Gold Coast Department of Soil and Land-Use Survey

Detailed Soil Survey of the Kpong Pilot Irrigation Area

H. Brammer

Check for 98 maps in pocket at back.

WOSSA C

7

Duplicate (see also I.D. 45417 or 23975)

ERRATUM

Detailed Soil Survey of the Kpong Pilot Irrigation Area

By H. BRAMMER

P. 19, 3rd paragraph, 2nd sentence. Transpose ' leached out ' and ' accumulated ' so that the sentence reads as follows: ' These conditions obtain in the Black Clays belt of the Accra plains where the weathering of the hornblende-rich rock gives rise to soils with a high clay content and releases ample amounts of bases and silica which are accumulated rather than leached out because of the low rainfall and high evaporation and the slow internal drainage of the soils on the peneplain relief.'

Since going to press, the name of the experimental station set up at Kpong, on the site referred to in this report as the Kpong Pilot Irrigation Area, has been established as the Kpong Irrigation Research Station, and all references to it should be made under this name.

PRICE 10/-

To be obtained from :
The Crown Agents
for Oversea Governments and Administrations,
4 Millbank, London, S.W.1
and The Government Printer,
P.O. Box 124, Accra, Gold Coast

Printed in 1955 *by Eyre & Spottiswoode Ltd.,*
at The Thanet Press, Margate, England.

FOREWORD

This report aims at being a blue-print for investigations into mechanized irrigation agriculture on the Black Clays of the Accra plains and at providing the basic information that has been lacking in post-war development schemes.

Particular attention has been devoted to the making of detailed recommendations regarding the course investigations should pursue. These have been based on careful study of the environmental conditions prevailing not on the Kpong Pilot Area alone but on the Black Clays as a whole, whilst results obtained under similar conditions on similar soils in other parts of the tropics have been taken into consideration as well. The analytical data include results of analyses of two similar soils to the Black Clays obtained from South Africa, that for some time have been employed for mechanized irrigation agriculture under similar conditions as are found in the Gold Coast. The recommendations, it may be emphasized, have as their purpose the integrated development of all the potential resources of the Black Clays and are not directed towards production of any particular crop or towards any form of husbandry.

It must be stressed that successful development of the Accra plains by means of mechanized irrigation agriculture depends upon efficient large scale development following adequate investigation of the techniques to be employed. This has now been recognized and it is hoped that the information already secured by this Department will prove of considerable value to the specialists being recruited by F.A.O. to initiate these investigations.

CECIL F. CHARTER, O.B.E.,
Director,
Soil and Land-Use Surveys.

KUMASI
August, 1954.

CONTENTS

PART I. GENERAL

PART II. SYSTEMATIC SOIL DESCRIPTIONS

PART III. RECOMMENDATIONS

(In conjunction with C. F. Charter)

PART I. GENERAL

INTRODUCTION

Purpose of the survey

The survey which this report covers was carried out, in the first place, to confirm the suitability of a specified area of land near Kpong for a small scale, pilot irrigation scheme. This area had been selected, after a rapid survey of the Accra plains early in 1950 (1), as a suitable site on which the possibilities of mechanized irrigation agriculture on the Black Clays soils could receive investigation. This information was required before it could be decided whether or not a large area of similar soils and land in the region should be developed with the aid of water brought from a projected high-level dam in the Volta gorge near Ajena which was to be built primarily to provide hydro-electric power for an aluminium industry.

In the second place, the survey had as its aim the provision of detailed and fundamental information upon which the layout of the experimental area should be based, and which would determine, in large measure, the nature of the investigations that should be undertaken.

Previous history

There had been several previous proposals in recent years to develop the Accra plains, and particularly the Black Clays it contains, by large or small scale irrigation schemes.

The two members of the Empire Cotton Growing Corporation, who visited the Gold Coast in December, 1947, and the British West African Rice Mission, which came in the early part of 1948, both suggested that the Black Clays might be suitable for development by local irrigation schemes (2, 3). The Rice Mission recommended that, since little was known of the behaviour of these soils under irrigation and mechanized agriculture, there should first be a small scale experimental scheme, with a competent soil chemist in charge, which should run for at least 10 years before any larger irrigation project was launched. It was recommended that, before any experimental station was set up, a detailed soil survey of certain areas of the Black Clays should be made. Two surveys were undertaken by M. Akenhead of the Department of Agriculture in the middle of 1948, and short reports were produced (4). One of the surveys covered an area between the Shai Hills and Prampram ; the other an area south-west of Akuse.

In April, 1949, a brief survey was made by C. F. Charter, then Chief Soil Scientist, of the soils within the Kpong-Akuse-Somanya triangle, where

Nene Mate Kole, the Konor of Manya Krobo, had offered land for an agricultural station (5). It was expected that the area would be irrigated by water piped from the new Krobo waterworks then being constructed at Kpong.

In October, 1949, the Crown Agents for the Colonies retained the services of Sir William Halcrow and Partners, Civil Engineers, to act as consultants to the Gold Coast Government on the development of the water power of the river Volta. Included in their terms of reference was a request to investigate the possibility of irrigating the Accra plains with water from the projected dam in the Volta gorge.

The Consultants' plan (6) absorbed and superseded all the results of previous surveys and reports. The Black Clays were considered to be the soils most suitable for early development by irrigation. It was recommended that a pilot scheme should be started as soon as was practicable ; and an area of one square mile within convenient reach of the waterworks at Kpong should be acquired on which an initial scheme should be started on 80 acres of land. H. Vine, Senior Soil Scientist of the Soil Survey Division of the Department of Agriculture, made a rapid soil survey of the triangle of land between the river Volta, the Akuse-Somanya road and the Okwe stream, and advised (1) that a suitable area for initial development lay in the northern part of the area surveyed. Before the scheme should commence, he recommended, there should be a detailed soil survey of the selected area. This survey is the one dealt with in the present report.

Location and extent (Map 1)

The land selected for the Pilot Irrigation Scheme is situated approximately fifty miles north-north-east of Accra, about one mile south-east of Kpong on the Kpong-Akuse road. The area is roughly triangular in shape, and is just over one square mile in extent.* It is bounded in the north-west by the Okwe stream ; in the south, by a line running east-west from the Okwe in the west through a survey pillar, G.C.S. C.F.P./214, to a point 42 chains east of this pillar ; and in the east, by a line running due north from the eastern end of the southern boundary line to the Kpong-Akuse road, and thence roughly north-westwards along this road to the Okwe stream. The grid reference of pillar 214 is 0° 04′ 20″ E., 6° 07′ 40″ N.

Methods employed and personnel engaged

The Detailed Soil Survey of the area was carried out by five reconnaissance survey teams of the Soil Survey Division of the Department of Agriculture,† with C. W. Montgomery, Soil Survey Officer, in charge. The survey commenced on April 4th, 1951, from a field base at Akuse, and was completed by May 26th, 1951. The teams were not engaged on the survey of the Pilot Area during the whole of this period, however : a certain amount of work was

* Subsequent to the production of the first manuscript edition of this report, a small area to the south and east of the original boundaries of the Kpong Pilot Area has been acquired on the recommendation of the Consultants. This brings the total area of the station to 1.4 square miles.

† The Soil Survey Division of the Department of Agriculture was elevated to the status of an independent department entitled " Department of Soil and Land-Use Survey " in June, 1951.

also carried out in the area on the Reconnaissance Soil Survey of the Accra plains. Mr. Montgomery was joined on May 2nd by H. Brammer, Soil Survey Officer, who took charge of the survey after the former fell ill on May 15th.

The cutting of the base line and the major traverses was commenced by J. W. Acquah, Chief Traverse Marker, using a 2-inch prismatic compass. These lines were later checked* and completed by A. D. A. Tagoe, then First Division, later Assistant Surveyor, seconded from the Survey Department, who used a 4½-inch theodolite.

The base line was cut from the survey pillar G.C.S. C.F.P./214 for 42 chains due east, and for 80 chains to the Okwe stream due west. The main traverse, Traverse 0, was cut due north from the pillar for 72 chains to the Okwe stream. At 20, 40, and 60 chains along Traverse 0, lines were cut due east and west to the boundaries of the area. These lines were called, from south to north, Check Lines 1, 2 and 3.

From points at 1-chain intervals along the Base Line, the field teams cut traverses due north until they met either the Kpong-Akuse road or the Okwe stream. Traverses 1 to 42 lay to the east of pillar 214 ; traverses 43 to 122 to the west. The accuracy of these traverses was checked by the Chief Traverse Marker wherever they crossed a check line, and, where necessary, they were re-aligned. No gross errors were discovered. (For the layout of traverses, see Map 1.)

At one-chain intervals along the traverse lines, inspection holes were dug by soil chisel and auger to a depth of thirty-six inches, or deeper where possible. The soil was described and identified by soil recorders attached to each team. Soils which could not be identified in the field were sampled and taken back to the Field Base for identification by A. K. Akutor and G. K. Klu, Assistant Soil Survey Officers. These officers also checked descriptions and identifications in the field.

At each inspection hole, a vegetation recorder collected information on vegetation and land utilization, as well as on such miscellaneous phenomena as termite mounds, rock outcrops and gullies. Specimens of the vegetation were collected for identification either at the field base by S. A. Gyadu, Chief Vegetation Recorder, or at Main Base by C. F. Charter, Chief Soil Scientist. Unidentifiable grass specimens were sent to the herbarium at the University College, Achimota, or to the Royal Botanic Gardens, Kew, for identification. The Chief Vegetation Recorder also carried out a special investigation into the rooting habits of the different tree species found on the area.

During July and August, two first-year B.Sc. students from the University College, Achimota, F. O. M. Sakyiama and R. B. Kissi-Asomani, carried out grassland investigations on the distribution of species on, *inter alia*, the Black Clays of the Pilot Area. Their findings are incorporated in this report.

Altogether more than eighty miles of traverse lines were cut and recorded, and over two thousand six hundred inspection holes dug and sampled. Thirty profile pits were dug and sampled, and one ' borrow-pit ' was inspected and

* The errors discovered were not significant on the map scales used.

sampled. Six samples of 100 pounds, each representing the surface horizons of the different soils of the Area, were collected and sent to the laboratory of the Town and Country Planning Board in Accra for testing with a particular view to discovering their relative suitabilities for the construction of field access roads, earth dams and bunds, or the manufacture of stabilized building blocks, bricks, tiles, and pottery. The position of all the pits is shown on the soil map (Map 5).

From the information collected, the following maps were constructed : layout of traverses ; soil series ; depth to bedrock ; depth to calcium carbonate concretionary horizon ; vegetation ; land-use ; tree-spot ; and miscellaneous information.

On July 21st of the same year, R. K. Quartey, a Second Division Surveyor seconded from the Survey Department, commenced the detailed levelling of the Pilot Area. He was joined on October 2nd by A. D. A. Tagoe. The levelling was carried out on the chain by chain grid. Heights were supplied to an accuracy of 0.1 feet and a large scale map (1 : 1,250), contoured at 1-foot intervals, was produced. This work, together with a cadastral survey for acquisition of the Pilot Area, was completed on May 2nd, 1952.

Ninety-one horizon samples from the Pilot Area have been analysed in the Department's laboratories.* A note on methods of analysis used is given with the analytical tables at the end of Part II.

A limited amount of qualitative analytical work was also carried out at Main Base, then at Aburi, and at the Field Base, using rapid approximate methods. Soil texture has been determined by a simple manipulative test ; the presence of calcium carbonate, manganese dioxide and chlorides has been checked by reaction tests with, respectively, hydrochloric acid, hydrogen peroxide and silver nitrate ; and colour has been defined by comparison with Munsell Soil Colour Charts (1949).

THE PHYSICAL ENVIRONMENT

Climate†

The nearest meteorological station to the Pilot Area is at Akuse, approximately 4 miles to the south-east. Conditions prevailing there may be considered to be broadly representative of those to be expected on the Pilot Area.

Rainfall.—The mean annual rainfall at Akuse over the 35 years 1915 to 1951 (less 1941 and 1949) was 43.33 inches. This statement, however, needs considerable qualification if it is not to give a misleading impression of the agricultural potentiality of the area, for the rainfall is characterized by its great variability. Not only does the annual total vary significantly from year to year,

* The original laboratories of the Soil Survey Division at the West African Cacao Research Institute at Tafo were vacated in October, 1951, when the Analyst moved to the Department's new Headquarters at the Central Agricultural Station, Kumasi. From then until he went on leave early in 1953, the Analyst was primarily concerned with fitting out the new laboratories, so that detailed analyses of the soils from the Kpong Pilot Area have only become available towards the end of 1953.

† Climatic data have been supplied by the Gold Coast Meteorological Service, Accra, but totals, means, and the information contained in Table B (Percentage variation of rainfall) have been calculated by this Department.

but the monthly totals vary from year to year, too. The annual totals have actually varied from a minimum of 24.69 inches in 1932 to a maximum of 63.54 inches in 1933.

Most of the rain falls in two periods of the year : the main rainy season, from April to June ; and the second, or lesser, rainy season, from September to November. The main dry season occurs from December to February, which months are occasionally completely rainless, when the effects of the drought are intensified by the drying winds (the Harmattan) which blow down from the Sahara during this period. There is a lesser dry season during July and August, but the effects of the low rainfall during this period are to some extent mitigated by the high humidity and degree of cloudiness which then prevail.

Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean annual total
0.90	1.79	4.09	5.03	5.94	6.97	2.73	1.61	3.78	4.84	4.00	1.52	43.33

Table A. Akuse : Mean monthly rainfall in inches. (1915-1951 less February-May, 1941 and October, 1949—January, 1950.)

Under tropical conditions it is considered that the minimum rainfall required for crop growth is four inches in each of three consecutive months. From the data given in Table A it appears that these conditions are satisfied during the main rainy season, but fall short of fulfilment during the second rainy season. The variability from year to year (Table B), however, would be such as to render the undertaking of modern organized agriculture an extremely hazardous operation without the support of irrigation.

Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
127	82	46	33	42	51	92	129	69	69	48	72	20

Table B. Akuse : Percentage variation from mean monthly rainfall (1915 to 1951).

(Percentage variation $= \frac{\text{standard deviation}}{\text{mean}} \times 100$.)

The rainfall characteristically occurs in heavy thunder showers, during which several inches of rain may fall within a very few hours. This factor will have to be taken into consideration when planning the disposal of drainage water from the cultivated plots. The storms are often accompanied by squally winds.

It must be stated here that the compilation of rainfall data into monthly totals is not wholly satisfactory. The fact that the number of days in different months varies makes exact correlation of data impossible ; and the month is, in any case, too large a unit to permit the detailed study of rainfall distribution. For instance, there is reason to believe that the rainfall of July occurs almost entirely in the first fortnight of the month, and that of September mainly in the last two to three weeks of the month. This distribution is of agricultural importance : the first rains probably normally cease, not at the end of June as the monthly figures suggest, but in the middle of July ; and, although less distinctly the case, the second rains probably commence around the middle of September, and not at the beginning of October. Further, it is desirable to know how often the normal crop-growing seasons are punctuated by short droughts ; and also, for some crops, how often showers may interrupt the dry seasons. The true picture can only be revealed by the compilation of rainfall data into shorter periods than the month ; and, to this end, the Meteorological Service commenced in 1952 the publication of reports showing the distribution of rainfall in pentads (= five-day periods).

Temperature.—Monthly mean temperatures vary from a minimum of slightly less than 80°F. in July and August to a maximum of slightly more than 84°F. in the months February to April. Temperatures during the short dry season, July-August, tend to be low because of the greater prevalence of cloud during this period.

The monthly mean maximum temperatures vary from 87.6°F. in July to 94-96°F. in the months January to April. The corresponding mean minima vary from slightly below 71°F. in December-January to 73-74°F. in the months March to May.

Monthly mean extreme maximum temperatures exceed 95°F. except during the period June to September ; and absolute maxima as high as 105°F. are recorded during the main dry season in occasional years. Monthly mean extreme minima are of the order of 67°F. during the main dry season and in August-September ; but absolute minima of the order of 60°F. are liable to occur during these periods in some years.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Mean max.	94.0	95.9	94.6	94.8	93.1	90.1	87.6	88.3	90.1	91.6	92.7	93.3	92.2
Mean min.	70.7	72.8	73.7	73.5	73.2	72.3	71.4	71.5	71.4	70.9	71.3	70.8	71.9
Mean temp.	82.4	84.4	84.2	84.2	83.2	81.2	79.5	79.9	80.8	81.3	82.0	82.1	82.1

Table C. Akuse : Temperature °F. (1921-1951).

$$\text{Mean} = \frac{(\text{maximum} + \text{minimum})}{2}$$

Humidity.—Relative humidity readings are taken at Akuse at 0900, 1500 and 2100 hours. Afternoon humidities average 68 per cent. in June, but only 42 per cent. in January. Throughout the year, however, deposits of dew and, particularly during the main dry season, occasional morning mists show that the humidity must be effectively 100 per cent. during the latter part of the night.

Hours	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
0900	79	71	73	72	75	77	76	75	75	75	76	80	75
1500	42	43	54	56	63	68	65	63	62	65	64	52	58
2100	81	79	86	86	89	91	89	87	89	91	93	89	87

Table D. Akuse : Mean monthly relative humidity (1946-51).

Geology

The Pilot Area is almost entirely underlain by a metamorphosed basic rock, garnetiferous hornblende orthogneiss which locally contains small intrusions of pyroxenite and, more rarely, of quartz. This rock has been classified and mapped by the Geological Survey as Archaean ; but it may possibly represent altered Upper Birrimian lavas (7). Towards the northern boundary of the Area, the composition of the rock changes, and acidic gneisses have been observed to underlie certain soils in the extreme north.

The floodplain deposits along the Okwe stream consist of a mixture of alluvia which this stream and its tributaries have transported from the Akwapim Hills where the major streams rise, and from the Black Clays belt and, to a lesser degree, from the acidic gneiss areas which they traverse before reaching the Pilot Area. Towards the Kpong-Akuse road, these sediments intermingle with alluvium deposited by the river Volta when in flood. These various alluvia are for the most part clayey or silty ; but they appear generally to be underlain at a variable depth by a bed of well-rounded quartz pebbles.

Accumulations of similar pebbles occur sporadically on the higher ground in the south of the Pilot Area, and elsewhere pebbles are found locally on the slopes as a stone-line separating the soil from the underlying rock. These pebbles appear to be remnants of a former high-level, river- or marine-terrace deposit, now almost entirely dissected and eroded.

Relief and drainage (Map 3)

The Pilot Area lies on an outer part of the gentle outward slope surrounding Krobo Hill, 4 miles to the south. The surface slopes more or less regularly at around 1 per cent. from a height of 87 feet above Accra Datum just to the west of pillar 214, to 40-50 feet at the edge of the Okwe-Volta floodplain. In two places the slopes are appreciably steeper than the average. Slopes of 3 to 4 per cent. occur along a narrow belt running north-west to south-east in the north-east of the area, and in a short belt running north to south in the west of the area. These steeper slopes appear to have resulted from undercutting by the Volta in the former case, and by the Okwe in the latter case, at some earlier period. On the Okwe-Volta floodplain, the gradient is almost indeterminable.

Ninety per cent. of the Pilot Area drains either west, north, or north-east to the Okwe. In the south-east, a small area drains towards the Kablu, a small stream which crosses the extreme south-east corner of the Pilot Area in its north-easterly course to the Volta.

A few shallow rill-channels and minor gullies are found on the steeper slopes, but drainage is characteristically by sheet flood. Wide cracks which appear in the Black Clays when they are dry quickly close up when the soil becomes wet. Within the first few minutes of the onset of a storm the clay becomes virtually impermeable, and water then flows over the surface of the ground in a more or less continuous sheet from one to twelve inches deep.

Because of this rapid runoff, streams draining from the Black Clays tend to flow, albeit violently, only for a few hours during and after rainfall. This applies to the small stream in the south-east of the area. The Okwe stream, however, rises in the Akwapim Hills where the sandy soils and fissured rocks are able to absorb a certain amount of rain water. This water is released more slowly, and the Okwe stream often runs continuously during the rainy seasons, and, after a very wet year such as was 1951, almost through the main dry season, too. Since it also drains a large area of the Black Clays, it is, however, subject to violent fluctuations in flow.

Drainage is poor on the floodplain of the Okwe stream, and the ground becomes waterlogged during the two rainy seasons. This area is flooded to a depth of a foot or more periodically, but only, it is believed, during the second rainy season if heavy rainfall over the catchment area of the Okwe coincides with a high flood of the Volta, which normally reaches its peak level in October. The Volta itself floods back up the Okwe stream onto the north-east corner of the Pilot Area in years of high flood. Exceptional rainfall in the area in October, 1951, (20.87 inches at Akuse, compared with a previous average October rainfall of 4.43 inches), coinciding with an almost record high and prolonged flood of the river Volta, caused extensive flooding on the Pilot Area during a period of three weeks, although the Kpong-Akuse road was closed, due to flooding nearer Akuse, for over five weeks (October 7th to November 13th). There are not sufficient records to show how often flooding of the Pilot Area may be expected to occur.

On the floodplain alongside the Okwe, there are numerous short, narrow gullies running towards the main stream. One or two longer and broader depressions in the west represent old channels of the Okwe, now cut off. These channels are dammed by local people at the end of the rainy season so that fish entering when floods occur can be trapped, and also to maintain a water supply during the dry seasons.

Vegetation (Maps 6 and 8)

The greater part of the Pilot Area, including almost the whole of the Black Clays, is covered with open medium grassland with scattered coppice shoots. Locally, the coppice shoots develop into trees and give open medium grassland with scattered trees. Much of the floodplain along the Okwe is covered with tall grasses of floodplain savannah ; but in the south-west some of this has been cleared in the past for cultivation and has been replaced in some places by thicket and in other places by open tall grassland with scattered trees. A thin strip of high forest fringes the whole length of the Okwe stream, and there is a more extensive occurrence in swampy ground in the extreme south-east of the area and along one of the cut-off channels in the west. Only a few minor patches of cultivation were recorded on the Pilot Area.

In the area mapped as open medium grassland with scattered bushes, grasses greatly predominate over woody species. *Vetiveria fulvibarbis* Stapf is dominant ; *Brachiaria falcifera* Stapf is very frequent ; *Schizachyrium semiberbe* Nees and *Euclasta condylotricha* Stapf are occasional ; and *Andropogon canaliculatus* Schum., *Andropogon Gayanus* Kunth, *Sporobolus pyramidalis* P. Beauv., *Heteropogon contortus* Roem. and Schult., *Imperata cylindrica* Beauv., *Cymbopogon giganteus* Chiov. and *Ctenium Newtonii* Hackel also occur, the latter two species more particularly towards the edge of the floodplain. Two legumes, *Tephrosia elegans* Sch. and Thonn. and *Cassia mimosoides* Linn., are commonly found, as well as a sedge, *Bulbostylis barbata* Kunth, the latter more particularly over the more shallow soils of Kloyo series and Prampram subseries where the topsoils are more sandy.

The grasses characteristically form tussocks, leaving bare ground exposed between them. The basal cover made by grasses on the Pilot Area, averaging only 16 per cent., appears very low by European pasture standards. The investigations carried out by the two University students, however, showed that it was, in fact, appreciably higher than in Black Clays areas further south, where the cover fell as low as 10 per cent. or less in some areas.

