in portion. A transparent polybag was inverted over the grafted plant to prevent drying out. Cutting into the hypocotyl of the rootstock, inserting the scion wood and binding were extremely delicate procedures. The scion piece tended to slip out because of the slimy mucilage. Although results of preliminary trials were quite satisfactory (about 55%), no further work was carried out as it did not appear to be practicable and convenient for large-scale propagation.

Cleft-grafting

Four-week-old seedlings were employed as rootstocks. The stock plant was excised at an angle, just below the cotyledons (*Figure 1*). The same procedure was repeated on the other side so that a wedge-shaped structure resulted. At the same time, a two-leaf, softwood or semi-hardwood cutting (with the leaves trimmed by half) was prepared and the base was split to form a cleft to fit over the wedge in the rootstock. The scion was inserted in position onto the rootstock and the arrangement was bound together tightly with Parafilm, a laboratory material whose suitability for binding was recognized just then in order to ensure a good union as well as prevent the entry of water. The binding was performed starting from the base of the stock plant so as to help hold the scion and prevent it from slipping out.

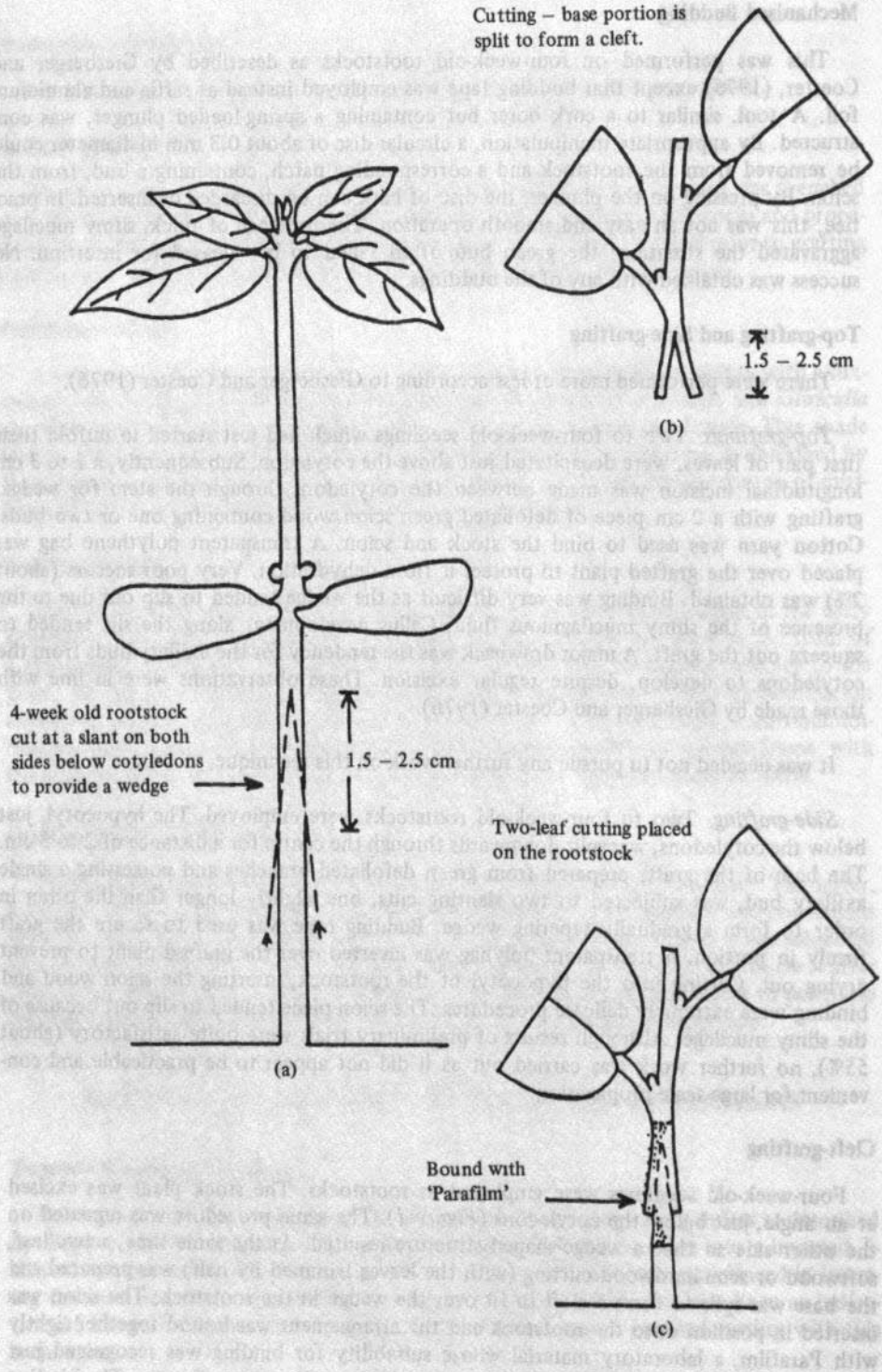


Figure 1. Cleft-grafting

Lateral Grafting

This is in fact a variation of the cleft-grafting technique. The rootstock was cut at a slant below the cotyledons. Similarly, the base of the cutting was also cut at a slant so that it fitted on to the prepared rootstock (*Figure 2*). The technique could be modified to employ two rootstocks, each cut at a slant and fitted on to a scion with a V-shaped basal end.

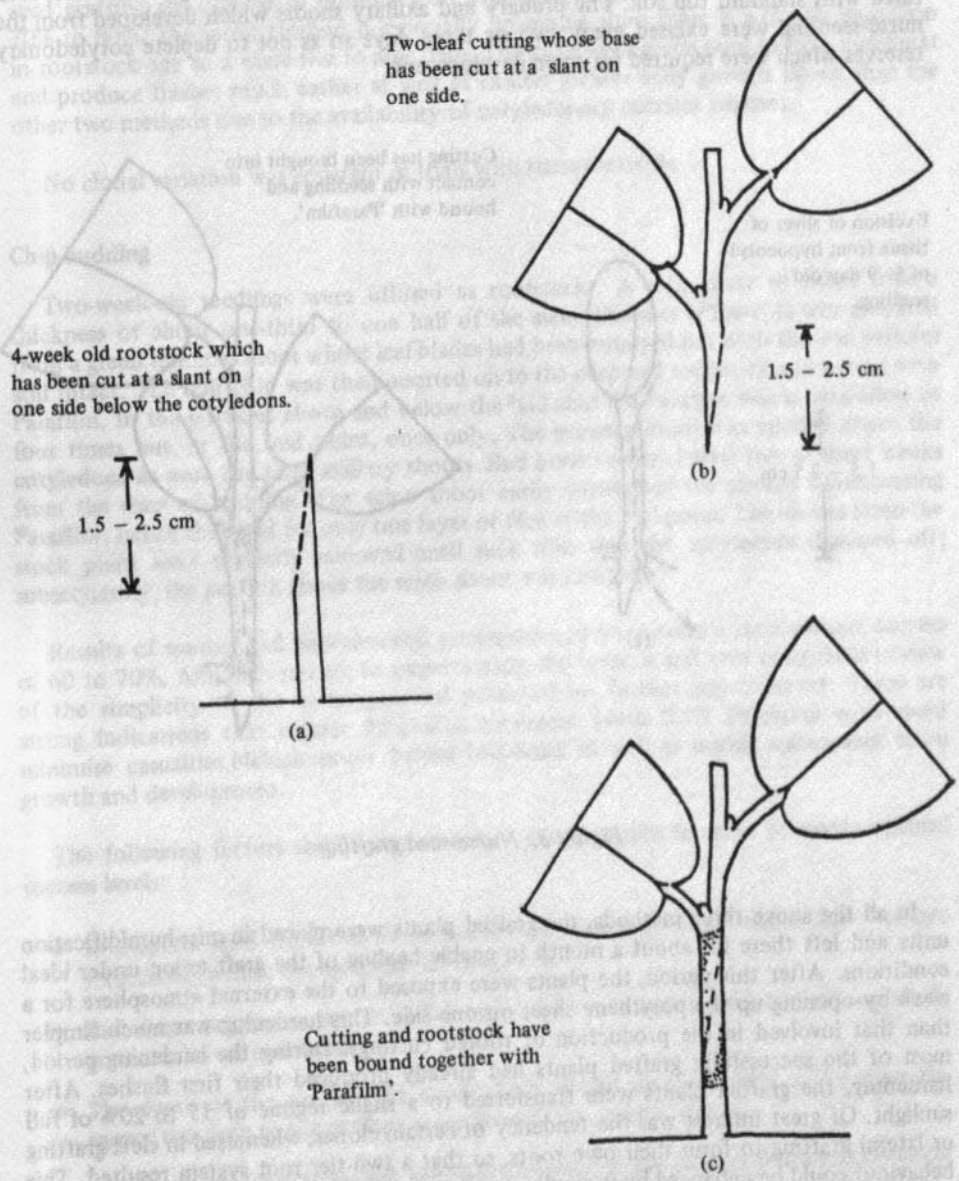


Figure 2. Lateral grafting

Nurse-seed Grafting

Five to nine-day-old seedlings, which were germinated in sandbeds, were washed and the moisture subsequently eliminated by placing them on tissue paper. A sliver of tissue was removed on one side of the hypocotyl (*Figure 3*). A trimmed two-leaf soft-wood or semi-hardwood cutting was cut similarly on one side and brought into contact with the cut surface of the hypocotyl, and bound firmly with Parafilm. The grafted plant was subsequently planted in 15 cm x 26 cm perforated black polybags which had been filled with standard top soil. The primary and axillary shoots which developed from the nurse-seedling were excised every two or three days so as not to deplete cotyledonary reserves which were required for scion development.

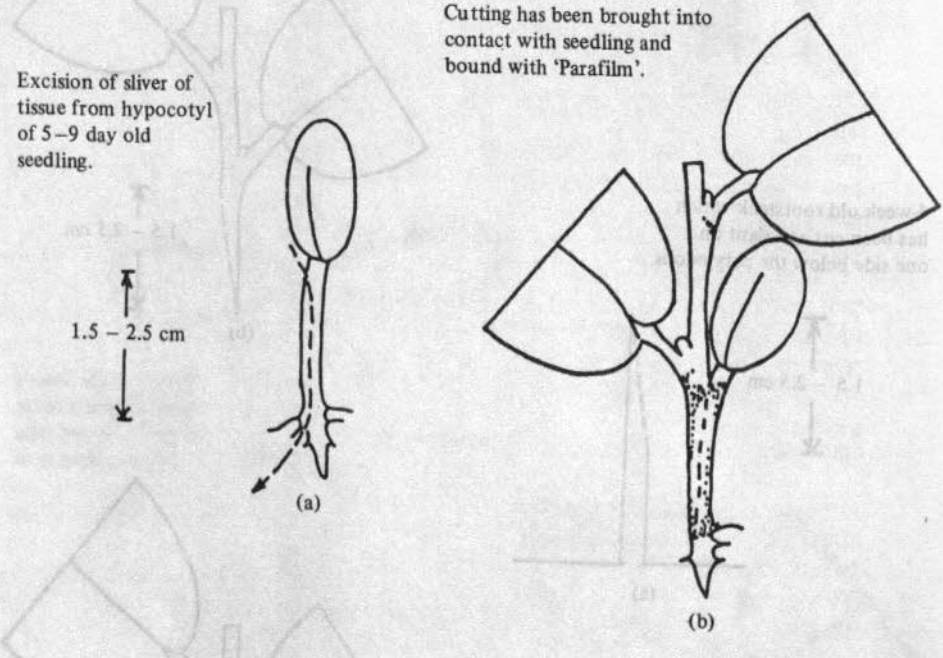


Figure 3. Nurse-seed grafting

In all the above three methods, the grafted plants were placed in mist-humidification units and left there for about a month to enable healing of the graft union under ideal conditions. After this period, the plants were exposed to the external atmosphere for a week by opening up the polythene sheet on one side. This hardening was much simpler than that involved in the production of rooted cuttings. During the hardening period, most of the successfully grafted plants had already produced their first flushes. After hardening, the grafted plants were transferred to a shade regime of 15 to 20% of full sunlight. Of great interest was the tendency of certain clones, when used in cleft-grafting or lateral grafting to form their own roots, so that a two-tier root system resulted. This behaviour could be enhanced by mounding earth around the base. This response was most pronounced in UIT 1. It should be also mentioned that no real difference was apparent in terms of success between cleft- and lateral grafting; the former, however, produced a mechanically stronger graft union in the earlier stages of growth and development. It is

also noteworthy that both softwood and semi-hardwood scion material could be exploited. A point of interest is the fact that the excised portions of stock plants in cleft and lateral grafting can be easily rooted and recycled for use as root-stocks. In the case of nurse-seed grafting, in the event of failure, the nurse seedling can be allowed to develop for use as a rootstock for other techniques.

Based on the results of routine and experimental propagation, cleft-grafting and nurse-seed grafting are capable of producing an acceptably high level of final success, that is, 70% to 80%. The latter method is especially promising since there is a drastic reduction in rootstock age to a mere five to nine days. The nurse-seed grafts tend to have bud-burst and produce flushes much earlier as well as exhibit greater early growth vigour than the other two methods due to the availability of cotyledonary nutrient reserves.

No clonal variation was apparent in trials with these methods.

Chip-budding

Two-week-old seedlings were utilised as rootstocks. A thin silver of tissue with a thickness of about one-third to one half of the stem diameter (*Figure 4*) was prepared from a green terminal shoot whose leaf blades had been removed but with the leaf petioles still intact. The bud chip was then inserted on to the prepared rootstock and bound with Parafilm. In the portions above and below the bud chip the Parafilm was wound three or four times but, at the bud point, once only. The primary shoot was excised above the cotyledons as were the later axillary shoots. Bud-burst occurred after two or three weeks from the time of budding. The scion shoot easily penetrated the already deteriorating Parafilm; hence the need for only one layer of film at the bud-point. The shoots from the stock plant were regularly removed until such time that the cotyledons dropped off; subsequently, the portion above the scion shoot was excised.

Results of routine and experimental propagation, demonstrate a final average success of 60 to 70%. Although not up to expectations, the level, is still very acceptable in view of the simplicity of the technique and potential for further improvement. There are strong indications that regular fungicidal treatment (with 0.1% Difolatan w/v) could minimise casualties, which occur before bud-burst as well as during subsequent scion growth and development.

The following factors should be taken into consideration in order to ensure optimal success levels:

- Rootstocks aged from five to sixteen weeks produced better results than younger rootstocks (within the age range investigated).
- Bud chips, ranging in size from 2.5 cm to 1.2 cm in length were ideal. If too small, poor results were obtained.
- The depth of the cut into the stock plants should be about 50% of the stem diameter; too deep or too shallow a cut lowered the level of success.
- A critical requirement is that watering should be in the form of a fine mist in order to prevent any disturbance to the grafted plants.
- Shade should be less than 15 to 20% full sunlight.

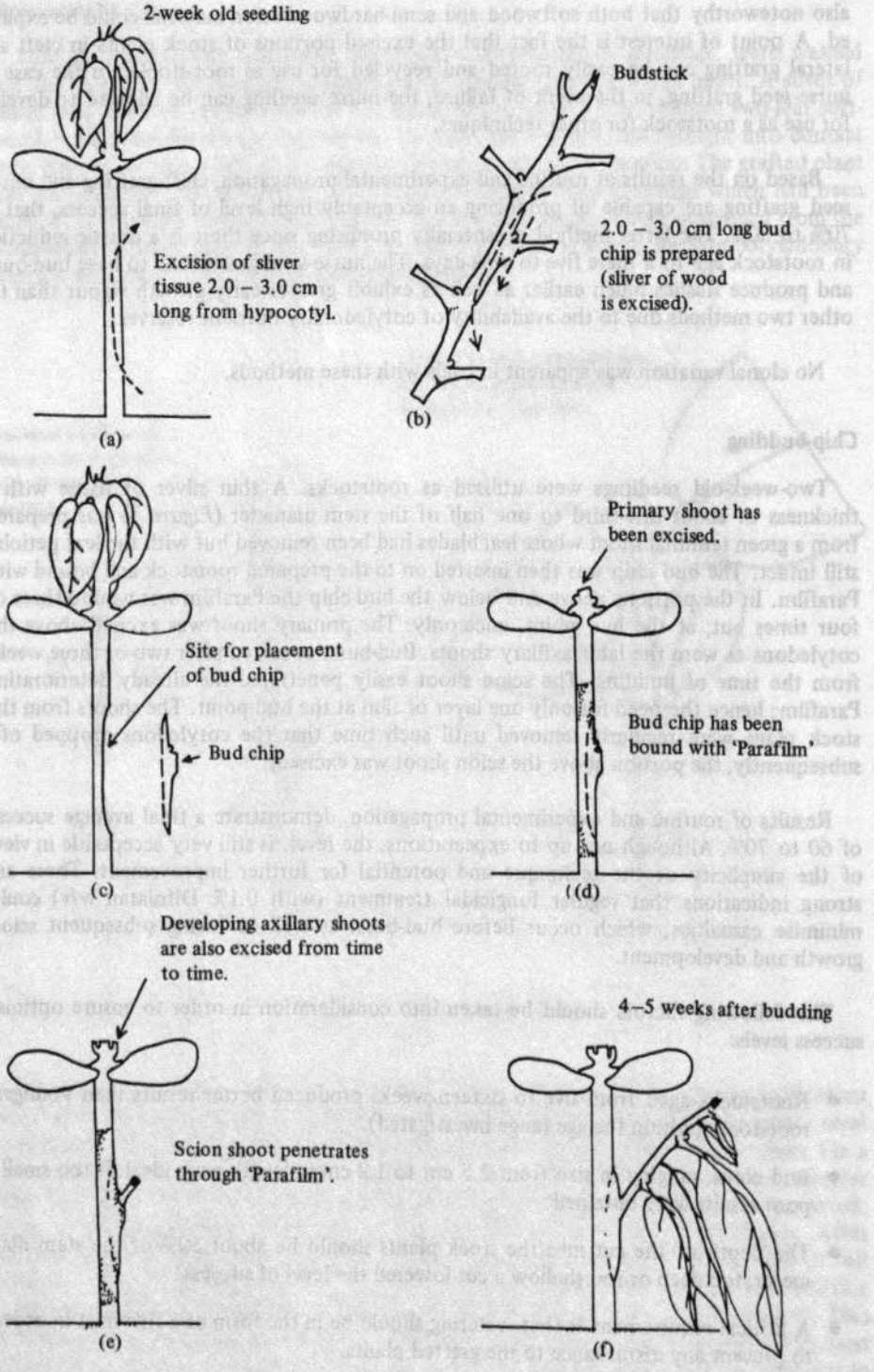


Figure 4. Chip-budding

- It was advantageous to excise the terminal shoot above the cotyledons at least one week before budding. The hypocotyl becomes thicker and harder, so that budding is facilitated at about three weeks. Excision should be performed at least at the time of budding. Any further delay may lead to failure of the graft union of scion shoot emergency.

No clonal variation was apparent. The performance of chip-budding in the field was observed to be comparable with that of plants from conventional bud-grafting, at least in terms of vegetative growth and development. *Figure 5* shows a two-year-old chip-budding plant in the field.



Figure 5. Two-year-old chip-budded plant in the field.

Cost analysis

The cost per nursery plant, produced by the various selected propagation methods, is presented in *Table 1*. Costing has taken into account what was involved in setting up the propagation facilities and running them, labour requirements and maintenance of the propagated plants in the nursery up to six months. Chip-budding is the cheapest method at all levels of success and compares very favourably with seedlings. On the other hand,

TABLE 1. COST ANALYSIS FOR DIFFERENT METHODS OF PROPAGATION

Method of propagation	*Cost per plant ($)*		
	50% success[a]	*Actual average success*[b]	*90% success*[c]
Seedling production	$0.91	$0.57 (80.0%)[e]	$0.50
Cuttings:			
i. Polythene sheet method	$1.08	$0.95 (57.5%)	$0.66
ii. Mist humidification	$1.09	$0.86 (68.3%)	$0.69
Budding[d]	$1.72	$1.14 (79.0%)	$1.02
Cleft grafting[f]	$1.16	$0.84 (73.2%)	$0.71
Nurse-seed grafting[g]	$1.09	$0.76 (75.8%)	$0.65
Chip-budding[h]	$0.94	$0.59 (65.0%)	$0.53

[a] Minimum success for acceptability of method
[b] Percentage success indicated within brackets
[c] Desired minimum level of success
[d] Six-month-old rootstocks
[e] 20% culling
[f] One-month-old rootstocks
[g] Seven-day-old rootstocks
[h] 3-week-old rootstocks

old (conventional) budding is the most expensive at all levels of success, as a result of the long nursery period, so that cleft-grafting, nurse-seed grafting and chip-budding become very attractive propositions.

DISCUSSION AND CONCLUSION

Developments in vegetative propagation technology follow closely in the wake of the growing importance of clonal propagation in the cocoa industry in Malaysia. It is not intended that newer methodology completely displace the old conventional bud-grafting practice; rather it is envisaged that newer techniques will facilitate nursery management operations in relation to availability of propagation material and field planting schedules wherein the conventional bud-grafting technique has still an important, though somewhat reduced, role. Conventional bud-grafting practice will always have a ready application in field budding operations and in the utilisation of semi-hardwood budwood.

Of the methods screened, chip-budding is the most attractive in terms of its simplicity and cheapness, involving no specialised propagation facilities, and could readily be adopted for commercial exploitation. In fact, the technique has been already adopted (and perhaps even adapted) by various quarters in the cocoa industry. Further streamlining of the methodology could result in higher success levels and correspondingly reduced costs. Compared with the old conventional bud-grafting and rooted cuttings, the skill requirements are relatively minimal. The possible extension or adaptation of the technique to older nursery rootstocks could result in more plentiful production and efficient utilisation of budwood. Although green buds can be used in conventional bud-grafting, it is

restricted to material which can be peeled and that, too, with difficulty. The chip-budding technique will enable material to be taken from the much younger portion of the mature terminal shoot. It has been already established in investigations that chip-budding can be successfully performed on rootstocks up to four months old although cotyledonary reserves are not available. There is strong evidence that the technique can be successfully adapted to much older rootstocks in both the nursery and the field, including the budding of mature trees in cocoa rehabilitation (Mohd. Jelani Bahaudin *et al.*, 1984)

Nurse-seed grafting, in terms of reducing the rootstock age, is the most effective since it employs stock plants which are only five to nine days old. Cotyledonary reserves are available to the graft resulting in earlier bud-burst and more vigorous scion development. The method can be further simplified and rendered more economical by means of simply inverting transparent polythene bags over individual grafted plants or placing polythene sheets, with some minimal support, over a number of grafted plants arranged closely together in order to ensure highly humid surroundings. The use of natural shade can result in further cost savings. In large-scale propagation, the use of intermittent mist may be more beneficial and convenient instead of polythene covers. Similar consideration also apply to cleft-grafting or lateral grafting.

It is noteworthy that in nurse-seed, cleft and lateral grafting, there exists the possibility of recycling rootstock materials. In case of failure, the nurse-seedling can be allowed to develop for use as a rootstock for cleft or lateral grafting or chip-budding. Excised upper portions of rootstocks for cleft and lateral grafting can be easily rooted and recycled for use as rootstocks for the same techniques or chip-budding, if there is no objection to the fact that the material is from above the cotyledons. Budding or grafting below the cotyledons eliminates the possibility of emergence and development of foreign axillary shoots.

A point of major interest in cleft-budding is the capability of some clones to form their own roots so that a two-tier root system results. It is possible that this could confer advantages in terms of plant performance since Cope (1953) has demonstrated that good clones tend to perform better on their own root system than on foreign rootstocks. A two-tier system could give rise to a superior root system. Efforts to induce such a system in all the grafting techniques described herein by hormonal means as well as subsequent monitoring of root growth and development in relation to plant performance, merit consideration.

The use of green buds seems to confer a tremendous advantage in that bud emergence and scion development vigour are superior to that derived from older material from semi-hardwood budwood. In fact, it would appear that green-budded plants can be transplanted much earlier into the field, that is, as early as four months from grafting. Possibly, if green buds could be used in conventional budding, the post-budding nursery period can be significantly shortened. The major thrust of investigations has been the reduction of rootstock age; in fact, serious consideration should be also directed towards the determination of the right rootstock age which corresponds to optimal performance of plants derived from green buds or grafts. Possibly, the use of very young rootstocks with their relatively poor root development, may be a constraint to the vigorous scion development inherent in the use of green propagation materials. Successful application of the technique to budding of mature trees in the field could pay high dividends in terms of shortening the immaturity period.