Trees are occasional and well-scattered on the deeper Akuse soils ; but on the steeper slopes where shallower soils of Prampram subseries and Kloyo series occur they are more frequent. Coppice shoots, however, are abundant throughout the Area. Because of the annual burning of the savannah, the majority of young trees are unable, except in favoured localities, to develop beyond the stage of coppice shoots. Probably only by escaping damage by fire in two or three consecutive years do they reach the size of a tree and become fire-resistant. Even then, they are characteristically gnarled and stunted in appearance. Of the tree species found, *Combretum ghasalense* Engl. and Diels is dominant ; *Anona senegalensis* Pers. is very frequent ; *Bauhinia Thonningii* Schum., *Pterocarpus erinaceus* Poir., *Bridelia ferruginea* Benth. and *Lannea* spp. (? *L. Schimperi* Hochst. ex A. Rich. and ? *L. acida* A. Rich.) are frequent ; and *Gymnosporia senegalensis* Loes. is occasional.

In the small area in the south-west mapped as open medium grassland with scattered trees, tree species are perhaps actually no more frequent than in the area just described, but presumably because this area is near and to the lee of the damper, poorly-drained floodplain, which is here covered with thicket, and may so be protected from the grass fires which seasonally ravage the greater part of the Pilot Area, the trees are enabled to develop beyond the stage of coppice shoots. *Combretum ghasalense* and *Pterocarpus erinaceus* are the predominant species.

The floodplain savannah is dominated by tall grasses of *Andropogon* species amongst which occur frequent small trees of *Mitragyna inermis* O. Kuntze. The species of *Andropogon* give way locally to colonies of a short grass, *Ctenium Newtonii.*

In the part of the floodplain disturbed by former cultivation, the characteristic grasses have largely been replaced by *Panicum maximum* Jacq., *Cymbopogon giganteus*, *Schizachyrium semiberbe* and *Vetiveria fulvibarbis*, but *Mitragyna inermis* remains the characteristic tree. Where thicket occurs in this area, *Mitragyna* still persists, but the vegetation unit is characterized by such species as *Clausena anisata* Oliv., which is very abundant ; *Carissa edulis* Vahl and *Grewia carpinifolia* Juss., which are abundant ; *Bandeiraea simplicifolia* Benth., *Fluggea virosa* Baill., and *Capparis erythrocarpa* Isert, which are very frequent ; and *Flacourtia flavescens* Willd. and *Fagara xanthoxyloides* Lam., which are occasional to frequent.

In the fringing forest and secondary forest, *Mitragyna* occurs abundantly amongst *Kigelia africana* Benth., *Vitex Cienowskii* Kotschy and Peyr., *Bussea occidentalis* Hutch., *Lannea* spp. (? *L. Schimperi* and ? *L. acida*), *Diospyros mespiliformis* Hochst., *Dialium guineensis* Willd., and, in the south-east, *Millettia Thonningii* Baker.

The tree spot plan shows trees which are more than 18 inches in girth at breast height. Few of these reach 30 feet in height. The trees are characteristically shallow-rooting, main roots frequently extending no deeper than 18 inches, and only rarely more than 3 feet. On the other hand, the roots extend laterally from 20 to 50 feet. The concentration of roots, which are usually 2 to 3 inches thick, in the topsoil may considerably interfere with the initial ploughing of the Area. There will be few actual trees to clear from the areas to be irrigated ; but although the superficial parts of coppice shoots may be easily cleared, these frequently spring up from a large bole, which may be expected to have the roots of an actual tree. Interference with ploughing may therefore be expected, not only in the immediate neighbourhood of actual trees, but generally throughout the savannah.

Termitaria (Map 4)

Four types of termite mounds were recognized and mapped on the Pilot Area : tall, conical (' Gothic ') mounds, 3 to 8 feet high ; dome-shaped mounds, 3 to 6 feet high ; flat, dome-shaped mounds less than 3 feet high ; and small, ' sugar-loaf ' mounds, generally less than 18 inches high. The latter type, although common on the area, are soft and easily destroyed. They offer no obstacle to the layout and cultivation of the irrigated plots, and, accordingly, they have not been included on the accompanying map.

The other three types, either because of their bulk or because of their compactness, are liable to interfere with mechanical cultivation, and those which occur on the experimental plots will need to be destroyed before cultivation commences. The ' Gothic ' structures are those under construction by termites at present. They are riddled with tunnels, and should be readily destroyed either by manual labour or by bulldozers. Less than half a dozen of this type will be encountered on the plots to be cultivated.

The dome-shaped mounds may present a greater problem. It appears probable that these types are formed from the washing down of the ' Gothic ' type during rains. The termites either die out or evacuate the mound after a number of years, and the tunnels become filled with clay. The larger type—those mapped as from 3 to 6 feet high—may be up to 20 feet in diameter. As the mounds wash down further, they become more extensive in area and more compact. Eventually they may become covered with slope-wash material and remain as ' fossil ' mounds in the soil. They may then, because of their compactness, interfere with ploughing and drainage. None of the latter type were actually recognized on the Pilot Area ; but the two dome-shaped types—i.e. old, partly down-graded, ' Gothic ' mounds—are relatively common, and many will need to be destroyed. Perhaps the simplest and most effective method of destruction, with the ' Gothic ' as well as the dome-shaped types, would be to blow them up with small explosive charges.

Soils (Map 5)

The Pilot Area lies at the northern extremity of the 300 square mile belt of Black Clays soils which extends northward from the neighbourhood of Prampram on the coast through the centre of the Accra plains to the edge of the Volta floodplain for 4 to 5 miles on either side of Akuse (see Map 2). These soils cover the greater part of the Pilot Area ; but, in the extreme north, soils are found developed over acidic gneisses and in alluvial deposits along the Okwe-Volta floodplain.

The Black Clays of the Accra plains are predominantly derived from the weathering of garnetiferous hornblende gneiss, a metamorphosed basic rock, which with rare exceptions everywhere underlies the belt. These soils are essentially associated with very gentle slopes, savannah vegetation and a sub-humid to subarid climate, and are characterized by the fact that their clay mineral is montmorillonitic, by their dark colour and by the presence of calcium carbonate concretions in the lower part of the profile.

Base exchange data for the Black Clays had already suggested that the dominant clay mineral must be montmorillonitic. This has now been confirmed by X-ray diagrams of the clay fractions (less than 0.002 mm. particle size) from a Black Clays profile from the Accra plains obtained by the Soil Analyst during a recent period spent at Rothamsted Experimental Station. The dominant reflections in orientated aggregates are the 001 reflections of montmorillonite, showing the typical lattice expansion from 14 Å to 18 Å in glycerol-treated samples. Although it is general to find a considerable amount of unweathered minerals in the conventional clay fraction (less than 0.002 mm. particle size), the diagrams show that montmorillonite predominates, with only small amounts of quartz and probably some kaolinite present.

Montmorillonitic clays appear generally to be synthesized under conditions of poor drainage where a plentiful supply of bases and silica exists. These conditions obtain in the Black Clays belt of the Accra plains where the weathering of the hornblende-rich rock gives rise to soils with a high clay content and releases ample amounts of bases and silica which are leached out rather than accumulated because of the low rainfall and high evaporation and the slow internal drainage of the soils on the peneplain relief.

The black colour of the soils is not attributable to a high content of organic matter : the organic matter status of the soils is, in fact, low. Where similar soils have been studied elsewhere—in India, South Africa and Australia—their colour has been variously attributed to titanic magnetite (8), to the occurrence of iron in the ferrous rather than the ferric form (9), and to dispersed humus in the form of calcium humate (10). Insufficient analytical data are available on the local soils definitely to confirm or refute any of these suggestions. However, in the field, the soils can often be seen to become paler in colour with depth ; and in the laboratory, after the destruction of organic matter by treatment with hydrochloric acid and hydrogen peroxide, the soil material is seen to be pale grey in colour, which lends support to Hosking's view that the dark colour of these soils is due to the impregnation of the mineral particles with base-saturated humus (10). Preliminary investigations indicate that rather high contents of manganese peroxide—a few tenths of a per cent.—occur in the Accra plains soils. This will serve to intensify their dark colour.

The montmorillonitic clay is characterized by great volume expansion on wetting. When moist, the soils are heavy, plastic and impervious ; when dry, they become very compact and crack widely from the surface into large polygonal columns. The plastic nature of the clays when wet results in very poor internal drainage and aeration. This limits or inhibits the oxidation of the iron compounds. It also prevents the leaching of alkaline earth carbonates from the soil. These tend to accumulate in the lower parts of the soil profile as mixed carbonates of calcium and magnesium, usually in the form of small, hard concretions.

The underlying rock is usually only moderately weathered. This is particularly the case in the northern part of the Black Clays belt, including the Pilot Area. Here the rock may be brashy or powdery : it has rarely decomposed to a clay.

Despite the close coincidence of the Black Clays of the Accra plains with the garnetiferous hornblende gneiss, the soils are not, strictly speaking, truly sedentary in origin. Between the black clay and the underlying rock there is occasionally found a stone-line of quartz gravel or, in the case of the Pilot Area, even of well-rounded pebbles. Even where this stone-line is not apparent, there is characteristically a sharp break between the rock and the superficial clay, and the rock itself appears to have been roughly planed off regardless of the dip of the foliation planes. The soils, too, usually contain varying quantities of ironstone concretions which from their disposition in the profile can scarcely have been developed *in situ.*

These factors suggest that the surface of the hornblende gneiss—as, in fact, of the other rocks over the Accra plains—has been planed off at some time in the recent past by some agency, probably during fluctuations in climate and sea-level which took place during the Pleistocene epoch, leaving it more or less bare except for lag gravel derived from former peneplain and terrace deposits. This surface, together with the lag gravel, has later been covered to a variable but usually shallow depth with the material in which the present soils have developed. It is difficult to decide whether this material has been mainly derived by outwash of debris from the weathering of the large rocky inselbergs (such as Krobo Hill, the Shai Hills, Ningo (or Osudoku) Hill, etc.), or mainly by biotic agents, such as termites and ants, bringing up particles of weathering bedrock which then further weather and are redistributed locally by surface wash during sheet flood. Certainly, in the southernmost part of the Black Clays belt, there are no rock outcrops from which such material could reasonably be considered to have been derived within four or five miles of some of the upper-slope soils.

The ironstone concretions are presumed to have been derived from the ferruginized mantle covering a former peneplain. This mantle has been almost entirely eroded now ; but small remnants still occur around the feet of Ningo and Bundase Hills in the Black Clays belt, as well as elsewhere on the Accra plains. The ferruginous concretions from these former drifts are considered to have been transported locally by streams and sheetflood during the dissection of the peneplain and to have been left behind on the rock surface as lag gravel before becoming incorporated in the present soils in the form of an intermittent and irregular stone-line. Locally, ironstone concretions are found scattered irregularly throughout the soil profile, but, in these cases, concretionary residuals can be found upslope. From these the concretions have been transported by surface sheetflood, and have become incorporated in the present soils by dropping down the wide cracks which open when the soils dry out. This observation, too, indicates that the stone-lines found on the Accra plains are not the result of ' self-mulching ' of the soils during repeated shrinking and swelling, for if this were so the stone-line would resolve out at the depth of vertical cracking which normally ends where the zone of calcium carbonate accumulation begins, not, as is, in fact, invariably the case, at the base of the profile.

Since drainage is almost entirely by sheetflood over the whole surface of the ground, slopewash material has filled in depressions in the surface of the bedrock ; but over projections in the rock surface, this cover tends to be more or less shallow. The irregular distribution pattern of the deep and shallow subseries of Akuse series on the slopes of the Pilot Area is a reflection of the small scale irregularities in the generally well-planed surface of the bedrock.

Where the slopes are steeper, as they tend to be in the northern half of the Black Clays belt where the river Volta and its tributaries are cutting into the piedmont slopes surrounding Krobo and Ningo Hills, sheetflood and minor gullies are removing material as quickly as, or perhaps even more quickly than, it is being supplied. Here, therefore, the soils tend generally to be shallow with numerous small rock outcrops, and deeper soils are only found in hollows in the surface of the bedrock.

Originally, the Black Clays were separated into two series : Prampram series and Akuse series. Early views on the formation of these soils have been modified as a result of experience gained on the Reconnaissance Soil Survey of the Accra plains. Formerly, there was thought to be a simple topographical relationship between these two soils : Prampram series was regarded as consisting of sedentary soils found on the upper slopes of undulations, and Akuse series of soils developed in material which had been washed down from these upper slopes to accumulate on the lower slopes and along the valley bottoms.

It is now considered, as described above, that the Black Clays are almost entirely developed in locally-derived slopewash material, almost regardless of topography. The sedentary soils are relatively rare, and are now recognized, where they occur on gentle topography, as the Krobo subseries of Kloyo series. Prampram soils are recognized now merely as a subseries of Akuse series, from the normal soils of which they are differentiated solely by difference of depth. In the normal Akuse soils there is more than 30 inches of black clay above the bedrock : in Prampram subseries, bedrock is encountered at less than this depth. This criterion is used because thirty inches is considered to be the limiting depth for satisfactory flood irrigation on these soils. It is of practical importance, therefore, since it is intended to develop the Black Clays by irrigation, to separate soils which will require to be developed by different irrigation methods.

On the floodplain in the north of the Pilot Area, soils are developed in the alluvial deposits of the Okwe stream (Tachem series) and the river Volta (Amo series). On the Pilot Area, Amo series is not everywhere typically developed since the Volta alluvium, which forms the parent material, is here mixed to a greater or lesser extent with alluvium brought down by the Okwe stream. Both soils are waterlogged during the rainy seasons and are liable to be inundated to varying extents when the Okwe floods. Both soils are acidic in reaction.

The boundary between the Black Clays and the floodplain alluvial clays is not distinct. At the edge of the floodplain (more probably the edge of a former floodplain at a slightly higher level than the present one), there is a transitional zone from 1 to 5 chains in width, where slopewash from the Black Clays has accumulated over the brown alluvial clays. This slopewash becomes thinner in depth as it spreads over the floodplain. Where the black clay is deeper than 18 inches, the soils have been mapped as Black Clays ; where it is less than this depth they have been included with one of the Brown Alluvial Clays.

Two small patches of soils whose origin is uncertain occur in the north of the Pilot Area. The parent materials of these soils appear possibly to be alluvial in origin ; but since the profile characteristics are identical with those of soils which are widely developed over acidic gneiss areas of the Accra plains, even to the point of themselves overlying acidic gneisses at depth in some cases, they have been included with these soils and mapped as Agawtaw series.

Present land-use (Map 7)

Present land utilization on the Pilot Area is representative of that found over the remainder of the Black Clays belt. The soils almost everywhere are left uncultivated, except, very rarely, where the soils are rather shallow and lighter in texture, as in a small patch in the south-east corner of the Pilot Area, where cassava is, or has been, grown. Elsewhere, the Black Clays are too compact to be cultivated by the hoe, the only implement used by local farmers. There are no habitations on the Area at present, but there are indications of former settlement on some of the shallower soils in the way of broken pottery and in high contents of acid-soluble phosphorus in some of these soils (cf. APA 363, **Kloyo** (*Krobo*) series in Table I).

In the central and southern part of the Black Clays belt, the characteristic medium grassland these soils support is occasionally, but not systematically, grazed by large herds of cattle from peripheral villages such as Dawhwenya, Afienya, Mobile, Doyum, Kodiabe and Luum. Two herds seen at Akuse did not graze so far afield as the Pilot Area, and the savannah areas are in consequence mapped as ' Grassland : Ungrazed '. The vegetation is burned annually, either directly by hunters or indirectly by cattle herders who start fires on grazing areas to the south-west which spread on to the Pilot Area. The floodplain of the Okwe is covered with swamp vegetation, and is unused.

Firewood is cut from trees over the whole area, but particularly from the savannah species, perhaps because the wood of these trees is closer-textured and burns better than that of other types.

Stones are collected from a few shallow pits in the north-east where the rock outcrops or comes near to the surface. Some of the stones are used in the maintenance of the nearby Kpong-Akuse road ; others are collected by local people, usually women, for sale to private contractors for use in building and road-making.

Pieces of the hornblende gneiss rock are also collected, for the feldspar it contains is used in making a glaze for earthenware (made from ' Amo ' clays at Kpong and elsewhere down the banks of the Volta).

PART II. SYSTEMATIC SOIL DESCRIPTIONS

CLASSIFICATION OF SOILS OF THE KPONG PILOT AREA

The soils of the Kpong Pilot Area can readily be grouped into four categories on the basis of differences in parent material.

BLACK CLAYS

Soils developed in locally-transported material derived from the weathering of garnetiferous hornblende gneiss.

Akuse series

Normal series

Black clay deeper than 30 inches.

Prampram subseries

Black clay shallower than 30 inches.

BROWN SEDENTARY CLAYS

Soils developed in the weathering products of garnetiferous hornblende gneiss and pyroxenite which have remained more or less in place.

Kloyo series

Krobo subseries

GREY-BROWN CLAYS

Soils developed in locally-transported material derived from the weathering of acidic Archaean gneisses.

Agawtaw series

BROWN ALLUVIAL CLAYS

Tachem series

Soils developed in alluvial deposits of the Okwe stream.

Amo series

Soils developed in alluvial deposits of the river Volta.

SOIL SERIES DESCRIPTIONS

BLACK CLAYS

These soils are dark-coloured, very compact or plastic, neutral to alkaline clays developed in the locally-transported weathering-products of garnetiferous horneblende gneiss. They occur on the slopes of the Pilot Area, but locally extend onto the outer edge of the combined Okwe and Volta floodplain. Externally, they are well drained, except at the edge of the floodplain. Internally, they are badly drained. Calcium carbonate concretions characteristically occur in the lower part of the profile.

As has already been explained, the Black Clays on the Pilot Area have been separated into two divisions of Akuse series, normal and Prampram, the sole criterion being depth of soil above bedrock. Because of the significant differences between their agricultural potentialities, the two divisions are described separately below.

Akuse series

Normal series

Description of the soil.—The normal soils of the series have developed in the locally-transported weathering-products of garnetiferous hornblende gneiss which everywhere underlies them at a depth greater than thirty inches.

The surface horizon, 4 to 6 inches thick, consists of dark brownish grey or blackish grey clay or light clay. The surface may be covered with a fraction of an inch of fine sand in which garnets are prominent. This sand is washed out and deposited during rain storms, but afterwards quickly becomes mixed with silt and clay brought to the surface by ants or, more rarely, by earthworms. When moist, the clay is plastic ; but on drying, it becomes compact and nutty to cloddy in structure, cracking widely from the surface. Because of the abundant root channels it contains, this horizon is somewhat more permeable than those below it. In reaction, it is usually neutral, with pH values ranging from 6.8 to 7.2 ; but at the edge of the floodplain, occasional profiles give pH values as low as 6.4.

The succeeding horizon varies considerably in thickness, from 12 inches or less in shallow profiles, to 5 feet or more in deep ones. On the Pilot Area, its base usually lies at a depth of 24 to 36 inches from the surface. In colour, this horizon is very dark grey. The clay is heavy, plastic and impervious when moist ; when dry, is very compact, and cracks widely into broad vertical columns, continuous from the surface of the profile. The columns break into large clods, on the outside of which polished slip-surfaces are developed. Small, soft, black concretions containing manganese dioxide are occasional to frequent in this layer. Some profiles, as at traverse 28/32, also contain ironstained, calcium carbonate concretions. These have not developed *in situ*, but have been eroded from profiles higher up the slopes, to become incorporated in soils lower down. Despite any such ' alluvial ' calcium carbonate concretions it may contain, the clay in this horizon is usually only neutral to slightly alkaline in reaction, with pH values ranging between 7.0 and 7.5, although occasional deeper profiles may show slight acidity, pH values of 6.5 occasionally being recorded.

The transition from this horizon to the next is only marked by the appearance of calcium carbonate concretions in the profile. These are not of the ' alluvial ' type mentioned above, but have developed *in situ.* These concretions increase in frequency, and occasionally in size, too, with depth, being rare at the top and abundant towards the base. Occasionally they may become dominant and form a separate layer resembling travertine. The calcareous horizon varies in thickness from 12 to 30 inches. The colour gradually changes from dark grey at the top to pale grey or yellowish grey at the base ; where calcium carbonate is very abundant, the lower part may be almost white. The clay is compact and cloddy near the top, but becomes very plastic and almost structureless towards the base, especially in deep profiles. The presence of large amounts of calcium carbonate makes some profiles more friable at the base. Small, soft concretions containing manganese dioxide occur throughout the horizon. Alkalinity increases with depth, pH values increasing from around 7.5 at the top to 8.5 or higher near the base.

At the base of the last horizon there is commonly a stone-line, rarely more than an inch or two in thickness, formed of rounded quartz pebbles. Below this occurs the bedrock. The degree to which this has weathered varies considerably. In deep profiles it has occasionally weathered to a yellowish brown, plastic clay. More commonly it is loamy in texture, and contains brash of less-weathered rock, and occasional calcium carbonate concretions. The reaction varies from pH 7.0 where the rock is little-weathered, to pH 8.5 where the rock has weathered completely. Values as high as pH 9.1 have been obtained in the zone of weathered rock in occasional profiles elsewhere in the Black Clays belt, and may be expected to occur locally on the Pilot Area, too.

Throughout the whole profile, from the surface down to the stone-line, there often occur occasional small, hard, polished ironstone concretions and fine quartz gravel. These are never of sufficient importance to influence the consistency or the drainage properties in any part of the profile.

Analyses have confirmed the statement made in Part I above (p. 19), that the dark colour of the Black Clays cannot be attributed to a high content of organic matter. Few profiles—and these usually in low-lying sites—contain more than 4 per cent. organic matter in the surface six inches, and the majority have less than 3 per cent. The amount decreases only relatively slowly with depth, however, and there is generally more than 1.5 per cent. at a depth of one foot, and more than 0.75 per cent. at a depth of thirty inches, with small amounts, of the order of 0.1-0.2 per cent., still detectable at depths of five or six feet. Individual profiles may vary rather considerably from this general pattern, but none can be said to be more than moderately provided.

Gross mechanical analyses show that the non-calcareous upper horizons consist almost entirely of fine earth, with gravel and ironstone concretions rarely accounting for more than 5 per cent. of the total. In the calcareous horizon, the proportion of hard calcium carbonate concretions varies considerably from profile to profile, so that whereas the majority of profiles continue to show more than 90 per cent. fine earth, occasional profiles show as little as 50 per cent.

The presence of a stone-line of pebbles occasionally increases the proportion of stones to over 30 per cent. in the lowest horizon. The proportions of fine earth in the upper part of the weathered rock varies according to the degree to which this has decomposed, from more than 90 per cent. in some profiles to less than 10 per cent. in others.

Ultimate particle-size analyses show that the proportion of clay is nowhere higher than 60 per cent. and only occasionally more than 50 per cent. Proportions between 30 and 50 per cent. are the general rule, although surface horizons with as little as 20 per cent. occur locally. There is a general tendency for the proportion of clay to increase steadily with depth, but this is not always well-marked, and may be entirely masked in some profiles by the occurrence of calcium carbonate in the lower horizons. The proportion of clay in the weathered rock is almost always less than 30 per cent., and sometimes less than 10 per cent., with the proportion tending to decrease rapidly with depth.

The silt fraction is everywhere less than 10 per cent., and tends to diminish slightly in proportion with depth. Coarse and fine sand together generally amount to 30-50 per cent., at least in the upper horizons, but where large amounts of calcium carbonate occur the proportion may fall below 20 per cent. in lower horizons. There is no uniformity between different profiles in the individual proportions of coarse and fine sand, but their proportion relative to each other in individual profiles tends to remain constant down the profile until weathered rock is reached. Within the weathered rock zone the proportions of coarse and fine sand, both relative to each other and to the finer fraction, vary very considerably. The sand consists predominantly of garnet fragments, but variable quantities of quartz also occur.

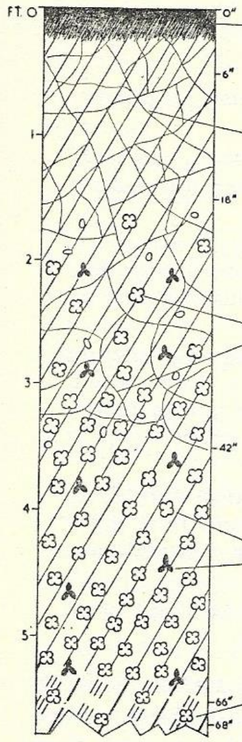
Description of representative profiles.—In the following descriptions soil colour has been defined by comparison with Munsell Soil Colour Charts (1949). It should be noted that the colour refers to that of the dry fine earth sample which is commonly rather paler than that of the fresh soil in the profile.* Reaction, expressed in pH units, has been determined in the laboratory by the glass electrode unless otherwise stated. In the case of consistency and texture, visual observations supported by a simple manipulative test which ensures uniformity of description have been used since, with many soils, this information gives a more realistic indication of their cultivation characteristics than do data derived by formal mechanical analysis.

(a) **Akuse (normal) series** (See Fig. 1)

* The slight discrepancies between the Munsell values given in the following profile descriptions and those given in the analytical tables are accounted for by the fact that, in the former case, the determinations were made shortly after the samples had been collected, and, in the latter case, after the samples had been stored for some months awaiting analysis.

PROFILE NUMBER : APA 368/1-6.   LOCALITY · Kpong Pilot Area : Traverse 5, Chain 18.

VEGETATION : Open Medium Grassland.   SITE · Depression on middle slope of gentle undulation.



Very dark grey (2·5 Y 3/O), slightly crumbly, plastic clay; humous; containing frequent grass roots; pH 6·4

Very dark grey (2·5 Y 3/O), cloddy, plastic clay; rare roots; pH 6·9.

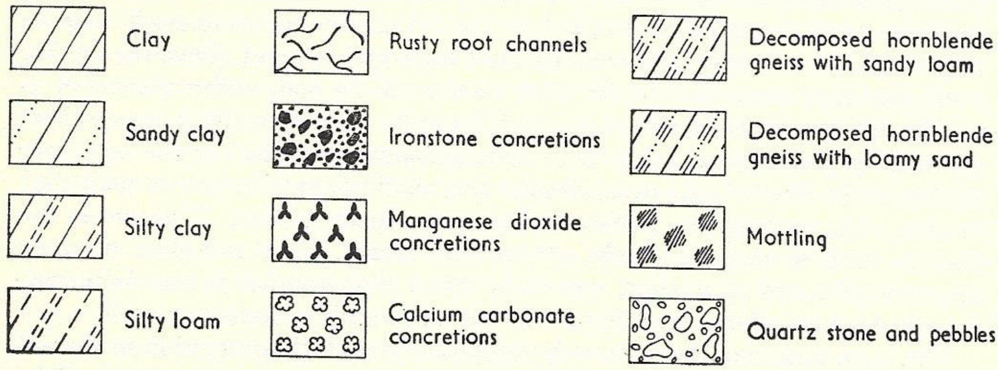
Dark grey (2·5 Y 4/O), cloddy, plastic clay; occasional very fine quartz gravel and small manganese dioxide concretions; calcium carbonate concretions rare at the top increasing to frequent at the base; pH 8·O - 8·2.

Grey (1O YR 5/1), compact, structureless clay; occasional manganese dioxide concretions; abundant calcium carbonate concretions; pH 8·4.

Light grey (2·5 Y 7/2) clay with decomposed garnetiferous hornblende gneiss, frequent small rock brash and occasional small quartz fragments; frequent calcium carbonate concretions; pH 8·5.

Fig. 1. Akuse (normal) series

KEY TO FIGS. 1–6



(b) **Akuse (normal) series**

Profile Number :	APA 370/1-8.
Locality :	Kpong Pilot Area ; traverse 28, chain 32.
Site :	Middle slope of gentle undulation.
Vegetation :	Open medium grassland.
0—5½ *inches*	Very dark grey (10 YR 3/1), crumbly, plastic clay ; humous ; abundant grass roots ; pH 6.4.
5½—15 *inches*	Dark grey (10 YR 4/1), cloddy, plastic clay ; rare 'alluvial' calcium carbonate concretions ; occasional very fine quartz gravel ; pH 7.0.
15—30 *inches*	Dark grey (10 YR 4/1), cloddy, plastic clay ; occasional 'alluvial' calcium carbonate concretions ; rare manganese dioxide concretions ; rare, small, polished ironstone concretions ; pH 8.2-8.3.
30—48 *inches*	Grey (10 YR 5/1), cloddy, plastic clay ; frequent calcium carbonate concretions (developed *in situ*) ; rare small, polished, ironstone concretions ; occasional fine quartz gravel. Prominent stone-line of well-rounded quartz pebbles (up to 2 inches diameter) at base ; pH 8.4.
48—57 *inches*	Greyish brown (2.5 Y 5/2), slightly stained orange and black, structureless sandy clay of decomposing garnetiferous hornblende gneiss ; frequent calcium carbonate concretions ; pH 8.4.
57—72 *inches*	Greyish brown (2.5 Y 5/2), sandy loam with abundant brash of undecomposed rock ; pH 8.6.

Moisture relationships.—As has already been indicated, the surface relief is such that the Black Clays on the Pilot Area are externally well drained, except towards the edge of the floodplain, but the nature of the clay is such that internal drainage is impeded.

Because of the high clay content and the nature of the dominant clay mineral, the soils show considerable shrinking on drying and expansion on wetting : tests made at the laboratories of the Town and Country Planning Board showed volume changes of 40 to 50 per cent. between the wet and the dry states. For the same reason, the moisture content at wilting point is high. Although no directly determined data for the wilting coefficient are available, moisture determinations at 50 per cent. humidity indicate that the wilting coefficient and the moisture content at which the clay begins to swell must be very close. As it is generally assumed that the water content above the wilting coefficient represents the mobile water content of the soil, water movement in the Black Clays must be very slow, both laterally and vertically, because there are no free pore-spaces available. This accounts *inter alia* for the apparent aridity of the Black Clays areas despite the relatively satisfactory rainfall they receive. On wetting, the surface soil quickly absorbs water. This causes the clay to swell so that all cracks are quickly closed. The soil then becomes impermeable, and thereafter, especially when high rainfall intensities occur, the greater part of the precipitation is lost to the soil by surface runoff.

The open nature of the savannah vegetation gives little protection to the soil from the effects of the wind and the sun, and moisture in the upper part of the soil is evaporated fairly quickly after the end of the rainy season. This causes the clay to shrink and crack, so exposing the deeper layers of the soil to evaporation. Below a depth of 30 inches, and even nearer the surface in the centre of structural units, the soil remains perennially moist. This moisture is so strongly held by the clay, however, that much of it is probably unavailable to plants. The cracking of the soil into columns and clods on drying may, in any case, break fine roots, and so limit the ability of plants to take up moisture.

Irrigation techniques will require to be adjusted to these characteristics of the Black Clays. The impermeability of the soils is such that seepage losses are unlikely to be significant unless the zone of weathered rock is exposed by excessive land-levelling. For furrow-irrigation, water will require to be held on the soil for relatively long periods to encourage adequate absorption, or, alternatively, the rate of absorption might be increased by cultivation methods designed to improve the soil structure.

Cultivation characteristics.—The initial preparation of these soils for cultivation is unlikely to be unduly difficult, provided that suitable mechanical equipment is made available. There will be few trees to clear ; but ‘ bush-ploughs ’ will be required to deal with the lateral-spreading roots of these trees and of the more ubiquitous coppice shoots. There will be no impedance from stones or rock outcrops in these soils.

It will be a matter for investigation to discover the most suitable soil-moisture conditions for tillage operations. The optimum conditions, however, are likely to occur over only a narrow range of moisture contents. The uncertainty of these both in occurrence and duration, together with the need for adherence to a strict programme of operations in large scale farming, will demand that the soil be ploughed under less ideal conditions. The majority of the ploughing will therefore be carried out during the dry seasons. The compactness of the dry soil will demand the use of the heaviest tractors and implements. Some alleviation of the soil might be achieved if fields can be irrigated at a suitable interval before they are to be ploughed. For the tillage of moist soils, tractors equipped with broad crawler tracks will be essential, for the plasticity of the soils is such that they will not support wheeled vehicles. The relatively large content of garnet sand in the compact clay may cause excessive abrasion of tillage implements. Fortunately, on furrow-irrigated land at least, the soils should gradually become largely self-mulching.

The surface drainage of these soils on the Pilot Area raises no problems since, in any case, the lowest-lying areas will be used for flood-irrigation of rice. The soils on the slopes will automatically be drained by the furrows used to distribute irrigation water to the crops. It will be essential to ensure that the field channels are adequate to take off the large quantities of water which normally runs off over the surface during rainstorms. Adequate interceptor drains must be provided upslope of plots, too, to protect them from water draining from the higher slopes. These drains must be so designed that there is no danger of them developing into gullies and so causing accelerated erosion.

The internal drainage of these soils, almost non-existent under present conditions, is likely to be improved by cultivation. The raising of the surface soil into ridges between the furrows will effect a great deal. This is likely to be enhanced if lime is brought up from the calcareous horizon during ploughing, for this will give a more friable structure to the topsoil. On the plots under flood-irrigation, improved internal drainage is not so essential.

After the initial ploughing, there should be no further physical difficulties to overcome. Because of the continual wetting and drying of the soil under irrigation and the consequent swelling and shrinking, the soils on the furrow-irrigated plots will become largely self-mulching. Weed control should therefore be relatively simple on the furrowed plots. It is possible that the improved drainage and aeration of these soils under furrow-irrigation will change their colour from black to dark brown by permitting the oxidation of some of the iron compounds.

Under flood-irrigation, the soil may not have the opportunity to dry out and crack into clods as it does at present during the dry season. Van der Merwe states (11) that when the Black Clays under irrigation on the Springbok Flats, South Africa, remain moist throughout the year, they appear to deteriorate in structure. This effect can probably be kept down to a minimum by leaving the soil in large clods after ploughing. This will greatly increase the surface area of the soil and so increase the evaporation. This in turn, will allow the clods to crack and moulder down to a suitable tilth for the following crop. The cultivation of a ' dry-land ' crop between successive flood-irrigated crops would serve a similar useful prupose.

Weed control in rice cultivation can be achieved by thorough ploughing of the flooded fields just prior to the transplanting of the seedlings from the nursery plots. This gives the rice crop several weeks' advantage over weeds, the growth of which also tends to be inhibited by the continuous inundation of the paddies until the ripening of the crop.

Nutrient relationships.—It is difficult to assess the nutrient status of these soils in the absence of field crop production data with which the results of chemical analysis could be correlated. The quantitative analytical data given below, therefore, can only serve to provide a qualitative appreciation of the nutrient relationships which will be encountered, and the comments upon these relationships must necessarily be general rather than definitive.

(*a*) *Organic matter.*

Unlike the chernozems or prairie soils of temperate latitudes with which the tropical Black Clays have sometimes been compared (12), but from which they differ in several important respects (13), these soils do not possess a large capital reserve in the way of accumulated organic matter which could be exploited on their cultivation. The organic matter status of these soils, as has already been stated, is low.

The humus is well decomposed, and yields a very dark solution on treatment with sodium pyrophosphate. A preliminary survey of the oxidability of the organic matter in the Black Clays showed that the recovery of organic carbon in the routine wet combustion determination (Walkley-Black) amounts to between 60 and 67 per cent. of the values obtained by dry combustion, whereas in the soils of the forest zone the recoveries are significantly higher, giving values of 77 to 80 per cent.

The nitrogen content is low, although it is more deeply distributed through the profile than in the majority of soils. With improved moisture status, the calcium saturation of the soils would encourage intensive nitrification. For continuous cropping, however, it is always necessary to add nitrogenous fertilizers.

The carbon/nitrogen ratios are fairly high, of the order of 14-16 : 1 with a tendency to decrease with depth. This is somewhat contrary to the well-decomposed nature of the organic matter in these soils and requires further investigation. It may be that some of the carbon is not present in the form of organic matter but as charcoal produced during the annual burning of the vegetation.

(*b*) *Phosphorus.*

The Black Clays appear to be less well provided with phosphorus than might have been expected considering their derivation from a basic igneous rock. Such rocks frequently contain apatite, the primary source of soil phosphorus, as an accessory mineral. The local rocks however, contain only very minor amounts of this mineral.

The soluble phosphorus content, as determined by the Truog method, is rather low. Some exploratory determinations of the total phosphorus indicate that this is likely to be low also. Although no field crop data are available by which the applicability of the Truog method to these soils could be assessed, the general indication afforded by the analyses is that the phosphorus status of the Black Clays is relatively poor.

(*c*) *Base status.*

Because of their predominantly montmorillonitic clay these soils have a high exchange capacity, usually of the order of 30-50 m.e./100 gms. soil. The adsorption complex is saturated throughout, the soils being weakly acid or neutral in reaction near the surface and distinctly alkaline in the deeper layers. Typically, pH values do not exceed 8.5-8.6 in the calcareous subsoil, but occasionally, values up to pH 9.1 have been obtained in the zone of weathered rock.

The adsorption complex is saturated predominantly with calcium and magnesium, the relative proportions of which vary appreciably from profile to profile, presumably according to the nature of the rock detritus forming the parent material and upon the subsurface topography of the bedrock. Calcium always exceeds magnesium in amount in the surface horizons, but there is occasionally a slight excess of magnesium in the deeper layers.

The potash status appears to be poor, with only a few tenths of a milli-equivalent present in all soils analysed from the Accra plains to date. Sodium is present in very minor amounts in the upper part of the profile, but occurs in amounts up to several milliequivalents in the weathered rock, presumably due to the weathering plagioclase feldspar. A peculiar constituent of these highly calcium-saturated soils is strontium which may occur up to 0.2 m.e. in some profiles.

The content of calcium carbonate varies considerably from profile to profile. In the upper horizons the content is low, usually of the order of nil to 0.2 per cent. In the lower horizons—below 18-24 inches—there is often 30-40 per cent., and occasionally more than 50 per cent. Profiles towards the lower slopes often show lesser amounts than those on the slopes above, and one such profile from the Pilot Area showed less than 2 per cent. in all horizons down to six feet. Analyses usually reveal less than 1 per cent. in the zone of weathered rock.

Besides actual differences in content from profile to profile, the differences in mode of occurrence of the calcium carbonate undoubtedly go far to explain the widely divergent values obtained by analysis. The analytical data refer to calcium carbonate occurring in the fine earth fraction. However, considerable amounts of calcium carbonate occur in concretionary form and are removed as gravel or stones during the separation of the fine earth for analysis.

The amount of magnesium carbonate occurring with the calcium carbonate in the fine earth fraction is not known. A single analysis carried out on hard concretionary material from a profile near M.P. 28 on the Dawhwenya-Prampram road in the southern half of the Black Clays belt gave the following results :—

SiO_2	1.86	per cent.
Al_2O_3	0.59	,, ,,
Fe_2O_3	0.96	,, ,,
TiO_2	0.06	,, ,,
CaO	51.50	,, ,,
MgO	1.88	,, ,,
CO_2	41.74	,, ,,
H_2O + 105°C.	0.93	,, ,,
H_2O — 105°C.	0.54	,, ,,
Total	100.06	,, ,,

Analyses of concretions from the Kpong-Somanya-Akuse triangle made by the Geological Survey Department (14) showed less than 3 per cent. magnesium and approximately 40 per cent. calcium.

(*d*) *Harmful substances.*

The surface horizon of the Black Clays is generally neutral to slightly acid in reaction. This condition is usually considered the most suitable for crop growth for then most plant nutrients, if present, are in available form ; or the toxic effects which arise from excessive availability of some minerals under more acidic conditions are absent. Carbonate of lime is often added to cultivated soils, in fact, not only to improve their structure, but also to reduce their acidity to a pH value of around 6.5.

In the lower horizons of the Black Clays, however, the reaction becomes distinctly alkaline, and free calcium carbonate is found in more-or-less considerable amounts. If, due to excessive land-levelling or deep cultural operations, this horizon is exposed or brought to the surface, nutritional disturbances may be expected to occur in crops. The presence of more than 2 per cent. of calcium carbonate in the soil, and/or a pH value higher than 7.5, reduces the availability of phosphorus to plants (15) : under these conditions, the phosphorus is fixed in the form of an insoluble compound, calcium carbonato-phosphate. Many other elements which, although needed only in very small amounts, are essential to healthy plant growth, are liable similarly to be fixed by the calcium carbonate.

However, calcareous soils are cultivated, and with great success, elsewhere in the world. It is essential in these cases to add fertilizers containing the elements not available in the soil. Although these are sooner or later fixed by the calcium carbonate, they are available over a sufficient period to benefit the plants.

Sodium, although present in appreciable amounts in the adsorption complex, is unlikely to introduce difficulties because of the overwhelming predominance of calcium. No appreciable amounts of soluble salts occur in the upper horizons, and in the deeper layers they only amount to 0.1-0.2 per cent. Sulphates account for almost the whole of this amount there being only negligible proportions of chlorides. It is fortunate for the future irrigation of the Accra plains that the water in the river Volta has a very low salt content, too.

A preliminary examination of a profile from the southern part of the Black Clays belt indicates that copper, cobalt, nickel, vanadium and chromium are not present in excessive proportions : the quantities estimated were of the order of 50 parts per million. Gallium was also present in appreciable, but not excessive, quantities.

Constructional properties.—Tests carried out by the Town and Country Planning Board on a sample of soil from Akuse series showed, as might have been expected from its plasticity when wet, that this soil is unsuitable for use in road building. For the manufacture of stabilized building blocks, a mixture of sixteen parts of soil to one part of cement was found satisfactory, although no long-weathering test was made. The soil was not considered suitable for use in the manufacture of bricks, tiles or pottery. Permeability tests showed that the soils can safely be used in the construction of earth dams and bunds—so long as they are kept moist : on drying, they would crack widely, so possibly reducing the water-tightness of any earth structure.

Variants.—Although the soils of Akuse series vary within rather broad limits from place to place with regard to intensity of the black colour, content of sand, ironstone concretions or calcium carbonate concretions and depth to calcareous horizon, these variations are regarded as characteristic of the series and need not be discussed separately. At the edge of the Okwe-Volta floodplain, however, there is a narrow belt of transitional soils where slopewash from the Black Clays has spread over old alluvial deposits of a totally different character. In mapping, these transitional soils have been allocated to Akuse series or to one or other of the Brown Alluvial Clays according to whether the black clay is deeper or shallower respectively than 18 inches (normally regarded as the maximum depth of the cultivated layer).

These soils differ from the normal soils in that they are poorly drained externally as well as internally, and are generally neutral to slightly acid in reaction to a depth of approximately thirty inches, although they become slightly to moderately alkaline below. They do not contain large accumulations of calcium carbonate in the lower portion of the profile, or at least within six feet of the surface. Soluble salts, mainly sulphates, may be present in amounts up to 0.2 per cent.

The superficial black clay is essentially similar in its physical properties to the normal soils of Akuse series although because of less satisfactory surface drainage the topsoils have a higher content of organic matter. The alluvial deposits which underlie the black clay are brown to yellowish brown in colour, and slightly mottled. They consist of a very compact and structureless sandy clay, which appears so dry in the profile as to suggest that no moisture permeates through from the black clay above.

These soils will only be encountered, if at all, on the sites proposed for rice cultivation. Their cultivation characteristics and requirements do not differ significantly from those of the normal soils of Akuse series described in detail above, except in so far as they contain only minor amounts of free calcium carbonate within rooting depth.

(a) **Akuse series : transitional variant**

Profile Number :	APA 180/1-8.
Locality :	Kpong Pilot Area ; traverse 70, chain 52.
Site :	Lower slope, at edge of floodplain.
Vegetation :	Floodplain savannah.
0—3 *inches*	Very dark brown (10 YR 2/2), cloddy clay ; humous ; abundant grass roots ; pH 6.1.
3—10 *inches*	Very dark greyish brown (10 YR 3/2), cloddy clay ; less humous ; rare fine quartz gravel ; pH 5.7.
10—21 *inches*	Very dark greyish brown (10 YR 3/2), cloddy clay ; occasional small, soft, yellow-brown ironstone concretions ; pH 6.1.
21—30 *inches*	Very dark greyish brown (10 YR 3/2), cloddy clay ; rare soft manganese dioxide concretions ; rare fine quartz gravel ; pH 6.5.
30—39 *inches*	Very dark greyish brown (10 YR 3/2), compact clay ; rare soft manganese dioxide concretions ; pH 7.1.
39—59 *inches*	Yellowish brown (10 YR 5/4), stained grey, orange and black, very compact, structureless clay ; pH 7.7.

59—65 *inches*	Yellowish brown (10 YR 5/6), mottled grey and yellow, very compact, structureless clay ; occasional manganese dioxide concretions ; occasional fine and coarse quartz gravel ; rare calcium carbonate concretions ; pH 8.0.
65—74 *inches*	Yellowish brown (10 YR 5/6), mottled grey and yellow, compact, structureless clay ; frequent manganese dioxide concretions ; frequent calcium carbonate concretions ; pH 8.2.

The underlying rock was not reached in this pit.

(b) **Akuse series : transitional variant**

Profile Number :	APA 172/1-6.
Locality :	Kpong Pilot Area : traverse 18, chain 51.
Site :	Lower slope at edge of floodplain.
Vegetation :	Open medium grassland.
0—4 *inches*	Dark grey (10 YR 4/1), silty and porous, light clay ; humous ; pH 6.5.
4—18 *inches*	Very dark greyish brown (10 YR 3/2), compact clay, with wide vertical cracks when dry ; occasional to frequent manganese dioxide concretions ; pH 7.3.
18—34 *inches*	Dark brown (7.5 YR 3/2), compact, cloddy clay ; occasional soft manganese dioxide concretions ; occasional small, hard, polished, ironstone concretions ; pH 7.2.
34—38 *inches*	Dark reddish grey (5 YR 4/2), moist, structureless clay ; abundant soft, orange, ironstone concretions ; pH 7.3.
38—54 *inches*	Brownish yellow (10 YR 6/6), moist, structureless clay ; frequent soft, red, ironstone concretions ; pH 7.5.
54—68 *inches*	Strong brown (7.5 YR 5/6), mottled grey and orange, friable clay ; pH 7.4.

The underlying bedrock was not reached in this pit.

Prampram subseries

Description of the soil.—These soils differ from the normal soils of the series in that bedrock is encountered within thirty inches of the ground surface. The profile is similar in morphology to that of the normal soils, except that the individual horizons, and especially the calcareous horizon, tend to be less thick. Often too, the topsoil tends to be lighter in texture and the whole soil rather more brown in colour than is characteristic of the deeper soils of the series.