The recent development of multiple shoot induction in *in vitro* culture by MARDI marks a major breakthrough in cocoa vegetative propagation (Mohd. Senawi Mohd. Tamin, 1984). When perfected in the future, apart from other applications, it will offer scope for production of complete plantlets (including much-desired chupon material) and clonal rootstocks. The eventual exploitation of materials produced by this method will, needless to say, be dependent on practical considerations and costing.

The methodology of the grafting techniques and chip-budding is interim and requires streamlining based on further research. Due emphasis should be concentrated on botanical factors which influence final success. In this context, phytosanitary measures merit serious attention, both during the pre- and post-propagation phases. Although observations to-date appear to indicate that the performance of these materials in the field, at least in terms of vegetative growth, is comparable to that of plants derived from contentional bud-grafting, there is still a need to monitor this in greater detail.

ACKNOWLEDGEMENT

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Evaluation of Several Mature Budding Techniques of Cocoa

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Mature budding techniques of cocoa are of prime importance in rehabilitation exercise for diseased and unproductive trees using clonal materials. Currently most of the smallholders' areas are planted with untested materials and the yield per tree is very variable. Hence, there is a need to look into the various mature budding techniques, which facilitate transfer of clonal materials to smallholders. Emphasis is upon the ease and success of grafting.

This paper reports on the various budding techniques including chips mature budding. Percentage success, timing of budding tape removal and other pertinent observations on the techniques are presented.

EVALUATION OF SEVERAL MATURE BUDDING TECHNIQUES OF COCOA

Cocoa cultivation in Malaysia has been expanding at a rapid rate since 1970. The area under the crop in 1982 was about 170,000 ha. However, to ensure the continued healthy development of the cocoa industry, the problem of low yield and poor quality beans experienced by the smallholders, giving poor returns has to be tackled immediately. Approximately half of the area under cocoa in Peninsular Malaysia is in smallholders. Yusof (1981) reported that the smallholder cocoa only produced about 500 kg dry beans per hectare in comparison with 1,300 kg per hectare per year for estates.

Rehabilitation

The main objective of any rehabilitation programme is to restore or improve the plant yield to a profitable position. In cocoa the main reasons for low yield are the use of unsuitable (unselected) varieties or progenies, trees over the economic age, competition with shade trees especially in nutrients uptake, water and sunlight; unbalanced shade regime; incorrect cultural practices and depredations of pests and diseases.

The initial requirement for rehabilitation for cocoa in Peninsular Malaysia arose when large plantings were affected by vascular streak dieback (VSD) caused by *Oncobacidium theobromae* resulting in severe yield depression (Ang, 1976). In 1959, the dieback problems had increased to such an extent that the Minister for Agriculture announced that cocoa could no longer be recommended as a smallholder crop. Amelonado seedlings were found to be highly susceptible to the disease. Ang (1976) carried out rehabilitation by replanting and budding to regenerate trees in order to counter the VSD problem.

The need for rehabilitation remains because of substantial planting by smallholders of unselected F2 generation seedlings, which give low yield and are prone to diseases.

Generally the recommended mixed hybrid give reasonably satisfactory yield, but the pattern distribution within the seedlings is variable. The best 30% of the trees of the progenies accounted for about 50% of plot yield (Lee, 1978). In overcoming these problems, clonal plantings are the solution for new areas, but rehabilitation for existing cocoa areas will probably have to be carried out extensively.

The techniques of rehabilitations must also be considered in terms of farmers' acceptance. The method of growing young cocoa under old cocoa trees (under planting) is favoured in Colombia, Costa Rica and Nigeria, since the farmers are assurred for reasonable returns from their old cocoa, while the young are being established (Are, 1969). Jayawardena *et al.*, (1978) also agree with the attractive proposition when recommending underplanting, mature budding and budding on basal chupons as measures against VSD incidence.

The cocoa industry in Malaysia is still young. In rehabilitating unproductive cocoa areas, replanting and underplanting techniques automatically remove the existing young cocoa (8–15 years). Instead, if mature budding techniques are considered, then the existing plant will be maintained as the root stock. Ang (1976) indicated that the replacement scion might commence yielding eighteen months after budding. With mature budding, large areas of smallholder plantings can be successfully rehabilitated into clonal plantings in a relatively short period.

As visualised, mature budding has potential for rehabilitation and for improvement of yield from poor quality seedling plants. It should produce more uniform performance within cocoa stands.

MATERIALS AND METHODS

Techniques of Mature Budding

The age of the root stocks (mixed Sabah hybrid) were about nine years. Approximately 90–120 cm tape is required.

Mature budding – scrapping method. Three techniques of mature budding were described by Ramadasan *et al.*, (1981). The scrapping technique is the most popular among the three. It is a modification of the green budding technique (Shepherd *et al.*, 1981) that has been applied for budding cocoa seedlings in the nursery. This technique is used as a control in this paper (see *Figures 1a–g*). Using a budding knife, the area to be budded is scrapped to a thickness of about that of the oncoming budpatch. A horizontal cut of about 6–8 mm is made into the rootstock to cambium depth. The bark is then carefully peeled upwards to expose a panel of cambium, 6–8 mm wide and 3–4 cm long for receiving the budpatch. The flap is trimmed to 1 cm length to provide a tongue at the upper end of the stock panel which will help hold the budpatch in place *(Figure 1g).* Ramadasan *et al.*, (1981) recommended semihardwood bud stick for budding. A budpatch narrower than the fresh exposed stock panel is placed against it. The orientation of the bud which should be above the petiole remnant should be ensured. Strict cleanliness should be practised in avoiding any possible contamination with soil or other matter on cambial surfaces. The budpatch is positioned firmly against the stock panel by means of transparent budding tape of 2.5 cm wide. Binding starts below the panel and the tape is wound clockwise and upwards, each turn overlapping the preceding one to ensure satisfactory seal.

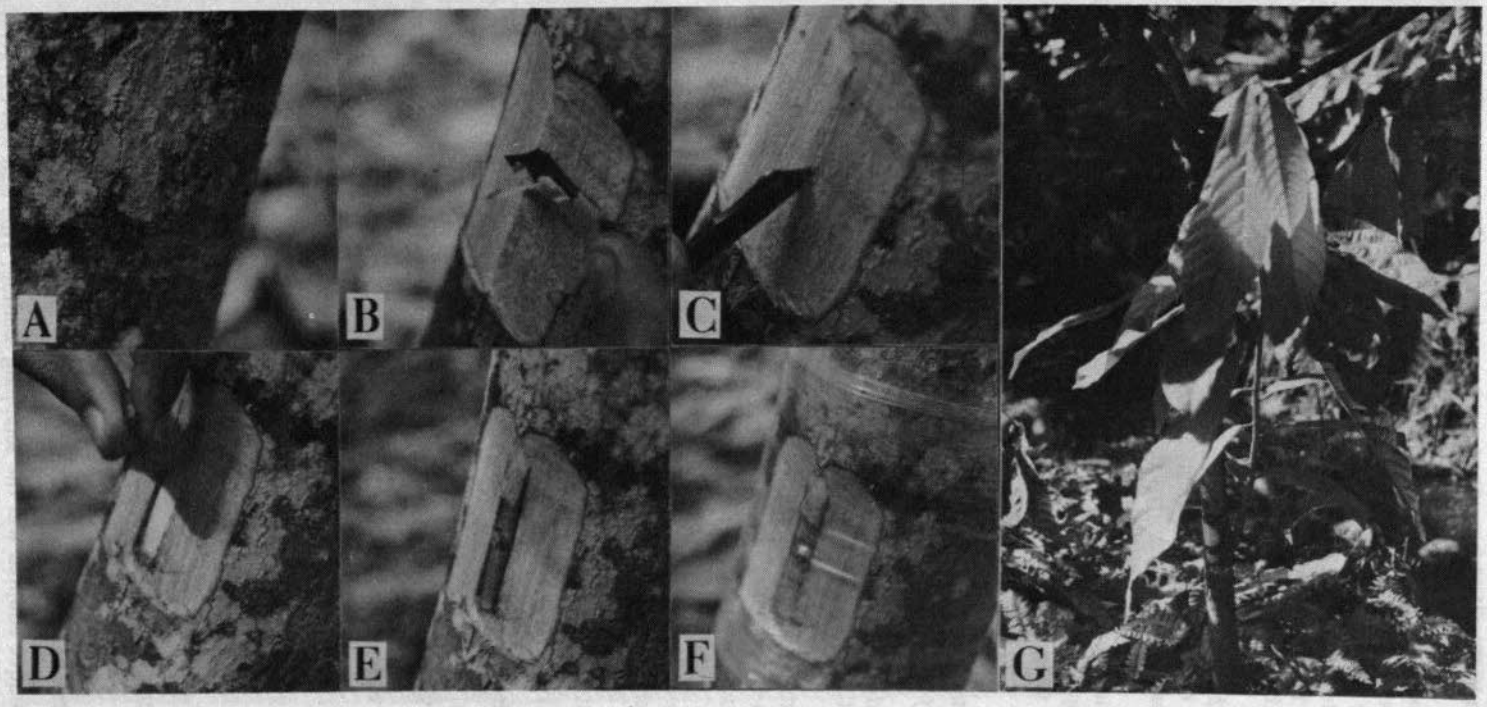


Figure 1. Mature Budding Technique By Scrapping.

Mature budding – closed method. The closed mature budding method is actually modified and simplified from the scrapping technique *(Figures 2a–f).*

The process is the same as that of the scrapping method, except that there is no scrapping and trimming of the bark and flap respectively. Once the budpatch is placed against the freshly exposed stock panel *(Figure 2c),* it is closed up by reinstating the bark flap to its original position with the help of the budding tape *(Figure 2e).* In this method it is important to ensure that the petiole remnant is taller than the bud when reinstating the bark flap.

Mature budding – without budding tape. This is a modification of closed budding. Here once the budpatch is placed against the freshly exposed stock panel, it is closed up by reinstating the bark flap to its original position with the help of a carpenter's thumb pin and covered up with plasticine. *(Figures 3a–i).* In this technique, the bark flap is trimmed off, of about 1 cm at the lower end of the stock panel. This is to act as a drainage system if ever water is found to be collected *(Figure 3d).* The plasticine is used in order to prevent air from entering, which might lead to the drying of the budpatch.

Other modification of the closed method. There were four other techniques that have been tried. The processes were the same except that:

- The stock panel is closed up by reinstating the bark flap to its original position with only the help of a carpenter's thumb pin.
- The stock panel is closed by reinstating the bark flap to its original position with the help of a carpenter's thumb pin and covered up with a mixture of starch (tapioca flour) and benlate..
- The stock panel is closed by reinstating the bark flap to its original position with the help of a carpenter's thumb pin and covered with Santar A.
- The stock panel is closed by reinstating the bark flap to its original position with the help of a carpenter's thumb pin and covered with paint.

Timing of Budding Tape Removal

For this trial, the scrapping and the closed mature budding techniques were chosen. The treatments involved removal of budding tapes at varying intervals as follows:–

- Tape removed five days after budding.
- Tape removed ten days after budding.
- Tape removed fifteen days after budding.
- Tape removed twenty days after budding.

Seventy-five plants were used per treatment. The data were collected two weeks after the removal of the budding tape. This is in order to be sure about the percentage success.

Choice of Bud Wood

The technique adopted was the scrapping method. This trial was carried out to com-

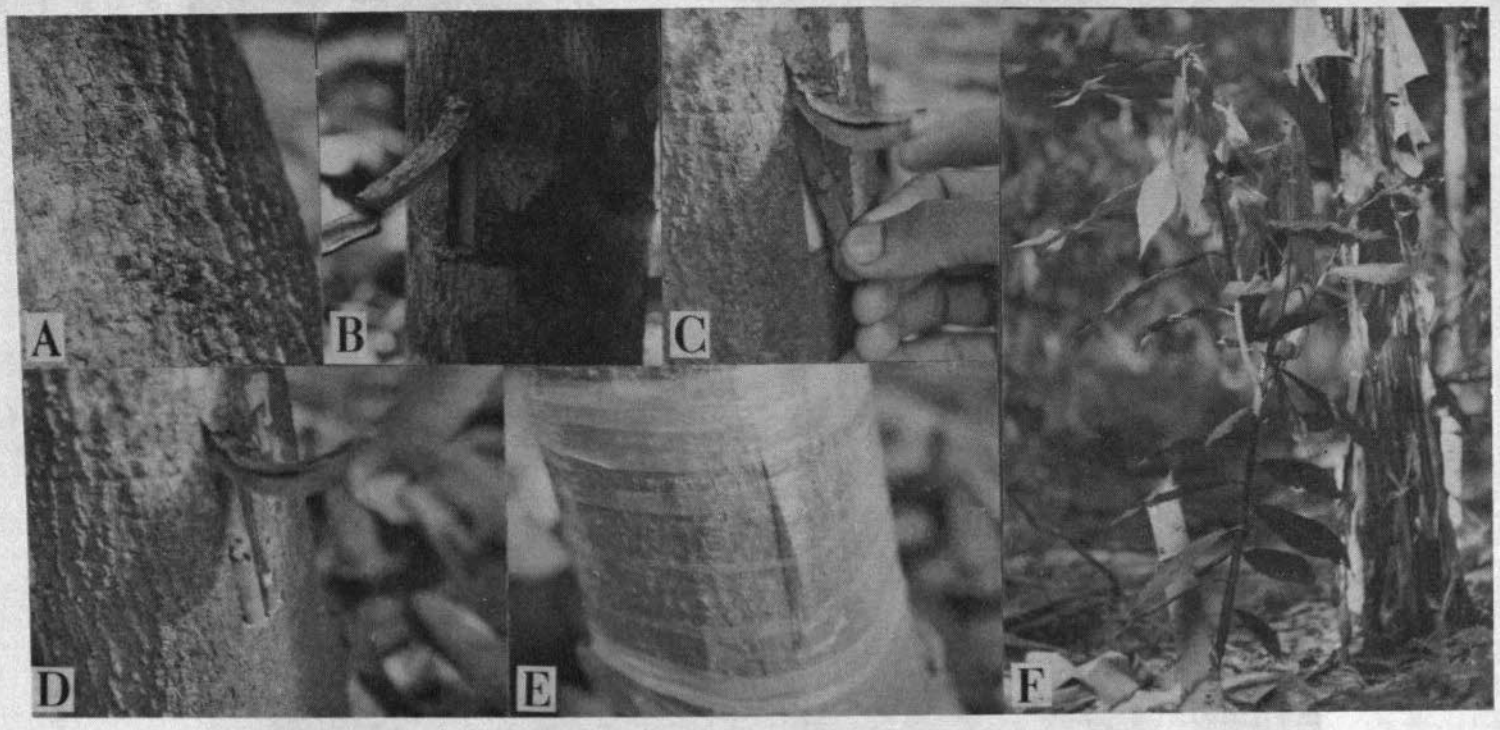


Figure 2. Mature budding (close method).

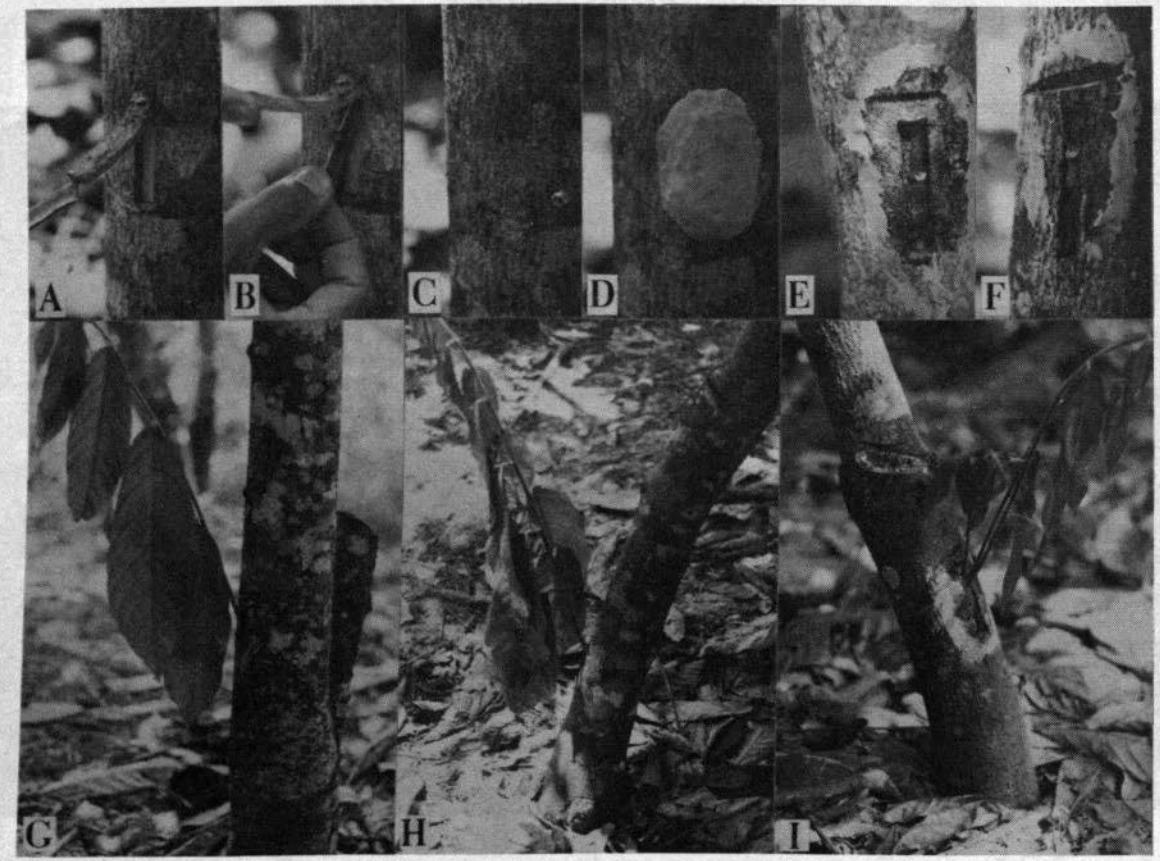


Figure 3. Mature Budding Without budding tape (using plasticine).

pare the performance of budpatchs from semihardwood and budpatchs or chips from softwood *(Figure 4)* for mature budding.

The budding tape was removed ten days after budding. The percentages for budding success were recorded and the percentages of points showing scion growth were recorded at weekly intervals.

RESULTS

Technique of Mature Budding.

The data of percentage success of the various techniques tested are summarised in *Table 1.* Out of the seven techniques tested, only three, including the control, were found to have potential value. The techniques are, close budding with the help of budding tape, close budding with the help of carpenter's pin and plasticine, and the control (the scrapping method).

TABLE 1. PERCENTAGE SUCCESS OF VARIOUS MATURE BUDDING TECHNIQUES

Treatments	*Success (%)*
Close budding + Carpenter pin	4
Close budding + Carpenter pin + mixture of starch and benlate	23
Close budding + Carpenter pin + Santar A	5
Close budding + paint	2
Close budding + budding tape	73
Close budding + carpenter pin + plasticine	71
Control – mature budding (scrapping method)	71

100 plants of about nine years old were used in each treatment.
The trial was carried out by using ICS 95 and ICS 84.

Timing of Budding Tape Removal.

The result of the timing of budding tape removal are summarised in *Table 2.* Both techniques tested, *i.e.* mature budding closed method and scrapping, gave high percentage

TABLE 2. TIMING OF BUDDING TAPE REMOVAL

Treatments (No of days after budding)	*Percentage success on removal of budding tape*		*Percentage success one week after budding tape removal*		*Percentage success two weeks after budding tape removal*	
	Close method	*Scrapping method*	*Closed method*	*Scrapping method*	*Closed method*	*Scrapping method*
5	100	100	56	5	30	3
10	91	98	87	87	87	82
15	90	83	82	80	73	72
20	3.3	70	0	58	0	57

45 plants of about nine years old were used for each treatment.



Figure 4. Mature budding – Scrapping techniques using softwood bud
1 AND 2 – Softwood budstick
A – H – Steps of the techniques.

success when the budding tapes were removed after the 10th day. Even after the 15th day the success was high.

Choice of Budwood.

The results from *Table 3* indicate that, budwood taken from the softwood budsticks is not only comparable in terms of budding success to the semihardwood but also is better in terms of percentages for scion growth.

TABLE 3. PERFORMANCE OF BUDPATCH/BUDCHIP FROM SEMIHARDWOOD (S.H.W) AND SOFTWOOD (S.W.) BUDSTICK ON PERCENTAGE OF SCION GROWTH.

Time	*Percentage points with bud emergence*	
	Semihardwood	*Softwood*
1 week after budding tape removal	9.3	40
2 weeks after budding tape removal	22.6	69.4
3 weeks after budding tape removal	30.6	80.0
4 weeks after budding tape removal	36.0	81.2

Number of matured plant budded with the semihardwood were 100.
Number of matured plant budded with the softwood were 114.
Percentage of budding success for the semihardwood was 75.0 and for the softwood 74.6

DISCUSSION

With mature budding, large areas of smallholders low quality F2 generation seedlings can be successfully transformed into a high quality clonal plantings in a relatively short period at a low cost. The technique adopted should not only emphasise success but also ease of grafting. This paper introduces two more potential techniques which are found to be simpler than the control at the same level of success *(see Table 1)*. As for the close budding technique, the budders are not required to acquire the scrapping skill, which is normally a problem. If they are not careful they can expose the cambium.

With the introduction of plasticine the tying skill required of the budders is removed. Thus less skill is needed in this technique. The plasticine can be reused (indication of less cost) and the budding can be carried at any position on the trunk, even beside a chupon or pod, without any problems.

Even though *Table 2* shows 0% success in the closed budding technique if the budding tape was removed 20 days after budding, some success was experienced even up to 30 days during the clear months of the year (mild rainfall). The low percentage success was due to the accumulation of water under the bark flap.

Even if the percentage of budding success is high, that does not mean we have achieved our goal. In many occasions a high percentage of successful buddings remains dormant. With the introduction of chip mature budding, the percentage of scion growth can go up to 80% in the third week after budding tape removal *(see Table 3)*. This could be due to the meristematic parenchyma cells of the softwood remaining active. Future

research should attempt to preserve the flush for longer period of time where there is need to transfer budsticks to a distant place.

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10 Some Aspects on Spacing and Thinning in Cocoa

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This paper reports the results from two experiments on spacing and thinning of cocoa. Close spacing of single stem plants with and without thinning, single versus multiple-stem plants at lower densities and various methods of thinning hybrid cocoa planted at high density were investigated.

In the first trial, highest yields were obtained from the close-spaced planting with and without thinning. The remaining trees after selective thinning yielded as well as those with the no-thinning treatment on an area basis, and also gave better yields than those of the single and multi-stem treatments at equivalent density from planting. Trees in the wider spacing produced more pods per tree but less yield per hectare. No statistical difference between yields of single and multi-stem treatments in a given spacing was noted.

In the second thinning trial, high density gave significantly higher early and cumulative yields. Progressive thinning on the basis of geometry plus vigour resulted in the final selection of trees yielding better and being more manageable than trees in the no-thinning treatment.

Plant density is an important factor affecting the yield of cocoa per unit area of land. Previous workers (Blencowe & Hubbard, 1972) have advocated planting cocoa at a spacing much closer than the assumed optimum density for a given soil and climatic situation, with later thinning out to maintain a more manageable and economic stand for the long term.

A factor which has a direct bearing on the potential pod set and subsequent yield of cocoa is the number of flowers produced by a single tree. Since flowering cushions arise in leaf axils on the old wood and branches, the production of multiple-stems would be to increase the surface area of the main stems, thus increasing the number of leaf axils and hence potential flowering sites on a single cocoa tree. The situation of multiple-stem treatment would probably be comparable to the planting of a single stem tree at a higher density (Lee, 1976). An opportunity to test different spacing as well as single versus multiple-stems cocoa at the lower densities was provided in the first trial.

In accepting that close spacing should give the highest yield in the early years, and having planted at high density to exploit this merit, the planter is soon faced with the situation on how best to go about thinning and shaping of the final selection of trees. The second trial examined the various approaches to the thinning of hybrid cocoa initially planted at 3.96 m x 1.83 m (1380 trees/ha).

METHODS

Both the trials were sited on deep young basaltic soil in Table Estate and has been previously described by Phillips & Armstrong (1978).

Trial I

Details of the experiment have been reported by Armstrong (1976). For ease of reference, the experimental layout and brief history are given below.

A commercial field, planted in July/August 1969 at a uniform spacing of 3.96 m x 1.83 m (1380 trees/ha) was chosen for the trial. The experiment was initiated in March 1970. Seven months later, the requisite trial densities were achieved by removing unwanted cocoa within the row. Layout was a randomised block design with four replicates of six treatments, each plot being 39.6 m x 36.6 m (0.145 ha). Four cocoa hybrids, namely Am1 x Pa7, UIT1 x Na32, Pa7 x Na32 and UIT1 x Na33 were used in the trial and progeny was confounded with replicates. The experimental treatments were as follows:

1. HDU (SS) – Cocoa at 3.96 m x 1.83 m (1380 trees/ha) throughout life. Single stem.
2. HDT (SS) – Cocoa at 3.96 m x 1.83 m (1380 trees/ha) initially, thinning to 3.96 m x 3.66 m equivalent* (690 trees/ha). Single stem.
3. MD (SS) – Cocoa at 3.96 m x 3.66 m (690 trees/ha) throughout life. Single stem.
4. MD (MS) – Cocoa at 3.96 m x 3.66 m (690 trees/ha) throughout life. Multiple stem**.
5. LD (SS) – Cocoa at 3.96 m x 5.49 m (460 trees/ha) throughout life. Single stem.
6. LD (MS) – Cocoa at 3.96 m x 5.49 m (460 trees/ha) throughout life. Multiple stem**.

In the early establishment, shade was provided by a mixture of *Gliricidia maculata* and commercial abaca. The latter was eliminated at an early stage following *Gliricidia* establishment throughout the area at a spacing of 3.96 m x 1.83 m.

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* For the first five years the first and second treatments were identical. From October to December 1974, selective pruning and a final elimination of trees to half the original density was completed in the plots of the second treatment. Trees were evaluated in pairs and the least desirable tree of the pair was pruned and then removed. This made for an irregularly spaced stand but resulted in the retention of a larger proportion of high-yielding trees than would have been the case if regular alternate tree removal was followed. The second and third treatments had identical plant densities from January 1975.

** In the multiple-stem treatments the aim was to have four chupons per tree arising at near ground level. The procedure for the induction of multiple stems is described below.

The stem of the seven-month-old cocoa seedling was cut half way through and the top portion was then bent to ground level. In this trial the incision was made at 30 cm above ground level. Strong development of chupons from below the cut occurred within two months. Five months after incision, multiple-stemmed trees were pruned to limit the number of stems to four, although some trees failed to produce as many as four chupons. A light bamboo ring with a diameter of 30 cm was tied between the four stems of each multiple-stemmed tree at approximately 90 cm above ground level in an attempt to induce symmetrical tree development.

Gliricidia was thinned uniformly and progressively from 3.96 m x 1.83 m to 3.96 m x 3.66 m (September 1970) and then to 7.92 m x 3.66 m (July 1971). All overhead shade with the exception of the peripheral rows was removed from the first and second treatment plots in January 1972 and at the same time, shade trees in the other four treatments were thinned to 7.92 m x 7.32 m spacing. The delay in canopy formation in the wider spacings was necessarily accompanied by a greater dependence on overhead shade than was the case in closer plantings. Final removal of overhead shade in these plots took place in June 1976 and since then only *Gliricidia* shade was retained along plot boundaries.

In applying fertilizer throughout this experiment, the aim was to apply equal quantities of nutrients per tree when the cocoa plants were small and thereafter to apply equal quantities of nutrients per unit area. As far as was known, nutrient supply was not a limiting factor.

Clean weeding was practised throughout the duration of the trial. Much difficulty was experienced in the early years in controlling weeds in the low-density treatment. Within two and a half years of planting there was little need for weeding in the 3.96 m x 1.83 m close-spacing plots, whereas in the plots where cocoa was planted at 3.96 m x 5.49 m, spot-spraying with paraquat was still necessary at two to three rounds per year.

All trees were restricted to one jorquette until the trees reached three years of age, thereafter a second jorquette per stem was allowed to develop.

The trial was relatively free of pests and disease in the early years. Apart from the occasional sporadic outbreaks of *Helopeltis spp.* and sometimes damage to new foliage by *Rhyparida irridipenis*, no major pests and diseases were encountered. In the later years, White Thread Blight, *Marasmius scandans* and Horse Hair Blight, *Marasmius equicrinis* were more frequently found on the denser and more intertwined canopy of the closely planted cocoa in the no-thinning treatment and occasionally on the multi-stem trees. This was most noticeable when pruning and canopy sanitation operation was behind schedule.

Harvesting commenced in this experiment in March 1971, some 19 months after planting. Monthly records were kept of the number of pods per tree and weight of wet beans produced per plot. As a direct consequence of the surgical methods employed in inducing multiple-stem habits, trees in these treatments came into bearing some six months later than the single-stem trees.

Trial II

This trial was also conducted on a commercial field of cocoa planted in July 1969. The experiment was of randomized block design with six replicates of six plots each giving a total of 36 plots. Each plot initially comprised 30 trees (10 x 3) at a uniform spacing of 3.96 m x 1.83 m. Three cocoa hybrids namely UIT1 x Na32, Pa7 x Na32 and UIT1 x Na33 were used in the trial and again progeny was confounded with replicates. The experimental treatments were as follows:

Treatment A. Geometrical elimination of alternate trees along the row to leave a final stand of 690 trees/ha *i.e.* 50% of the original.

Elimination of trees selected for removal was carried out over a protracted period by progressive branch tip pruning to allow normal development of those trees selected to remain.

One chupon plus a second jorquette was allowed to develop on all trees at start of trial on September 1971.

Treatment B. As A above, but no chupon nor second jorquette allowed to develop on any tree until July 1972 when the trees were three years of age.

Treatment C. As A above, but one chupon and second jorquette allowed to develop immediately on those trees selected for thinning out.

Trees selected to remain were allowed to grow a second jorquette when three years of age was reached.

Treatment D. Thinning based on geometry plus vigour. Trees along the row arranged in pairs and the less vigorous tree of each pair eliminated by progressive pruning to leave a final stand of 690 trees per hectare.

No chupon or second jorquette allowed to develop on any tree until the cocoa has reached three years of age.

Treatment E. As D above, but trees along the row arranged in threes with the least vigorous of each group of three being eliminated by progressive pruning to leave a final stand of 920 trees per hectare.

Treatment F. No thinning. Stand maintained at 1380 trees per hectare. Limited pruning and branch lifting for access. No chupon or second jorquette allowed to develop until the cocoa reached three years of age.

Pre-treatment recording of individual tree girths and yields commenced in May 1971. Wet bean weights on plot basis were recorded from May 1972.

Treatments were initiated in early September 1971 and repeated at two-monthly intervals to ensure unimpeded development of the permanent trees. A total of 11 rounds of progressive pruning of cocoa trees scheduled for elimination was carried out with the final round completed in July 1975. Thus, subsequent yields after this date would be the direct effects due to treatments. Fertilizer application during both the immature and mature years followed estate manuring policies. Shade regime was similar to that in the first trial reported in this paper. All *Gliricidia* shade trees within the trial were poisoned in May 1972, leaving three 'shade boxes', each box enclosing two replicates.

RESULTS

Trial I

Tree growth. As commented by a previous worker (Armstrong, 1976), growth rate as recorded by stem diameter measurements taken at 30 cm above ground level showed little difference. At 16 months, the set-back to growth caused by the induction of multi-stem habit could be seen in *Treatments 4* and *6*. However, full recovery took place in 24 months. It is the exception for the main stems of multiple-stemmed trees to exhibit uniform vigour of growth. In the trial, generally one or two stems became dominant.

Healthy ripe pods. The seasonal and cumulative pod yields and equivalent dry cocoa beans per hectare for the period March 1971 to August 1983 are summarized in *Tables 1* and *2*. Cumulative yields of healthy ripe pods is illustrated in *Figure 1*. Highest yields

TABLE 1. SEASONAL AND CUMULATIVE POD YIELD FOR PERIOD MARCH 1971 – AUGUST 1983

Treatment [a]	Healthy ripe pods (No./ha) [b]													
	3/71–8/71	9/71–8/72	9/72–8/73	9/73–8/74	9/74–8/75	9/75–8/76	9/76–8/77	9/77–8/78	9/78–8/79	9/79–8/80	9/80–8/81	9/81–8/82	9/82–8/83	Cumulative 3/71–8/83
1 HDU (SS)	6,052	60,329	58,718	56,539	23,381	57,760	72,927	71,778	53,346	42,986	56,712	43,660	58,463	662,651
2 HDT (SS)	5,698	60,814	61,068	54,108	25,310	60,275	69,195	70,367	52,563	45,363	58,054	46,358	55,365	664,538
3 MD (SS)	4,285	48,644	42,679	41,881	18,132	42,711	67,688	66,082	50,364	44,851	55,195	42,055	51,840	576,407
4 MD (SS)	329	48,355	45,835	42,338	20,548	42,501	70,891	69,902	56,949	45,657	58,681	43,553	58,928	604,467
5 LD (SS)	2,088	30,433	27,945	33,316	15,881	35,926	57,281	59,546	47,184	39,536	57,041	42,186	55,428	522,791
6 LD (SS)	208	36,200	30,112	32,936	19,916	34,391	64,460	60,692	50,134	40,497	53,752	43,459	52,528	519,285
S.E. Between two means	±1,332	±3,222	±2,387	±2,926	±2,486	±3,029	±2,794	±3,057	±2,396	±3,986	±5,486	±3,385	±5,777	±18,693
	L.S.D. between two means													
@ P = 0.05	2,837	6,867	5,090	6,237	5,298	6,454	5,953	6,515	5,105	8,494	11,690	7,213	12,311	39,031
@ P = 0.01	3,924	9,496	7,037	8,624	7,327	8,925	8,233	9,009	7,060	11,747	16,165	9,975	17,025	55,086
C of V %	60.5	9.6	7.6	9.5	17.1	9.4	5.9	6.5	6.6	13.1	13.7	11.0	14.7	4.5

[a] HDU = High density unthinned
HDT = High density thinned
MD = Medium density
LD = Low density
(SS) = Single Stem
(MS) = Multi-Stem

[b] Data from 3/71 to 8/76 – after K.B. Armstrong, 1976.

TABLE 2. EQUIVALENT DRY BEAN WEIGHT FOR PERIOD MARCH 71 – AUGUST 83

Treatment[a]	Mean Dry Cocoa Beans (kg/ha)[b]													Cumulative
	3/71–8/71	9/71–8/72	9/72–8/73	9/73–8/74	9/74–8/75	9/75–8/76	9/76–8/77	9/77–8/78	9/78–8/79	9/79–8/80	9/80–8/81	9/81–8/82	9/82–8/83	3/71–8/83
1 HDU (SS)	239	2,429	2,197	2,629	1,045	2,466	3,212	3,170	2,381	1,955	2,712	2,112	1,135	27,682
2 HDT (SS)	251	2,461	2,290	2,442	1,109	2,517	2,922	3,028	2,237	2,138	2,737	2,205	1,040	27,377
3 MD (SS)	182	1,883	1,509	1,924	839	1,892	2,925	2,884	2,248	1,997	2,597	2,015	1,043	23,938
4 MD (MS)	15	1,871	1,714	1,972	890	1,843	3,063	2,986	2,509	2,028	2,753	2,069	1,112	24,825
5 LD (SS)	90	1,204	999	1,476	685	1,522	2,424	2,558	2,084	1,730	2,706	2,059	984	20,521
6 LD (MS)	10	1,371	1,105	1,553	879	1,529	2,785	2,799	2,220	1,897	2,589	2,104	969	21,810
S.E. Between two means	±29	±145	±89	±138	±106	±130	±133	±144	±112	±201	±305	±151	±32	±941
	L.S.D. between two means													
@ P = 0.05	62	308	189	294	226	277	283	306	239	429	650	321	69	2,006
P = 0.01	86	427	261	406	313	383	391	423	330	594	899	444	95	2,773
C of V %	33.2	11.0	7.7	9.7	16.5	9.4	6.5	7.0	6.9	14.6	16.1	10.2	13.6	4.6

[a] Refer to *Table 1* for treatment code.
[b] Data from 3/71 to 8/76 – after K.B. Armstrong, 1976.

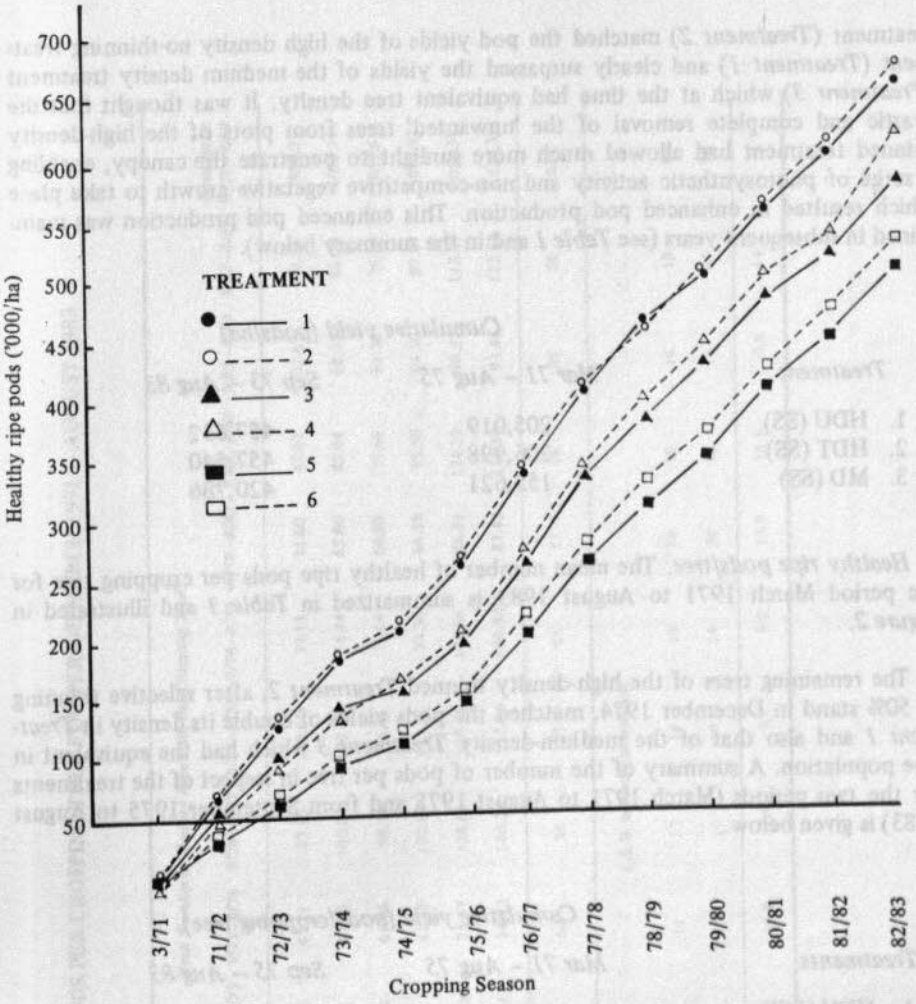


Figure 1. Cumulative yields of healthy ripe pods

were obtained from the closer spacings, statistically significant increase being obtained in number of pods per hectare.

The differences in cumulative pod numbers between single and multiple-stemmed trees at the same spacing were not significant.

Pod numbers per hectare for any spacing appeared to stabilise at a very early age. Any changes have been slight since the second cropping year. This is so despite the fact that all trees in general and those in the less densely planted plots in particular, have continued to increase in size and cover a greater surface area of the plot with their canopies. This makes it improbable that inter-tree competition has caused stabilisation of pod numbers in plot with wide spacings.

Referring to *Table 1* again, it should be noted that subsequent to selective thinning to 50% stand in October/December 1974, the remaining trees in the high-density thinned

treatment (*Treatment 2*) matched the pod yields of the high density no-thinning treatment (*Treatment 1*) and clearly surpassed the yields of the medium density treatment (*Treatment 3*) which at the time had equivalent tree density. It was thought that the drastic and complete removal of the 'unwanted' trees from plots of the high-density thinned treatment had allowed much more sunlight to penetrate the canopy, enabling a surge of photosynthetic activity and non-competitive vegetative growth to take place which resulted in enhanced pod production. This enhanced pod production was maintained in subsequent years (see *Table 1* and in the summary below).

	Cumulative yield (pods/ha)	
Treatment	*Mar 71 – Aug 75*	*Sep 75 – Aug 83*
1. HDU (SS)	205,019	457,632
2. HDT (SS)	206,998	457,540
3. MD (SS)	155,621	420,786

Healthy ripe pods/tree. The mean number of healthy ripe pods per cropping tree for the period March 1971 to August 1983 is summarized in *Table 3* and illustrated in *Figure 2.*

The remaining trees of the high-density thinned *Treatment 2*, after selective thinning to 50% stand in December 1974, matched the pods yields of double its density in *Treatment 1* and also that of the medium-density *Treatment 3* which had the equivalent in tree population. A summary of the number of pods per tree in respect of the treatments for the two periods (March 1971 to August 1975 and from September 1975 to August 1983) is given below.

	Cumulative yield (pods/cropping tree)	
Treatments	*Mar 71 – Aug 75*	*Sep 75 – Aug 83*
1. HDU (SS)	149.26	337.01
2. HDT (SS)	*169.15	665.62
3. MD (SS)	226.71	612.90
4. MD (MS)	228.32	654.05
5. LD (SS)	239.23	855.31
6. LD (MS)	260.04	866.27

*36.81 as against 17.05 for high-density no-thinning *Treatment 1* in the 1974/1975 seasons.

Generally, trees in the wider spacings gave a significantly higher number of pods per cropping tree than trees in higher-density plantings. There was a tendency for trees in multiple-stem treatments to show an increased number of pods per tree as against the trees in single-stem treatment of the same spacing but this did not reach significant difference levels.

Dry beans per hectare. The yields presented in *Table 2* are calculated from actual weight of wet beans recorded from the plots and multiplied by a constant factor. An overall 40% extraction ratio has been adopted.

TABLE 3. MEAN HEALTHY RIPE PODS PER CROPPING TREE FOR PERIOD MARCH 1971 – AUGUST 1983

Treatment[a]	Mean Number of Healthy Ripe Pods Per Cropping Tree[b]													Cumulative
	3/71–8/71	9/71–8/72	9/72–8/73	9/73–8/74	9/74–8/75	9/75–8/76	9/76–8/77	9/77–8/78	9/78–8/79	9/79–8/80	9/80–8/81	9/81–8/82	9/82–8/83	3/71–8/83
1 HDU (SS)	4.40	43.89	42.75	41.17	17.05	42.11	53.13	52.64	39.13	31.60	42.02	32.67	43.71	486.27
2 HDT (SS)	4.15	44.29	44.50	39.40	36.81	87.66	100.63	102.28	74.44	65.80	85.04	68.27	81.50	834.77
3 MD (SS)	6.24	70.91	62.19	61.07	26.30	61.96	98.18	95.85	73.06	64.90	79.69	62.38	76.88	839.61
4 MD (MS)	0.48	70.14	66.48	61.41	29.81	61.65	102.83	102.30	83.36	66.58	85.56	64.50	87.27	882.37
5 LD (SS)	4.56	66.43	61.00	72.69	34.55	78.17	124.63	129.56	102.66	86.31	124.59	90.52	118.87	1,094.54
6 LD (MS)	0.77	78.77	65.52	71.65	43.33	74.82	140.25	132.05	109.08	87.45	116.50	93.44	112.68	1,126.31
S.E. Between two means	±4	±13	±8	±4	±4	±4	±5	±7	±5	±7	±9	±6	±8	±29
	L.S.D. between two means													
@ P = 0.05	9	29	18	9	8	11	12	14	10	14	19	14	18	63
@ P = 0.01	13	40	25	13	11	15	16	19	14	20	26	19	25	86
C of V %	64.1	11.0	7.5	10.5	17.3	10.8	7.4	9.1	8.5	13.9	14.1	0.6	14	4.7

[a] Refer to *Table 1* for treatment code.
[b] Data from 3/71 to 8/76 – after K.B. Armstrong, 1976.

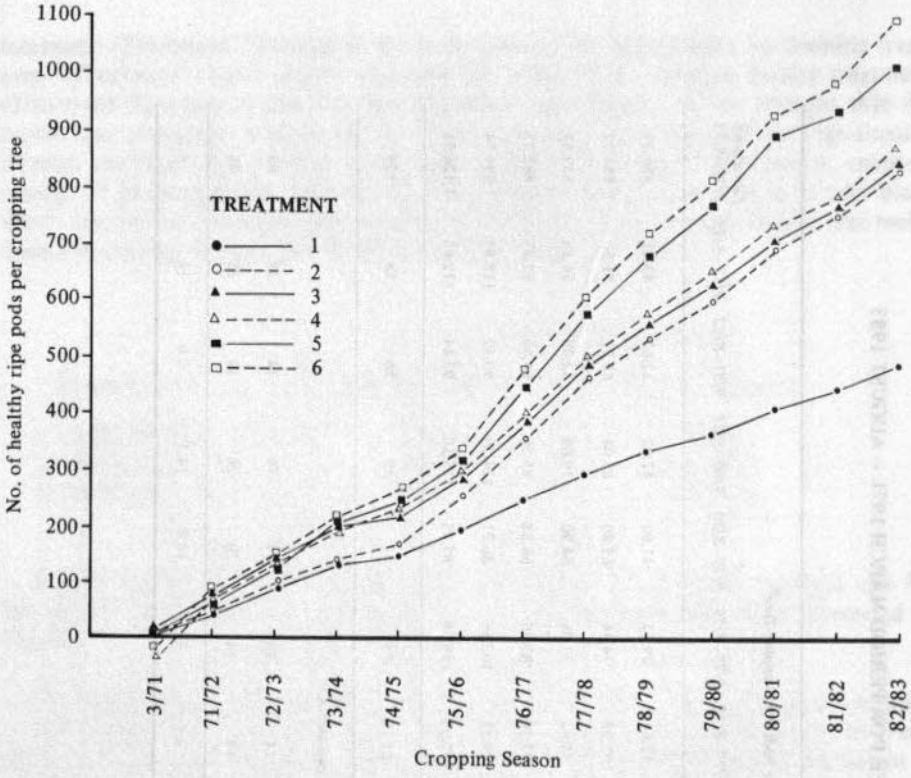


Figure 2. Cumulative number of healthy ripe pods per cropping tree

As can be seen from the yield data summarized in *Table 2* and from cumulative pod yields in *Figure 1*, the high-density *Treatments 1* and *2* held an advantage in terms of dry cocoa per hectare and this advantage continued up to the current time. The relative yield advantage in medium-density *Treatments 3* and *4* in comparison with low density *Treatments 5* and *6* was marked in the early years but was hardly noticeable in the cropping season 1980/1981. Nevertheless the cumulative yields were significantly better in the higher of these two densities.

There were no yield differences between the single and multiple-stem treatments of the two higher densities.

Trial II

The yield data for the duration of the trial are summarised in *Table 4*.

The cumulative number of healthy ripe pods per hectare are illustrated in *Figure 3*. The highest pod yield was achieved in the no-thinning treatment (*Treatment F*) followed closely by *Treatment D* (thinned on the basis of one in two based on geometry plus vigour).

The cumulative number of healthy ripe pods per permanent tree in the treatments are illustrated in *Figure 4*. As was the case in the first trial, the remaining trees of *Treatment D* after thinning yielded twice as many pods as did trees in the unthinned treatment.