On the Pilot Area the surface of the ground where Prampram soils occur is frequently covered with a layer of scattered pebbles. The humous horizon is generally three or four inches thick, and is dark brownish grey to blackish grey in colour. It is granular to nutty in structure. In shallow profiles, the texture in this layer may be somewhat lighter, giving a sandy loam occasionally, and the consistency may be more friable. Permeability is greater than in lower horizons or than in the corresponding horizon of Akuse series, especially in shallow profiles. It is usually neutral in reaction, with pH values ranging from 6.8 to 7.2 ; but the more sandy layer found in shallow profiles is commonly slightly acid, with a pH of around 6.5.

Below this, there is from six to twenty inches of dark grey to dark brown, nutty or cloddy, plastic clay, containing frequent small, soft, manganese dioxide concretions, and occasional small, polished ironstone concretions. This layer is neutral to slightly alkaline in reaction, with pH values generally between 7.0 and 7.5.

The succeeding horizon is usually shallow, ranging from four to twelve inches in thickness. It consists of mid-grey to pale grey, or yellowish grey, nutty to cloddy, plastic clay containing frequent to abundant calcium carbonate concretions, frequent manganese dioxide concretions and fine quartz gravel. In reaction it is moderately to very alkaline, with pH values of 8.0 to 8.5, and locally as high as 9.0.

At the base of the last horizon, there is often a well-marked stone-line of rounded quartz pebbles. This rests on the surface of the bedrock. The degree to which this has weathered varies. Occasionally the rock is relatively fresh in appearance ; more usually it has crumbled to a greenish grey, sandy loam, containing less-weathered rock brash ; rarely has it decomposed to a clay. The reaction varies considerably, from neutral in some profiles, with pH values around 7.0, to very alkaline in others, with pH values as high as 9.0.

The depth of soil above the bedrock varies from approximately twelve inches to the maximum depth of thirty inches, but occasional small rock outcrops occur locally throughout the major areas covered by the soils. When the black clay ' drift ' is thinner than about twelve inches it becomes mixed with so much fresh material brought up from the underlying bedrock by biotic activity as to assume more or less the character of a sedentary soil. These soils were formerly known as a shallow subseries of Prampram series ; they are now recognized as Kloyo series, and will be described separately.

Profiles containing large amounts of quartz gravel or ironstone concretions are recognized as variants and are described later.

The soils appear generally to contain rather lower amounts of organic matter than the normal soils of the series, although the distribution pattern down the profile is similar. No soils containing more than 3 per cent. organic matter in the topsoil have been encountered, and some have less than 2 per cent.

Gross mechanical analyses show that the soils consist almost entirely of fine earth down to the weathered rock, although pebbles and/or ironstone concretions may occur locally and reduce the proportion of fine earth to around 90 per cent.

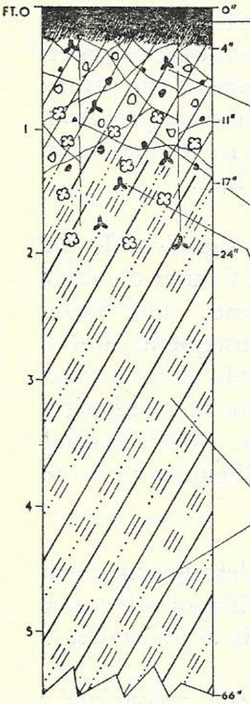
Ultimate particle-size analyses show a substantially lower clay content, especially in the topsoils, than is found in the normal soils, some profiles containing less than 20 per cent. clay in the surface horizon and less than 30 per cent. in the subsoil. This is presumably attributable to the fact that Prampram soils characteristically occur on rather steeper slopes than do the normal soils and so suffer a certain amount of eluviation of their finer fractions during sheetflood.

Description of a representative profile.—

Akuse (Prampram) series (See Fig. 2)

PROFILE NUMBER : APA 369/1-5 LOCALITY : Kpong Pilot Area: Traverse 8, Chain 50.

VEGETATION : Open Medium Grassland. SITE : Middle slope of gentle undulation.



Very dark greyish brown (10 YR 3/2), slightly compact, nutty light clay; humous; pH 6·8.

Dark greyish brown (10YR 4/2), compact, cloddy clay, cracking vertically into large prismatic blocks; occasional manganese dioxide concretions; occasional small, polished, ironstone concretions; occasional small, rounded quartz pebbles; pH 7·4.

Greyish brown (10 YR 5/2), compact, cloddy clay with vertical cracks continuous from horizon above; occasional calcium carbonate concretions; occasional manganese dioxide concretions; occasional small, polished ironstone concretions; pH 8·5.

Dark grey (10 YR 4/1), compact sandy clay (decomposed rock) with occasional small, soft rock brash; occasional calcium carbonate concretions; rare manganese dioxide concretions; pH 8·6.

Little-decomposed garnetiferous hornblende gneiss with small amount of light brownish grey (2·5 Y 6/2), sandy loam; pH 8·9

Fig. 2. Akuse (Prampram) series

Moisture relationships.—Soils of Prampram subseries generally occur on steeper slopes than those of the normal soils. They are externally well drained. Internally, they are usually poorly drained ; but shallower profiles, which are lighter in texture and more open in structure near the surface, are relatively better drained.

The clays shrink and crack into columns on drying, and swell and become more or less impervious on wetting. Because of their shallower depth, they are less retentive of moisture during dry seasons than the normal soils of the series.

Cultivation characteristics.—Trees and coppice shoots are more frequent in occurrence on Prampram soils than is generally the case on the deeper Black Clays. This is particularly the case on the belt of Prampram soils in the north-east of the Pilot Area where some of the cultivation plots will be situated.

Apart from the variations in depth to bedrock within the soils of the subseries, areas of Prampram soils usually enclose, or are associated with, small patches of very shallow soils of Kloyo series or actual hard rock outcrops. If Prampram soils are to be cultivated, mouldboard ploughs will be useless, because of the risk of damage if hard rock is struck. Disc ploughs may overcome some of the difficulty.

The compactness of the clay when dry, and its sticky nature when wet, will again demand the use of heavy tractors with broad crawler tracks. Once cultivated, the soils should become largely self-mulching.

The problems of drainage, both internal and external, are similar to those already discussed under the normal soils of Akuse series. There is likely to be an added problem under irrigation, however, because of the wastage of water which may occur on the patches of shallow soils. It must be one of the prime functions of the Kpong Pilot Irrigation Scheme to discover if there are practical economic means of cultivating and irrigating Prampram soils, since these soils are areally important in the northern half of the Black Clays belt.

Nutrient relationships.—These soils are unlikely to differ significantly in nutrient status from the normal soils already described, and a further detailed treatment of the subject here would, therefore, seem superfluous. The major differences arise from the generally lower clay content, with consequently lower base-exchange capacity ; and from the shallowness of the profile which brings the calcareous horizon relatively nearer the surface and the zone of weathering rock, with its higher content of soluble salts, mainly sulphates, within normal rooting depth. These factors do not present insuperable difficulties to large scale irrigation farming.

Constructional properties.—As would be expected from the description given above, the Town and Country Planning Board found no significant difference in properties of Prampram soils from those of the normal soils of the series.

Variants.—Two variants of Prampram subseries have been recognized : (*a*) Gravelly ; and (*b*) Ironstone concretionary. These are described briefly below.

(*a*) *Gravelly variant.*

Soils of this variant occur in very frequent small patches amongst normal Prampram soils wherever these are found on the Pilot Area. The soils are broadly similar to the normal soils of Prampram subseries, but they are characterized by the presence in the profile of abundant quantities of medium-sized quartz pebbles. These are presumed to have formed part of a former river or marine terrace higher up the slope, and to have been washed down over the Pilot Area before or at the same time as the accumulation of the Black Clays drift.

The soils are, generally speaking, rather shallow, but occasional profiles deeper than thirty inches are encountered. Strictly speaking, the latter should be allocated to the normal soils of Akuse series. It is considered justifiable to include them within Prampram subseries, however, since the effect of the pebbles is to improve the internal drainage of the soils to a variable degree, depending on their abundance and concentration in the profile. Prampram soils were not separated from normal Akuse soils at the depth of thirty inches for arbitrary reasons, but because this depth was regarded as the minimum for the safe practice of flood-irrigation. The presence of large amounts of pebbles in the soils under discussion is considered to render them unsafe for flood irrigation, and they have accordingly been included with Prampram subseries, i.e. those soils which are unsafe for flood-irrigation, but are potentially suitable for development by furrow-irrigation.

A representative profile is described below.

Akuse (Prampram) series : gravelly variant

Profile Number :	APA 183/1-4.
Locality :	Kpong Pilot Area : traverse 5, chain 54.
Site :	Upper slope.
Vegetation :	Open medium grassland.
0—7 *inches*	Very dark greyish brown (10 YR 3/2), light sandy clay ; humous ; abundant grass roots ; frequent manganese dioxide concretions ; pH 7.1.
7—19 *inches*	Dark brown (10 YR 3/3), coarse sandy clay ; occasional manganese dioxide concretions ; abundant rounded quartz pebbles (up to 2 inches diameter) ; pH 6.8.
19—22 *inches*	Dark brown (10 YR 3/4), cloddy clay ; occasional manganese dioxide concretions ; frequent fine quartz gravel ; pH 7.9.
22—38 *inches*	Reddish brown (5 YR 4/4), coarse garnet sand (decomposed rock) ; frequent calcium carbonate concretions ; frequent fine quartz fragments ; pH 8.4.

With regard to cultivation characteristics, these soils are likely to differ from the normal soils of Prampram subseries chiefly in their greater permeability and in the fact that there will be greater wear and tear on tillage implements. After several years of cultivation it may be that the pebbles will accumulate on the surface to such an extent as to warrant their removal by women or children employed for the purpose.

(*b*) *Ironstone concretionary variant.*

These soils are confined to the summit of the ridge which crosses the southern part of the Pilot Area. They were formerly recognized as Tepanya series ; but their occurrence on the Pilot Area is so extremely limited that it has been thought more convenient for the purposes of this Report to include them merely as a variant of Prampram series.

The soils are similar morphologically to those of the gravelly variant just described, but with accumulations of small, polished, ironstone concretions in the lower half of the profile in place of the quartz pebbles. The concretions are not considered to have developed *in situ*, but to have been transported to their present site during the dissection of a former ferruginous peneplain mantle. Of significance in this respect is the occasional occurrence of well-rounded quartz pebbles in the concretionary horizon. These soils are usually less alkaline in reaction than the normal Prampram soils, and may even be slightly acid in the concretionary horizon.

A representative profile is described below.

Akuse (Prampram) series : ironstone concretionary variant

Profile Number :	APA 174/1-5.
Locality :	Kpong Pilot Area ; traverse 46, chain 3-4.
Site :	Summit of gentle undulation.
Vegetation :	Open medium grassland.
0—2 *inches*	Very dark greyish brown (10 YR 3/2), nutty light clay ; humous ; pH 6.7.
2—11 *inches*	Dark brown (10 YR 4/3), small cloddy clay ; less humous ; occasional very small, polished ironstone concretions ; pH 6.5.
11—17 *inches*	Dark brown (10 YR 4/3), plastic clay ; abundant small, polished, ironstone concretions ; occasional small quartz pebbles ; pH 6.9.
17—24 *inches*	Olive brown (2.5 YR 4/4), light clay ; abundant small brash of rock ; frequent calcium carbonate concretions ; pH 8.0.
24—32 *inches*	Small brash of little-decomposed garnetiferous hornblende gneiss ; pH 8.0.

With regard to cultivation characteristics under natural conditions these soils are little better drained internally than the normal soils of Prampram subseries ; but on cultivation, the presence of abundant amounts of the concretions may be expected to improve the permeability of the soils. The concretions themselves are insoluble.

Concerning constructional properties, these were the only soils on the Pilot Area recommended by the Town and Country Planning Board to be suitable for use as subgrade material for roads. They occur in such small amounts, however, as to be of negligible importance for this purpose. In other respects, the soils do not differ significantly from normal Akuse and Prampram soils.

BROWN SEDENTARY CLAYS

Kloyo series

These soils are dark brown, sandy light clays developed in the weathering-products of pyroxenite and garnetiferous hornblende gneiss which have remained more or less *in situ*. They normally occur on the steep, well-drained slopes of the large inselbergs such as Krobo Hill. For this reason, the soils found on the gentler slopes of the Accra plains, although essentially similar, have been distinguished as a low-level subseries and given the name Krobo.

Krobo subseries

Description of the soil.—These soils differ from the true Black Clays in that they are developed in material which has accumulated predominantly from the weathering products of garnetiferous hornblende gneiss and pyroxenite which have remained more or less *in situ*, and not in drift material. As compared with the soils of Prampram subseries which in many ways they resemble, they are usually brown rather than black in colour, lighter in texture, almost always less than twelve inches deep and do not possess a calcareous horizon.

The surface horizon, about three inches in thickness, consists of very dark brown or very dark grey, humous heavy loam or light clay. This is generally rather friable and granular in structure, and contains large quantities of sand, chiefly garnets and crystals of hornblende or augite, derived from the rock below. In reaction it is slightly acid, with pH values between 6.5 and 7.0.

Below this, there is a shallow horizon, less than nine inches thick, consisting of dark brown or dark grey, heavy loam to light clay. In shallow profiles, this horizon is usually loose ; but in slightly deeper ones, it may be rather compact and nutty. It may also contain occasional concretions containing manganese dioxide, and small, fine, angular quartz gravel. It is slightly to moderately acid in reaction, with pH values ranging between 5.8 and 6.6.

This horizon grades into the weathering bedrock. This is usually rather sandy and loose for a few inches, but hard, little-decomposed rock is usually reached within twelve to eighteen inches from the ground surface. This zone varies in reaction between different profiles, but the majority become at least slightly alkaline.

It has been observed that the garnetiferous hornblende gneiss beneath these soils is frequently permeated by bands of pyroxenite. It seems probable that these bands have increased the resistance of the rock to weathering, so that it now projects above the general level of the bedrock, and protrudes through the Black Clays drift. The steeper slopes on which it occurs have prevented the accumulation of deep soils. Interspersed about the small patches of these soils are occasional small rock outcrops.

In the single profile of this series from the Pilot Area which has been analysed, the organic matter content appears rather higher than would normally be expected, perhaps because the pit from which the samples were taken was in a relatively shaded site in savannah woodland vegetation. This profile shows 3 per cent. organic matter in the surface three inches, with 1.7 per cent. at one foot depth. Elsewhere on the Accra plains, profiles from this subseries have contained only 2 per cent. in the surface horizon and less than 1.5 per cent. at a depth of one foot.

In the superficial soil, there is usually more than 95 per cent. fine earth, with a clay content of 15 to 25 per cent. No uniformity in the proportion of fine earth or of clay content can be expected in the zone of weathered rock because of the heterogeneity on a small scale of the underlying parent rocks : in some profiles the rock has weathered to a loam or clay ; in others it is brashy and contains little fine earth.

Description of a representative profile.—

Kloyo (Krobo) series (See Fig. 3)

PROFILE NUMBER : APA 363/1-7. LOCALITY . Kpong Pilot Area : Traverse 28, Chain 38.

VEGETATION : Stunted Tall-Grass Savannah transitional to Savannah Woodland. SITE : Middle slope of gentle undulation.

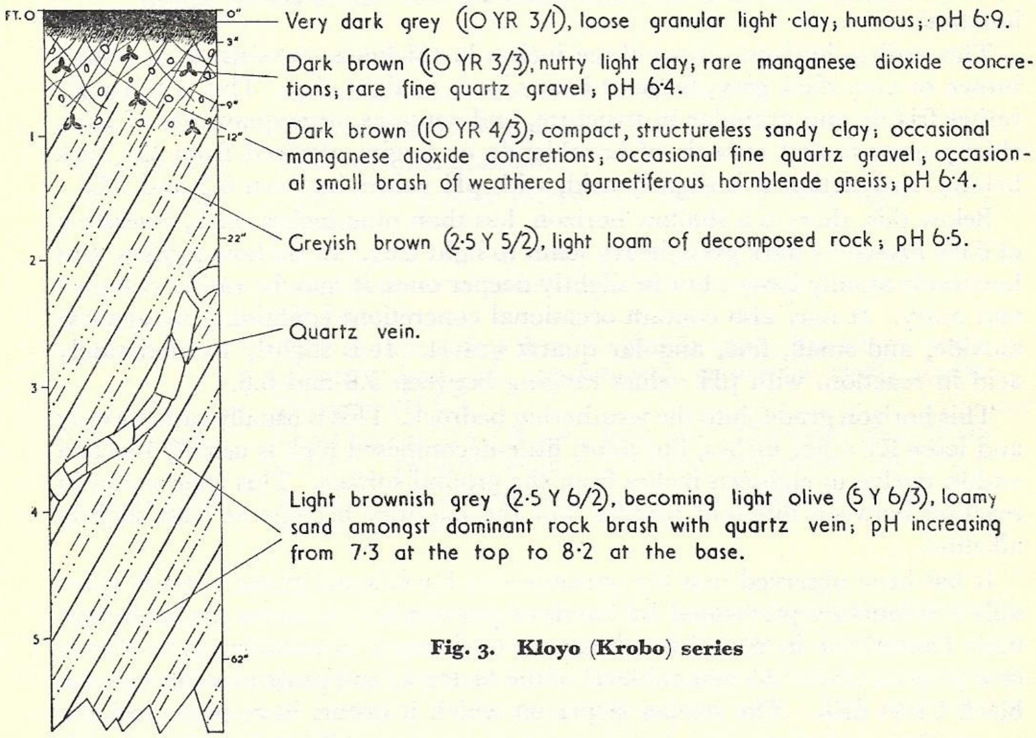


Fig. 3. Kloyo (Krobo) series

Moisture relationships.—These soils are both externally and internally well drained. Because of their shallowness, and because of the broken nature of the underlying rock, they have little power to retain moisture during the dry season.

Cultivation characteristics.—So far as the Pilot Area is concerned, the importance of these soils lies not in any virtues they may possess, but in the fact that they are shallow soils occurring within the soils of Prampram subseries which it is intended to cultivate. So far as possible, soils of Kloyo series should be avoided both for cultivation and irrigation, because of the considerable risk of damage to ploughs by striking hard bedrock, and the wastage of irrigation water, which will drain through the weathered underlying rock.

Nutrient relationships.—In the upper part of the profile the nutrient relationships are essentially similar to those in the upper part of shallow Prampram soils. Since little-weathered bedrock is usually reached at less than twelve inches from the surface, and because there is no calcareous horizon, the lower layer is less well-provided with available nutrients.

Constructional properties.—No sample of soil from this series was sent for testing by the Town and Country Planning Board. The soil's greatest value is likely to lie in the fact that relatively unweathered rock, of use for foundation material for roads and buildings, is to be found at no great depth from the surface.

GREY-BROWN CLAYS

Agawtaw series

Description of the soil.—These are grey-brown sandy clays, loamy and porous for a few inches at the surface, but with a characteristic hardpan horizon, cracking prismatically, in the subsoil, below which they become cloddy and plastic and contain calcium carbonate concretions. They are developed in material indirectly derived from the acidic Archaean gneisses which normally underlie them, below a shallow stone-line, at a moderate depth. These very interesting soils are of limited areal extent on the Pilot Area, and will consequently not be treated in detail here ; but since over the Accra plains as a whole they are second only in importance to the Black Clays, covering approximately 200 square miles, they will be more fully described in the Report on the Reconnaissance Soil Survey of the Accra Plains (in preparation).

The soils occurring on the Pilot Area are not entirely typical of the series as a whole. The major profile characteristics are identical with those of Agawtaw soils occurring elsewhere in the region ; and, in fact, beneath the pebble-bed which underlies the Pilot Area profiles, acidic Archaean gneiss, with which the soils are elsewhere invariably associated, is normally found, although this was not the case in the profile described below. But the presence of this pebble-bed, and the occurrence of the soils on low spurs a few feet above the level of the floodplain and strongly suggestive of forming river terraces, point to the strong possibility that these soils may have developed in material of alluvial origin.

The soils are normally neutral to slightly acid in reaction in the surface horizon, and moderately acid in the hardpan horizon, but then become moderately alkaline in the lower part of the profile, sometimes becoming very alkaline in the zone of weathered rock. Rather different values were obtained in the profile described below, since calcium carbonate concretions occur at an unusually shallow depth in the profile.

There is rarely more than 2.5 per cent. organic matter in the surface few inches, and often less than 2.0 per cent. The lower part of the topsoil usually contains only 1.0 to 1.5 per cent., but there is characteristically slightly more than this in the upper part of the subsoil. Lower horizons contain only negligible amounts.

Except in the horizon containing the stone-line, the profile consists almost entirely of fine earth, and the underlying rock has usually weathered to a state where it can easily be ground into fine earth, too. There is generally only

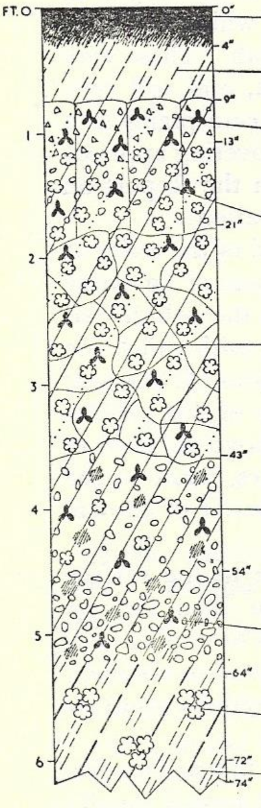
5-10 per cent. clay in the topsoil, but there is a sudden increase to around 30 per cent. in the hardpan layer, and a steady increase to around 35 per cent. in lower layers. The proportions of silt and of coarse and fine sand vary irregularly down the profile.

Description of a representative profile.—

Agawtaw series (See Fig. 4)

PROFILE NUMBER : APA 179/1-9 LOCALITY : Kpong Pilot Area : Traverse 65, Chain 64.

VEGETATION : Tall-Grass Savannah SITE : Low undulation above level of floodplain.



Greyish brown (10 YR 5/2), humous, loose light loam ; pH 6·8.

Greyish brown (10 YR 5/2), slightly loose light loam ; pH 6·4.

Brown (10 YR 5/2), compact, sandy clay, cracking into prismatic columns on drying ; frequent soft manganese dioxide concretions frequent quartz grit ; pH 6·8.

Pale olive brown, (2·5 Y 5/4), compact, sandy clay, cracking prismatically on drying ; occasional manganese dioxide concretions ; occasional fine quartz gravel ; frequent calcium carbonate concretions ; pH 8·5.

Yellowish brown (10 YR 5/4), compact, cloddy, coarse sandy clay ; occasional manganese dioxide concretions ; frequent calcium carbonate concretions ; pH 8·3.

Yellowish brown (10 YR 5/4), stained orange, compact clay ; rare manganese dioxide concretions ; frequent fine quartz gravel ; rare calcium carbonate concretions ; pH 8·4.

Pale olive brown (2·5 YR 5/4), faintly mottled orange clay with abundant small quartz pebbles ; occasional manganese dioxide concretions ; pH 8·3.

Pale olive (5 Y 6/3), sandy loam (decomposed garnetiferous hornblende gneiss) ; patches of calcium carbonate ; pH 8·4.

Little-weathered brash of garnetiferous hornblende gneiss ; pH 8·1.

Fig. 4. Agawtaw series

Moisture relationships.—The porous topsoils allow the soils to absorb a higher proportion of the rainfall they receive than can the Black Clays, but even so the amount is restricted by the impervious nature of the subsoil. Externally, the soils are seasonally poorly drained because of their situation at the edge of the floodplain.

The sandy topsoil has little power to retain moisture, and dries out very badly during the dry season. The upper part of the subsoil dries out, too, as indicated by the development of the prismatic structural units ; and, although the interior of these columns may retain moisture effectively, this is unlikely to be available to plant roots. Few roots can penetrate this horizon to the lower subsoil ; but field observations suggest that little moisture is likely to be available in these lower horizons. Stronger mottling in the pebble-bed suggests that there is more moisture available in this horizon, provided by lateral seepage rather than by vertical percolation through the profile.

Cultivation characteristics.—These soils are covered only with savannah vegetation and would require little clearing for cultivation. It is unlikely that this will be required on the Pilot Area, however, because of their limited areal extent and their situation on the edge of the Okwe floodplain, the flooding of which cannot be controlled at present. It is recommended in fact that no investigatory work designed to elaborate techniques for the large scale development of the Agawtaw soils of the Accra plains should be attempted on the Pilot Area since the soils occurring here are doubtfully representative of those occurring extensively on different topography elsewhere in the region.

Nothing is known at present about techniques for cultivating these soils : they are totally ignored by local farmers. The presence of the hardpan at a shallow depth is likely to restrict root development, and techniques for breaking up this layer will need to be worked out before cultivation of the soils on a large scale can be considered practicable. On the other hand, the subsoils are highly impervious and would seem suitable for any form of irrigation which might be required.

Nutrient relationships.—The nutrient status of Agawtaw soils is less favourable than that of the Black Clays. The organic carbon and nitrogen contents are low to very low. As in the Black Clays, the carbon/nitrogen ratios tend to be high.

Comparison of the base-exchange capacity with the clay content indicates that the clay minerals are not so predominantly montmorillonitic as in the Black Clays. Exchange capacities are low in the topsoil, but increase to around 25 m.e. in the lower layers. The adsorption complex is usually not fully satisfied in the upper part of the profile, although this is not the case in the single Pilot Area profile examined. Calcium and magnesium together account for almost the whole of the bases present except in the deeper layers near and in the zone of weathering rock where sodium may increase to provide 30 per cent. of the total. Exchangeable potash is low throughout the Pilot Area profile.

Soluble phosphorus data show that Agawtaw soils are poorly provided in this respect. There are no data for total phosphorus, but little is expected to be present.

Harmful substances.—Appreciable quantities of soluble salts occur in the lower layers of these soils. These are considered predominantly to be present as sulphates, perhaps in amounts up to 0.4 per cent. There are no indications in the vegetation anywhere on the Accra plains that undue accumulation of sodium chloride has occurred in these soils.

Constructional properties.—The Town and Country Planning Board did not regard these soils as suitable for use in road making. For building purposes the soil could be stabilized at one part of cement to sixteen parts soil. They were not regarded as suitable for the manufacture of brick, tiles, or pottery. Their impermeability, however, would make them suitable for use in constructing earth dams or bunds.

Subseries and variants.—No subseries of Agawtaw series have been recognized in the soils on the Pilot Area. Two variants, ' gravelly ' and ' shallow ', have been mapped. These merely indicate soils in which respectively the pebble-bed or bedrock is found within thirty inches of the surface. They have been recognized separately solely because of their doubtful suitability for flood irrigation, and will not be dealt with further here.

BROWN ALLUVIAL CLAYS

These are brown, somewhat mottled, badly-drained, acid clays derived from river and stream alluvia. They are found on the combined floodplain of the Okwe stream and the river Volta.

Tachem series

Description of the soil.—The soils of this series, although variable to a degree on the Pilot Area, are, typically, mid-brown to dark brown, plastic clays, acid in reaction, developed in the floodplain alluvia of the Okwe stream. They are poorly drained, both internally and externally, and are waterlogged or inundated during the rainy seasons.

At the surface there is from six to nine inches of very dark brown or dark grey, humous, crumbly clay or light clay. This contains abundant grass roots, the sides of whose channels through the soil may be ironstained.

Below, there is a medium to dark brown, sometimes faintly stained orange, compact, plastic clay, which is occasionally seen to crack prismatically. This horizon is six to nine inches in thickness, and is a transitional zone between the surface humous horizon and the horizon to be described next.

The succeeding horizon, which normally commences at a depth of twelve to eighteen inches, is very variable in thickness. In some profiles it is scarcely represented : in others, it has been recorded as being more than eight feet in thickness. In colour, this layer is greyish brown, mottled orange and yellow. It consists of a highly impervious, very compact clay, which is plastic when moist. Frequent manganese dioxide concretions are developed ; and rarely, calcium carbonate concretions, probably alluvial in origin, may be found at depth.

Below this occurs a layer of quartz pebbles, immediately overlying the bedrock. It appears probable that it is the irregular thickness of the pebble-bed which causes the variations in thickness of the soil. Sometimes the pebbles are found near the surface ; more usually they are not encountered within thirty inches from the surface, and occasionally, not within nine feet. The pebbles are contained in a matrix of plastic clay, and do not appear to affect the drainage of the soil. Rock has only been encountered rarely : in every case is was hornblende gneiss, well-weathered, and sometimes containing abundant calcium carbonate.

The profile above the stone-line may contain coarse sand, fine quartz gravel and small, hard, polished, ironstone concretions in small quantities, but because of the highly plastic nature of the clay—in part, at least, montmorillonitic—these have no influence on the constitution of the soil.

In reaction, the soils are normally only slightly acid in the surface horizon, with pH values around 6.5, but usually become very acid below with pH values of 5.0 to 5.5. Some profiles on the Pilot Area, however, are atypical in that they become neutral to alkaline with depth, with some showing an accumulation of calcium carbonate in the weathered rock zone.

Despite their position on the floodplain, the soils do not appear to have accumulated large amounts of organic matter, although that present has been dispersed through a greater depth of the profile than is the case in most soils. The topsoils appear generally to have 3-4 per cent. organic matter ; and thereafter the amount decreases gradually with depth to 1.5-2.0 per cent. at eighteen inches, and more than 1.0 per cent. still at thirty inches.

Above the stone-line, gross mechanical analyses of the soils rarely show less than 99 per cent. fine earth. The clay content of this fine earth is normally 40-50 per cent. in the topsoil, and 60-70 per cent. below, with fine sand accounting for the greater part of the remainder ; but profiles showing rather lower clay contents, especially in the topsoil, can be expected to occur locally on the Pilot Area.

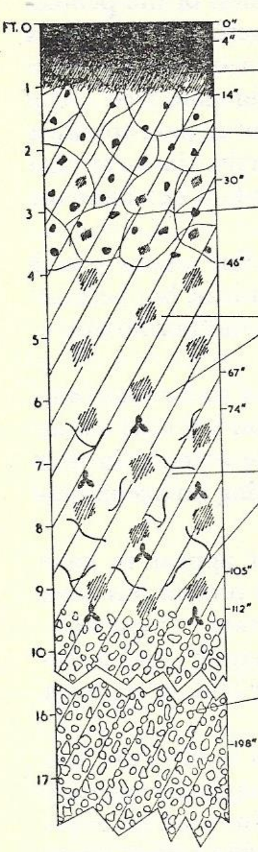
Description of representative profiles.—The single pit dug in soils of Tachem series on the Pilot Area did not reveal a profile typical of the series as a whole.* A more representative profile from elsewhere on the Accra plains (from the floodplain of the Jawpa stream, near Gigiduku) is therefore described instead.

Tachem series (See Fig. 5)

* Many of the soils mapped as Tachem series on the Pilot Area were separated during the Reconnaissance Soil Survey of the Accra Plains and recognized as Okwe series. These alluvial soils are similar to Tachem series in the upper part of the profile but below are less strongly mottled and may become calcareous. Locally, topsoils are loamy and porous as a result of the recent deposition of silty alluvium. A typical profile consists of six inches or so of dark grey, humous, friable to nutty light clay to clay, underlain by several feet of dull brown, cloddy, plastic clay faintly mottled orange or yellow below approximately eighteen inches and with calcareous concretions becoming apparent at depths between eighteen inches and five feet ; a pebble-bed underlies the profile. Representative analytical data are given under profile APA 175 below (Tables G and J).

PROFILE NUMBER : APA 107/1-9 LOCALITY Strip 23/40. (Preliminary Survey of the Accra Plains).

VEGETATION : Floodplain Savannah. SITE Floodplain



Dark greyish brown (2·5 Y 4/2), humous cloddy clay; pH 5·6

Dark greyish brown (2·5 Y 4/2), less humous cloddy clay; pH 5·6.

Dark brown (10 YR 4/3), cloddy clay; rare small, soft, orange ironstone concretions; pH 5·6

Brown (10 YR 5/3), stained red, cloddy clay; rare small, soft, orange ironstone concretions; pH 5·9

Grey, red and orange, strongly mottled, plastic clay; pH 5·1 - 5·2

Grey, yellow and orange mottled, plastic clay; ironstained old root channels; rare, soft manganese dioxide concretions; pH 6·3 - 6·6

Yellowish brown (10 YR 5/4), plastic clay with very abundant small, rounded and sub-angular quartz stones; pH 7·6.

Fig. 5. Tachem series

Moisture relationships.—The soils are poorly drained both internally and externally. They tend to be waterlogged during the rainy seasons, and they are liable to be inundated to a depth of up to three feet whenever the Okwe stream floods. This probably only occurs, as was suggested in Part I above (p. 16), during the second rainy season. The soils, except where shallow, should retain water well during the dry season.

Cultivation characteristics.—These soils in themselves offer no physical obstacle to mechanical cultivation. They are covered at present with floodplain savannah with thicket in various parts, which does not present insuperable difficulties to clearing. Several gullies and old channels of the Okwe would require to be filled in, unless they could be utilized as natural field drainage channels. Areas of shallow soils are rare and localized, so that there would be little danger in the initial ploughing, so long as 'bush ploughs' were used to deal with tree roots. The clays themselves are compact, and would demand the use of heavy tractors in ploughing. They show no signs of forming a hard crust on drying, and they are probably, to a certain degree, self-mulching. Post-preparatory tillage for weed control would not therefore be difficult.

The soils could only be used for cultivation, however, if the flooding of the Okwe and the surface runoff from the Black Clays soils on the slopes to the south could be controlled. Since this control cannot be exercised, it is not proposed to experiment with the cultivation of these soils on the Pilot Area. With adequate control of floodwater and runoff these soils could be utilized for rice production by flood-irrigation ; but it would be necessary considerably to improve the internal drainage by a system of closely spaced deep channels if other crops were to be grown.

Nutrient relationships.—These soils have a considerably better nutrient status than the majority of Gold Coast alluvial soils since they are largely derived, not from the erosion of ironpan or of soils long ago leached of all their minerals except quartz, iron and alumina, but from the Black Clays which contain valuable unweathered minerals and are rich in soluble bases.

The soils are fairly well provided with organic matter, with rather more than 2 per cent. organic carbon in the topmost few inches, the amount decreasing only slowly with depth so that at twelve inches there is around 1.5 per cent., at thirty inches slightly less than 1.0 per cent., and at sixty inches approximately 0.4 per cent. The nitrogen content is moderate to low, although again, well distributed down the profile. Carbon/nitrogen ratios are fairly high at 13-14 : 1 near the surface, but decrease to 10-11 : 1 at a depth of two feet.

The correlation of exchange capacity with clay content indicates that the clay is predominantly, although not entirely, montmorillonitic. With clay contents of 40-50 per cent. near the surface increasing to 60-70 per cent. at depth, exchange capacities correspondingly increase from around 30 to 40-45 m.e./100 gms. The adsorption complex is not completely saturated since the soils are very acid in reaction below the surface horizon. Nevertheless, there are still 15-20 m.e. calcium present throughout the profile, as well as 10-15 m.e. magnesium near the surface and 15-20 m.e. below thirty inches. Potash status appears to be satisfactory, with 0.5 m.e. or more in horizons down to 18 inches. There are negligible amounts of sodium in the surface horizons, but 2-3 m.e. below approximately five feet.

Only small amounts of soluble phosphorus, decreasing rapidly with depth, are found, and the total phosphorus reserve can only be expected to be low.

Harmful substances.—Appreciable quantities of soluble salts occur in the lower horizons of Tachem soils, but these appear predominantly to be present as sulphates, and no difficulties due to salinization are anticipated if ever the soils are brought under cultivation.

Constructional properties.—The Town and Country Planning Board reported adversely on the possibility of using Tachem soils as subgrade road material.

For building purposes, the soil could be stabilized at a ratio of sixteen parts soil to one part cement. The linear shrinkage test designed to discover the value of the soil for brick, tile or pottery manufacture, resulted in an arch formation instead of breaking or showing the usual shrinkage, but there was thought to be no harm in trying them for the purpose suggested.

*Subseries and variants.**—No subseries of Tachem series have been recognized. Two variants, ' shallow ' and ' gravelly ', have been mapped. These merely indicate soils in which bedrock or the pebble-bed is found within thirty inches of the surface. They have been distinguished solely because of their unsuitability for flood-irrigation, and will not be discussed further here.

Towards the outer edge of the floodplain, there is a transitional belt where the Okwe alluvium has been covered with slopewash from the Black Clays on the slopes above. The soils of this belt have been sufficiently described under Akuse series, except that in those soils allocated to Tachem series the superficial black clay is less than eighteen inches in thickness. These soils do not differ significantly in any of their major properties or potentialities from the normal soils of Tachem series.

Amo series

Description of the soil.—These soils are developed in fine-textured alluvial deposits of the river Volta. They differ from the soils of Tachem series in their more yellowish colour and their silty rather than plastic nature. They are subject to seasonal waterlogging and occasional flooding, but appear to dry out very thoroughly during the dry seasons. On the Pilot Area the soils are not everywhere typically developed because of the intermixture of varying amounts of more highly plastic Okwe alluvial clay with the Volta alluvium ; and, on the higher sites at least, which are possibly only rarely, if ever, flooded today, because of the less strongly acidic reaction of the lower horizons.

At the surface, there are from three to six inches of dark grey to dark brown, humous, porous, very fine sandy to silty loam or light clay, which becomes rather loose when dry. This horizon is normally slightly acid to neutral in reaction ; but one profile sampled on the Pilot Area was moderately acid in this horizon, with a pH value of 5.6.

There follow twelve inches or more of yellowish brown or orange-brown, rather compact, very fine sandy or silty clay, sometimes on the Pilot Area showing a tendency towards the development of prismatic structure on drying. This horizon is usually moderately acid in reaction, with pH values between 5.5 and 6.0.

Below this, there is a great depth of grey, yellow, orange and red mottled, structureless, very fine sandy or silty clay. Ideally, the reaction in this lower layer should be very acid throughout, with pH values of 5.0 to 5.5 ; but on the Pilot Area, the profiles sampled have shown a tendency for conditions to become less acidic or even slightly alkaline below a depth of five feet.

Bedrock has not been reached in any pits dug in the normal soils ; but there

*See footnote, page 47.

is evidence, outside the Pilot Area, that the pebble-bed which underlies the Okwe alluvia is continuous beneath the Volta sediments too.

On the Pilot Area, these soils appear to have a moderate organic matter content, with around 3 per cent. in the surface six inches, less than 2 per cent. at twelve inches, and around 1 per cent. at eighteen inches to two feet.

Gross mechanical analyses show the soils to consist entirely of fine earth. In profile APA 173, clay amounted to 36 per cent. in the topsoil, almost 60 per cent. in the succeeding horizon and thereafter, to four feet, around 70 per cent. Silt amounted to 34 per cent. in the topsoil, and around 20 per cent. in lower horizons. Fine sand throughout the profile accounted for almost the whole of the remainder, coarse sand nowhere amounting to more than 1 per cent.

Description of a representative profile.—

Amo series (See Fig. 6).

PROFILE NUMBER : APA 173/1-7 LOCALITY : Kpong Pilot Area : Traverse 16, Chain 56.
VEGETATION · Floodplain Savannah. SITE : Floodplain

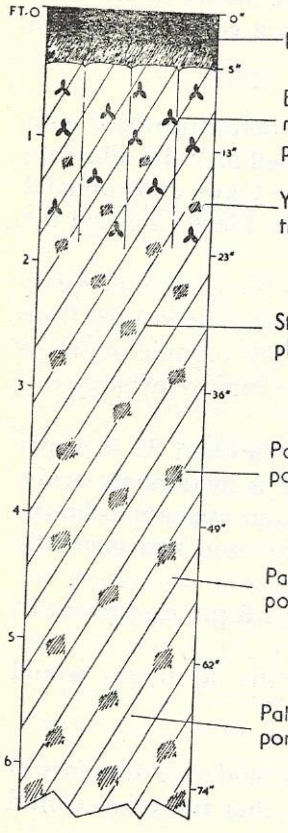


Fig. 6. Amo series

Moisture relationships.—The soils tend to be waterlogged during the rainy seasons, and are inundated for a time during the second rainy season if the Volta floods. Except where mixed with appreciable quantities of Okwe alluvium, it appears that they do not retain water well during the dry seasons, but dry out deeply and become very compact.

Cultivation characteristics.—Clearing should present no difficulty on these soils since there are few trees, except along the immediate stream bank. There are no rock outcrops or areas of shallow soils. A few gullies might require to be filled in, unless they could be utilized as field drains. Initial ploughing should not be difficult since the soil is generally light in texture near the surface, but ' bush ploughs ' would be required to deal with the roots of the few trees which occur. Later, ploughing and weed control should not be difficult, for the soil shows no signs of baking hard on drying.

If the soils were to be cultivated, it would be necessary to improve the internal drainage. It is not proposed to cultivate the soils on the Pilot Area, however, because surface drainage, from the Okwe, the Volta and slopes above, cannot be controlled.

This is one of the few alluvial clay soils utilized by Gold Coast farmers, because it is sufficiently light-textured to be cultivated with the hoe. The soils are intensively cultivated from the Volta gorge down to the mouth of the river, mainly for the production of cassava and maize ; but only a very minor patch has been cultivated on the Pilot Area.

Nutrient relationships.—On the Pilot Area, Amo soils are better provided with nutrients than would normally be expected of soils developed in Volta alluvium because of the admixture of Black Clays alluvium from the Okwe and colluvial wash and base-rich drainage water coming down from the Black Clays on the adjoining slopes.

Analytical data for APA 173 (Tables G and J) show that the soil is moderately well provided with organic matter, and carbon/nitrogen ratios decreasing from 12 to 8 with depth indicate that it is well decomposed. The organic matter is only an ephemeral constituent of the soil, and would be rapidly exhausted if the soils were cultivated.

However, the soil has a moderate exchange capacity (around 35 m.e. per cent. clay), and although the greater part of the profile is moderately acidic in reaction, it is still well provided with bases. Magnesium appears to be the dominant base, but potash at 0.8 m.e. in the surface horizon and generally around 0.4 m.e. below is present in satisfactory amounts.

The soil is deficient in soluble phosphorus, with only 2.6 p.p.m. present in the humous topsoil and 0.5 p.p.m. in the third horizon.

For continuous cropping, nitrogenous and phosphatic fertilizers would require to be added.

Harmful substances.—Soluble salts are likely to occur in moderate amounts in the lower horizon but there is nowhere any indication that irrigation would introduce difficulties due to salinization of the soils.

Constructional properties.—For all constructional purposes, the Town and Country Planning Board reported, soils of Amo series had similar properties to soils of Tachem series. It is, however, worth while adding that Amo clay is the one used locally for pottery-making. It is considered most suitable when obtained from near the Okwe stream, where there has been intermixture of Volta and Okwe alluvia.

Subseries and variants.—Although the content of Okwe alluvium in the parent material of the soils on the Pilot Area varies from place to place, giving rise to differences of consistency, internal drainage, and presumably nutrient relationships, too, it has not been found possible to map these variants. A small, detached area of Volta alluvium in the extreme south-east corner of the Pilot Area, however, contained appreciable quantities of calcium carbonate concretions almost to the surface, and weathered garnetiferous hornblende gneiss was encountered at a depth of three feet. This is thought possibly to be an eroded, shallow phase of a former Amo soil. Because of its relative insignificance on the Pilot Area it has not been fully investigated, and has merely been mapped for convenience as a calcareous concretionary variant of Amo series. It is not proposed to discuss the soils further here since they are not likely to be required for cultivation.

SOIL RELATIONSHIPS AND AFFINITIES

Local relationships

The classification of the soils of the Kpong Pilot Area used in this report is a purely local one, based more on lithology than on strictly pedological characteristics. A more formal classification has been attempted in compiling the Report on the Reconnaissance Soil Survey of the Accra Plains, to which reference can be made in due course if desired.

On the scale of the Reconnaissance Survey it has not been possible to map individual soil series but only topographical associations. The soils of the Pilot Area will be found grouped into the following associations :—

Akuse Consociation, consisting predominantly of Akuse series, but including relatively minor amounts of Kloyo series (Krobo subseries), Tepanya series (recognized on the Pilot Area merely as an ironstone concretionary variant of Prampram subseries), and other soils developed in various ways in the weathering products of the garnetiferous hornblende gneiss but not represented on the Pilot Area.

Korle-Okwe Complex, consisting of minor amounts of Agawtaw series amongst several other soils, not represented on the Pilot Area, developed in an area of complicated geology.

Tachem-Okwe Complex, consisting of Tachem series and other soils, not represented on the Pilot Area, occurring in the poorly-drained areas along the lower course of the Okwe stream.

Amo-Tefle Compound Association, consisting of Amo series and other soils, not represented on the Pilot Area, developed in Volta alluvia.

Since the Kpong Pilot Irrigation Scheme is designed specifically to discover the techniques of mechanized irrigation agriculture on the Black Clays, it is not proposed here to discuss the relationships of Agawtaw, Tachem and Amo soils to similar soils occurring elsewhere on the Accra plains. Sufficient let it be to state that the Tachem and Amo soils and their variants on the Pilot Area can be considered representative of those occurring in other places, but that this is doubtfully the case with the Agawtaw soils.

The interrelationships of the component soils of Akuse Consociation which occur on the Pilot Area have already been indicated in the individual soil descriptions. To recapitulate, the soils of the association are developed in the weathering products of a metamorphosed basic rock, garnetiferous hornblende gneiss.

In the case of Kloyo series, these weathering products have remained more or less *in situ*. The soils are shallow, and typically occur on the steep slopes of the inselbergs which project from the general level of the Accra plains ; but they occur locally, as on the Pilot Area, on the plains themselves, where they are associated with relatively steeper slopes of three per cent. or more and often with small rock outcrops.

The soils of Akuse series are developed in the locally-transported weathering-products of the parent rock which have accumulated on the more gentle slopes of the plains. The shallower Prampram soils generally occur on slopes of two to four per cent., whilst the deeper, normal, soils are generally found on slopes of less than two per cent.

Kloyo soils are well-drained externally, and moderately well-drained internally. Calcium carbonate, if present, is confined to the zone of weathered rock. Akuse soils are well-drained externally, although they may be covered with sheetflood during actual rainfall ; but internally they are poorly-drained, which has led to the accumulation of calcium carbonate, in concretionary form, in the lower part of the profile.