TABLE 4. YIELD DATA FOR THE PERIOD SEPTEMBER 1971 TO AUGUST 1981

			Period	Treatment A	B	C	D	E	F	S.E. of difference between two means (±)	L.S.D. between two means P = 0.05	P = 0.01	CV (%)
Mean Number of HR Pods	On Treatment Basis	Per Hectare	9/71–8/72	51,636	49,240	53,566	54,817	61,419	60,438	3,669	7,559	10,225	11.5
			9/72–8/73	40,678	35,427	39,904	37,604	40,364	42,195	3,023	NS	NS	13.3
			9/73–8/74	43,942	36,077	45,415	47,438	49,932	39,865	4,101	8,448	11,431	16.2
			9/74–8/75	26,632	23,358	26,034	30,705	27,230	27,230	2,678	5,518	7,462	17.3
			9/75–8/76	59,559	51,940	50,675	61,214	58,662	63,033	3,257	6,706	9,074	9.8
			9/76–8/77	56,915	51,945	47,967	58,217	58,533	64,520	3,731	7,687	10,398	11.5
			9/77–8/78	52,422	47,861	46,811	55,190	49,217	57,980	3,215	6,622	8,960	10.8
			9/78–8/79	38,486	36,200	40,164	46,059	37,067	39,358	3,583	7,381	9,988	15.7
			9/79–8/80	43,475	46,136	46,289	43,245	43,008	47,806	2,901	5,977	8,088	11.2
			9/80–8/81	46,559	48,481	49,250	51,755	50,957	51,886	3,057	6,299	8,520	10.6
			9/71–8/81	460,304	426,665	446,075	486,244	476,389	494,311	22,518	46,388	62,758	8.4
		Per Tree	9/71–8/72	38.44	35.71	38.85	40.32	44.55	43.84	2.82	5.81	7.86	12.1
			9/72–8/73	30.22	25.67	28.92	27.40	29.25	30.58	2.16	NS	NS	13.1
			9/73–8/74	32.70	26.14	32.91	34.74	36.18	28.89	3.02	6.22	8.42	16.4
	On Permanent Trees	Per Tree	9/71–8/72	52.55	47.77	54.37	58.20	54.35	43.84	4.36	8.98	12.15	14.6
			9/72–8/73	40.08	37.21	40.07	38.27	35.30	30.58	2.85	5.87	7.94	13.4
			9/73–8/74	44.53	39.92	38.14	52.09	43.18	28.89	4.27	8.80	11.90	18.0
			9/74–8/75	32.13	31.33	23.57	41.05	28.76	19.84	3.39	6.98	9.45	19.9
			9/75–8/76	87.61	75.28	73.44	88.72	62.59	45.68	4.51	9.29	12.57	10.8
			9/76–8/77	82.49	75.29	69.52	84.38	62.57	46.76	5.38	11.07	14.98	13.3
			9/77–8/78	75.98	69.37	67.85	79.99	52.76	42.21	4.54	9.36	12.66	12.2
			9/78–8/79	55.78	52.47	58.21	66.76	39.59	28.52	5.48	11.29	15.27	18.9
			9/79–8/80	69.35	68.15	67.09	62.68	45.99	35.00	4.32	8.90	12.04	12.9
			9/80–8/81	68.16	70.26	71.38	75.01	54.52	38.27	4.67	9.62	13.02	12.8
			9/71–8/81	608.66	567.05	563.64	647.15	479.61	359.59	28.52	58.75	79.49	9.7
Mean Weight of Wet Beans		Kg/ha	5/72–8/72	2,717	2,625	2,706	2,829	3,084	2,761	200	NS	NS	12.5
			9/72–8/73	4,357	3,839	4,154	4,013	4,545	4,324	308	NS	NS	12.7
			9/73–8/74	5,362	4,341	5,394	5,775	6,149	4,744	505	1,040	1,408	16.5
			9/74–8/75	3,111	2,688	3,007	3,508	3,184	3,189	314	646	874	17.5
			9/75–8/76	6,683	5,557	5,298	6,826	6,908	6,940	439	905	1,224	12.0
			9/76–8/77	7,013	6,262	5,815	7,081	7,174	7,853	442	911	1,223	11.2
			9/77–8/78	5,996	5,389	5,226	6,331	5,662	6,670	392	809	1,094	11.6
			9/78–8/79	4,577	4,351	4,539	5,102	4,296	4,742	447	920	124	16.8
			9/79–8/80	5,113	5,476	5,288	5,067	4,981	5,775	328	676	915	10.8
			9/80–8/81	5,454	5,799	5,916	5,940	7,294	6,392	738	1,519	2,055	20.8
			5/72–8/81	50,383	46,327	47,343	52,472	53,277	53,390	2,474	5,096	6,894	8.5

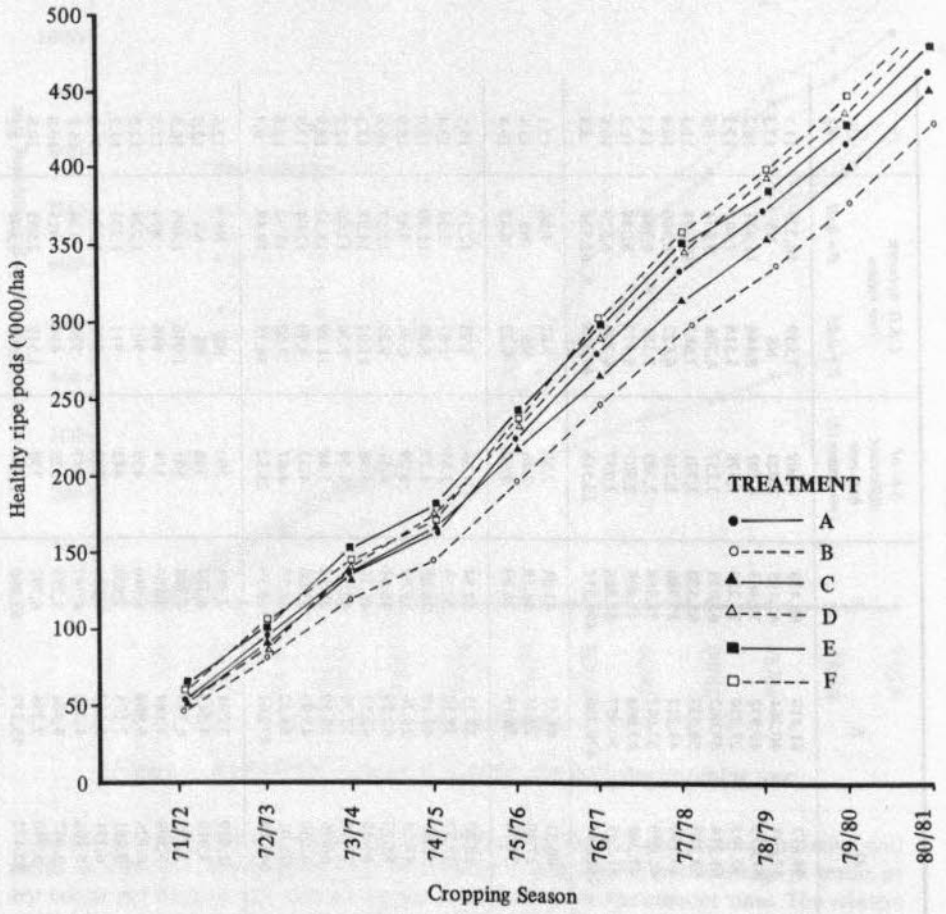


Figure 3. Cumulative number of healthy ripe pods per hectare

A comparison of the pod yields in respect of the treatments for the two periods (September 1971 to August 1975), when the trees selected for thinning were being progressively pruned, and the post-thinning period (September 1975 to August 1981) are tabulated below. The pods per permanent tree are shown within brackets.

		Yield (pod/ha)	
Treatments		*Sep 71 – Aug 75*	*Sep 75 – Aug 81*
A		162,888 (169)	297,416 (439)
B		144,102 (156)	282,563 (411)
C		164,919 (156)	281,156 (407)
D		170,564 (189)	315,680 (458)
E		178,945 (161)	297,444 (318)
F		169,728 (123)	324,583 (236)
	Mean	165,191 (159)	299,807 (378)

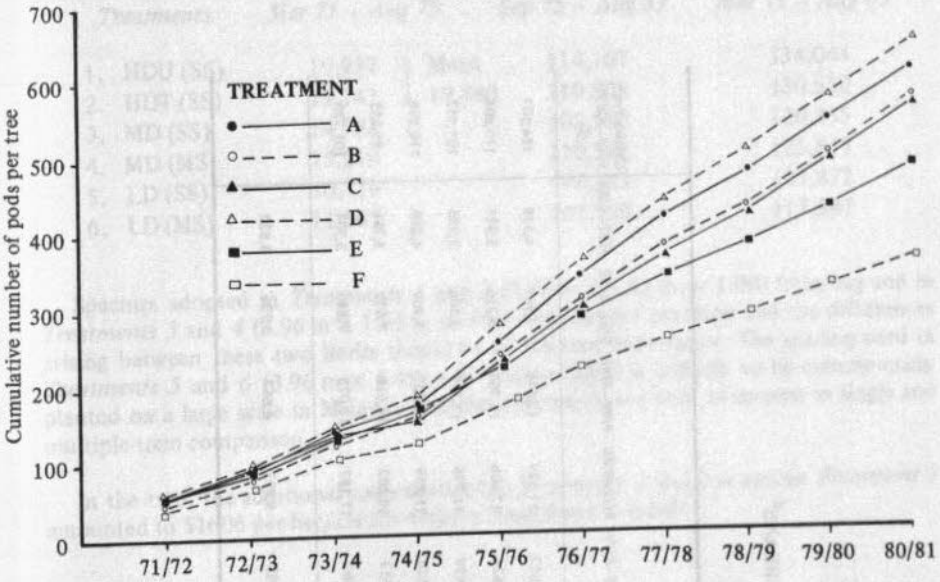


Figure 4. Cumulative number of healthy ripe pods per permanent tree

The differences obtained in yields in the first period were the cumulative effects of treatments which were being achieved over a period from September 1971 to July 1975. On pods per permanent tree, there was already a distinct increase of some 35% more pods from the trees in the treatments that were being progressively thinned.

In the post-treatment period from September 1975 to August 1981, the highest yield per hectare was still obtained from *Treatment F* (1380 trees/ha) followed closely by *Treatment D* (690 trees/ha) which yielded 2.75% less. This latter treatment was similar to *Treatment 2* which performed best in the first trial, the final stand of trees having yielded 94% more pods per tree than the trees in the no-thinning treatment. These trees also yielded 9% more pods than those which remained after thinning with no selection.

DISCUSSION

Results from the first trial showed that from the commencement of the experiment, the close-spacing *Treatment 1* held an advantage in terms of pod yields and in dry bean weights. This advantage continued up to the current time.

Much of the data given in *Tables 1* and *2* show statistically significant differences between treatment means at the different spacings. It is therefore valid to make use of this data to calculate the financial advantage of these yields using the nett contracted prices realised at various times during the period.

The differences in gross financial returns per hectare in respect of the treatments are presented in *Table 5* and a summary is given below. These are discussed under two periods (from March 1971 to August 1975), when thinning in *Treatment 2* was implemented, and in the post-treatment period (September 1975 to August 1983).

TABLE 5. GROSS FINANCIAL RETURNS FROM DRY COCOA BEANS[a]

Treatment	Financial returns ($/ha)														
	3/71–8/71	9/71–8/72	9/72–8/73	9/73–8/74	Cumulative 9/74–8/75 M$	3/71–8/75	9/75–8/76	9/76–8/77	9/77–8/78	9/78–8/79	9/79–8/80	9/80–8/81	9/81–8/82	9/82–9/83	Cumulative 9/75–8/83 ($)
1. HDU (SS)	349	3,675	4,196	8,739	2,978	19,937	7,963	27,620	25,515	16,627	11,529	12,646	7,869	4,338	114,107
2. HDT (SS)	367	3,723	4,374	8,117	3,161	19,742	8,127	25,126	24,372	15,621	12,608	12,763	8,216	3,975	110,808
3. MD (SS)	266	2,849	2,882	6,395	2,391	14,783	6,109	25,152	23,213	15,698	11,776	12,110	7,508	3,986	105,552
4. MD (MS)	22	2,831	3,274	6,555	2,537	15,219	5,951	26,338	24,034	17,520	11,959	12,837	7,709	4,250	110,598
5. LD (SS)	131	1,822	1,908	4,906	1,952	10,719	4,915	20,843	20,589	14,553	10,202	12,618	7,672	3,761	95,153
6. LD (MS)	15	2,074	2,111	5,162	2,505	11,867	4,937	23,948	22,529	15,502	11,187	12,073	7,840	3,704	101,720
Nett contracted price per tonne in M$	1,462	1,513	1,910	3,324	2,850		3,229	8,599	8,049	6,983	5,897	4,663	3,726	3,822	

See *Table 2.*

Treatments	Gross financial returns ($/ha) Mar 71 – Aug 75		Sep 75 – Aug 83	Mar 71 – Aug 83
1. HDU (SS)	19,937	Mean	114,107	134,044
2. HDT (SS)	19,742	19,840	110,808	130,550
3. MD (SS)	14,783		105,552	120,335
4. MD (MS)	15,219		110,598	125,817
5. LD (SS)	10,719		95,153	105,872
6. LD (MS)	11,867		101,720	113,587

Spacings adopted in *Treatments 1* and *2* (3.96 m x 1.83 m or 1380 trees/ha) and in *Treatments 3* and *4* (3.96 m x 1.83 m or 690 trees/ha) are common and the differences arising between these two limits should be of relevant importance. The spacing used in *Treatments 5* and *6* (3.96 m x 5.49 m or 460 trees/ha) is unlikely to be commercially planted on a large scale in Malaysia and the differences are only of interest in single and multiple-stem comparison.

In the trial, the additional costs incurred in *Treatments 1* and *2* as against *Treatment 3* amounted to $1606 per hectare for which a breakdown is listed.

Additional establishment costs from higher density	346
Maintenance during immature period	1062
Mature tree management	198
Total	$1606

The increased gross financial return for closer spacing (mean of *Treatments 1* and *2*) over *Treatment 3* in the first five cropping years totals $5057 per hectare. Even allowing for the additional cost above and also for harvesting and processing of the additional 2209 kg of cocoa (at $300/tonne), there should be a nett profit of $2788 per hectare.

The small financial advantage obtained from the multiple-stem over single-stem treatments in the two wide spacings tested (*Treatments 4* and *6*), are unlikely to show any real benefit if one considers the extra costs of inducing multiple-stem habit and the subsequent costs of pruning and training of the extra stems.

In the second period covering eight cropping seasons, *Treatment 1* again yielded the highest and showed a gross financial advantage of $3299 over *Treatment 2* and $8555 over *Treatment 3*. Since the latter two treatments had the same tree populations, it would be proper to imply that the advantage of $5256 in favour of *Treatment 2* was attributable to the selection of a larger number of higher bearing trees.

Multiple-stemmed trees (*Treatments 4* and *6*) accumulated yield advantages of $5046 and $6567 over single-stemmed trees of *Treatments 3* and *5* respectively. It would appear from this that the wider the spacing, the greater would be the advantage in favour of multiple-stem habit.

Looking at the overall gross financial returns over the duration of the experiment, *Treatment 1* with a full stand of 1380 trees per hectare maintained the financial advantage. This is followed closely by *Treatment 2*.

Results from the second thinning trial were similarly looked at for financial implications. The weights of wet beans in respect of the treatments shown in *Table 4* are converted to dry bean equivalent in the first instance, using an overall 40% extraction ratio. The differences in gross financial returns per hectare were calculated using the same contracted prices adopted in the first comparison. These are summarized in *Table 6* and discussed below.

	Gross financial returns ($/ha)		
Treatments	*May 72 – Aug 75*	*Sep 75 – Aug 81*	*May 72 – Aug 81*
A	15,649	87,073	102,722
B	13,357	81,954	95,311
C	15,413	79,851	95,264
D	16,456	90,831	107,287
E	17,147	89,183	106,330
F	14,920	96,240	111,160

In the first period when pruning and thinning operations were being carried out, all thinned treatments with the exception of *Treatment B*, realised better gross financial returns than the no-thinning *Treatment F*. The position, however, was somewhat altered in the second period covering six full cropping seasons. *Treatment F* had shown the highest gross financial return followed by *Treatment D* which had only half the tree population of *Treatment F*. The position is also true for the full duration of the trial.

In the *Treatments A, B, C* and *D*, progressive thinning on the basis of geometry plus vigour (*Treatment D*) showed the highest yield and financial returns.

CONCLUSION

Highest yields and financial returns were obtained from close spacing of cocoa planted initially at 3.96 m x 1.83 m, the equivalent of 1380 trees per hectare as compared with stands planted at 690 and 460 trees per hectare.

Thinning on the basis of geometry plus vigour to retain the best of all pairs of trees and leave a final stand of 690 trees per hectare yielded as well as the no-thinning treatments.

The treatment which removed the least vigorous of a group of three trees (*Treatment E*) in the second trial which retained a final stand of 920 trees per hectare performed equally well.

The remaining trees which remained after selective thinning, were more readily manageable and yielded almost twice as many pods per tree as trees in the no-thinning treatment.

Trees in the wider spacing generally produced more pods per tree but less on a per-hectare basis.

No statistical differences between yields of single and multi-stem in a given spacing were observed.

TABLE 6. GROSS FINANCIAL RETURNS FROM DRY COCOA BEANS EQUIVALENT[a]

Treatment	*Financial returns ($/ha)*											
	5/72–8/72	*9/72–8/73*	*9/73–8/74*	*9/74–8/75*	*Cumulative 5/72–8/75 M$*	*9/75–8/76*	*9/76–8/77*	*9/77–8/78*	*9/78–8/79*	*9/79–8/80*	*9/80–8/81*	*Cumulative 9/75–8/81 ($)*
A	1,645	3,329	7,130	3,545	15,649	8,631	24,120	19,302	12,786	12,059	10,175	87,073
B	1,589	2,934	5,770	3,064	13,357	7,178	21,540	17,354	12,150	12,914	10,818	81,954
C	1,637	3,174	7,173	3,429	15,413	6,842	20,001	16,822	12,681	12,472	11,033	79,851
D	1,713	3,066	7,678	3,999	16,456	8,815	24,352	20,380	14,252	11,953	11,079	90,831
E	1,867	3,472	8,177	3,631	17,147	8,922	24,679	18,231	11,997	11,747	13,607	89,183
F	1,670	3,304	6,309	3,637	14,920	8,964	27,009	21,475	13,247	13,622	11,923	96,240
Nett contracted price per tonne in ($)	1,513	1,910	3,324	2,850		3,229	8,599	8,049	6,983	5,897	4,663	

See *Table 4.*

ACKNOWLEDGEMENT

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Intercropping Cocoa and Oil Palm — Eleven Years of Trial Results

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This paper reports for their results of an earlier reported trial on the performance of intercropped cocoa and oil palm. At the end of 11 years, the treatment with single row oil palm interplanted with three rows of cocoa emerged as the most promising of the intercrop treatments. The treatment produced 88% of the monocrop oil palm yield and 55% of the cocoa monocrop. In a simple cost-benefit analysis, this treatment was also shown to produce steady incomes at fluctuating prices of oil palm and cocoa.

Further monitoring or modifications of the trial is proposed.

Following the highly profitable combination of cocoa and coconut (Leach *et al.* 1969, Blencowe 1971, Lim & Chai 1980, Chai 1982), there is general speculation that cocoa under oil palm will be an even more profitable venture. Although early experiences of underplanting oil palm with cocoa have not produced encouraging results (McCulloch 1968), preliminary results of a later trial by Lee and Hanafi (1980) demonstrated the feasibility of intercropping the two crops. This paper reports results of the latter trial which has reached its 11th year. The feasibility of intercropping cocoa and oil palm is re-examined in light of these results.

MATERIALS AND METHODS

Details on the layout of this trial have been described by Lee and Hanafi (1980). Briefly, the trial compares three systems of cocoa/oil palm intercropping to monoculture cocoa and oil palm. It consists of the following treatments:–

Treatment 1 – Normal oil palm monoculture at 9 m triangular spacing (143 palms/ha)

Treatment 2 – Double row oil palm at 25 m/2 x 7 m with 5 rows of cocoa in between at 25 m/5 x 3 m (114 palms/ha + 667 cocoa/ha)

Treatment 3 – Single row oil palm at 10 m x 7 m alternative with single row cocoa at 10 m x 2.5 m (143 palms/ha + 400 cocoa/ha)

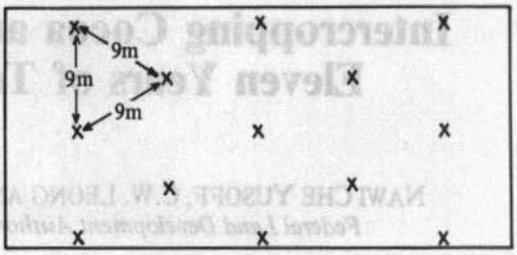
Treatment 4 – Single row oil palm at 13 m x 7 m with 3 rows of cocoa in between at 13 m/3 x 3 m (110 palms/ha + 761 cocoa/ha)

Treatment 5 – Normal cocoa monocrop at 3 m x 3 m square planting (1111 cocoa/ha)

The planting patterns for the various intercrop treatments are shown in *Figure 1*. Each treatment occupies approximately 1 ha and is replicated three times in a randomised

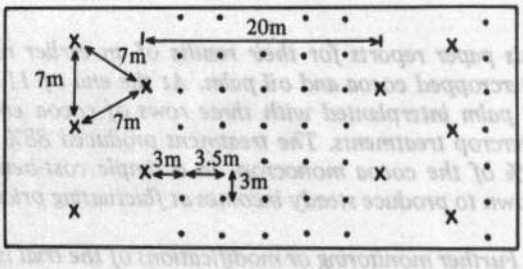
Treatment 1

Monocrop oil palm
(143 palms/ha)



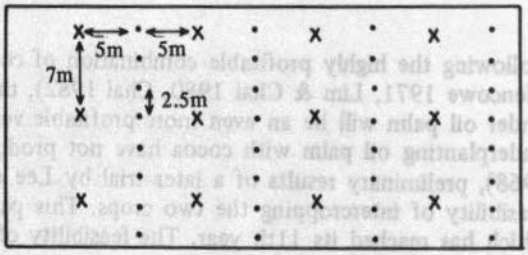
Treatment 2

2 rows oil palm
(114 palms/ha)
5 rows cocoa
(667 trees/ha)



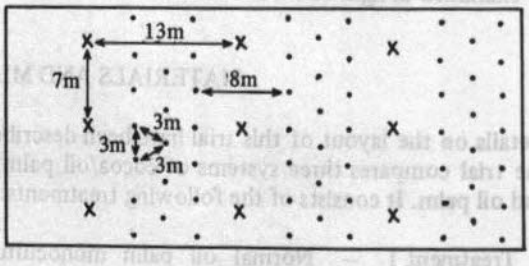
Treatment 3

1 row oil palm
(143 palms/ha)
1 row cocoa
(400 trees/ha)



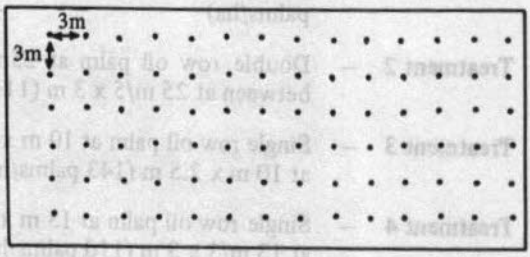
Treatment 4

1 row oil palm
(110 palms/ha)
3 rows cocoa
(761 trees/ha)



Treatment 5

Monocrop cocoa
(1,111 trees/ha)



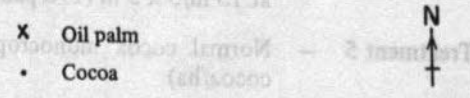


Figure 1. Planting pattern of cocoa and oil palm and their intercrop treatments.

block design. The avenue palms were planted in a north-south direction to minimise self-shading but maximise shading of the cocoa. Soil type is dominantly Durian series (an ultisol) although pockets of Malacca series (a lateritic oxisol) are also present. Planting of oil palm seedlings commenced in October 1970. Cocoa seedlings (Seed garden hybrid materials from Department of Agriculture, Sabah) were planted in August 1971.

Each plot was guarded by a 10 m guard space planted with cocoa. *Gliricidia* was planted in the cocoa interrow as well as in the guard space in late 1970 but these were removed in the intercrop plots four years later. Bush cover, *Moghania macrophylla*, was also established to provide initial lateral shade for the cocoa but was eradicated a year after cocoa establishment.

Manuring for both crops until the seventh year of planting has been described by Lee and Hanafi (1980). Later, from 1978 to 1983, the cocoa received an annual average of 122 g/plant N (as urea), 96 g/plant P_2O_5 (as CIRP), 118 g/plant K_2O (as MOP) and 13 g/plant MgO (as Kieserite). This was supplemented by a total of 1.25 kg/plant of ground magnesium limestone in 1980 and 1983. For the oil palm, fertiliser rates of 2.1 kg/palm urea, 3.5 kg/palm MOP, 0.5 kg/palm CIRP and 0.75 kg/palm Kieserite were applied by the 13th year of planting.

RESULTS

Growth of Cocoa

Early growth of cocoa trees measured by their basal stem diameter at the eighth month after transplanting was reported to be comparable amongst the various treatments (Lee & Hanafi 1980). Measurements made in the 13th year in the field revealed again that growth had not been significantly different (*Table 1*).