The soils of Kloyo series cannot be regarded as suitable for irrigation because of their shallowness and the difficulties introduced in designing field layout on the relatively steeper slopes on which they occur. The normal soils of Akuse series are regarded as entirely suitable for development either by flood- or furrow-irrigation ; but Prampram soils are not considered suitable for flood-irrigation because of the possible loss of water through the weathered rock where this occurs within thirty inches of the surface. They should prove suitable for development by furrow-irrigation, however, provided they are not too badly interrupted by occurrences of Kloyo soils and small rock outcrops.

The purpose of the Pilot Scheme, as already stated, is to learn the techniques of handling Black Clays soils under mechanized irrigation agriculture, before launching a more comprehensive scheme for the development of the large area of these soils which occurs on the Accra plains. It is important to consider here, therefore, how far the Pilot Area is representative of the remainder of the Black Clays belt.

The soils of Akuse Consociation cover approximately 300 square miles of the Accra plains. This is the area which has been referred to in this report as the Black Clays belt. This belt can be subdivided into three regional types, as follows :—

Type 1. Regions in which the normal soils of Akuse series are predominant, and in which soils of Prampram subseries and Kloyo series are rare. These conditions prevail in the southern half of the belt, roughly to the south of latitude 6° 00′ N.

Type 2. Regions in which Akuse (normal), Akuse (Prampram) and Kloyo (Krobo) soils, together with small rock outcrops, are intimately associated. This complexity occurs in the northern half of the Black Clays belt and in a smaller area between the Shai Hills and Dawhwenya (Milepost 25 on the Accra-Ada road).

Type 3. The steep, rocky inselbergs, such as Krobo Hill, Ningo (Osudoku) Hill, the Shai Hills and numerous smaller hills, on which soils of Kloyo series and large rock outcrops occur.

This distribution is shown on Map 2 which has been compiled from information collected during the Reconnaissance Soil Survey of the Accra Plains. It must be made clear that this map is rather generalized, and should be regarded as no more than a sketch map.

The Pilot Area lies at the extreme northern end of the Black Clays belt. It is representative, as an area, of the distribution pattern of soils, slopes, rainfall, and vegetation which are found in the northern half of the belt (Type 2, above). It is less representative in these respects of the southern half of the belt, where the soils are almost uniformly of Akuse (normal) series, where the slopes are more regular and less steep, where the rainfall is lower and more erratic, and where the savannah vegetation contains fewer trees and coppice shoots.

However, so far as individual soils are concerned, the Pilot Area can be regarded as entirely representative of all parts of the Black Clays belt likely to be cultivated, the differences of total rainfall between the north and south being of little importance, since, in any case, irrigation water will be required throughout the belt. Prampram and Akuse soils occur on characteristically different degrees of slope, and information required for the development of these individual soils elsewhere on the Accra plains can satisfactorily be collected on the Pilot Area.

World relationships

Soils comparable to the Black Clays of the Accra plains occur in India (the 'regur' or 'black cotton soil' of the Deccan), Australia (Darling Downs of Queensland and Liverpool Plains of New South Wales), and South Africa (Springbok Flats, Transvaal). They have all developed from basic igneous rocks on low relief under a tropical climate showing a marked seasonal distribution of rainfall, and are collectively known as Tropical and Sub-Tropical Black Clays (13). The Black Tirs of Morocco are closely related soils.

Brief comparison of the Accra plains Black Clays with the South African Black Clays

In order that the local soils could be critically compared with Black Clays elsewhere which are known to be successfully cultivated with the aid of irrigation, two profiles similar to the Hartebeestpoort and Crecy profiles described by van der Merwe (16) have been obtained from South Africa and analysed alongside the Accra plains soils.* The Hartebeestpoort profile compares very closely with Akuse soils, and is described below ; the Crecy soil is more closely comparable with lower-slope soils identified on the Accra plains as Bumbi series.

Description of South African Black Clays profile

Profile Number :	OS 1/1-5.
Locality :	Losperfontein Farm, Brits District, South Africa.
Site :	Very gentle slope of rolling ridge.
Vegetation :	Grass.
0—9 *inches*	Black (10 YR 2/1), slightly humous, compact, nutty clay with rare fine quartz gravel and abundant grass roots ; cracks slightly on drying ; pH 7.7.
9—25 *inches*	Black (10 YR 2/1), large-cloddy, compact clay with rare calcium carbonate stains and occasional grass roots ; pronounced cracks on drying ; pH 7.8.
25—40 *inches*	Black (2.5 Y 2/0), large-cloddy, compact clay with rare, minute, calcium carbonate concretions and rare grass roots ; cracks fading out with depth ; pH 7.8.
40—43 *inches*	Very dark grey (2.5 Y 3/0), heavy and tenacious clay with frequent calcium carbonate concretions and very rare grass roots ; pH 7.8.
43—50 *inches*	Very dark grey (2.5 Y 3/0), clayey decomposing norite with abundant calcium carbonate concretions ; pH 8.3.

(This profile was taken some ten yards from the spot where the Hartebeestpoort profile, described in van der Merwe's " Soil Groups and Sub-Groups of South Africa," p. 75, was taken.)

From visual inspection of the South African Black Clays profiles and from van der Merwe's description of these soils (16), it is obvious that there are no significant differences in physical properties between these soils and those occurring on the Accra plains. Laboratory analyses, too, do not reveal any significant differences in nutrient status between the soils. Since the South African soils have been developed by large scale, mechanized, irrigation agriculture, therefore, there is every reason to be optimistic that, granted efficient organization, similar methods should succeed on the Black Clays of the Accra plains.

* Due to an unfortunate error in selecting a profile from the Indian regur, the profile obtained from this source turned out to be less closely comparable with the local soils.

The content of organic matter in the Hartebeestpoort profile, whilst no higher in the surface horizon than in some Accra plains Black Clays, is relatively higher in lower horizons, 1.0 per cent. organic carbon still being recorded at 40 inches, an amount which is several times the quantity normally found at this depth in the local soils. The nitrogen content, below the surface horizon, is rather higher, too. Carbon/nitrogen ratios differ from those experienced in the Accra plains soils since they increase considerably with depth, from around 11 : 1 in the surface horizon to around 16 : 1 at 40 inches.

The clay content, at 50-60 per cent., is higher by about 10 per cent. than that normally found locally, and exchange capacities at 60-70 m.e./100 gms. soil are higher by approximately 20 m.e. throughout the profile. Calcium and magnesium together similarly dominate the adsorption complex, although the ratio between them varies considerably more from profile to profile in the South African Black Clays than in those from the Accra plains : in the Hartebeestpoort profile the calcium/magnesium ratio decreases from 9 : 1 at the surface to 5 : 1 in the lowest soil horizon ; but, according to van der Merwe's descriptions (17), profiles occur in which magnesium dominates the exchange complex, a condition unknown on the Accra plains. There is appreciably more exchangeable potassium than in the Accra plains soils, but less sodium.

ANALYTICAL TABLES

Analytical methods used

In the tabulated analytical data given below results have been determined by the following methods :—

Colour.—By comparison of the fine earth sample ((*a*) air-dry ; (*b*) at plastic limit) against Munsell Soil Colour Charts (1949).

Gross mechanical analysis.—Piper (18).

Mechanical analysis of the fine earth.—Piper (19).

Calcium carbonate.—Scheibler-Passon.

Moisture constants.—(*a*) Hygroscopic moisture of the air-dry sample.
(*b*) Ignition loss corrected by deduction of organic matter and CO_2 ($CaCO_3$ per cent. $\times$ 0.44).

Organic matter.— (*a*) Carbon : Walkley-Black (20).
(*b*) Organic matter : Organic carbon $\times$ 1.72.
(*c*) Nitrogen : Kjeldahl.

pH.—Glass electrode.

Base exchange.—Peech *et al.* (21).

Soluble phosphorus.—Truog (22). (No determinations made on samples containing more than 0.01 per cent. $CaCO_3$).

Explanation of terms used in the tables

(By A. S. de Endredy, Soil Analyst)

Colour.—In the first column the colour of the air-dry soil is given, while in the second column the colour of soil is shown after mixing the sample with an amount of water equivalent to the moisture content at the plastic limit (see below).

Stones.—Particles retained by a 20 mm. ($\frac{3}{4}$-inch) sieve.

Coarse gravel.—Particles passing the 20 mm. sieve, but retained by the 6.25 mm. sieve.

Fine gravel.—Particles passing the 6.25 mm. sieve, but retained by the 2 mm. sieve.

Fine earth.—The part of the total soil passing the 2 mm. sieve. This fraction is used for any further analysis ; therefore when calculating, e.g. amounts of nutrients in the natural (total) soil, it must be borne in mind that the fine earth may represent only a fraction of the natural (total) soil, depending upon the quantity of coarser particles.

Very coarse sand.—Particles of the size 2.0-0.625 mm.

Coarse sand.—Particles of 0.625-0.2 mm. size.

Fine sand.—Particles of 0.2-0.02 mm. size.

Silt.—Particles of 0.02-0.002 mm. size.

Clay.—Particles of less than 0.002 mm. (= 2 micron) diameter.

$CaCO_3$.—Calcium carbonate.

Loss on solution.—The amount of mineral and organic matter going into solution upon treatment for mechanical analysis and not included in the previous fractions from very coarse sand to calcium carbonate. It includes the whole of the soil organic matter and some aluminium and iron hydroxide, plus the manganese peroxide present in the soil. Earlier it was assumed that the mineral part of the loss on solution originated mostly from the clay and it was customary to add it to the clay fraction, after deducting the organic matter. However, at present it is considered that coatings of aluminium and iron hydroxide on coarser particles are the most likely main sources of the mineral ' loss on solution ' and thus it is tabulated separately. Naturally, the exchangeable bases are also included in the loss on solution, but their amount rarely exceeds one per cent. Where $CaCO_3$ is present, it has been deducted from the loss on solution.

Total.—The sum of all fractions from very coarse sand to clay and of $CaCO_3$ and ' loss on solution '. When a mechanical analysis is correct this total must be within the limits 98 to 102 per cent. The upper limit may be exceeded in strongly calcareous soils by a few tenths of one per cent.

C.—The amount of organic carbon present in the soil, determined by the wet combustion method.

N.—The nitrogen content of the soil determined by the Kjeldahl method.

C/N.—The carbon/nitrogen ratio, obtained by dividing the percentage carbon present by the percentage nitrogen present.

Organic matter.—It is customary to convert organic carbon to organic matter by multiplying the amount of the former by 1.72, corresponding to a carbon content of 57 per cent. of the soil organic matter.

Reaction.—The pH was determined by the glass electrode in a 1 : 1 soil to water paste.

Cation exchange capacity.—This expresses the total amount of cations (bases) which a given soil can retain in such a form that these cations can later be released upon action of a salt solution. Under natural conditions the carbon dioxide dissolved in the soil water can act as a releasing agent. The results are expressed in milliequivalents per 100 gms. soil.

Total exchangeable bases (cations).—The sum of the individual cations subsequently listed. This figure should theoretically be identical with, or smaller than, the cation exchange capacity, but unavoidable analytical errors and other factors not yet investigated may cause positive differences of several milliequivalents.

Exchangeable calcium (Ca), magnesium (Mg), manganese (Mn), potassium (K) and sodium (Na).—These represent the amount of bases present in the soil in a form accessible to plants.

$NaHCO_3$, $NaCl$ *and* Na_2SO_4.—The amount of sodium bicarbonate, sodium chloride and sodium sulphate present in the soil.

Acid-soluble P.—The amount of phosphate expressed in terms of elemental P dissolved by treating the soil with a sulphuric acid solution having a pH of 3.0. The figures indicate only the relative abundance of soluble P and for full utilization they must be correlated with field experiments or other production data.

ND.—No data.

Profile No. and Series	Horizon Depth in Inches	Colour (Munsell)		Total Soil, Per Cent.				Oven-Dry Fine Earth, Per Cent.							
		Air-Dry	Wet (Plastic Limit)	Stones	Coarse Gravel	Fine Gravel	Fine Earth <2mm.	Very Coarse Sand	Coarse Sand	Fine Sand	Silt	Clay	$CaCO_3$	Loss on Solution	Total
APA 368	0 — 6	2.5 Y 3/2	5 Y 2/2	Nil	Nil	Nil	100.0	2.7	12.8	23.6	8.5	47.6	0.09	5.5	100.79
Akuse	6 — 18	5 Y 5/2	5 Y 3/1	Nil	0.1	0.2	99.7	4.9	6.7	24.3	7.8	52.5	0.11	5.2	101.51
(*normal*)	18 — 32	5 Y 5/2	5 Y 3/1	Nil	2.0	2.2	95.8	3.9	12.7	17.8	7.7	49.9	3.5	5.3	100.8
	32 — 42	5 Y 6/3	5 Y 4/1	Nil	0.6	0.6	98.8	7.7	4.2	14.5	7.7	51.4	17.1	Nil	102.6
	42 — 66	5 Y 6/3	2.5 Y 4/2	Nil	12.0	0.5	87.5	3.7	5.3	9.5	4.5	34.4	41.9	3.6	102.9
	66 — 88	5 Y 7/2	5 Y 5/2	11.7	7.1	1.1	80.1	9.0	18.2	26.8	8.9	19.5	15.9	2.1	100.4
APA 370	0 — 5½	10 YR 4/1	5 Y 2/1	Nil	Nil	Nil	100.0	2.6	18.0	38.9	7.3	32.2	0.05	1.6	100.65
	5½ — 15	10 YR 4/1	5 Y 2/2	Nil	0.1	0.4	99.5	8.6	14.4	29.5	7.0	36.8	0.09	4.7	101.09
Akuse	15 — 24	10 YR 5/1	5 Y 3/1	Nil	0.5	3.5	96.0	2.4	9.4	32.5	8.9	42.0	2.2	4.2	101.6
(*normal*)	24 — 30	10 YR 5/1	5 Y 3/1	2.4	1.0	3.8	92.8	2.3	6.4	28.4	9.0	46.1	5.0	4.0	101.2
	30 — 41	10 YR 5/2	5 Y 4/1	30.6	18.9	3.5	47.0	4.3	5.5	18.8	7.6	39.7	18.8	7.1	101.8
	41 — 48	2.5 Y 5/2	5 Y 4/2	1.7	12.4	2.8	83.1	4.7	7.1	23.5	10.6	40.9	12.1	2.2	101.1
	48 — 57	2.5 Y 5/2	5 Y 4/2	Nil	1.1	0.8	98.1	3.8	17.5	36.7	11.0	27.2	2.0	2.6	100.8
	57 — 72	2.5 Y 5/2	5 Y 4/2	16.1	1.4	0.5	82.0	3.4	21.8	47.8	10.4	13.8	0.65	2.5	100.35
APA 180	0 — 3	2.5 Y 5/2	10 YR 2/1	Nil	Nil	Nil	100.0	0.9	16.5	29.6	12.0	34.4	0.08	7.9	101.38
	3 — 10	2.5 Y 4/2	10 YR 2/1	Nil	Nil	0.1	99.9	1.4	15.8	26.4	10.0	40.8	0.14	6.9	101.44
Akuse	10 — 21	2.5 Y 4/2	10 YR 3/1	Nil	Nil	0.1	99.9	1.8	16.5	28.6	8.3	41.8	0.07	4.7	101.77
(*transitional*	21 — 30	10 YR 4/2	10 YR 3/1	Nil	Nil	0.1	99.9	2.1	17.2	30.5	7.6	40.8	0.05	2.9	101.15
variant)	30 — 39	10 YR 4/2	10 YR 4/1	Nil	Nil	0.1	99.9	2.5	19.9	31.1	6.2	37.7	0.02	3.4	100.82
	39 — 59	10 YR 5/4	10 YR 4/2	Nil	Nil	0.1	99.9	2.6	22.0	32.5	4.8	33.4	0.09	4.7	100.09
	59 — 65	10 YR 6/4	10 YR 5/4	Nil	0.2	0.5	99.3	4.3	23.4	33.5	4.5	31.7	0.24	2.1	99.74
	65 — 74	10 YR 6/4	10 YR 5/4	Nil	0.3	0.5	99.2	3.1	23.0	34.0	4.7	32.7	0.54	2.2	100.24
APA 369	0 — 4	10 YR 3/2	10 YR 3/1	Nil	Nil	Nil	100.0	0.4	19.2	59.6	3.3	15.3	0.05	2.2	100.0
	4 — 11	10 YR 4/2	10 YR 3/2	1.4	1.8	0.9	95.9	4.6	16.7	49.4	3.5	22.3	0.04	2.0	98.5
Akuse	11 — 17	2.5 Y 5/2	5 Y 4/2	Nil	0.4	1.0	98.6	0.9	14.7	47.1	4.3	28.0	1.6	3.6	100.7
(*Prampram*)	17 — 24	5 Y 5/2	5 Y 4/2	Nil	0.5	0.8	97.7	1.9	15.7	46.2	4.9	24.4	2.4	7.1	101.4
	24 — 66	5 Y 6/3	5 Y 4/2	Nil	Nil	0.1	99.9	7.2	46.9	38.2	1.8	3.3	0.09	3.3	100.7

Table E. Colour and particle-size distribution.

Profile No. and Series	Horizon Depth in Inches	Colour (Munsell)		Total Soil, Per Cent.				Oven-Dry Fine Earth, Per Cent.							
		Air-Dry	Wet (Plastic Limit)	Stones	Coarse Gravel	Fine Gravel	Fine Earth <2mm.	Very Coarse Sand	Coarse Sand	Fine Sand	Silt	Clay	$CaCO_3$	Loss on Solution	Total
APA 183	0 — 7	10 YR 3/2	10 YR 3/1	Nil	0.2	0.1	99.7	2.22	13.74	55.06	4.13	18.34	Nil	6.78	100.27
Akuse (*Prampram : gravelly variant*)	7 — 18	10 YR 3/2	10 YR 3/1	44.8	34.4	1.8	19.0	3.15	14.10	55.06	4.39	17.82	0.03	6.21	100.76
	18 — 22	10 YR 4/3	10 YR 3/3	0.7	2.7	2.1	94.5	6.50	22.13	44.56	4.00	17.93	0.31	6.05	101.48
	22 — 38	10 YR 5/3	10 YR 4/2	0.6	13.3	3.6	82.5	3.26	9.16	43.12	4.66	15.22	16.51	7.78	99.71
	38 — 42	2.5 Y 5/2	2.5 Y 4/2	83.2	2.0	3.6	11.2	25.38	30.88	34.25	1.66	2.31	2.85	3.53	100.86
APA 174	0 — 2	10 YR 3/2	10 YR 3/1	Nil	0.2	0.5	99.3	5.4	18.1	34.4	6.0	30.2	0.03	6.9	101.03
Akuse (*Prampram : ironstone concretionary variant*)	2 — 11	10 YR 3/2	10 YR 3/1	Nil	0.1	1.2	98.7	11.2	19.3	28.9	5.0	30.8	Nil	6.6	101.8
	11 — 17	10 YR 4/3	10 YR 3/2	Nil	1.9	26.7	71.4	28.8	16.0	16.5	4.3	29.1	0.07	6.2	100.9
	17 — 24	10 YR 4/3	10 YR 4/2	Nil	22.1	18.6	54.3	22.5	22.1	23.2	4.0	23.0	2.9	3.6	101.3
	24 — 32	2.5 Y 5/2	10 YR 3/2	15.8	35.6	12.0	36.6	11.3	31.9	26.9	3.6	22.6	2.1	3.0	101.4
APA 363	0 — 3	2.5 Y 3/2	5 Y 3/1	Nil	Nil	Nil	100.0	0.2	13.9	49.6	7.0	23.7	0.071	5.9	100.37
Kloyo (*Krobo*)	3 — 9	2.5 Y 4/2	2.5 Y 3/2	2.0	1.8	1.5	94.7	2.8	14.3	49.7	6.5	22.4	0.055	4.8	100.56
	9 — 12	10 YR 4/2	10 YR 4/2	22.2	12.9	2.3	62.6	6.8	15.5	47.9	6.2	18.5	0.038	5.9	100.84
	12 — 22	10 YR 5/3	10 YR 4/2	Nil	0.1	0.5	99.4	4.5	31.9	45.1	5.7	9.2	0.016	4.9	101.32
	22 — 40	2.5 Y 6/2	2.5 Y 4/2	6.4	Nil	Nil	93.6	8.2	43.5	39.6	3.6	2.9	0.016	3.2	101.02
	40 — 53	5 Y 6/3	5 Y 5/2	Nil	0.2	0.7	99.1	2.0	6.7	53.5	9.0	20.8	0.731	7.3	100.03
	53 — 62	5 Y 6/3	5 Y 4/3	2.5	0.6	1.1	95.8	7.8	31.5	45.4	5.2	5.1	0.454	3.0	98.45
APA 179	0 — 4	10 YR 5/2	10 YR 2/2	Nil	Nil	0.1	99.9	0.3	13.6	66.0	10.8	6.3	0.14	2.8	99.94
	4 — 9	7.5 YR 6/2	10 YR 4/2	Nil	Nil	0.1	99.9	2.2	17.7	59.3	10.0	8.3	0.12	2.5	100.12
Agawtaw	9 — 13	7.5 YR 6/2	10 YR 5/2	Nil	0.3	3.2	96.7	34.6	12.3	29.9	6.4	12.2	0.08	3.2	98.74
	13 — 21	10 YR 6/3	10 YR 4/2	Nil	0.3	4.3	95.4	6.8	7.0	38.3	12.5	30.1	3.8	3.0	101.5
	21 — 43	10 YR 6/3	10 YR 4/2	Nil	1.3	2.4	96.3	4.6	5.3	35.1	13.8	33.8	6.1	2.2	100.9
	43 — 54	10 YR 6/4	10 YR 5/4	0.6	5.6	37.5	56.3	31.0	7.4	15.2	6.8	35.3	2.8	2.9	101.4
	54 — 64	10 YR 5/6	10 YR 5/4	Nil	2.0	23.7	74.0	48.2	8.2	6.3	2.3	33.6	0.68	2.1	101.38
	64 — 72	10 YR 5/3	2.5 Y 4/2	Nil	3.7	3.1	93.2	12.0	31.7	27.0	5.5	21.6	0.37	3.1	101.27
	72 — 74	2.5 Y 5/2	2.5 Y 4/2	11.5	0.3	0.1	88.2	ND	ND	ND	ND	ND	0.42	ND	ND

Table F. Colour and particle-size distribution.