TABLE 1. BASAL STEM DIAMETER OF COCOA EIGHT MONTHS AND THIRTEEN YEARS AFTER PLANTING

Treatment	*Diameter (cm)*	
	8th month	*13th year*
1	–	–
2	2.17	6.97
3	2.38	7.00
4	2.15	6.81
5	2.14	6.94
Mean	2.21	6.94
Se (±)	0.10	0.13

Measurements made at 15 cm above ground

Growth of Oil Palm

Growth measurements of oil palm in the 13th year after field planting (*Table 2*) showed that all the intercropped palms were taller than monocropped oil palm, particu-

TABLE 2. GROWTH MEASUREMENTS OF OIL PALM AT 13TH YEAR IN FIELD

Treatment	*Height at Frond 49 (m)*	*Leaf area (m^2)*	*Leaf dry weight (kg)*
1	4.34	10.5	4.13
2	4.98	10.7	4.63
3	4.60	11.5	4.90
4	4.50	11.1	5.26
5	–	–	–
Mean	4.61	11.0	4.73
Se (±)	0.31	0.58	0.30

Leaf area and leaf weight were both recorded from Frond 17

larly Treatment 2 consisting of twin rows of oil palm planted at 7 m triangular spacing. However, the differences were not significant. The intercropped palms also generally appeared to have increased leaf area and frond weight.

Yields

Oil palm and cocoa yields over the entire duration of the trial are presented in *Table 3*, while *Figure 2* illustrates yields of the intercropped oil palm and cocoa expressed as percentages of the respective monocrop yields.

Oil palm. Ffb yields were not significantly different amongst treatments in the first three years, but in the following years, definite yield trends were observed.

There was a clear declining yield trend in Treatment 2 comprising oil palm planted closely in twin rows at 25 m/2 x 7 m. Interpalm competition had apparently set in as the palms grew older and the results were seen as early as in the fourth year of harvesting. By the eighth year of harvesting, the yield was only about 50% of the monocrop yield. Cumulative yield over the trial period was only 67% of the monocrop.

Treatment 3 (one row oil palm/one row cocoa) produced ffb yields comparable to the monocrop yield for the whole of the duration reviewed. The yield fluctuated between 82% and 145% of the monocrop yield. Cumulative yield was 4% more than the monocrop. The yields fluctuated closely to the monocrop yield from the sixth year of harvesting but apparently encountered a depression in 1983.

Treatment 4 (one row oil palm/three rows cocoa) yielded between 77% and 104% of the monocrop yield. Overall yield performance was 88% of the monocrop. This lower yield was probably attributed to the lower palm stand (110 palms/ha or 77% of the monocrop). The yields appeared to be relatively stable in the later years.

Oil palm yields were significantly reduced in 1983 for all the treatments as a result of the severe drought occurring in the first four months of the year (*Appendix*). Bunch abortion was commonly observed in April and May. The monocrop experienced a crop

TABLE 3. OIL PALM AND COCOA YIELDS IN OIL PALM/COCOA INTERCROPPING TRIAL (1973 – 1983)

No.	Treatment	Palms/ ha	Oil palm yield (tonnes/ffb/ha) 1973 Mac–Dec 1st year	1974 2nd	1975 3rd	1976 4th	1977 5th	1978 6th	1979 7th	1980 8th	1981 9th	1982 10th	1983 11th	Total	Mean
1	Monoculture oil palm (control)	143 (100)	3.04 (100)	7.78 (100)	21.22 (100)	17.59 (100)	15.08 (100)	12.91 (100)	21.80 (100)	24.81 (100)	23.78 (100)	29.95 (100)	21.30 (100)	199.26	18.11 (100)
2	2 rows oil palm + 5 rows cocoa.	114 (80)	2.76 (91)	6.97 (90)	19.14 (90)	11.80 (67)	11.62 (77)	8.31 (64)	16.02 (73)	12.59 (51)	14.66 (62)	17.86 (60)	11.26 (53)	132.99	12.09 (67)
3	1 row oil palm + 1 row cocoa	143 (100)	3.58 (118)	11.30 (145)	23.60 (111)	18.61 (106)	19.60 (130)	12.63 (98)	23.02 (106)	23.29 (94)	24.68 (104)	28.96 (97)	17.46 (82)	206.73	18.79 (104)
4	1 row oil palm + 3 rows cocoa	110 (77)	2.74 (90)	7.49 (96)	20.98 (99)	13.73 (78)	13.29 (88)	13.51 (104)	18.05 (83)	22.45 (90)	21.38 (90)	24.53 (82)	17.53 (82)	175.68 (88)	15.97 (88)
5	Monoculture cocoa (control)	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Mean		3.03	8.38	21.24	15.43	14.90	11.83	19.72	20.57	21.73	25.36	16.88	178.66	16.24
	Se (±)		0.31	1.41	2.73	1.06	1.21	2.06	1.91	2.85	2.35	2.80	0.61	12.07	
	LSD (P = 0.05)		0.76	3.45	6.68	2.59	2.96	5.04	4.67	6.97	5.75	6.85	1.49	29.54	
	LSD (P = 0.01)		1.15	5.23	10.12	3.93	4.49	7.64	7.08	10.56	8.71	10.38	2.26	44.74	

Figures in parenthesis represent percentage of tree stand or yield over control

TABLE 3. CONT'D

No.	Treatment	Cocoa points/hd	Cocoa yield (kg dry bean/ha) 1973 Mar–Dec 1st year	1974 2nd	1975 3rd	1976 4th	1977 5th	1978 6th	1979 7th	1980 8th	1981 9th	1982 10th	1983 11th	Total	Mean
1	Monoculture oil palm (control)	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2	2 rows oil palm + 5 rows cocoa	667 (60)	86 (55)	441 (68)	439 (59)	506 (55)	448 (92)	478 (59)	1012 (64)	837 (76)	837 (53)	959 (62)	513 (53)	6556 (64)	596 (64)
3	1 row oil palm + 1 row cocoa	400 (36)	102 (66)	395 (61)	299 (40)	359 (39)	187 (38)	234 (29)	362 (23)	331 (30)	277 (18)	482 (31)	268 (28)	3296 (31)	299 (31)
4	1 row oil palm + 3 rows cocoa	761 (68)	105 (68)	504 (78)	497 (67)	503 (55)	326 (67)	453 (56)	709 (45)	622 (57)	564 (36)	930 (60)	553 (57)	5766 (55)	524 (55)
5	Monoculture cocoa (control	1111 (100)	155 (100)	644 (100)	744 (100)	917 (100)	489 (100)	813 (100)	1584 (100)	1095 (100)	1569 (100)	1558 (100)	967 (100)	10535 (100)	958 (100)
	Mean		112	496	495	571	363	495	795	721	812	982	500	6538	594
	Se (±)		38	53	106	39	45	67	121	184	131	113	35	443	
	LSD (P = 0.05)		93	130	259	95	110	164	296	450	321	277	86	1084	
	LSD (P = 0.01)		141	196	393	145	167	248	449	682	486	419	130	1642	

Figures in parenthesis represent percentage of tree stand or yield over control

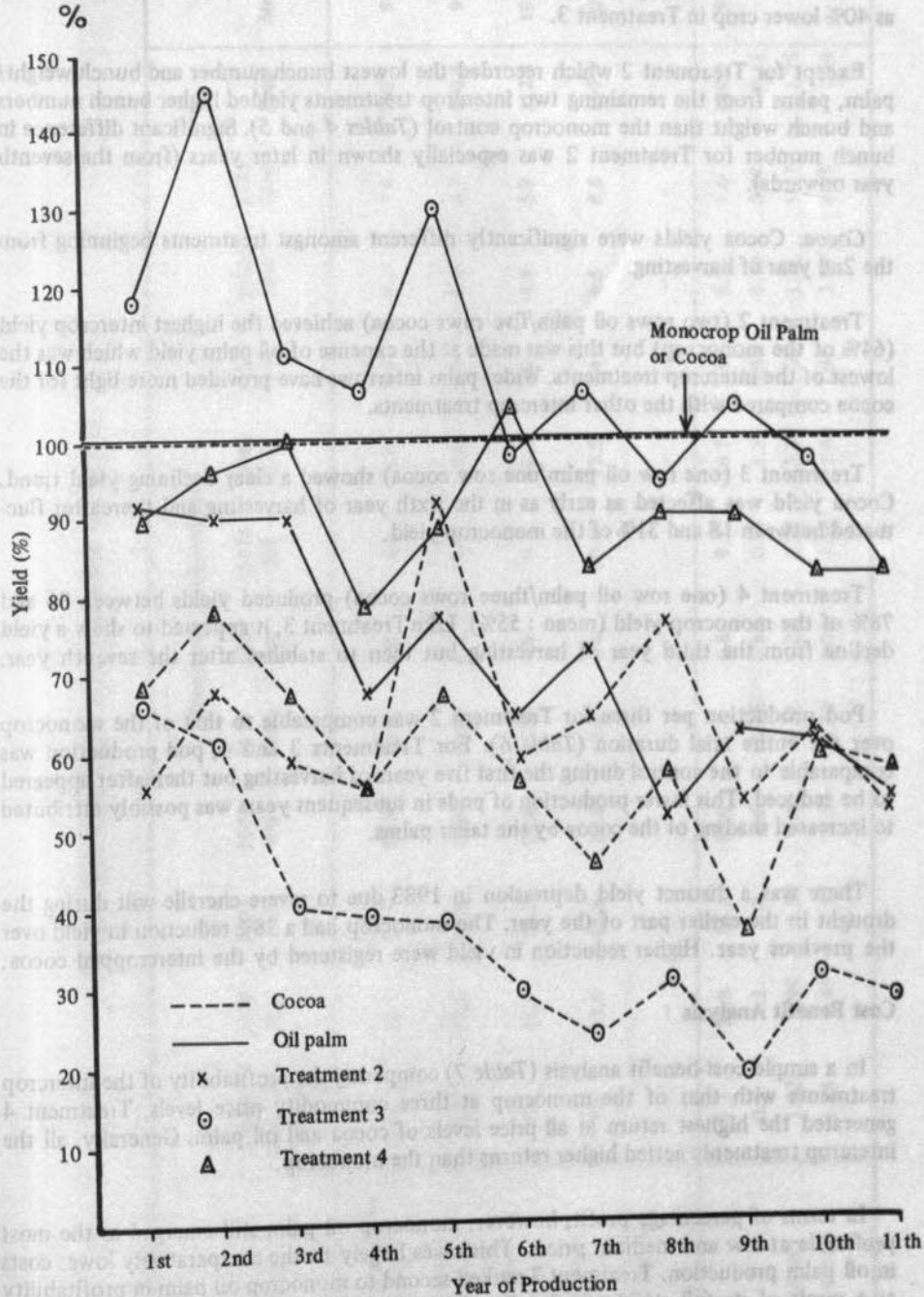


Figure 2. Ffb and cocoa bean yields of intercropped oil palm and cocoa expressed as percentages of monocrop yield

reduction of 29% but higher reductions were found in Treatments 2 and 3 with as much as 40% lower crop in Treatment 3.

Except for Treatment 2 which recorded the lowest bunch number and bunch weight/ palm, palms from the remaining two intercrop treatments yielded higher bunch numbers and bunch weight than the monocrop control (*Tables 4* and *5*). Significant difference in bunch number for Treatment 2 was especially shown in later years (from the seventh year onwards).

Cocoa. Cocoa yields were significantly different amongst treatments beginning from the 2nd year of harvesting.

Treatment 2 (two rows oil palm/five rows cocoa) achieved the highest intercrop yield (64% of the monocrop) but this was made at the expense of oil palm yield which was the lowest of the intercrop treatments. Wider palm interrows have provided more light for the cocoa compared with the other intercrop treatments.

Treatment 3 (one row oil palm/one row cocoa) showed a clear declining yield trend. Cocoa yield was affected as early as in the sixth year of harvesting and thereafter fluctuated between 18 and 31% of the monocrop yield.

Treatment 4 (one row oil palm/three rows cocoa) produced yields between 36 and 78% of the monocrop yield (mean : 55%). Like Treatment 3, it appeared to show a yield decline from the third year of harvesting but then to stabilise after the seventh year.

Pod production per three for Treatment 2 was comparable to that of the monocrop over the entire trial duration (*Table 6*). For Treatments 3 and 4, pod production was comparable to the control during the first five years of harvesting but thereafter appeared to be reduced. This lower production of pods in subsequent years was possibly attributed to increased shading of the cocoa by the taller palms.

There was a distinct yield depression in 1983 due to severe cherelle wilt during the drought in the earlier part of the year. The monocrop had a 38% reduction in yield over the previous year. Higher reduction in yield were registered by the intercropped cocoa.

Cost Benefit Analysis

In a simple cost-benefit analysis (*Table 7*) comparing the profitability of the intercrop treatments with that of the monocrop at three commodity price levels, Treatment 4 generated the highest return at all price levels of cocoa and oil palm. Generally, all the intercrop treatments netted higher returns than the monocrop.

In terms of percentage profit, however, monocrop oil palm still emerged as the most profitable at low and medium prices. This owes largely to the comparatively lowe. costs in oil palm production. Treatment 3 ranked second to monocrop oil palm in profitability as a result of its full stand of oil palm and lower density of cocoa. This was followed closely by Treatment 4 with fewer oil palms and more cocoa. At high prices, monocrop cocoa was distinctly the most profitable. Treatment 4 ranked second. The least profitable was that of monocrop oil palm.

TABLE 4. MEAN OIL PALM BUNCH NUMBER (1973–1983)

No.	Treatment	Mean bunch (number/palm) 1973 Mac–Dec. 1st year	1974 2nd	1975 3rd	1976 4th	1977 5th	1978 6th	1979 7th	1980 8th	1981 9th	1982 10th	1983 11th	Total	Mean
1	Monoculture oil palm (control)	6.1	10.7	13.5	12.9	10.7	6.0	9.0	11.8	8.5	9.7	7.6	106.6	9.7
2	2 rows oil palm + 5 rows cocoa	7.9	12.3	15.9	12.6	11.0	6.0	8.1	7.8	6.2	6.8	5.9	100.5	9.1
3	1 row oil palm + 1 row cocoa	7.6	15.3	15.2	14.1	11.9	5.6	9.7	10.8	7.4	8.8	5.9	112.3	10.2
4	1 row oil palm + 3 rows cocoa	7.4	13.0	15.8	12.5	12.8	5.4	10.4	12.5	9.4	9.5	8.6	117.3	10.7
5	Monoculture cocoa (control)	–	–	–	–	–	–	–	–	–	–	–	–	–
	Mean	7.3	12.8	15.1	13.0	11.6	5.8	9.3	10.7	7.9	8.7	7.0	109.2	9.9
	Se (±)	0.5	1.2	0.8	0.6	0.36	0.83	0.96	1.51	0.52	0.70	0.48	0.51	
	LSD (P = 0.05)	1.22	2.94	1.56	1.47	0.88	2.03	2.35	3.69	1.27	1.71	1.17	1.25	
	LSD (P = 0.01)	1.85	4.45	2.97	2.22	1.33	3.08	3.56	5.60	1.93	2.59	1.78	1.89	

TABLE 5. MEAN OIL PALM BUNCH WEIGHT FROM 1973 TO 1983

No.	Treatment	Mean weight (kg/bunch)												
		1973 Mar–Dec 1st year	*1974 2nd*	*1975 3rd*	*1976 4th*	*1977 5th*	*1978 6th*	*1979 7th*	*1980 8th*	*1981 9th*	*1982 10th*	*1983 11th*	*Total*	*Mean*
1	Monoculture oil palm (control)	3.10	4.65	11.05	9.62	9.83	15.07	16.97	14.80	19.42	21.52	19.6	145.63	13.24
2	2 rows oil palm + 5 rows cocoa	3.01	5.03	10.84	8.55	9.65	13.50	17.68	14.78	20.82	23.27	17.60	144.73	13.15
3	1 row oil palm + 1 row cocoa	3.12	4.99	11.57	9.59	11.59	16.17	16.63	15.22	23.54	22.97	19.45	154.84	14.08
4	1 row oil palm + 3 rows cocoa	3.07	4.94	11.50	9.53	9.98	18.82	15.87	16.02	20.67	23.34	18.66	152.40	13.85
5	Monoculture cocoa (control)	–	–	–	–	–	–	–	–	–	–	–	–	–
	Mean	3.08	4.90	11.24	9.32	10.26	15.89	16.79	15.21	21.11	22.78	18.83	149.40	13.58
	Se (±)	0.05	0.09	0.26	0.58	1.12	3.31	1.23	0.47	1.64	1.31	0.97	0.6	
	LSD (P = 0.05)	0.12	0.22	0.64	1.42	2.74	8.09	3.00	1.15	4.01	3.20	2.37	1.46	
	LSD (P = 0.01)	0.19	0.33	2.37	2.15	4.15	12.30	4.56	1.74	6.08	4.86	3.60	2.22	

TABLE 6. AVERAGE COCOA POD YIELD (1973–1983)

No.	Treatment	Average yield (pods/tree)											
		1973 Mar–Dec 1st year	*1974 2nd*	*1975 3rd*	*1976 4th*	*1977 5th*	*1978 6th*	*1979 7th*	*1980 8th*	*1981 9th*	*1982 10th*	*1983 .11th*	*Total*
1	Monoculture oil palm (control)	–	–	–	–	–	–	–	–	–	–	–	–
2	2 rows oil palm + 5 rows cocoa	3.9 (93)	19.8 (116)	19.7 (96)	22.8 (92)	20.1 (152)	21.5 (97)	45.4 (106)	37.6 (127)	37.6 (89)	43.1 (102)	23.1 (88)	291.6 (108)
3	1 row oil palm + 1 row cocoa	7.7 (183)	29.6 (174)	22.4 (109)	26.9 (108)	14.0 (106)	17.6 (80)	27.1 (63)	24.8 (83)	20.8 (49)	36.1 (86)	20.0 (76)	247 (88)
4	1 row oil palm + 3 rows cocoa	4.1 (98)	19.9 (117)	20.1 (98)	19.8 (80)	12.9 (98)	17.9 (81)	28.0 (65)	23.4 (79)	22.3 (52)	26.2 (86)	21.8 (83)	226 (86)
5	Monoculture cocoa (control)	4.2 (100)	17.0 (100)	20.5 (100)	24.8 (100)	13.2 (100)	22.0 (100)	42.8 (100)	29.6 (100)	42.4 (100)	42.0 (100)	26.1 (100)	284.6 (100)
	Mean	5.0	21.6	20.7	23.6	15.1	19.8	35.8	28.9	30.8	39.4	22.0	262.4
	Se (±)	1.6	2.7	3.8	1.8	1.8	2.4	3.9	7.7	4.8	3.2	1.4	4.0
	LSD (P = 0.05)	3.9	6.6	9.3	4.4	4.4	5.9	9.5	18.8	11.7	7.8	3.4	9.8
	LSD (P = 0.01)	5.9	10.0	14.1	6.7	6.7	8.9	14.5	24.5	17.8	11.9	5.2	14.8

Figures in parenthesis represent % pod yield over control.

TABLE 7. COST AND REVENUE OF COCOA/OIL PALM INTERCROPPING

Treatment	Trees/ha		Mean annual yield (11 yrs)		Cost ($/ha)		Total Cost	Revenue ($/ha)			Total revenue ($)	Net revenue ($)	Profit (%)
	Cocoa	Oil Palm	Cocoa (kg dry bean/ha)	Oil Palm (tonne ffb/ha)	Cocoa	Oil Palm		Price Level[a]	Cocoa	Oil Palm			
1	–	143	–	18.11	–	1694	1694	Low price	–	2173	2173	479	28
								Med. price	–	2898	2898	1204	71
								High price	–	3622	3622	1928	114
2	667	114	596	12.09	1424	1276	2700	Low price	1788	1451	3239	539	20
								Med. price	2384	1934	4318	1618	60
								High price	3576	2418	5994	3294	122
3	400	143	299	18.79	790	1716	2506	Low price	897	2255	3152	646	26
								Med. price	1196	3006	4202	1696	68
								High price	1794	3758	5552	3046	122
4	761	110	524	15.97	1453	1369	2822	Low price	1572	1916	3488	666	24
								Med. price	2096	2555	4651	1829	65
								High price	3144	3194	5338	3516	125
5	1111	–	958	–	2333	–	2333	Low price	2874	–	2874	541	23
								Med. price	3832	–	3832	1499	64
								High price	5748	–	5748	3415	146

	Dry cocoa bean ($/kg)	Oil palm ffb ($/tonne)
[a]Low price	3.00	120.00
Medium price	4.00	160.00
High price	6.00	200.00

Cocoa costs include upkeep & cultivation, and general charges which are proportioned to the intercropped treatments according to tree stand. Additional costs on harvesting and transport @ 87¢/kg dry bean and processing @ 23¢/ kg dry bean are based on actual crop produced.

Oil palm costs on upkeep and cultivation, and general charges are proportioned to the intercropped treatments based on palm stand. Added are costs on harvesting and transport @ $32/tonne ffb.

DISCUSSION

Oil palm yields in the control plots are considered poor by commercial standards but are anticipated in view of the presence of poorer soils of Durian and Malacca series. Monocrop cocoa yields are within acceptable levels.

Comparatively better yields of the intercropped oil palm in Treatments 3 and 4 were obtained with respect to their planting density The mean bunch number and bunch weight of these two treatments also exceeded those of the control. Better performance was apparently attributed to the avenue planting of palms which were able to exploit a larger volume of soil in the interrow for nutrients and moisture. In Treatment 2, however, triangular spacing of oil palms at only 7 m apart created severe competition between the palms. Reduced yields were evident as early as in the fourth year of harvest and thereafter yields showed a definite decline. With a palm stand which is 80% of the monocrop stand, the cumulative yield of Treatment 2 till the 11th year was only 67% of the control. Interpalm competition here also produced lower bunch numbers and bunch weight than the rest of the intercrop treatments. This is expected as close spacing among adult palms generally lead to a decrease in sex ratio and bunch weight (Hartley 1969). A certain degree of etiolation arising from interpalm competition also probably occurred with the more closely-planted palms, particularly Treatment 2 which at its 13th year in the field recorded the highest height measurement (this was however not significantly different).

Among the intercrop treatments, cocoa yields were highest in Treatment 2. In fact, the individual pod yield per tree here exceeded that of the monocrop control. This shows that the wider interrow spacing of 25 m in Treatment 2 provides adequate spatial and light requirements for the cocoa. Treatment 2 can thus be potentially viable if oil palm yields could be improved by possibly increasing the triangular spacing from 7 m to 9 m. Sly and Chapas (1968) investigated the effect of different spacings in avenue planting on oil palm yields; their conclusions were that spacing between the palms in the rows must be near to the normal planting distance (9 m) since closer spacings failed to compensate for the heavier and more numerous bunches in the wider spaced palms.

For the intercrop Treatments 3 and 4, individual tree pod yield of cocoa was lower than that of the control. Treatment 3, which was the best treatment until 1977 (the fifth year) (Lee & Hanafi 1980), appeared less lucrative in the later years. Although this had the highest ffb yield, the cocoa yield was only 31% of the monocrop control. Here, pod production per tree exceeded that of the control until the fifth year of harvest but thereafter assumed a decline. In the case of Treatment 4, pod production also appeared to be affected after the fifth harvest. The result of reduced pod production and lower yields in the later years is probably a reflection of inadequate light. Visual observations of the cocoa in Treatments 3 and 4 showed that the canopies were poor by comparison to the monocrop cocoa. Light penetration would be further limited as the palms grew taller, thus it would be interesting to ascertain if the intercropped cocoa could sustain its production with time.

One possible method of alleviating the problem of over-shading in future plantings would be to orientate the hedge palm rows in an east-west rather than the present north-south direction. Another method is to increase the planting distance between avenue palms from 7 m to 9 m although it is uncertain if this can reduce interpalm competition for light and space and thereby increase yields that would offset production at a lower density of palms. It is also possible that the present closely planted stand be reduced on

a selective basis. To a certain extent, palm fronds may be cut to facilitate greater light penetration.

Taking both crops as a whole, Treatment 4 (one row oil palm/three rows cocoa) appeared to be the most promising intercropping system to-date with yields of 55% and 88% of monocrop cocoa and oil palm respectively. Cost/benefit-wise, Treatment 4 was shown to return steady incomes at fluctuating prices of oil palm and cocoa.

Intercropped systems of cocoa and oil palm would thus be probably ideally suited to smallholders who wish to maximise returns from the limited size of their holdings. Intercropping is also one way of buffering incomes by price fluctuation of any one commodity. However, further experimentation is necessary to determine the best spatial arrangement in relation to plant morphology for oil palm and cocoa in order to maximise income in such smallholdings.

CONCLUSION

Close planting of oil palm in twin rows and at 7 m triangular spacing (Treatment 2) resulted in severe interpalm competition and thereby depressed oil palm yields. However, when planted in single rows (Treatments 3 and 4), encouraging yields were obtained.

For cocoa, only Treatment 2 maintained consistently good yields. This probably resulted from better light penetration on a wider interrow spacing between the palms. Treatment 3 showed a distinct declining yield trend. Evidently, the interrow width of 10 m between the palms was too close for the cocoa resulting in increased inter-competition in the later years. Cocoa production in Treatment 4 was comparable but there were indications that the yield may decline with increasing shade from the oil palm.

Performance-wise, Treatment 4 appears to be the most promising of the intercrop treatments. Treatment 4 generates the highest return per hectare (revenue minus cost) at all the price levels considered. Profit-wise, Treatment 4 may not be as lucrative as monocrop oil palm at low and medium prices but at inflated prices, Treatment 4 is distinctly the more profitable.

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APPENDIX MONTHLY RAINFALL AT TUN RAZAK AGRICULTURAL SERVICES CENTRE FROM 1972 TO 1983

Year	Monthly 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

Influence of Timing and Frequency of Pruning on Yield of Hybrid Cocoa

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There are several advantages in carrying out pruning on cocoa. Besides maintaining the shape of the developing tree, pruning also ensures easy access to the trees for spraying and harvesting. It also helps in controlling pests and diseases. Ultimately, higher yields and optimum return from the trees could be expected. To reap all these benefits, it is important to determine, among others, when is the best time or period in the year to carry out this operation. Apart from knowing the appropriate time of pruning, it is also important to determine how frequent should pruning be carried out.

This paper reports the results from a pruning trial initiated in 1978 to investigate the effect of pruning on yield of five-year old unpruned cocoa plantings in Sabak Bernam, Selangor. The time and frequency of pruning were considered in this trial. For the conditions at the locality and from yield data, pruning once a year in the middle of the harvest cycle is recommended.

Cocoa, *Theobromae cacao* L., has no unusual botanical characteristics and unique growth habit. Initially, the cocoa seedling grows as a single stem to a height of about 0.9 to 1.5 m. Subsequently, the terminal bud ceases to grow and develops into a jorquette, comprising normally about five plagio-tropic fan branches. Further increases in height is made by the development of orthotropic shoots or chupons, as they are popularly known, from below the jorquette. If uncontrolled, this process will only result in a relatively tall plant with a lot of undesirable vegetative growth. This phenomenon encourages the incidence of pest and diseases, makes harvesting a difficult operation and in cases where cocoa is planted on soft terrain, strong winds may cause lodging. Thus, pruning is obviously an essential operation to minimise or eliminate these problems.

Significance of Pruning

Pruning is a means of increasing the efficiency of partitioning or assimilates controlling plant height and obtaining suitable tree shape. Pruning facilitates harvesting as well as control of pests and disease incidences so that, ultimately, higher yields are achieved. The influence of pruning on yield, however, depends on many factors, especially on the nature and timing or frequency of pruning. Hall (1961) and Bonaparte (1966) have reported that proper timing and judicious pruning normally lead to increased yield. Pruning, if carried out ideally, not only increases yield but also maintains the health of the plants. Overpruning can expose the plant thus leading to drying up of the branches and increased susceptibility to disease. On the other hand to underprune leads to undesirable vegetative growth which only encourages the incidence of disease and pests. Al-

though pruning practice has been generally standardised, little consideration has been given to frequency and timing operation, including the intensity which we define as the "amount of material removed out at any given time."

Current Pruning Practices

The current pruning practices can be grouped into three categories: formation pruning, reformation pruning and maintenance pruning.

Formation pruning. Formation pruning is carried out, aimed at achieving suitable tree height and canopy shape. In Peninsular Malaysia, the cocoa plant is normally allowed to develop into only a single jorquette of about 1.4 to 1.8 m, and other axillary chupons are removed at regular intervals (Shepherd *et al.*, 1976). Under normal conditions, if a plant forms a jorquette below 1.4 m, this abnormality can be corrected by excising the first jorquette as soon as it forms (Denamany *et al.*, 1981). Normally, several chupons will be produced below the cut (excising point) and only the healthiest and most erect is chosen and allowed to develop. If the required height is still not acquired, the same process is repeated. After about 30 months in the field, all branches and adventitious shoots within 46 cm of the jorquette are removed to facilitate harvesting. Retention of three to four main branches (fans) is normally practised in Hilir Perak to achieve a balanced architecture and to minimise any tendency of branches to bend. Once the canopies of the adjacent trees touch each other, light pruning is carried out. Fan branches growing downwards, inwards and across the central axis of the tree are removed where necessary to improve ventilation and light penetration. Branches growing too close together should be thinned, for better ventilation.

Reformation pruning. Reformation pruning is carried out in order to achieve the shape of the plant. The operation is the same as that of the formative pruning. Pruning is a continuous operation but excessive foliage removal should be avoided in order to avoid any detrimental effects on growth and yield. In this context the frequency and timing of pruning practices assume considerable significance. At present such information is limited. Hence this experiment was instituted with such objective.

Maintenance pruning. Water shoots and drooping of branches are removed regularly in conjunction with harvesting to improve ventilation. (Shepherd *et al.*, 1976).

Improved ventilation in pruned trees has been observed by Rocha and Machado (1972) to reduce the incidence of black pod due to reduction in shade. Excessive branches and those affected by disease should be pruned. It has been reported by Chan and Syed Kamaruddin (1976) that pruning of affected branches can reduce the incidence of vascular streak dieback (VSD) and cutting 45 cm after the observed appearance of symptoms on the branch has been recommended. Lee (1974) has observed that if pruning is not carried out in the early years, basal chupons are produced, and as a result, the trees tend to be rather flat with spreading branches, making harvesting a difficult operation. Overlapping of branches with neighbouring trees should be avoided in order to reduce mutual shading which can lead to the spread of diseases.

In this paper, the influence of timing and frequency of pruning on yield of five years old mixed hybrid cocoa is reported. It is hoped that results from this study can be used in formulating pruning programmes.

MATERIALS AND METHODS

The trial was initiated in March 1978 on five-year old unpruned cocoa plantings at Sabak Bernam, Selangor. The cocoa plantings, of mixed hybrid origin, were planted at 1.8 m apart within rows and 3 m apart between rows in twin rows under 40 years old Malayan Tall Coconuts. The coconuts were planted at 9 m x 8.4 m rectangular planting. The soil series was Selangor – Kangkong Association.

Four treatments were tested, comprising:–

- T_1 – Pruning at the end of first peak harvest. (Mac/Apr)
- T_2 – Pruning at the end of second peak harvest. (Oct/Nov)
- T_3 – Pruning at the end of both peaks.
- T_4 – Control, whereby no pruning was carried out.

These operations involved shaping the tree with routine maintenance pruning.

Randomised complete block design with three replication was employed. Each plot size was about 6 m x 64.8 m. The yield data were collected from 30 treatment plants. The hanging-card system of collecting data was employed, whereby, at each trees, a card is left hanging, and everytime the pods harvested, the number was written on it. The card was covered by plastic to prevent damage from rain.

A compound fertilizer (17-8-17) at the rate of 230 g per tree was given twice a year at the end of April and November. Ground magnesium limestone at a rate of 340 g, per tree was applied once a year in June. Pesticide sprays was carried out whenever necessary.

RESULTS

Effect of Pruning on Yield

Table 1 shows the effect of pruning on yield per plot per year. It was found that the yield of the control treatment (no pruning) was always lower than those of other treatments throughout the three-year experiment. Even though there was no significant difference between the yield of the control and that of the pruning treatment at the end of the first peak (Mac/Apr), the yield of the pruning treatment was higher than that of the control by 30%, 83% and 133% in 1979, 1980 and 1981 respectively. It is interesting to note that there was no significant difference between pruning at the end of second harvesting peak (Oct/Nov) and pruning treatment at the end of the first and second harvesting peak. The yield of both treatments were significantly higher than that of the control.

Effect of Pruning on Fruiting Season

The bimonthly pod production per plot for three years are listed in *Table 2*. It was found that the timing of pruning did not affect the pod production during the first peak (February to April) as well as the off fruiting season (May to August). There was no significant difference between the yield of Treatments 1, 2 and 3 during these seasons. However, the fruiting or pruning significantly affected the pod production during the second peak season (September to December)

TABLE 1. EFFECT OF PRUNING ON YIELD OF COCOA

Treatments	*Total plot yield (Pods)*			*Total 3-year yield ($\bar{x}$ of 3 rep) pods*	*$\bar{x}$ per year (pods)*	*Expected yield* (tonnes dry beans/ha/year)*
	1979	*1980*	*1981*			
Pruning at end of the first peak (Mac/Apr)	451 bc	378 b	656 b	1465 b	495	0.55
Pruning at the end of second peak (Oct/Nov)	536 b	686 a	1925 a	3147 a	1049	1.17
Pruning at end of both peaks	692 a	757 a	1448 a	2894 a	965	1.07
Control (No pruning)	346 c	206 c	281 b	882 b	294	0.33

*The yield (dry bean) was calculated on the basis of 815 plants per hectare.

Values within a column followed by the same letter are not significantly different at P = 0.05 by Duncan's multiple range test.

TABLE 2. EFFECT OF PRUNING ON FRUITING SEASON
(Total of three year yield, 1979–81)

Treatments	*Bimonthly yield (pods)*					
	Jan.	*March*	*May*	*July*	*Sept.*	*Nov.*
Pruning at end of the first peak (Mac/Apr)	308 ab	457 ab	163 a	51 b	119 ab	385 b
Pruning at end of the second peak (Oct/Nov)	595 a	643 a	120 a	150 a	294 a	1342 a
Pruning at end of both peaks	507 ab	511 ab	203 a	162 a	254 ab	1257 a
Control (No pruning)	233 b	193 b	115 a	56 b	97 b	138 a

Means within a column followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

Pruning at the end of the second peak was important to ensure higher yield of the next second peak season (*Figure 1*). Pruning twice a year (Treatment 3) did not improve the pod production over the one-pruning treatment at the end of the second peak. On the otherhand, the one-pruning treatment at the end of the first peak reduced the pod production during the second fruiting season.

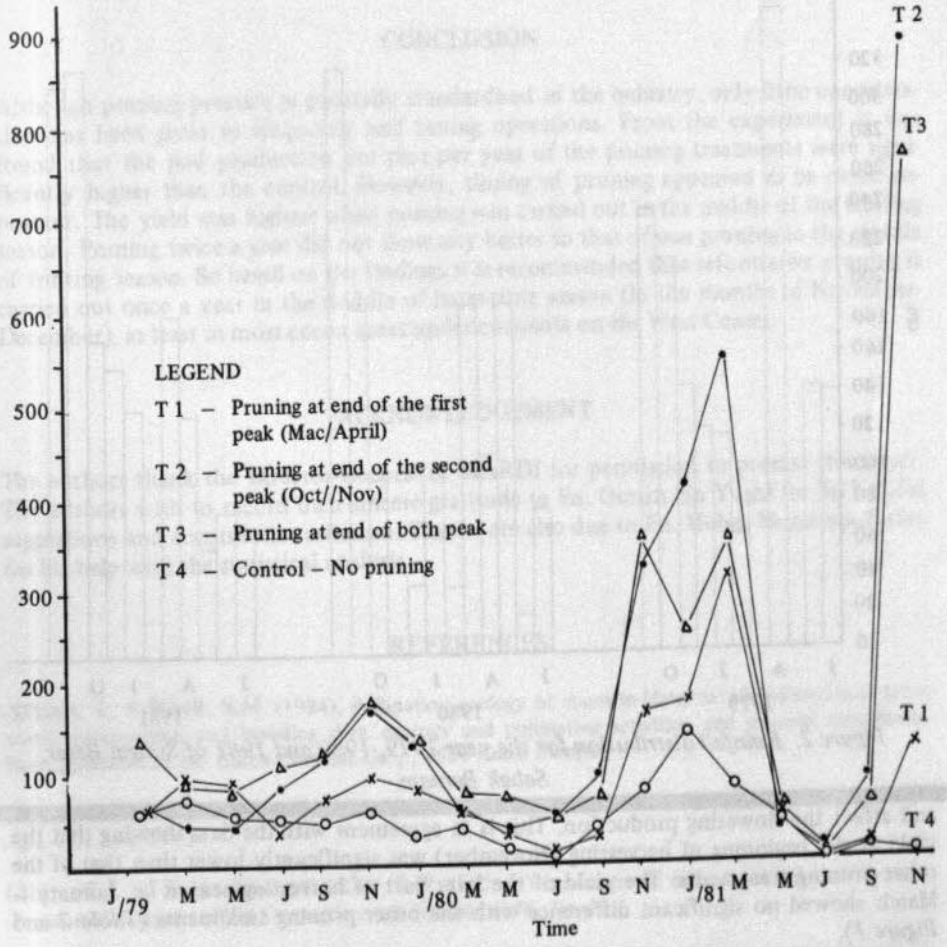


Figure 1. Number of pods per harvest in relation to time.

DISCUSSION

It is accepted that based on a calendar year there are two fruiting seasons for cocoa in Sabak Bernam, Selangor, and the surrounding areas. The first peak is in March/April and the second peak is in October/November. However, when the yield curves are drawn continuously from year to year (*Figure 1*) it is found that there is actually only one fruiting season extending from September to March of the following year. So basically there is a six-month off season followed by another six-month fruiting season. The discussion hereafter will be based on the above finding.

New flushes followed by heavy flowering were observed following the commencing of the rain (*Figure 2*) in late March and/or early April. Flushing and flowering were observed to have been continuous throughout April to September. These observations have also been reported by Azhar and Wahi (1984) and Omran (pers. comm., Mardi Hilir Perak).

Pruning at the end of fruiting season (March/April), will trigger the plant to flush heavily. This might create a greater photosynthetic sink to the newly developed leaves

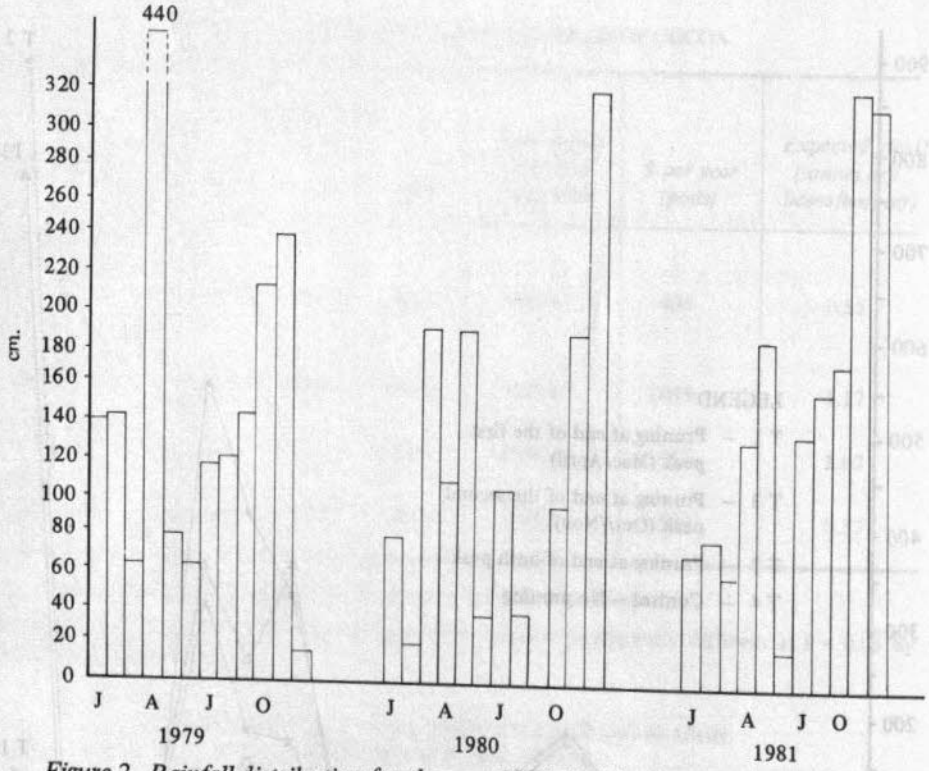


Figure 2. Rainfall distribution for the year 1979, 1980 and 1981 of Sungai Besar, Sabak Bernam.

and affect the flowering production. This is in agreement with the data showing that the yield at the beginning of harvesting (November) was significantly lower than that of the other pruning treatments. The yield of the later part of harvesting season *i.e.* January – March showed no significant difference with the other pruning treatments (*Table 2* and *Figure 1*).

Omran (pers. comm., Mardi Hilir Perak), found out that flushing during harvesting season (September – January) was less than during the off harvesting season. Thus, pruning during the middle of fruiting season (November – December) did not result in heavy flushing and interfere with the existing pod development. By the end of the harvesting season, flushing appeared at a normal phase rather than heavy flushing at once as shown by Treatment 1.

For Treatment 3, where pruning was done twice a year, the amount of removal was relatively less than that of Treatments 1 and 2. So the pruning exercise at the end of harvesting season of Treatment 3 did not have the same effect as Treatment 1. Even though the pruning did trigger flushing, the intensity of flushing was less than that of Treatment 1. The lesser intensity of flushing did not interfere with the flowering pattern of the tree and eventually the yield was not affected.

As expected, the yield of the control was the lowest and showed no improvement from year to year. The vegetative production was vigorous, thus producing a great quantity of sub-functioning or passenger organs which may create a greater sink for the photosynthate to support their respiration mechanism.

CONCLUSION

Although pruning practice is generally standardised in the industry, only little consideration has been given to frequency and timing operations. From the experiment it was found that the pod production per plot per year of the pruning treatments were significantly higher than the control. However, timing of pruning appeared to be more important. The yield was highest when pruning was carried out in the middle of the fruiting season. Pruning twice a year did not show any better to that of one pruning in the middle of fruiting season. So based on the findings it is recommended that reformative pruning is carried out once a year in the middle of harvesting season (in the months of November-December), at least in most cocoa areas under coconuts on the West Coasts.

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Observations on Cocoa Planting under Thinned Jungle Shade

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Case studies and large-scale development programmes indicate that the advantages of planting cocoa under thinned jungle shade could out-weigh those of planting under Gliricidia *shade.*

Where the jungle has been extensively logged and regenerating jungle trees afford ideal shade for cocoa, the authors advise against clearing the jungle to plant Gliricidia. *In remote areas and when the development programme is extensive and time a factor and where* Gliricidia *supply is a problem, the authors' argument is more convincing. Such constraints as uncertainty of weather conditions, soil type and terrain lend further weight to their findings.*

The attractiveness of using jungle shade to establish cocoa is further enhanced when one considers the financial advantage of lower initial cost outlay creating favourable cash flow, with a greater certainty of meeting targets in the planting schedule and a generally long term agronomic benefit of a more vigorous initial growth of the cocoa plant.

Cocoa is generally planted under established permanent shade following clear felling or under thinned jungle (Wood, 1973). It was introduced into Sabah some 30 years ago and was first grown under thinned natural jungle. In 1963, attempts were made to plant cocoa using *Leucaena glauca* as primary shade. The cocoa grew well, and in 1964 a complete fell-burn-clear method was introduced. However, by the end of 1965, *Leucaena* became unpopular because of its prolific seeding problem and *Gliricidia sepium (=maculata)*, first introduced as shade for tea, found its place in the cocoa industry and later became the primary top shade tree for cocoa in Sabah. Because of this and the favourable results that followed, the use of jungle shade was quickly replaced by the use of *Gliricidia* shade.

As the cocoa price rose in the mid seventies, there was considerable hurry to open up new tracts of jungle for cocoa cultivation. Large-scale development was tried employing mechanical clearing methods, but, these were often found to compact the soil and to greatly impede the growth of *Gliricidia* as well as the successful establishment and growth of cocoa.

Thinned out jungle was then re-employed to provide the initial shade for the young cocoa. In this way, large areas can be rapidly prepared for cocoa planting, eleminating the 9–12 month period required for *Gliricidia* shade to establish itself prior to cocoa planting.

In addition, at that time. *Gliricidia* planting material was not always readily available in large quantities. Nevertheless, inclusive of transportation and establishment costs, planting of *Gliricidia* requires a larger initial input of capital. Moreover, its growth and readiness to provide adequate shade for cocoa is largely dependent on weather conditions. With cocoa seeds also being in high demand, the dual uncertainty made the shade/cocoa planting schedule more difficult to plan and less flexible in practice.

These considerations led many planters and land owners from about 1979 onwards to use jungle shade again for cocoa. Subsequently, many variations of jungle shade thinning have been adopted for differing local conditions.

METHODS

Case studies of two basic methods of preparation of the jungle shade for cocoa planting and subsequent growth are described here. Conventional cocoa planting under *Gliricidia* shade provides the comparison.

Case One

Cocoa was planted in September 1980 at 3 m x 3 m square on soils which belong to the Tanjong Lipat Family of Rumidi Association soil, a sandy clay formed from interbedded sandstone and mudstone parent materials and with slopes of between 6° to 12° and located in the Sandakan district of Sabah.

In one field referred to as Block JI, cocoa was planted under thinned jungle shade after underbrushing, *i.e.* all undergrowth and saplings up to 8 cm diameter were cut down. After the cocoa rows were demarcated, trees that were located within 1 m of the cocoa row were felled and cleared. At the time of planting the cocoa, the overhead shade was estimated to cover about 80% to 90% of the ground surface but this quickly thickened. However, it was generally kept at between 70% and 80% up to mid 1982 and reduced to 20% to 30% by the end of 1983. Shade assessment was only visual and based on the ground shade at about noon time.

In another field, referred to as Block G1, cocoa was under *Gliricidia* shade planted about nine months earlier at a spacing of 3 m x 3 m. *Gliricidia* was regularly pruned to prevent any overhead shading of the cocoa bushes so that about 1.5 m of the *Gliricidia* interrows received direct sunlight. *Gliricidia* bushes were generally pruned to one to two main stems.

Case Two

Cocoa was planted in March 1981 in one field, referred to as Block J2, under jungle shade which had been underbrushed as in Block J1 and subsequently all large jungle trees, *i.e.* trees with diameter more than 20 cm. Also all trees within 1 m cocoa row were felled and cleared before cocoa were planted. Initial overhead shade was estimated at about 50% and this was progressively reduced by poisoning with arboricides to about 20% to 30% by mid 1982. Again, shade assessment was visual as in Case One. *Gliricidia* was then planted at about 6 m x 6 m in the cocoa interrows in the second half of 1982.

In another block, referred to as Block G2, cocoa was planted in January 1981 under conventional *Gliricidia* shade planted about nine months before cocoa planting. The

TABLE 1. DESCRIPTION OF BLOCKS

Item	*Block J1*	*Block J2*	*Block G1*	*Block G2*
Area	Between 8 to 15 ha each			
Shade – Type	Thinned Jungle	Thinned Jungle	Planted *Gliricidia*	Planted *Gliricidia*
– Detail	All saplings < 8 cm diameter felled.	All saplings < 8 cm diameter + all trees > 20 cm diameter felled. *Gliricidia* planted mid 1982 at 6 m x 6 m.	3 m x 3 m	3 m x 3 m
– Date	Mid 1980	Early 1981	January 1980	April 1980
Cocoa Planted	September 1980	March 1981	September 1980	January 1981
Shade (%) – Visually Assessed				
at planting	80 – 90	50	± 80	± 80
up to mid 1982	70 – 80	40	± 50	± 50
after mid 1982	20 – 30	20 – 30	± 20 – 30	± 20 – 30

Gliricidia was regularly pruned to prevent excessive overshading of the cocoa interrows. The *Gliiricidia* was planted at 3 m x 3 m in between the cocoa rows.

The soils in both the blocks were similar to those in Case One and located also within the same estate.

RESULTS

Cocoa planted under thinned jungle was observed to achieve more vigorous and greater vegetative growth within the first two years after planting out. As a result of their better growth, cocoa bushes were more uniform (except in places where overhead shade was thick) and more precocious. Generally, cocoa planted under thinned jungle and with proper management is at least six months ahead in terms of size and often in precocity compared to cocoa planted under normal established *Gliricidia* shade by the time the cocoa is one and a half to two years of age.