Profile No. and Series	Horizon Depth in Inches	Colour (Munsell) Air-Dry	Colour (Munsell) Wet (Plastic Limit)	Total Soil, Per Cent. Stones	Total Soil, Per Cent. Coarse Gravel	Total Soil, Per Cent. Fine Gravel	Total Soil, Per Cent. Fine Earth <2mm.	Oven-Dry Fine Earth, Per Cent. Very Coarse Sand	Oven-Dry Fine Earth, Per Cent. Coarse Sand	Oven-Dry Fine Earth, Per Cent. Fine Sand	Oven-Dry Fine Earth, Per Cent. Silt	Oven-Dry Fine Earth, Per Cent. Clay	Oven-Dry Fine Earth, Per Cent. $CaCO_3$	Oven-Dry Fine Earth, Per Cent. Loss on Solution	Oven-Dry Fine Earth, Per Cent. Total
APA 107	0 — 4	10 YR 4/1	10 YR 3/1	Nil	Nil	Nil	100.0	Nil	2.4	29.1	22.0	38.3	Nil	8.2	100.0
	4 — 14	10 YR 4/2	10 YR 3/1	Nil	Nil	Nil	100.0	0.4	6.4	19.4	16.8	48.6	Nil	8.0	99.6
	14 — 30	10 YR 4/2	10 YR 3/1	Nil	Nil	Nil	100.0	1.1	5.4	13.8	5.4	69.9	Nil	5.6	101.2
	30 — 46	10 YR 5/3	10 YR 4/3	Nil	Nil	Nil	100.0	2.0	5.2	14.1	5.0	70.1	Nil	3.5	99.9
Tachem	46 — 67	10 YR 5/3	10 YR 4/3	Nil	Nil	Nil	100.0	2.3	6.1	20.5	4.4	64.9	Nil	3.2	101.4
	67 — 74	10 YR 5/3	10 YR 5/3	Nil	Nil	Nil	100.0	4.1	7.0	23.2	4.3	59.9	Nil	3.5	102.0
	74 —105	10 YR 6/4	10 YR 4/2	Nil	Nil	Nil	100.0	0.7	14.3	50.5	3.4	29.4	0.03	2.1	100.43
	105 —112	10 YR 6/4	10 YR 4/2	Nil	Nil	Nil	100.0	2.0	10.1	38.0	4.6	44.3	Nil	2.8	101.8
	112 —198	10 YR 5/4	10 YR 4/4	Nil	13.3	0.2	86.5	21.7	31.9	15.2	2.8	28.6	Nil	1.5	101.7
APA 175	0 — 7	10 YR 4/1	10 YR 2/1	Nil	Nil	Nil	100.0	12.4		30.8	53.9		0.02	ND	ND
	7 — 13	10 YR 4/2	10 YR 2/1	Nil	Nil	Nil	100.0	6.7		39.3	52.4		0.03	ND	ND
Okwe	13 — 28	10 YR 4/2	10 YR 3/2	Nil	Nil	Nil	100.0	12.8		40.2	46.2		0.02	ND	ND
	28 — 40	10 YR 5/4	10 YR 3/3	Nil	Nil	Nil	100.0	9.1		49.1	41.8		0.02	ND	ND
	40 — 60	10 YR 5/4	10 YR 4/2	Nil	Nil	Nil	100.0	7.7		50.6	41.7		Nil	ND	ND
APA 173	0 — 5	10 YR 5/3	10 YR 3/3	Nil	Nil	Nil	100.0	Nil	0.7	24.2	34.3	36.5	0.09	4.8	100.59
	5 — 13	10 YR 6/4	10 YR 4/3	Nil	Nil	Nil	100.0	0.1	0.9	14.4	23.8	57.9	0.07	3.9	101.07
Amo	13 — 23	10 YR 6/6	10 YR 4/4	Nil	Nil	Nil	100.0	Nil	0.1	6.6	22.1	69.2	0.07	2.7	100.77
	23 — 36	7.5 YR 6/6	7.5 YR 5/6	Nil	Nil	Nil	100.0	Nil	Nil	5.3	20.0	73.1	0.10	2.2	100.70
	36 — 49	10 YR 6/6	10 YR 5/6	Nil	Nil	Nil	100.0	Nil	0.1	6.3	18.6	73.4	0.025	2.0	100.59
	49 — 62	10 YR 6/6	10 YR 5/6	Nil	Nil	Nil	100.0	0.1	0.7	20.8	22.3	54.8	0.07	1.8	100.47
	62 — 74	7.5 YR 6/6	7.5 YR 5/6	Nil	Nil	Nil	100.0	Nil	0.6	22.9	21.8	53.5	0.085	1.4	100.28
Union of	0 — 9	10 YR 3/1	10 YR 2/1	1.8	0.2	0.1	97.9	2.5	9.0	23.7	7.4	49.6	0.52	8.3	101.02
South Africa,	9 — 25	10 YR 3/1	10 YR 2/1	3.7	0.2	0.1	96.0	1.6	5.9	22.8	7.0	55.5	0.40	7.9	101.1
Hartebeestpoort	25 — 40	10 YR 3/1	10 YR 2/1	1.7	0.1	0.2	98.0	1.1	5.3	19.7	7.2	59.6	2.3	6.3	101.5
	40 — 43	10 YR 4/1	10 YR 3/1	Nil	0.1	0.3	99.6	3.6	9.3	16.3	7.3	52.7	6.8	5.5	101.5
	43 — 50	2.5 Y 6/2	5 Y 5/1	Nil	1.5	0.3	98.2	9.6	32.5	28.7	4.9	16.7	6.4	2.8	101.6
Union of	0 — 8	10 YR 3/1	10 YR 3/1	Nil	Nil	Nil	100.0	0.3	6.7	16.7	10.0	61.4	Nil	6.6	101.7
South Africa,	8 — 25	10 YR 4/1	10 YR 2/1	Nil	Nil	Nil	100.0	0.2	6.1	15.6	10.3	61.8	0.03	7.5	101.53
Crecy	25 — 38	10 YR 3/1	10 YR 3/1	Nil	Nil	Nil	100.0	0.1	4.9	14.0	10.5	65.3	0.03	6.5	101.33
	38 — 56	10 YR 4/2	2.5 Y 4/2	Nil	0.9	0.5	98.6	0.1	3.5	13.8	11.9	66.9	0.30	5.3	101.90

Table G. Colour and particle-size distribution.

Profile No. and Series	Horizon Depth in Inches	Oven-Dry Fine Earth, Per Cent.				pH	Per 100 gms. Oven-Dry Fine Earth m.e. Exchangeable							Oven Dry Fine Earth, Per Cent.			Acid Soluble P p.p.m.
		Org. C	Total N	C/N	Org. Matter		Cation Exch. Cap.	Total Bases	Ca	Mg	Mn	K	Na	NaCl	$NaHCO_3$	Na_2SO_4	
APA 368	0 — 6	1.52	0.105	14.5	2.6	6.4	41.8	39.93	29.3	10.1	ND	0.23	0.3	ND	ND	ND	2.0
	6 — 18	0.84	0.061	13.8	1.4	6.9	45.5	44.74	33.1	11.0	ND	0.14	0.5	ND	ND	ND	0.2
Akuse	18 — 32	0.53	0.035	15.1	0.9	8.0	47.0	48.92	33.4	14.3	ND	0.12	1.1	ND	ND	ND	ND
(*normal*)	32 — 42	0.34	ND	ND	0.6	8.2	45.5	48.03	30.7	15.8	ND	0.13	1.4	ND	ND	ND	ND
	42 — 66	0.06	ND	ND	0.1	8.4	31.2	33.53	20.8	11.4	ND	0.13	1.2	ND	ND	ND	ND
	66 — 88	Nil	ND	ND	Nil	8.5	24.9	27.17	15.6	10.5	ND	0.07	1.0	ND	ND	ND	ND
APA 370	0 — 5½	1.74	0.103	16.9	3.0	6.4	35.3	32.81	21.2	10.7	ND	0.31	0.6	ND	ND	ND	3.2
	5½— 15	0.84	0.058	14.5	1.4	7.0	35.8	34.48	22.7	10.6	ND	0.18	1.0	ND	ND	ND	0.2
Akuse	15 — 24	0.63	0.044	14.3	1.1	8.2	41.7	41.78	26.2	13.1	ND	0.28	2.2	ND	ND	ND	ND
(*normal*)	24 — 30	0.45	ND	ND	0.8	8.3	42.9	45.50	25.1	16.90	ND	0.40	3.1	ND	ND	ND	ND
	30 — 41	0.17	ND	ND	0.3	8.4	39.9	38.63	22.8	12.60	ND	0.13	3.1	ND	ND	ND	ND
	41 — 48	0.09	ND	ND	0.1	8.4	40.5	40.65	22.1	15.0	ND	0.35	3.2	ND	ND	ND	ND
	48 — 57	ND	ND	ND	ND	8.4	34.0	36.60	19.6	14.0	ND	0.20	2.8	ND	ND	ND	ND
	57 — 72	ND	ND	ND	ND	8.6	21.13	20.91	8.74	10.27	ND	0.19	1.71	ND	ND	0.012	ND
APA 180	0 — 3	2.31	0.177	13.1	4.0	6.1	35.5	ND	ND	ND	ND	0.42	ND	ND	ND	ND	4.3
	3 — 10	1.41	0.104	13.6	2.4	5.7	36.9	ND	ND	ND	ND	0.36	ND	ND	ND	ND	1.1
Akuse	10 — 21	0.70	0.059	11.9	1.2	6.1	34.7	ND	ND	ND	ND	0.37	ND	ND	ND	ND	Nil
(*transitional*	21 — 30	ND	ND	ND	ND	6.5	38.2	ND	ND	ND	ND	Nil	ND	ND	ND	ND	ND
variant)	30 — 39	ND	ND	ND	ND	7.1	30.6	ND	ND	ND	ND	0.44	ND	ND	ND	ND	ND
	39 — 59	ND	ND	ND	ND	7.7	25.1	ND	ND	ND	ND	0.49	ND	ND	ND	ND	ND
	59 — 65	ND	ND	ND	ND	8.0	23.0	ND	ND	ND	ND	0.31	ND	ND	ND	ND	ND
	65 — 74	ND	ND	ND	ND	8.2	22.3	ND	ND	ND	ND	0.25	ND	ND	ND	ND	ND
APA 369	0 — 4	1.09	0.076	14.3	1.9	6.8	15.5	15.75	8.8	6.1	ND	0.55	0.3	ND	ND	ND	8.6
	4 — 11	0.97	0.071	13.7	1.7	7.4	21.6	22.14	12.1	7.9	ND	0.34	1.8	ND	ND	ND	9.1
Akuse	11 — 17	0.55	0.049	11.2	0.9	8.5	24.1	28.44	13.6	10.5	ND	0.94	3.4	ND	ND	ND	20.7
(*Prampram*)	17 — 24	0.29	ND	ND	0.5	8.6	22.7	27.85	12.8	11.2	ND	0.25	3.6	ND	ND	ND	ND
	24 — 66	0.01	ND	ND	0.02	8.9	8.5	10.95	2.3	3.3	ND	0.55	4.8	ND	ND	ND	ND

Table H. Nutrient status.

Profile No. and Series	Horizon Depth in Inches	Oven-Dry Fine Earth, Per Cent.				pH	Per 100 gms. Oven-Dry Fine Earth m.e. Exchangeable							Oven-Dry Fine Earth, Per Cent.			Acid Soluble P p.p.m.
		Org. C	Total N	C/N	Org. Matter		Cation Exch. Cap.	Total Bases	Ca	Mg	Mn	K	Na	NaCl	$NaHCO_3$	Na_2SO_4	
APA 183	0 — 7	1.60	0.122	13.1	2.8	7.1	21.55	24.93	17.87	6.44	0.02	0.26	0.34	ND	ND	0.007	16.4
	7 — 18	1.25	0.101	12.4	2.1	6.8	18.65	21.12	13.57	5.93	0.04	0.17	1.41	ND	ND	0.010	14.2
Akuse	18 — 22	0.67	0.059	11.4	1.2	7.9	17.81	22.05	11.61	10.02	0.05	0.15	0.22	ND	ND	0.013	8.8
(*Prampram :*	22 — 38	ND	ND	ND	ND	8.4	18.21	27.03	22.79	3.76	0.01	0.14	0.33	ND	ND	0.016	ND
gravelly variant)	38 — 42	ND	ND	ND	ND	7.9	5.72	8.59	6.78	1.33	0.04	0.17	0.27	ND	ND	0.012	ND
APA 174	0 — 2	1.84	0.120	15.3	3.2	6.7	28.7	ND	ND	ND	ND	0.86	ND	ND	ND	ND	15.4
Akuse	2 — 11	1.38	0.099	13.9	2.4	6.5	26.9	ND	ND	ND	ND	0.43	ND	ND	ND	ND	3.7
(*Prampram :*	11 — 17	0.70	0.060	11.7	1.2	6.9	27.0	ND	ND	ND	ND	0.26	ND	ND	ND	ND	0.2
ironstone concre-	17 — 24	ND	ND	ND	ND	8.0	20.4	ND	ND	ND	ND	0.28	ND	ND	ND	ND	ND
tionary variant)	24 — 32	ND	ND	ND	ND	8.0	21.1	ND	ND	ND	ND	0.22	ND	ND	ND	ND	ND
APA 363	0 — 3	1.75	0.128	13.7	3.0	6.9	27.4	ND	8.4	9.2	ND	0.62	ND	ND	ND	ND	40.7
	3 — 9	1.18	0.090	13.1	2.0	6.4	25.1	ND	16.9	7.6	ND	0.36	ND	ND	ND	ND	40.3
Kloyo	9 — 12	0.39	0.075	12.9	1.7	6.4	22.5	ND	15.0	8.3	ND	0.33	ND	ND	ND	ND	44.5
(*Krobo*)	12 — 22	0.35	ND	ND	0.6	6.5	17.0	ND	12.6	4.9	ND	0.18	ND	ND	ND	ND	ND
	22 — 40	0.06	ND	ND	0.1	7.3	10.2	ND	8.3	3.2	ND	0.18	ND	ND	ND	ND	ND
	40 — 53	0.16	ND	ND	0.3	7.9	34.2	ND	24.6	7.3	ND	0.31	ND	ND	ND	ND	ND
	53 — 62	ND	ND	ND	ND	8.2	24.1	ND	17.8	8.0	ND	0.21	ND	ND	ND	ND	ND
APA 179	0 — 4	1.03	0.071	14.5	1.8	6.8	6.80	ND	1.60	2.95	ND	0.17	ND	ND	ND	ND	2.2
	4 — 9	0.91	0.072	12.6	1.6	6.4	6.8	ND	2.2	ND	ND	0.17	ND	ND	ND	ND	1.1
	9 — 13	0.96	0.071	13.8	1.7	6.8	12.3	ND	3.4	ND	ND	0.11	ND	ND	ND	ND	1.0
Agawtaw	13 — 21	ND	ND	ND	ND	8.5	24.1	ND	ND	ND	ND	0.16	ND	ND	ND	ND	ND
	21 — 43	ND	ND	ND	ND	8.3	25.1	ND	ND	ND	ND	0.10	ND	ND	ND	ND	ND
	43 — 54	ND	ND	ND	ND	8.4	26.7	ND	ND	ND	ND	0.14	ND	ND	ND	ND	ND
	54 — 64	ND	ND	ND	ND	8.3	26.0	ND	ND	ND	ND	0.12	ND	ND	ND	ND	ND
	64 — 72	ND	ND	ND	ND	8.4	22.5	ND	ND	ND	ND	0.03	ND	ND	ND	ND	ND
	72 — 74	ND	ND	ND	ND	8.1	7.1	ND	ND	ND	ND	0.14	ND	ND	ND	ND	ND

Table I. Nutrient status.

5

Profile No. and Series	Horizon Depth in Inches	Oven-Dry Fine Earth, Per Cent. Org. C	Total N	C/N	Org. Matter	pH	Per 100 gms. Oven-Dry Fine Earth m.e. Exchangeable Cation Exch. Cap.	Total Bases	Ca	Mg	Mn	K	Na	Oven-Dry Fine Earth, Per Cent. NaCl	$NaHCO_3$	Na_2SO_4	Acid Soluble P p.p.m.
	0 — 4	2.22	0.170	13.1	3.8	5.6	34.58	32.52	17.68	13.23	0.43	0.63	0.55	ND	ND	0.018	6.9
APA 107	4 — 14	1.48	0.129	11.5	1.4	5.6	38.36	36.41	18.99	16.05	0.37	0.35	0.65	ND	ND	0.013	1.4
	14 — 30	0.80	0.081	9.9	1.0	5.6	46.37	43.94	22.05	20.17	0.03	0.34	1.35	ND	ND	0.019	1.0
	30 — 46	ND	ND	ND	ND	5.9	43.90	41.78	20.60	18.52	0.01	0.22	2.43	ND	ND	0.006	ND
Tachem	46 — 67	ND	ND	ND	ND	5.1	43.17	41.80	21.34	18.62	0.04	0.27	1.53	0.079	0.008	0.063	ND
	67 — 74	ND	ND	ND	ND	5.2	39.53	37.54	18.11	17.27	0.04	0.41	1.71	0.065	Nil	0.066	ND
	74 —105	ND	ND	ND	ND	6.6	18.96	20.10	9.22	8.53	0.05	0.28	2.02	ND	ND	0.018	ND
	105 —112	ND	ND	ND	ND	6.3	29.17	30.89	14.29	13.40	0.04	0.21	2.95	ND	ND	0.038	ND
	112 —198	ND	ND	ND	ND	7.6	18.16	18.94	9.09	7.06	0.02	0.93	1.84	ND	ND	0.016	ND
APA 175	0 — 7	1.65	0.168	9.8	2.8	6.0	31.7	ND	14.8	ND	ND	0.33	ND	ND	ND	ND	7.0
Okwe	7 — 13	0.91	0.096	9.5	1.6	5.8	30.0	ND	16.0	ND	ND	0.28	ND	ND	ND	ND	4.5
	13 — 28	0.43	0.046	9.3	0.7	6.6	25.5	ND	14.3	ND	ND	0.17	ND	ND	ND	ND	3.8
	28 — 40	ND	ND	ND	ND	7.3	21.5	ND	11.4	ND	ND	0.31	ND	ND	ND	ND	ND
	40 — 60	ND	ND	ND	ND	7.4	15.7	ND	9.3	ND	ND	0.25	ND	ND	ND	ND	ND
APA 173	0 — 5	1.82	0.144	12.6	3.1	5.6	19.36	8.58	3.05	4.23	ND	0.30	1.00	ND	ND	ND	2.6
Amo	5 — 13	1.00	0.101	9.9	1.7	5.9	23.71	14.59	3.10	7.33	ND	0.30	3.86	ND	ND	0.016	1.5
	13 — 23	0.57	0.071	8.0	1.0	6.3	25.25	21.76	6.40	8.42	ND	0.32	6.62	ND	ND	0.086	0.5
	23 — 36	ND	ND	ND	ND	5.7	26.21	22.30	5.32	9.52	ND	0.31	7.15	ND	ND	0.146	ND
	36 — 49	ND	ND	ND	ND	5.1	25.70	19.78	5.28	7.96	ND	0.33	6.21	ND	ND	0.195	ND
	49 — 62	ND	ND	ND	ND	6.4	19.99	18.80	3.12	9.00	ND	0.38	6.30	ND	ND	0.080	ND
	62 — 74	ND	ND	ND	ND	6.5	19.50	20.05	3.20	9.52	ND	0.35	6.98	ND	ND	0.047	ND
Union of	0 — 9	1.77	0.156	11.3	3.0	7.7	59.88	61.18	54.2	5.9	ND	0.81	0.27	ND	ND	ND	3.2
South Africa,	9 — 25	1.19	0.099	12.0	2.0	7.8	66.27	68.71	60.1	7.6	ND	0.49	0.52	ND	ND	ND	8.7
Hartebeest-	25 — 40	0.98	0.060	16.3	1.7	7.8	69.15	73.02	60.2	10.9	ND	0.51	1.41	ND	ND	ND	10.8
poort	40 — 43	ND	ND	ND	ND	7.8	59.01	65.03	52.9	10.0	ND	0.91	1.22	ND	ND	ND	ND
	43 — 50	ND	ND	ND	ND	8.3	21.46	23.88	19.6	3.4	ND	0.30	0.58	ND	ND	ND	ND
Union of	0 — 8	0.95	0.076	12.5	1.6	6.5	51.29	52.98	28.60	20.97	0.17	1.63	1.61	ND	ND	0.011	4.7
South Africa,	8 — 25	0.88	0.058	15.2	1.5	7.0	52.03	54.65	29.60	20.82	0.18	1.49	2.56	ND	ND	0.013	4.9
Crecy	25 — 38	0.60	0.039	15.4	1.4	7.4	54.39	58.52	32.37	21.87	0.04	1.25	2.99	ND	ND	0.036	7.6
	38 — 56	ND	ND	ND	ND	7.5	55.36	58.70	30.38	24.11	0.01	1.10	3.10	ND	ND	0.093	ND

Table J. Nutrient status.

PART III. RECOMMENDATIONS

(In conjunction with C. F. Charter)

INTRODUCTION

The place of the Accra plains irrigation project in the economy of the Gold Coast

The Kpong Pilot Irrigation Scheme is designed to be the first stage in the proposed systematic development of the Accra plains. These plains lie to the north-east of Accra, the capital town of the Gold Coast. They are roughly triangular in shape, and are bounded by the Akwapim Range in the north-west, the lower part of the Volta river in the north-east, and the sea, from Ada in the east to the village of Lanma (10 miles west of Accra) in the south. Their total area is approximately 1,500 square miles (Map 2).

At present, the Accra plains are very sparsely populated except in the peripheral areas where lighter-textured soils have permitted cultivation by the hoe. Settlement is most intense in the north-west, on the better-watered soils at the foot of the Akwapim Range ; and in the north-east, on the lighter textured of the annually-flooded alluvial soils along the Volta floodplain, where, however, farming is considerably supplemented as a means of livelihood by trading and fishing. The central areas of the Accra plains are almost uninhabited. Here, the soils are generally too compact to be cultivated by the local hoe, and these areas are used only, if at all, for extensive cattle grazing. Pasturage is poor, however, and water supplies are scanty and precarious.

In a country which, despite the fact that the majority of its population are farmers, still needs to import large quantities of food, and in a world whose rapidly-growing population is clamouring for increased food production, the undeveloped Accra plains present both a challenge and an opportunity to the people of the Gold Coast. The rainfall over the region is both insufficient and too uncertain for large scale agricultural development without assistance from irrigation. A certain amount might be done by local irrigation schemes along the lines suggested by the Rice Mission in their report (3) ; but the construction of a high-level dam in the Volta gorge would make possible the irrigation of as much of the Accra plains as the soil conditions and landforms permit.

The primary purpose of any agricultural development scheme for the Accra plains must be to produce food for consumption in the Gold Coast itself. The rapid expansion of cocoa farming and the growth of such large towns as Accra during the past half-century have diverted much land and many people from subsistence crop production and made it necessary for the country to import increasing quantities of food. It is to be expected that the development of industry in the future, together with the natural growth of the population, will accelerate this trend. In addition, with the increasing adoption of European habits there has been a growing demand for such imported commodities as refined sugar, wheaten flour and tinned milk, some of which, or suitable alternatives, could be produced locally. Furthermore, the diet of a majority of the people, relying heavily upon cassava, yams, plantains and maize, would appear to contain an excessive proportion of carbohydrates and, in consequence, be somewhat unbalanced. There is patently a need, therefore, to increase the production of food, particularly protein food, in the country.

The most important food crop which could be grown on the Accra plains would be swamp rice, not only because physical conditions there are highly suitable for the production of this crop, but also because this cereal gives higher food yields per acre than other crops. Prior to World War II, very considerable quantities of rice were imported into the country ; but in recent years, due to shortages in the areas of production, importation has very greatly declined. To a considerable extent this decline has been compensated by increased imports of wheaten flour ; but there is reason to suppose that there was also increased home production of maize, until this crop was affected by ' rust '. Besides rice, other grain and vegetable crops could be produced satisfactorily. Many areas would be ideal for growing sugarcane, which would satisfy a long-felt demand for local production of this commodity. This region is also almost tsetse fly free, and it should be possible by improved pasturage and the production of fodder crops by irrigation, vastly to increase meat production from the area and to initiate dairy farming and the production of dried and/or condensed milk. This development would considerably enhance supplies of protein food available in the country.