From *Tables 2* and *3* and observations, the following comments can be made.

- The costs incurred in land preparation and field upkeep prior to planting cocoa is distinctly lower for the thinned jungle shade method as compared to the use of established *Gliricidia* shade. The costs are lower in Block J1 where felling of jungle trees was minimal and amounted to only about two thirds of that incurred in the establishment of *Gliricidia* shade. In Block J2, where more thinning of the jungle shade was carried out, the costs increased to around 80% of the *Gliricidia* shade method.

- Weeding costs were appreciably lower under thinned jungle during the first one and a half years. Thereafter when the jungle shade was severely thinned, the costs were reversed with the jungle shade weeding being more expensive. Over the three-year period, however, weeding costs were higher under *Gliricidia*. In jungle shade the avenues under large shade trees in J1 required less weeding than J2 with small shade trees. This is to be expected as weed growth is dependent on sunlight – the more light the more weeds.

- Lalang eradication and control cost were consistently lower in the jungle shade areas throughout the period under study and amounted to between 20% to 25% of the corresponding costs under the *Gliricidia* shade.

- Control of overhead shade for cocoa involved pruning in the case of *Gliricidia* and poisoning in the case of jungle shade. Shade control by thinning of jungle by poisoning with the arboricide 2,4,5-T cost less than pruning *Gliricidia*. Where the initial jungle stand has a higher density of large trees, the cost situation is reversed.

- In this study, pest and disease control costs were consistently lower in the jungle shade areas particularly in the first two years after the cocoa had been planted; costs were 20% to 60% lower than under *Gliricidia*. Disease was relatively unimportant so that pest control accounted for at least 85% of the pest and disease control cost. The major cocoa pests were leaf eaters (such as caterpillars and grasshoppers) and leaf suckers (such as the mosquito bugs).

- Fertiliser costs were marginally higher using *Gliricidia* shade because of the need to supply fertilisers to encourage the establishment and boost the growth of the *Gliricidia* cuttings.

TABLE 2. LABOUR COSTS FOR LAND PREPARATION UP TO COCOA PLANTING

Item	*Cost ($/ha)*			
	Block J1	*Block J2*	*Block G1*	*Block G2*
Underbrushing	124	124	99	99
Felling	100	136	124	124
Burning	0	0	25	25
Pruning, reburning	0	0	247	247
Row opening	271	371	0	0
Shade planting, upkeep	0	0	408	408
Lining, holding & planting of cocoa	225	225	188	188
Total	720	856	1091	1091
Mean	788		1091	

TABLE 3. MAINTENANCE LABOUR COSTS OF COCOA

	1981 Cost ($/ha)					*1982 Cost ($/ha)*					*1983 Cost ($/ha)*					*3rd Year Total Cost ($/ha)*				
	J1	*J2*	*G1*	*G2*	*GM*	*J1*	*J2*	*G1*	*G2*	*GM*	*J1*	*J2*	*G1*	*G2*	*GM*	*J1*	*J2*	*G1*	*G2*	*GM*
Weeding	257	268	368	411	390	84	136	103	116	110	82	106	22	44	33	423	510	493	571	532
– lalang	0	0	70	69	70	22	27	42	74	58	12	17	20	52	36	34	44	132	195	164
Shade – pruning	0	0	24	0	12	0	0	30	27	29	0	0	0	32	16	0	0	54	59	57
– poisoning	0	92	0	0	0	17	25	0	0	0	10	12	12	7	10	27	129	12	7	10
P & D control	23	19	51	47	49	37	15	47	22	35	22	30	32	27	30	82	64	130	96	113
Cocoa pruning	15	0	0	11	6	44	57	116	57	87	49	133	91	143	117	108	190	207	211	209
Manuring	50	45	65	46	56	57	54	64	69	67	42	49	47	40	44	149	148	176	155	166
Gliricidia Planting	0	36	0	68	34	22	25	0	0	0	12	17	0	3	2	34	78	0	71	36
Total	345	460	578	652	615	283	339	402	365	364	229	364	224	348	286	857	1163	1204	1365	1285
Mean	402		615			311		383			297		286			1010		1285		
Wet cocoa bean (kg/ha)	0		0			n/a		n/a			123	150	1044	434		123	150	1044	434	

J1 = Jungle shade, trees > 8 cm in diameter

J2 = Jungle shade, 8–20 cm in diameter

G1 and G2 = *Gliricidia* shade planted 3 m x 3 m

GM = Mean of G1 and G2

- The cost of maintenance in the first two years after cocoa had been planted was lower under both types of jungle shade. Maintenance was appreciably less in the Block J1 as compared to Block J2.
- The yield figures for 1982 are not available. They were only recorded for 1983. It will be unwise to draw any definite conclusions other than to observe that recorded yields in this study indicate that initial yields under *Gliricidia* are higher than under thick jungle shade and that under jungle shade itself higher initial yields were achieved where the remaining jungle shade was less heavy. Observations elsewhere have indicated that when the jungle shade is properly prepared, cocoa growth and yield are at least comparable to cocoa planted under established *Gliricidia* shade.

DISCUSSION

The choice of whether to plant cocoa under thinned jungle shade or under established *Gliricidia* shade depends on a number of factors which vary from situation to situation.

The type of jungle and the density of large trees are primary considerations in the successful use of thinned jungle shade for the planting of cocoa. Where the jungle has a high density of large trees and a corresponding lower stand of smaller lower storey trees, thinning of the jungle to provide suitable shade for cocoa will normally be difficult and require the planting of at least some shade trees. In such jungle areas, a large number of smaller trees will be brought down by the felling of the large trees. After such felling operations, the smaller trees will normally be so damaged that they are unable to provide adequate and reasonably uniform shade for subsequent successful establishment of cocoa. The large amount of felled timber on the ground also means that opening of the cocoa rows will be arduous and costly. Moreover, the large number of logs left on the ground severely restricts mobility and makes the ground maintenance job extremely difficult, until such time as the timber rots away. In dry weather, the dry wood material would also pose a very real fire hazard. On the other hand, if the large trees were to be retained and the smaller trees felled, initial establishment of cocoa will normally be simple and involve low costs. However, the problem is only deferred as the presence of these large trees is non-conducive to satisfactory cocoa performance, as illustrated in Block J1, and will have to be eliminated quickly after the cocoa has been planted out.

Large trees when poisoned will also pose a problem to the cocoa bushes and workers when the trees are felled in large pieces especially during periods of sudden strong winds and rain. Such fallen timber can break the branches or even the main stems of the cocoa bushes and hence set them back by six months to a year. Workers and supervisors also are generally reluctant to work in such areas as large fallen branches can also cause serious or even fatal injuries to them. Where the existing jungle area to be planted out consists of a few large trees and many smaller trees akin to secondary forest, the eventual choice of using either the clean-clearing of thinned jungle method will then depend on other factors including:

- Remoteness of the area – accessibility, roads, ease of availability of *Gliricidia* cuttings in quantities.
- Development schedule – size, rate of development and weather conditions.
- Cash flow position.
- Soil type and terrain.

As observed in this study, *Gliricidia* establishment costs can amount to about 40% of the total establishment costs. Such costs will be higher if the *Gliricidia* has to be transported in over long distances where bruising and the delay between cutting of the *Gliricidia* and planting can cause high casualties. A high casualty rate will require extensive and expensive supplying and cause delays in the subsequent schedule of cocoa planting. The development schedule must depend on the size of the area, the speed of development required and the timing of the operations to coincide with suitable weather conditions. It will also influence the choice and type of shade. Generally, thinned jungle will be favoured if the area to be developed is large, the jungle itself suitable, the speed of development demanded is high and the timing of the land preparation operations with expected weather conditions is exact.

Under jungle shade, initial land preparation and upkeep are less labour-intensive and less dependent on dry weather conditions for effective burning and wet weather for the planting and establishment of *Gliricidia* shade. In addition, the requirement of less labour means that a smaller number and slower influx of workers is required and hence more widely spaced requirements for housing, transport and other ancillary facilities. Supervisory staff build up will also consequently be more spread out, so such intakes can be better organised. In terms of cash flow and capital requirements, the lower initial costs and more protracted development costs would be an advantage coupled with the earlier onset of harvesting from the time of initiation of the development project. Although the total capital outlay would be much the same, repayment could start earlier.

An equally important consideration is the soil type and terrain of the area selected for development. Where soil erosion may become a problem, or where the effective rooting depth is shallow, the thinned jungle method is again preferred.

Experience suggests that jungle shade preference should be for the felling of all large trees leaving a stand of small trees to provide the necessary overhead shade and thinning after establishment to provide about 30% shade during the immature phase of the cocoa. The few remaining jungle trees are then progressively poisoned with arboricides as their canopies thicken with time.

It is the opinion of the authors that where:–

- the jungle trees can be appropriately thinned out (*i.e.* where the jungle shade from the lower storey or secondary jungle trees will provide fairly uniform shade),
- the cocoa rows are neatly opened and maintained,
- *Gliricidia* shade is planted out at about 6 m x 6 m within six months after the planting out of the cocoa, the cocoa growth and at least the initial yield can be as good, if not, as often happened, better than the corresponding cocoa growth under established *Gliricidia* shade.

From observations made on many estates in Sabah, maintenance costs under jungle shade have not necessarily been higher than under *Gliricidia* shade. Where primary jungle has been repeatedly logged, largely eliminating, the upper storey of the dipterocarp type forest, the result has been secondary forest where smaller and shorter trees predominate. Such logged forests are especially conducive to the thinned jungle method where the removal of the few large jungle trees are much less difficult and costly. In addition, the greater density of smaller trees will provide a greater possibility of obtaining uniform shade.

There are necessarily a number of agronomic factors (Lemee, 1955; Mainstone, 1971; Smyth, 1966; Wood, 1973) that influence and govern the success of cocoa establishment under thinned jungle shade and it is the authors' hope that more such works can be carried out so that the choice of the most appropriate methods can be made with greater certainty and profitability.

CONCLUSION

A case has been made for greater awareness and deeper consideration to be accorded to planting of cocoa under thinned jungle shade in Sabah. When properly carried out, the returns can be equal to, if not more rewarding than, planting under established *Gliricidia* shade. This offers an attractive alternative to the potential investor or developer.

ACKNOWLEDGEMENT

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Use of an Early Warning System for the Control of *Helopeltis theivora theobromae* in Cocoa

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Aggregation of Helopeltis sp. *has been noted in various parts of the world. Aggregation is defined as the congregation of individuals into discrete locations leaving the balance of the area almost pest-free.*

Given the fact of aggregation, the control of Helopeltis *can be effected by a system of regular monitoring; areas of aggregation are thus located in the early stages of the pest's development and those areas only are treated.*

Experience has shown that groups of four trees evenly distributed at 5.5 groups per hectare are adequate to demonstrate the degree of aggregation. Monitoring is carried out at eighteen day intervals since there is an average of twenty-one days egg-laying to fecundity. With this method one man can monitor up to 350 ha. Details are given of the division of an area into plots and sub-plots to allow satisfactory identification of aggregation: this permits highly efficient limitation, by chemical control, of Helopeltis *damage.*

Each inspected group of four trees is given a 0–5 score to indicate the degree of infestation. Recording of data – areas to be treated are identified. Practice has shown that only 0% to 15% of a 350-ha area requires treatment after each monitoring round. The annual average percentage of the area of 350 ha has, after each monitoring round, proved to be ca. 5% over the whole year, which means that an area equivalent to the whole 350 ha receives just over one round of treatment.

The economics of this early warning system is discussed.

The advantages of the system are: (1) It is virtually an integrated system pest control. (2) The limited area sprayed means that the micro-ecology of the area is disturbed as little as possible. (3) The possibility of a population explosion is very limited. (4) Other pests and diseases can be monitored at the same time. (5) Crop levels can be monitored.

The various species of mirids have been, and still are, serious pests throughout the cocoa-growing areas of the world. They are found from South America to West Africa and have appeared comparatively recently in Asia, particularly in Indonesia and Malaysia.

A considerable amount of research has been done, mainly in West Africa, on the control of these pests. With the rapid increase in the number of hectares planted with cocoa here in Malaysia, research in this country is being intensified. Research workers

have suggested a great variety of methods ranging from blanket fogging to controlled spot spraying. This paper describes a method of controlling these mirids using an Early Warning System (EWS). This system has been evolved over a period of three years in the North Johor/South Malacca region of West Malaysia. Cocoa was first planted on a large scale in this region in 1969 and it became necessary to find a method of mirid control for large areas. Necessity, therefore, was the progenitor of the EWS.

The species of mirid found in this particular area is predominantly *Helopeltis theivora theobromae.* Most mirids have similar life habits and one characteristic observed in many of them, and certainly in *H. theivora theobromae,* is the characteristic of aggregation. The aggregation of mirids has been noted in most cocoa-growing areas of the world by a number of research workers. P.F. Entwistle in his book 'Pests of Cocoa' (1972) quotes Youdeowi (1965), Lodos (1969) and Johnson (1971) all of whom noted the high aggregation of capsids. In South-East Asia, Conway (1971) mentions discrete 'patches' and 'pockets' of the mirid and Kalshoven & Van der Laan (1981) refer to the same phenomenon. Tan Gim Seng (1974a) notes that individual plants harbour high populations of *H. theivora theobromae.* Aggregation may, very simply, be defined as the congregation of many individuals into distinct and discrete locations leaving the remainder of an area almost pest-free: *viz.* in a given area of cocoa, mirids will congregate in a few specific places giving rise to 'patches' of infestation whilst the rest of the area is left virtually devoid of pests. The many reasons given for the aggregation of mirids are largely hypothetical and no really satisfactory explanation of the phenomenon has been advanced as yet. Some aggregations will occur in the more open areas of the cocoa where the likelihood of nascent young shoots is very high: other aggregation appear in areas of completely closed canopy where the sun never penetrates. It was Youdeowi who did extensive work in Nigeria on the characteristic of the aggregation of mirids and it was he who, whilst on a visit to Malaysia, suggested that a system of early warning might be evolved using this fact of aggregation.

METHOD AND ITS BASIS

The North Johor area of West Malaysia where the EWS described is employed covers ca. 1500 ha planted with mixed hybrid seedling cocoa. Plantings vary in age from 1969 to 1982 plantings with all intervening years represented. The planting distances are 3.3m x 3.3m, that is 1075 plants per hectare.

The total area of the cocoa is divided into sections of 300 to 350 ha. Experience has shown that one inspector and two helpers are able to cover such a section in four days to identify areas of aggregation.

Each section is then divided into plots of five hectares and each plot is identified by a letter. Within these plots groups of four trees at 5.5 per hectare (42.42m x 42.42m) are marked with the letter of the plot and also with an individual number. These groups of four trees are then known as 'sub-plots' (see *Figures 1–3*). Thus the situation is reached where the whole area is covered by evenly-distributed sub-plots, each one of four trees, and each numbered and lettered for the identification of mirid infestation.

Monitoring rounds over the whole area are done at eighteen day intervals. The eighteen day cycle was selected because the life cycle of *H. theivora theobromae* from egg to maturity varies from seventeen to twenty-one days, (Entwistle 1972; Tan Gim Seng 1974a; Kalshoven & Van der Laan 1981). It is reported that *H. theivora theobromae* feeds very actively from the first to the fifth instar – a period of thirteen to eighteen

days (Tan, 1974a). However during this period the mirid is not very mobile and the possibility of infestation spreading over a large area is remote. At the nymph stage the mirids will, when disturbed, merely crawl to the opposite side of the pod. The wings of mirids begin to develop only after the third instar (Entwistle 1972) and they reach full development only after the fifth instar. Moreover adult *H. theivora theobromae* are poor and reluctant flyers, (Tan, 1974a;Kalshoven & Van der Laan 1981). The mirid reaches maturity three to eight days after the fifth instar (Kalshoven & Van de Laan 1981). If, therefore, the eighteen day cycle, associated with immediate treatment where necessary, is maintained very few mirids will reach maturity and be capable of breeding. In this way the population distribution is severely restricted. The aim of the EWS is achieved because mirid populations are continuously being restricted within acceptable economic levels.

Monitoring is done by observing the actual number of insects within the four tree sub-plots at hand height and not by noting the amount of damage that is evident. Ideally a factor would be applied to the number observed, since there are obviously many more insects above hand height in the plant's canopy. The factor to be applied would be determined by an insecticide knock-down trial and would vary from five to twelve (Entwistle, 1972). This factor would depend upon locality, the season of the year, the amount of shade available and even upon the time of day. In the area under discussion no factor is applied since the establishment of a factor, however desirable, would be far too complicated for the following reasons: (i) the very large area covered by the EWS, (ii) the difference in age of the plants from one to fifteen years and hence the varying tree heights, (iii) the variety of shade conditions from heavy to very light shade, (iv) the varied terrain which ranges from hilly areas to swamp patches and (v) the diverse climatic conditions within the year when the area normally suffers one prolonged period of drought and two very wet periods. Instead of employing a factor, a very simple and arbitrary method of 'scoring' has been adopted for ease of management. A score of one to five is awarded to each sub-plot where mirids are observed. A score of one indicates one insect, two indicates two and so on but a score of five indicates that five or more than five insects have been observed. Sub-plots receiving a score of one or two are not treated but the score is recorded in the master book. This master book is a diagrammatic 'map' of the area showing the section divided into plots and sub-plots *(Figure 2)*. Experience has shown that treatment of these low-scoring sub-plots is unnecessary, as it frequently occurs that the same amount of infestation is observed in successive inspection rounds. It is uneconomic to spray such lightly-infested areas. Sub-plots with a score of three to five receive immediate treatment and the adjacent sub-plots are also treated.

The training of the pest inspectors is clearly of paramount importance. On each inspection round the inspector makes his observations in each sub-plot. If he notes any infestation he awards the correct score and records it, identifying the sub-plot by its own individual number and by the letter of the five hectare sub-plot in which it is situated. As the inspector has, at his command, this precise means of identifying a sub-plot, he saves a considerable amount of time by walking the length of the 300 ha section instead of circulating within the five hectare plot: in other words he works the whole section in one operation.

The new data is immediately recorded in the master book and, as the inspection progresses, a pattern of infestation appears. Inspection rounds should take no more than four days. This coverage can be accomplished quite easily as the inspector walks every fourteenth row (see *Figures 1-3)*. When an inspection round is complete and the

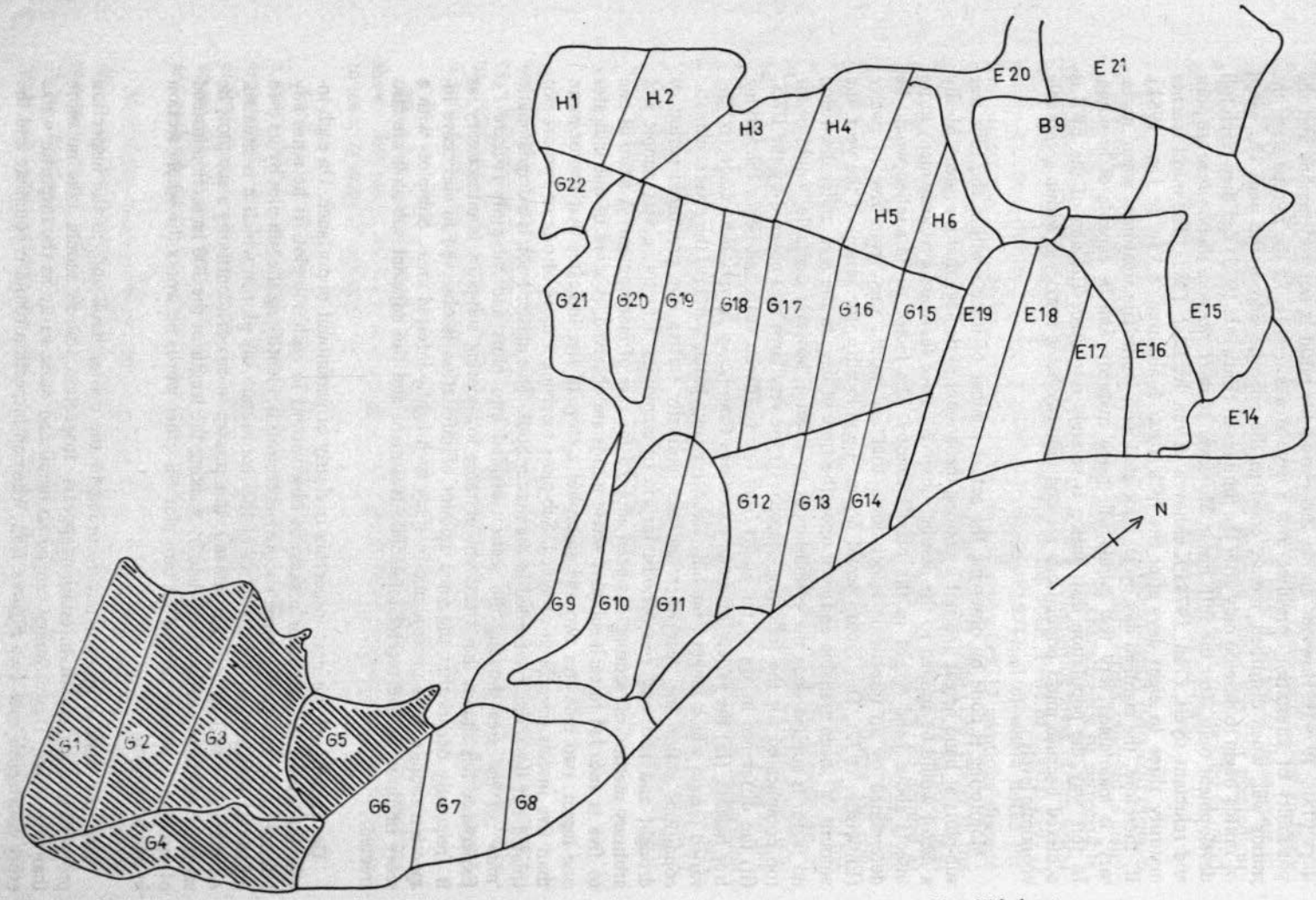


Figure 1. Step One in establishment of Early Warning System. Ca. 300 hectare section of fields. Hashed are projected in Figure 2.

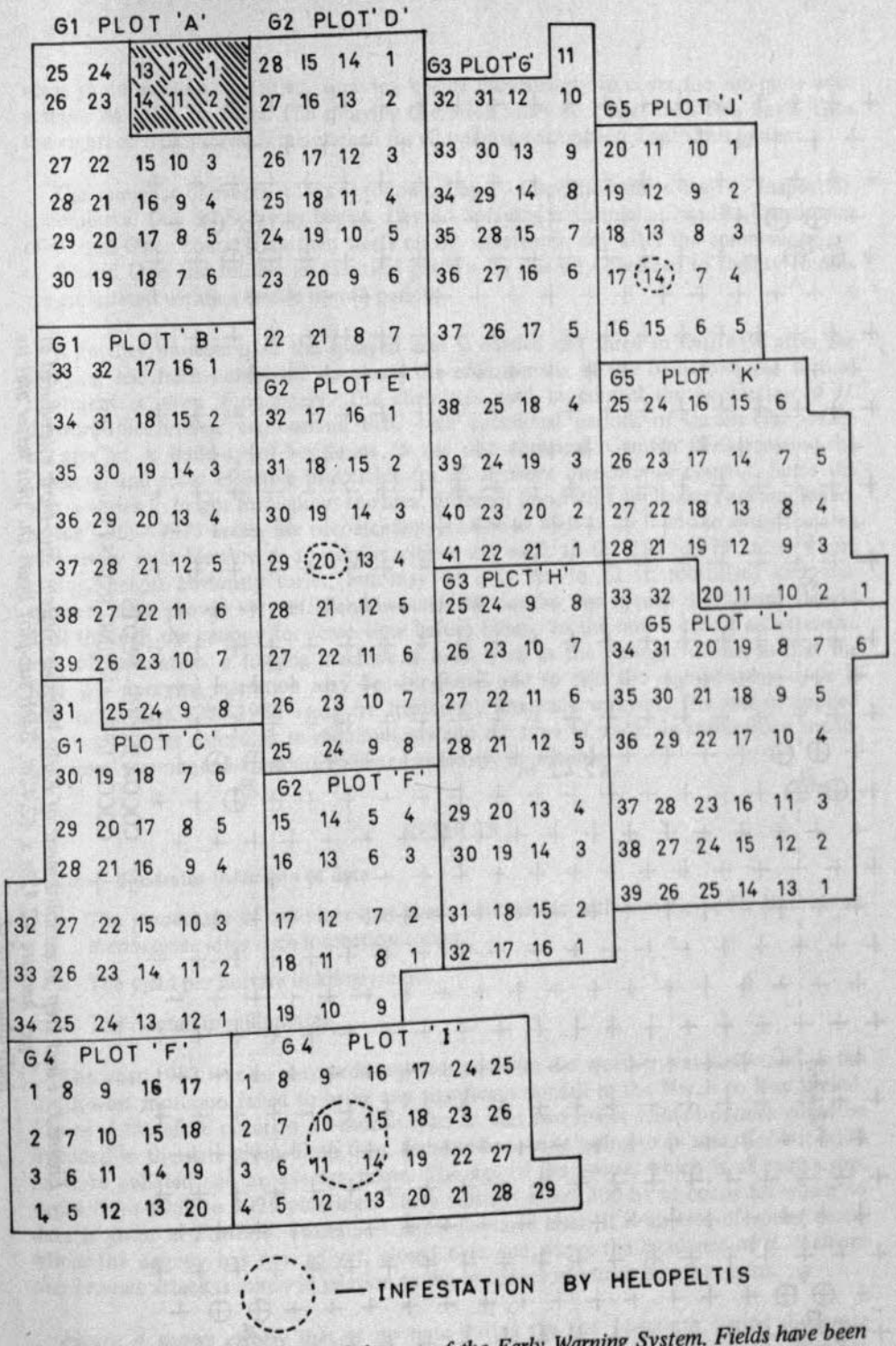


Figure 2. Step Two in the establishment of the Early Warning System. Fields have been divided into plots of approximately five hectares each and lettered. Projection of demarcated area of Plot 'A' is shown in Figure 3. *This diagrammatic 'map' forms the master book in which areas of infestation are recorded circling the sub-plots as shown.*

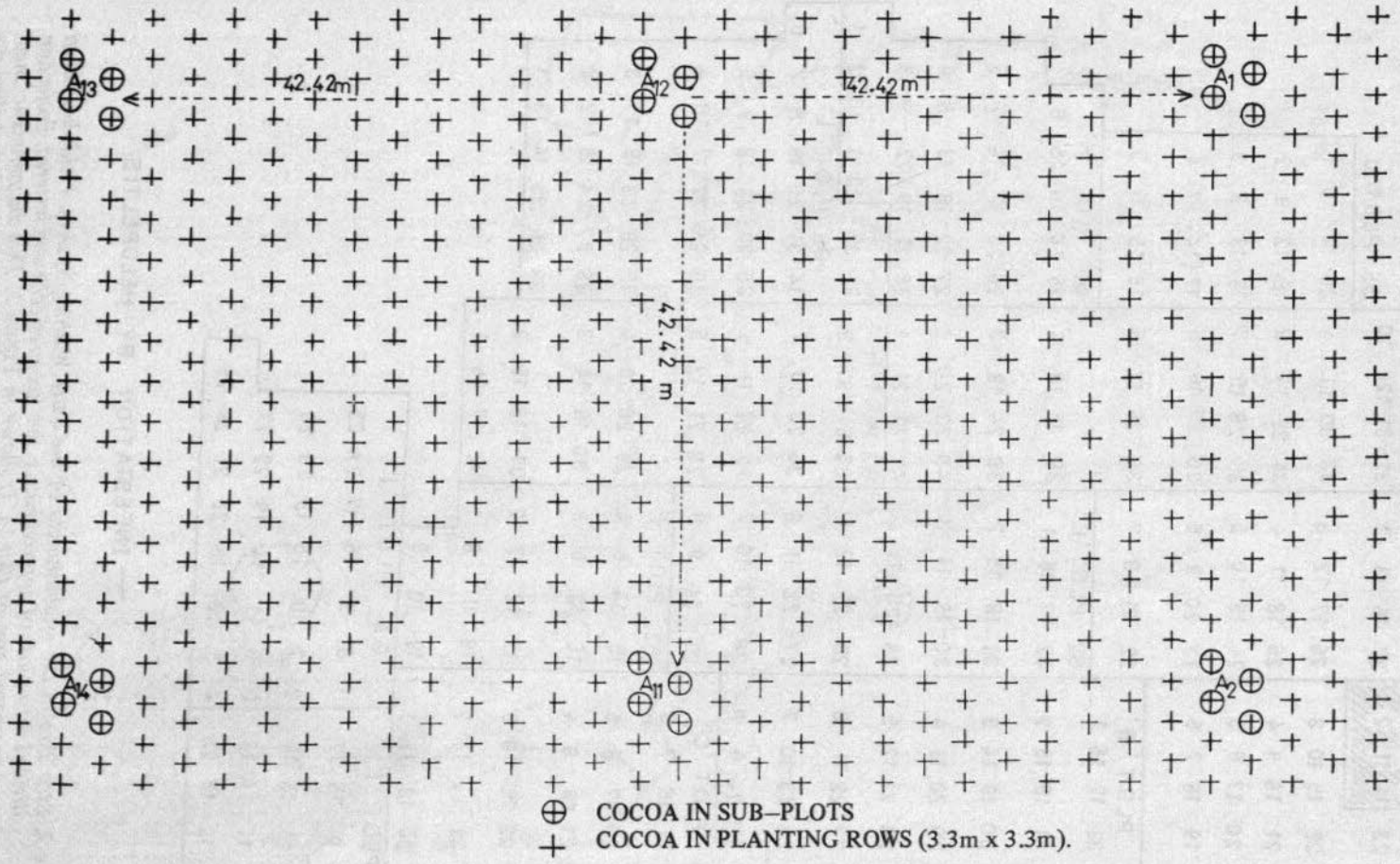


Figure 3. Final step in establishment of Early Warning System. Sub-plots established at 5.5 per hectare 42.42m x 42.42m. Each sub-plot bears the plot letter and its individual number.

areas of infestation identified, spraying begins immediately to cover the sub-plots with a score of three or more. The spraying operation takes no longer than four days. Thus the eighteen day interval is maintained for all operations connected with this system.

The sequence of events is thus as follows: Day 1:- Inspection starts. Day 4:- Inspection is complete. Day 5:- Spraying begins. Day 8:- Spraying is complete. Day 18:- Conclusion of Round One. Round Two then starts on the nineteenth day after the commencement of Round One and follows an identical pattern. In this way nineteen to twenty rounds are completed within a twelve month period.

A further inspection of the sprayed area is carried out three to four days after the spraying has been completed to check the effectiveness of the operation and further treatment is given if necessary. The chemicals used to control the population of *H. theivora theobromae* are Gamma BHC with occasional periods of Unden (Propoxur) to prevent a build-up of resistance to the one chemical. Gamma BHC remains the cheapest and most effective insecticide for *H. theivora theobromae* control. Since the cocoa varies in height throughout the area, different insecticide applicators are employed. In the 1969–1971 areas, the cocoa canopy can be as high as 25 ft and to spray the area effectively mist blowers or fogging machines are used. In the 1972-1979 areas, where canopy height obviously varies, but may be only ten to 12 ft, motorised knapsack sprayers have proved very efficient because the droplet size is such that chemicals will drift through the canopy for some time before falling. In the rare event of an extensive area of infestation, a fogging machine is used, even in the younger cocoa, so that the four day spraying operation may be completed and so that the eighteen-day cycle is not upset. The 1980-1982 areas are treated by knapsack sprayers. The rate of applied chemicals varies according to requirements and the type of pesticide applicators: manufacturers' recommendations are followed as closely as possible.

RESULTS

Figure 4 illustrates three sets of data:

- The percentage of sub-plots that needed treatment with insecticide for *H. theivora theobromae* after each inspection round.
- The yield per hectare in kilogrammes.
- The rainfall in millimetres.

The year 1983 was an extraordinary year as far as the weather was concerned as the south-west monsoon failed to bring any significant rainfall in the March to May period. *Figure 4* therefore covers a 15-month span so that two major rainfall periods could be included in the data given. Data from four sections, amounting to an area of about 1200 ha were collated and an average taken. The age of the cocoa, which is all monocrop, varies from 1969 to 1979 plantings. There remains about 300 ha of cocoa for which no data is given in *Figure 4*. This area will be discussed later. It is an area of young cocoa where the canopy has not, as yet, closed over and where the incidence of *H. theivora theobromae* attack is minor in relation to the incidence of attack by other pests.

Figure 4 shows clearly that at no time during the the 15-month period did more than 10 per cent of the area – that is 10 per cent of the sub-plots – need treatment after an inspection round. Further calculation shows that the average for the period over the entire area was just over five per cent.

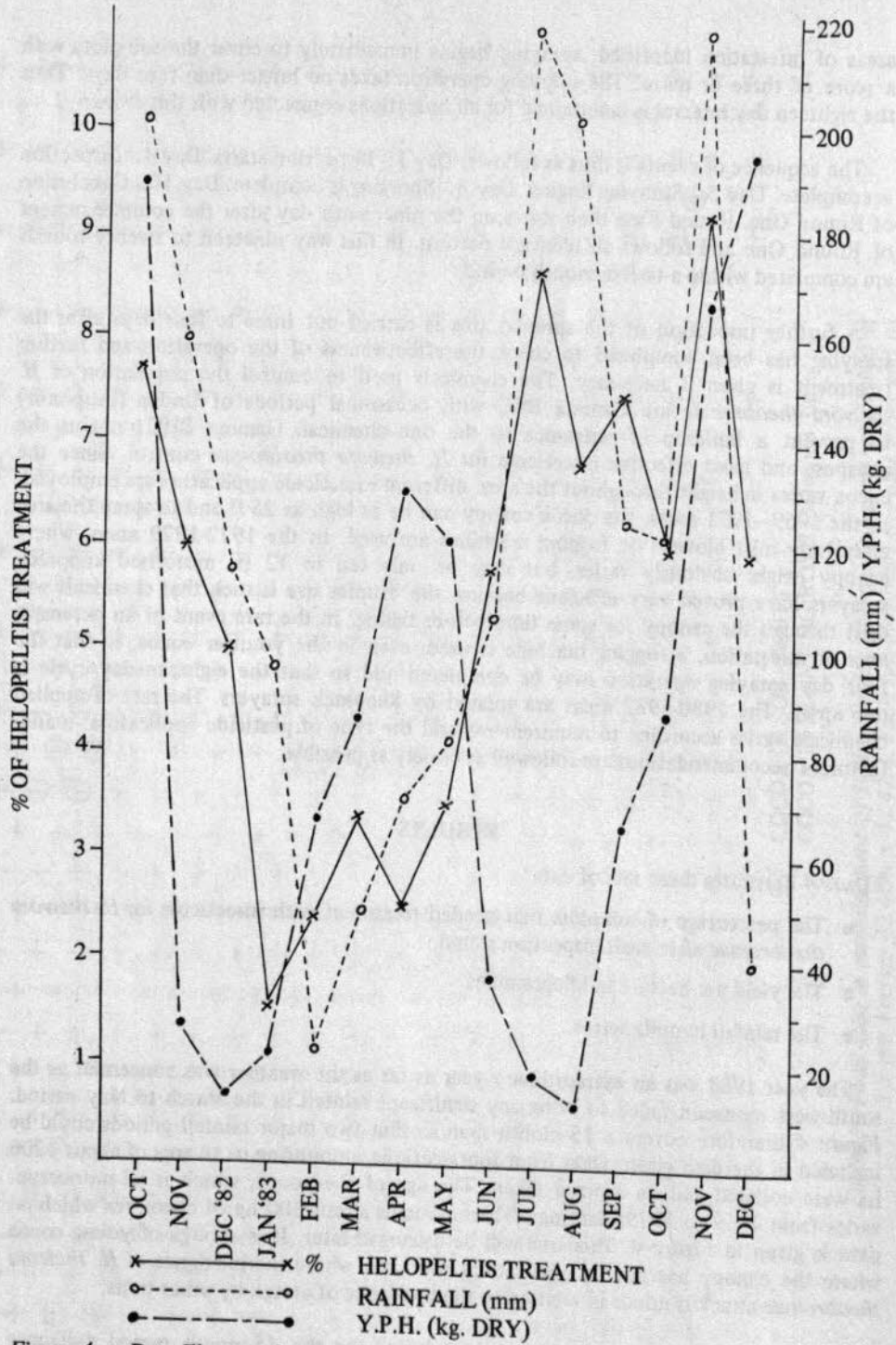


Figure 4. Data Illustrated.

i. The percentage of sub-plots that needed treatment with insecticide for H. theivora theobromae *after each inspection round;*

ii. The yield per hectare in kilogrammes;

iii. The rainfall in millimetres.

It must be noted that there were twenty-five rounds of inspection during those fifteen months which means that, during that time, the area of 1200 ha received only about one and a quarter rounds of treatment. If the figures are adjusted to cover a 12-month period, during which there would be 20 inspection rounds (355 ÷ 18 = 20.27), it is evident that the area received just over one round of treatment in a year. This indicates a dramatic and economic restriction of labour and insecticides.

Figure 4 also shows the relationship between rainfall and the incidence of *H. theivora theobromae* during this same 15-month period. The trends demonstrated in this figure confirm the work of Conway (1971); Tan Gim Seng (1974a), Kalshoven and Van der Laan (1981) which indicated that the population of *H. theivora theobromae* increases with increase in rainfall. However the relationship between crop and *H. theivora theobromae,* which is also shown in *Figure 4,* would appear to be more complex and this point will be discussed later.

DISCUSSION

It has been demonstrated that with an EWS of intensive monitoring and the subsequent spraying with insecticide, where necessary, after each inspection round, the population of *H. theivora theobromae* can be restricted to a very low level. In addition the possibility of a population explosion becomes minimal since 'pockets' of aggregation are identified at a very early stage of their development and are dealt with before any significant damage to plant or fruit takes place. *H. theivora theobromae* are not good fliers (Entwistle 1972, and Tan Gim Seng 1974a) and they prefer to remain within the area of aggregation: thus a population explosion is impossible unless the mirids are allowed to breed for several generations. It has already been noted that the breeding cycle of *H. theivora theobromae* is 17 to 21 days from egg to maturity so that, if the eighteen day cycle of inspection is strictly maintained and the necessary treatment given, the breeding opportunities become negligible.

Since infestation is restricted to about 5 per cent of the total area after any one inspection round and because the infested areas are in isolated 'pockets' the use of chemicals is kept to a minimum. This minimal use of chemicals represents a financial advantage but, even more importantly, it means that the micro-ecology of the area is left undisturbed: pollinators and predators may flourish freely because 95 per cent of the area needs no chemical treatment. In the past seasonal spraying was the recommended practice but this meant blanket spraying over the total area. As has been noted in this paper, *H. theivora theobromae* populations show a definite seasonal trend. For this reason Tan Gim Seng (1974b) advocated a first spraying after the onset of rains in March and April and a second spraying in October-November for pest control during the north-east monsoon. The report of the International Capsid Research Team (International office of Cocoa and Chocolate, 1965-1971) also suggested seasonal spraying programmes. Entwistle (1972), also in West Africa, recommended two double sprays at twenty-eight day intervals. The first spray was to control nymphs and adults and the second spraying to destroy the mirids that had emerged from the eggs since the time of the first blanket spraying. There was then to be spot spraying of re-infested pockets. It may be asked why, under the EWS, spraying continues through the dry period which is the time of minimum population but it was Entwistle (1972) who found that such dry period spraying prevented an escalation of the mirid as noted in untreated control areas. This theory was supported by Youdeowi (1969) because in dry periods there was little risk of the value of the insecticide being marred by rain and he further noted that these dry season sprays reduced the mirid population by a factor of five. Doubtless such seasonal

spraying programmes were effective but they were also costly and they disturbed the micro-ecology of an area very seriously.

As the inspection rounds of the EWS progress through the year, patterns begin to emerge highlighting the areas of constant infestation: once these areas are identified they can receive special treatment and attention. Such areas of constant infestation within the 1200 ha region confirm the findings of Tan Gim Seng (1974b) that *H. theivora theobromae* have a preference for areas of closed canopies which afford protection from sun and heavy rain. Kalshoven & Van der Laan (1981) also noted that in hot, dry periods *H. theivora theobromae* retreat to shady areas. In the area under discussion it has also been observed that *H. theivora theobromae* congregate in places where repeated pruning has been carried out thus inducing a considerable growth of new lead and shoots. These areas include roadsides, inspection paths and areas which have been extensively pruned to control *Oncobasidium theobromae.* These latter areas must receive very particular treatment for the control of *H. theivora theobromae.* Should the mirid attack get out of hand the Vascular-Streak Dieback plants would receive an even greater set-back. Their recovery, if it took place at all, would be very prolonged because of the reduced leaf area caused by the mirid attack and by the pruning.

In the 300 ha of young cocoa previously mentioned the EWS has proved very useful, not primarily for the detection of *H. theivora theobromae* but for the discovery of other pests such as *Adoretis sp.* and *Apogonia sp.* The incidence of *H. theivora theobromae* in young cocoa is not great: as has been noted *H. theivora theobromae* prefer shady areas thinned to allow the sun to penetrate, following the practice of accelerated shade reduction used in this area (Wills, 1981). For these reasons a large population of *H. theivora theobromae* is most unlikely. It is possible that an attack by the mirid will occur during a period of new leaf formation but this will be only in isolated areas adjacent to mature cocoa. Species of *Apogonia, Adoretis, Vallanga, mites* and *thrips* are a problem and have to be controlled if the young plants are to be protected from a set-back owing to loss of leaf area. It take months for a young plant to recover from such a set-back but with the regular rounds of inspection of the EWS the possibility of an uncontrolled outbreak of any pest is prevented.

As has been mentioned earlier, the relationship between rainfall and the incidence of *H. theivora theobromae* shown in *Figure 4* confirms the observations of Tan Gim Seng (1974a) in Malaysia and of Entwistle (1972) in Africa that the population of *H. theivora theobromae* is virtually governed by the rainfall pattern. As the rainfall increases so do the numbers of *H. theivora theobromae;* with the onset of a dry period the mirid population decreases. Many reasons have been put forward by researchers for the reduction in numbers of *H. theivora theobromae* in dry periods. These reasons are manifold and range over such facts as the desiccation of nymphs which require a humid climate for survival and the unfavourable food sources offered by water-stressed plants, but these factors are beyond the scope of this paper.

Tan Gim Seng (1974b) also observed that while the crop remained high and the rainfall low, the population of *H. theivora theobromae* also remained low, albeit that the mirid is acknowledged to have a preference for feeding on young cocoa fruit. Reference to *Figure 4* shows that during the period from November 1982 to February 1983, the trends both of rainfall and *H. theivora theobromae* are downward. During that same period there was a considerable number of cherelles and young fruit on the tree; these had been initiated in November for the 'peak' that occurred in April and May. The incidence of *H. theivora theobromae* stayed low during the whole of this time of plentiful

food sources. It was not until June when the yield was declining but when the rains increased that the *H. theivora theobromae* population increased following the rain pattern.

From June to July the rainfall stayed relatively high compared with the first half of the year; with this higher rainfall the numbers of *H. theivora theobromae* increased and stayed high until November when the trend began its decline which continued into the low rainfall of the month of December (the ultimate 'peak' occurred in January). It was during these months from July to November that all conditions were in favour of a very large escalation in the numbers of the mirid; the climatic condition was ideal; the rainfall was high; the humidity was high and there was an abundance of food prior to the 'peak'. Despite these optimum conditions the percentage of sub-plots that needed treatment after any one round of inspection remained at under ten per cent of the whole of the review period with the use of the EWS. The importance of an effective method of control has been well documented. Tan Gim Seng (1974b) quotes Collingwood (1964) as noting that he found that areas treated with four rounds of spraying gave twice the number of pod sets compared with untreated control plots. Entwistle (1972) in Ghana calculated that from 1951 to 1953 ca. 30 per cent of dry beans were lost annually owing to inadequate control methods. Conway (1971) noted that *H. theivora theobromae* preferred young cocoa pods and that new shoots were eaten only if young pods were unavailable. Kalshoven & Van der Laan (1981) established that *H. theivora theobromae* incur fruit fall of the immature pods. They too mention the preference of the mirid for young fruit plus fruit loss as a result of *Botryodiplodia theobromae* entering wounds caused by *H. theivora theobromae*. They further quote Malaysian sources as saying that in most months of the year 85 per cent of the cocoa pods show damage. Many factors such as shade policies, rainfall, fertiliser programmes and so on, help to improve yield but it is suggested that the rigid control of *H. theivora theobromae* by the EWS during this time when the fruit was at its most vulnerable stage to attack and to subsequent death from the mirid, contributed very largely to a far higher crop being harvested than could otherwise have been expected. The EWS is critical for achieving maximum or close to maximum cropping potential.

COST INDICATIONS

The information which follows is applicable to the area under discussion. In areas with different stands per hectare and different environmental conditions the EWS might have to be modified to suit the prevailing circumstances. As demonstrated by *Figure 4* the population of *H. theivora theobromae* varies considerably in relation to weather patterns. Thus the amount of spraying treatment required will also be governed by climatic variations. The information given relates only to the period under discussion and to the weather conditions of that period.

The information is divided into three sections. Section One deals with the man-days required to carry out inspection rounds every eighteen days. This cost remains constant regardless of seasonal variations and of differing degrees of infestation. Section Two deals with the man days required to implement the treatment of infested areas after each inspection round. This cost cannot remain constant for every round since the size and number of infested areas are subject to seasonal variations. The average area requiring treatment after any one inspection round is 5 per cent. Variations are from 0 to 10 per cent depending on the season and the rainfall, as demonstrated in *Figure 4*. Therefore an average is given of the man days required for treating the infested areas after one inspection round. Section Three deals with chemical applications.

Section One.

Inspection rounds.

i. 1 inspector x 4 days per round x 20 rounds p.a. = 80 days.

ii. 3 helpers x 4 days per round x 20 rounds p.a. = 240 days.

Re-inspection round after treatment.

i. 1 inspector x 2 days per round x 20 rounds p.a. = 40 days.

Total man days for 350 ha for one year of inspection rounds = 360 days. (ca. 1 man day per hectare p.a.)

Section Two.

Spraying rounds.

i. 1 inspector x 4 days per round x 20 days p.a. = 80 days.

ii. 4 sprayers x 4 days per round (to cover an average of 18 ha per round – 5% of 350 ha) x 20 rounds p.a. = 320 days.

iii. 2 water carriers x 4 days per round x 20 rounds p.a. = 160 days.

Re-spraying rounds.

i. 1 inspector x 2 days per round x 20 rounds p.a. = 40 days.

ii. 2 sprayers x 2 days per round x 20 rounds p.a. = 80 days.

iii. 1 water carrier x 2 days per round x 20 rounds p.a. = 40 days.

Total man days for 350 ha section for one year of spraying infested areas = 72 man days or 2 man days per hectare p.a.

Total labour required for 350 ha section p.a. = 3 man days per hectare p.a.

Section Three.

As has been demonstrated the area requiring treatment after any one inspection round was, on average, just over 5 per cent.

Therefore the following calculation applies:

5.20% of 350 ha = 18.20 ha.

20 rounds of inspection x 18.20 ha = 364 ha of treatment p.a. This is the equivalent of just over one complete round over the whole area per annum.

Gamma BHC (HCH) is used to treat the infested sub-plots using mist blowers. Variables inevitably occur such as the inconsistent walking speeds of individual sprayers and the varying engine speeds of the pesticide applicators; the latter, in turn, creating variations in the through-put of chemical. Chemical manufacturers' recommendations are followed as far as possible but over such a large area and given the variables mentioned, these recommendations serve only as a good guide.

The pest inspector observes other pest and disease problems on his inspection rounds and reports their locations using the sub-plot numbers and letters. He can then deal with such problem areas after he has completed his inspection for *H. theivora theobromae* and his spraying round, since this takes only a maximum of 10 days out of the 18 (four days' inspection, four days' spraying, a possible two days' re-spraying). The early

detection of pests other than *H. theivora theobromae* and of disease prevents problems becoming acute and thus saves expenditure.

CONCLUSION

An EWS such as the one described restricts the population of *H. theivora theobromae* to, on average, about five per cent in any given area at any one time. Such a system has many advantages:

i. It is a system of integrated pest contol.

ii. The micro-ecology of the area is upset as little as possible as the areas treated with chemical are limited to isolated, discrete areas amounting to no more than ten per cent of the whole, thus leaving the balance of the area undisturbed.

iii. The possibility of an uncontrolled outbreak of any pest or disease is kept to a minimum.

iv. The system can be used to monitor crop levels and even fertiliser requirements, given the great variety of soil types encountered, thus making it a valuable management tool.

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