Whilst the main emphasis in development should be placed on the production of food for home consumption, it would be desirable, if not essential, to grow crops for export in order to pay for essential imports, amongst them, fertilizers, mechanical farming equipment and skilled technical advice. Such exports might comprise cotton, jute or similar fibres, and food commodities produced in excess of local requirements. The production of these crops for home consumption and for export, with the concomitant development of industry in the country, would do much to broaden the basis of an economy which is at present too narrowly perched on the production and export of a single crop, cocoa.

Because of soil and climatic conditions, these crops could only satisfactorily be produced by means of mechanized irrigation farming. This Department considers that successful development could best be organized by a well-staffed, well-equipped and well-administered Agricultural Development Corporation which would run the scheme along industrial lines, with tractor drivers, mechanics and labourers working under a variety of technical officers and assistants of various grades. The corporation should be made responsible for all aspects, technical, financial and administrative, of the development scheme. Staff and labourers would be accommodated in suitably-located and planned towns and villages.

This Department holds that there is no demand at present for a large scale settlement scheme in the region : in fact it might be difficult to attract adequate numbers of suitable settlers to such a scheme in competition with industrial and urban developments at Tema, Kpong and Accra. Apart from this, it is not considered that the environment is suitable for a peasant-settler approach. Any development scheme for the Accra plains should be designed to produce food on a large scale by the most efficient means practicable. Mechanized irrigation farming, which the environment makes necessary, demands firm scientific control over use of irrigation water, drainage, times of sowing, use of fertilizers, weeding, crop rotations and, with a crop such as sugarcane, of harvesting operations too. This control could not be effected over small scale, independent peasant farmers, the more so since these have no inherited tradition of irrigation agriculture nor even of the cultivation of heavy lowland clays. Without adequate control over the technical aspects of irrigation, it would be folly to go ahead with such a large scale project as the development of the Accra plains involving, as it will, the investment of considerable capital for the construction and maintenance of irrigation canals, field channels, drains, weirs and access roads.

It might be asked why the Accra plains should be developed in preference to other regions in the Gold Coast enjoying a higher rainfall. The anwer lies in the superior facilities for mechanized and irrigation agriculture which the soil conditions and the topography on the Accra plains provide, as well as in the fact that almost the whole of the region could be commanded by irrigation canals led from the lake impounded by the projected high-level dam in the Volta gorge. So far as the production of swamp rice (which gives higher yields than hill rice) is concerned, there are no other extensive areas in the Gold Coast possessing more-or-less flat land with impervious soils which could be irrigated, irrigation being a *sine qua non* for swamp rice production. In the case of sugarcane, there is no comparable land available which would permit the mechanized production of this crop, mechanization being essential for commercial production ; and the proximity of the Accra plains to the coast and to the projected modern harbour at Tema would greatly facilitate the import and installation of extraction machinery. The Accra plains, again, provide the only soils in the Gold Coast which it is considered would produce high quality, Egyptian, long-staple cotton ; and Black Clays similar to those occurring in this region are reported to produce good quality ' bright ' tobacco in East* and South Africa (23) and in India.† The region also provides opportunities for expansion of stock-raising because of its relative freedom from tsetse fly and *trypanosomiasis*. The Accra plains as a region, in fact, possesses great advantages over other areas in the country for development, and moreover, development here could be such as to benefit not only the people who would settle in the region, but also the people of the country as a whole.

The Kpong Pilot Irrigation Scheme in relation to the Accra plains development project as a whole

There are considerable obstacles in the way of initiating irrigation agriculture in this country : local experience of crop production by irrigation is limited,

* Private information from a representative of the Nigerian Tobacco Company, Ltd., Lagos.

† Private information from Dr. P. Piekenbrock who in 1937 carried out a soil survey of the Black Clays of the Guntur area, 200 miles north of Madras in south-east India, where 150 square miles of the soils are devoted to the production of Virginia tobacco.

and there is hardly any traditional agriculture practised on the Black Clays at all. The object of the Pilot Scheme cannot be, therefore, as the Consultants originally proposed, " to accustom the people to the methods of irrigation " (24). Much has to be learned about the handling of these soils before peasant farmers can be trained in the novel methods. Following discussions between the technical departments of the Ministry of Agriculture and the Consultants, it has therefore been arranged that the first phase of development should be devoted entirely to investigatory work. After this phase, which may be expected to extend over a number of years, it can then be determined whether the Black Clays can economically be brought into use and what form of organization might be most suitable for ensuring successful development.

The object of the Kpong Pilot Irrigation Scheme, then, is to provide the detailed basic information required primarily for the development of mechanized irrigation agriculture on the Black Clays which cover approximately 300 square miles of the Accra plains. A great deal of this information would be applicable to other extensive soils in the region including, for example, soils of Agawtaw, Amo, Lupu, Songaw and Ada series which together have an extent similar to that of the Black Clays. These soils will be dealt with in the Report on the Reconnaissance Soil Survey of the Accra Plains. Much of the technical knowledge gained would also be applicable to possible future irrigation projects in other parts of the country.

INFORMATION REQUIRED FROM THE KPONG PILOT AREA AND RECOMMENDATIONS FOR OBTAINING IT

The information required from the Pilot Scheme is not whether in fact the Black Clays are fertile and will give profitable yields. What is required is the knowledge of handling these soils under mechanized irrigation agriculture under local environmental conditions. The Black Clays are regarded as potentially highly productive, and similar soils are successfully farmed in South Africa, India and Morocco. This Department has obtained samples of soils from all these areas. The profiles from South Africa are very closely similar to the Akuse series of the Accra plains ; but, due to a mistake in the profile sent for, the profile obtained from India turned out to be less closely similar to the local soils. However, confirmation that soils of Akuse series are directly comparable with the Indian regur was obtained from Dr. Piekenbrock.* The samples from Morocco have not yet been analysed.

The various categories of information required from the Pilot Scheme are treated under separate headings below.

PHYSICAL CONSIDERATIONS

Meteorological data

The information provided by the meteorological station at Akuse gives a general picture of the climatic conditions existing in the neighbourhood of the Pilot Area, but this will not suffice when research work begins on the

* See second footnote, p. 68.

experimental station. Precise information will be required, particularly to discover the loss of irrigation water by evaporation. Expert meteorological opinion at the present time leans towards the view that the evaporating power of the air can more satisfactorily be estimated from empirical formulae, using climatological records of temperature, hours of sunshine, humidity and wind velocity, than by direct measurement from evaporimeter tanks (25). It will be essential, therefore, to equip the station with a full range of meteorological instruments from the outset. There is no reason why these should not include an evaporation tank for correlation purposes.

At the same time, there is need to commence collecting evaporation data from the whole of the Accra plains, so that the loss of water by evaporation can be taken into account in planning further extensions of irrigation. The present meteorological stations in the region at Akuse, Aburi, Achimota, Accra, Ada and Nungwa Veterinary Farm,* are entirely peripheral in location, and do not provide the data required for the development of the central tracts. Proposals have already been made in separate memoranda to the Ministry of Agriculture and Natural Resources that a number of auxilliary meteorological stations should be set up on the Accra plains to collect the required data. It is considered essential that the station on the Pilot Area at least should be equipped with continuous-reading instruments, since the normal meteorological practice of taking readings at fixed hours during the day does not necessarily provide the detailed information required for agronomic and irrigational investigations.

Drainage control

It will be essential from the beginning to control the surface drainage over and in the neighbourhood of the cultivated plots. These plots have been sited above the limits of flooding of the Okwe and the Volta rivers, on whose flood-plains it is obviously impracticable to control the drainage at present. However, even if floodwater entering the Pilot Area down the Okwe valley cannot be controlled, it should at least be ensured that this water does not remain on the Pilot Area to interfere with the disposal of drainage water from the cultivated plots for any longer period than can be avoided.

Drainage would be greatly facilitated if the outlet of the Okwe stream to the Volta were improved. At present, after leaving the Pilot Area, the stream meanders through approximately two miles of channel before reaching the Volta, whereas, if it took a direct route, the distance would be less than 400 yards. It is recommended that the area between the Kpong-Akuse road bridge over the Okwe stream and the bank of the Volta should be investigated at once with a view to providing a shorter route for the stream between the Pilot Area and the Volta. It would be desirable to control the outlet of the stream into the Volta by means of a floodgate to prevent the latter river flooding back onto the Pilot Area. A survey should first be carried out in the area, however, to discover if such a structure would, by itself, provide effective control, or

* Since the publication of the first manuscript report, the Meteorological Service has commenced the collection of rainfall data from Ashaiman, Teshie, Odumasi, Kpong (waterworks), Osudoku and Aveime. With the exception of Ashaiman and Osudoku, all these stations are peripheral.

whether floodwater from the Volta could enter the lower Okwe valley either from other streams which cross the Volta floodplain in the neighbourhood, or by means of old cut-off channels of the Volta which may exist in the area. Further improvement of drainage could be effected by rationalizing the present tortuous channel of the Okwe stream along the northern boundary of the Pilot Area, but this would be of little assistance unless the outlet to the Volta were improved as well.

In connection with drainage on the cultivated plots and in their neighbourhood, it must be repeated that the Black Clays become almost totally impermeable within a few minutes of the onset of rain and that, thereafter, all water flows off the surface in a continuous sheet. The rain characteristically falls with great intensity, perhaps at a rate of up to six inches per hour for short periods within a shower. As soon as the station is established, lysimeters should be constructed to determine the amount of runoff over and drainage through the various soils under natural vegetation and when cultivated.

Sheetflood water running down the slopes above and alongside the cultivated plots must be intercepted in broad, shallow, well-grassed channels and led away so that it can do no damage. These interceptor drains must be adequate in number and capacity to take off the enormous quantities of water running over the surface, and they must be carefully sited and graded so that the water, when concentrated into channels, does not initiate gully erosion.

On the plots growing rowcrops, the field drains must be adequate to dispose of surface runoff water during rainfall, and serve, at the same time, to encourage internal drainage through the cultivated layer of the soil. The latter provision is essential, not only because it can be expected to improve the structure of the soil, but also to prevent the accumulation of salts left in the soil by evaporation of irrigation water.

On the rice plots, there must be an adequate number of outlets between paddies to prevent uncontrolled flooding from one to another during rainfall, with the consequent risk of breaches being made in the bunds.

Whilst the rapid disposal of drainage water during rainstorms might be a relatively simple matter to effect on the small area of the experimental station, it must be borne in mind that this would at a later stage be a much more serious problem over larger, intensively-cultivated irrigated areas on the impervious Black Clays. It is for this reason that it will later be recommended that extension of development from the Pilot Area should not be into arbitrarily selected and located areas but into natural landscape units within which complete control over local drainage could be effected.

Field layout in relation to topography, irrigation and mechanized farming

Of greater importance at first than experiments with crop production will be investigations into suitable forms of field layout. For mechanized farming, large rectangular fields are the most economical ; but for irrigation, such fields might be to a greater or lesser degree unsuitable, depending on the slope of the land and the permeability of the soil.

Investigations are required into two methods of irrigation : flood-irrigation and furrow-irrigation. Flood-irrigation would mainly be used for rice production, but is also suitable for the production of fodder crops. This method is only practicable on very gentle slopes since it is essential for good crop yields to ensure an even depth of flooding. The width of rice paddies is therefore controlled by the slope of the land, although a certain amount of artificial levelling might beneficially be carried out so that there is a difference in level of no more than three inches between inlet and outlet points in each paddy. In general, paddies on the Pilot Area might probably be no more than 30-50 feet in width and 300-500 feet in length.*

Slopes steeper than ½-1 per cent. could better be developed using furrow irrigation. Here it must be reiterated that the Accra plains is not an alluvial area. Many of the problems of field layout which will be encountered may well be almost unique, and experience gained on other irrigation schemes elsewhere in the world will not necessarily be applicable to their solution. Field layout on the deeper Akuse (normal) soils is expected to present few problems ; but the shallower soils and steeper slopes of Prampram subseries will raise difficulties, although these are not expected to prove insuperable. Plots have been sited on Prampram soils not because there were insufficient deep Akuse soils on the Pilot Area but in order to discover whether or not the shallower soils, and the steeper slopes on which they occur, are economically cultivable. This investigation is considered to be of the greatest importance, for Prampram soils occur in intimate association with deep Akuse soils throughout a considerable area in the northern half of the Black Clays belt. To avoid Prampram soils and cultivate only the Akuse (normal) soils in this area would lead to much wastage of land and dispersion of settlement, and might well prove uneconomic.

Reference to the literature on irrigation makes it obvious that not only is it practicable to irrigate slopes as steep as the maximum occurring on the Pilot Area but that satisfactory field shapes for their mechanical cultivation can also readily be arranged. Nowhere on the Pilot Area are slopes greater than 4 per cent. likely to be encountered ; yet in the United States of America slopes as steep as 15 per cent. are irrigated by the furrow method (27). Further, the rectangular fields which are most suitable for mechanical cultivation could be provided if, instead of open field channels, canvas or metal pipes, which could be run directly down-slope, were to be used. These could either be permanent fixtures, or temporary and portable. A suitable form would be the ' gated ' aluminium pipe which allows the flow of water from the field pipe to the furrows to be regulated as desired. (It might be possible to manufacture such aluminium pipes locally at a later date.)

Alternatively, with simple precautions, it would be possible to run open channels directly down-slope. To eliminate the risk of soil erosion such channels would require to be carried down-slope in a series of steps. The channels would consist of a series of almost level stretches—the actual length dependent on the

* On the 4,700 acres of the Mahaicony/Abary Rice Development Scheme in British Guiana—where, however, there is a maximum variation in level of only eighteen inches throughout the area—it has been found possible to manage fields as large as 500 × 6,000 feet (= 69 acres approximately) by mechanized cultivation (26).

degree of slope—with ' guarded drops ' to carry the water safely from one level to the next. If used on the Pilot Area such guarded drops might be constructed from termite-resistant Odum wood ; but at a later stage they might require to be made of concrete. Similar guarded drops would also be used in drainage channels. This method would demand a permanent form of field layout. Water could be transferred from the distribution channels to the furrows by syphons made of light-weight, curved lengths of pipe made of cellulose, aluminium, galvanized iron or of rubber.

Although the Black Clays themselves are highly impermeable, they are of limited depth and are underlain by permeable rock so that the use of open irrigation channels may prove wasteful of water.* Investigations should be carried out, therefore, into suitable methods of lining the major distribution channels at least. Bitumen lining would probably be the most effective, and would serve, too, to reduce maintenance costs on weed control.

So far as the internal arrangement of the fields is concerned there are two main points to consider : the effective irrigation of the crop ; and the avoidance of deleterious effects on the soil. These considerations both depend to a large degree on the permeability of the soil and the slope of the land. With permeable soils it is necessary to use a large flow of water for effective irrigation, and relatively steep slopes can be treated since the low degree of runoff does not encourage erosion. With less permeable soils, on the other hand, it is necessary to hold the water on the soil for a longer period to encourage adequate absorption ; and the high degree of runoff prevents the use of large flows of water and/or steep furrow slopes because of the danger of inducing soil erosion.

It is customary to run furrows directly down-slope, although careful inspection is required on steep slopes to prevent the development of accelerated soil erosion. Alternatively, furrows can be run across the slope, cutting the contour at a narrow angle. This latter method might be required on the impermeable Black Clays to encourage adequate absorption of water into the soil, but inconvenience might arise during intense rainstorms by the overflowing of furrows. It is recommended that both methods—i.e. running furrows directly down-slope, or more-or-less along the contour—should receive investigation on the Pilot Area.

The type of layout considered suitable for the investigational area is shown on Map 9. This differs from the layout proposed in the original manuscript report owing to the Consultants' subsequent re-alignment of the main pipeline to the balancing tank.

The layout shown provides suitable sites and acreages for investigations concerned with the irrigation of Prampram soils on slopes steeper than 2 per cent. and with the production of swamp rice. This Department regards both these investigations as of the greatest importance for the future development of the Black Clays, hence their inclusion in the revised plan.

* On the Black Tirs of Morocco which the writer has recently visited (April, 1954), irrigation water is usually delivered in pre-cast, pre-stressed concrete flumes supported on concrete trestles, but investigations were in progress near Petitjean into the use of bitumen-lined canals. A lining 18 mm. thick using a mixture of 10-15 per cent. bitumen with sand applied, for convenience, on a jute base had proved successful against drying tests. This rate of application cost 600 metropolitan francs (c. 12 shillings) per square metre.

The suggested layout shown in Map 9 is the most convenient to command the largest area of uniform Akuse (normal) soils on a uniform slope and for the irrigation of the major extent of Prampram soils and slopes of more than 2 per cent. Irrigation water for the plots to the east of the delivery pipeline would be led from the balance tank in an open channel along a north-easterly spur with a convenient gradient. Field irrigation channels would then lead water westwards more-or-less along the contours so that drainage was towards a main drainage channel, with guarded drops, running parallel with the delivery pipeline and main access road. A culvert would be required at the lower end of this channel to lead water under the road to a main drainage outlet into the Okwe.

For plots to the west of the delivery pipeline in the north, an open channel with guarded drops, or perhaps a pipe, would be required. This would lead irrigation water down-slope alongside the delivery pipeline and main access road until field channels could be taken off more-or-less along the contours to the appropriate investigational plots. From these plots drainage would be directed to the major drainage outlets which have been aligned along natural gullies leading to the Okwe.

This layout allows for the construction of open irrigation and drainage channels at gradients of 1 : 300 for main channels, 1 : 100 for field channels and 1 : 200 for field furrows, which are the gradients recommended by the Consultants. However, it would seem advisable at first that the main distribution channels at least should be relatively impermanent structures until investigations have shown the most suitable gradients for use on the Black Clays. The use of wooden flumes or portable pipes might be convenient for this purpose.

The proposed field layout shown on this map should not, therefore, be regarded as permanent. For the post of irrigation officer in charge of layout a person of considerable imagination and ingenuity is required who will be prepared and able to try out different methods of water-distribution and drainage on the various soils and slopes in order to effect a satisfactory compromise between the requirements of mechanized and irrigation agriculture. Further, it may be noted here that the same crop will not necessarily occupy the plots indicated on the map for the whole of the time. As will be explained further below, although rice and sugarcane might always be grown on the same plots, other crops—and rice and sugarcane, too, possibly—would normally form part of various crop rotations and accordingly occupy different plots in turn.

It was originally suggested that a water supply of 2 cu. secs. for six hours daily would be sufficient, although provision would later be made for a greater supply (10 cu. secs.) to be pumped from Kpong when extension of development from the research station became possible. It is probable that the investigations recommended by this Department will demand a greater supply of irrigation water than was originally envisaged, particularly since it is regarded as essential to experiment with the production of paddy rice : much depends on increasing the 'efficiency' of the rainfall. If the combined water supply from rainfall and the proposed irrigation supply is inadequate and a larger irrigation supply is not immediately available, then it might be necessary to scale down the size of the investigational area. Such a reduction, however, might seriously jeopardize the value of investigations to discover means of mechanically cultivating the Black Clays—one of the prime functions of the Kpong Pilot Irrigation Scheme.

Construction of roads and farm buildings

Field access roads and miscellaneous farm buildings will require construction on the experimental station. The constructional properties of the individual soils which occur on the Pilot Area have already been given in Part II of this report. The Town and Country Planning Board have reported adversely on the employment of any of the soils as foundation material for roads, and it is recommended that brash of quartz-mica schist should be imported from the neighbourhood of Kpong, where it occurs plentifully on the northern and western sides of the village. This type of rock has already been utilized, with apparent success, by the Public Works Department in the construction and maintenance of the Kpong-Akuse and the Dawhwenya-Prampram roads.

According to information from the Town and Country Planning Board, all clays could be recommended for the manufacture of stabilized building blocks. If brick, tile or pottery manufacture were required, Amo and Tachem clays were considered possibly suitable by the Town and Country Planning Board, although the Geological Survey Department seem more convinced of their suitability (28). This latter opinion is substantiated by the fact that pottery-making is practised at Kpong and elsewhere down the floodplain of the Volta.

Precautions against malaria

It is popularly thought that the extension of irrigation to the Accra plains and particularly the production of swamp rice in flooded paddies, would necessarily increase the incidence of malaria in the region by extending the breeding areas of anopheline mosquitoes. This view is not necessarily well-founded, for the swamp rice production areas of the plains of the Philippines, Indochina, Thailand, Burma and Assam are practically malaria-free, whilst in the neighbouring uplands, the disease is endemic (29).

Different species of *Anopheles* breed in different kinds of water, and it will be essential to discover whether any of the local species habitually breed in the rather muddy water containing humic acids such as will be found on the flooded rice paddies. If there were a risk that mosquitoes would breed on the rice paddies, it would be a relatively simple matter to eliminate them. This could be effected by draining off all the water periodically and allowing the rice fields to dry out for from twenty-four to forty-eight hours. The interval at which this operation would need to be carried out would depend upon the biology of the local malaria vectors ; and the length of the drying period would depend upon the rate at which the Black Clays soils dried out. This technique is effective in killing all mosquito larvae, without interfering with the cultivation of rice. It is patently a matter of importance to make an early study of the biology of the local species of *Anopheles* in order to discover if, in the first place, any of them are likely to breed in irrigation channels or rice paddies ; and if so, secondly, what modification of irrigation techniques would be effective in interrupting their life cycle.

Similar research might beneficially be made into the biology of other disease vectors which might find favourable breeding conditions in irrigation channels or flooded paddies.

CROPS TO BE GROWN AND METHODS OF CULTIVATION

Field crops to be grown

Emphasis during the early stages of development on the experimental station should be given to investigations designed to discover the most suitable methods of handling the Black Clays and to the collection of data on the water requirements of the various crops to be grown. Although the cultural requirements of these crops may already be known, there is no tradition of crop production on these soils in the Gold Coast, and it will largely be a matter for experiment to discover suitable cultivation techniques for each crop.

Generally speaking, the timing of cultural operations will be controlled by the fact that it will be desirable to harvest the major crops in the main dry season, from the end of November to early March. Fortunately, for the majority of crops, this arrangement would permit sowing and growth during one or other of the rainy seasons, which should make possible considerable economy in the use of irrigation water. Irrigation should not, in fact, be regarded as diminishing dependence on natural supplies of water, but only as supplementing these when deficiencies, caused by irregularities in the rainfall, occur. At Kpong, the average rainfall during the main rainy season (four months each with more than four inches) would be ample for crop production if it were reliable and if it were all absorbed into the soil ; and that in the second season would be almost sufficient. The opening up of the structure of the soil by cultivation and the provision of furrows and drainage ditches on the irrigated plots should considerably increase the efficiency of the rainfall ; irrigation will be required, in the main rainy season at least, mainly as a safeguard against unseasonal droughts. Investigations might usefully be carried out on the experimental station, however, to discover to what extent dry-land farming of these soils would be practicable ; land suitable for this work has been indicated on the map of the suggested layout (Map 9).

Recommendations for the crops which it is proposed should be grown are given below.

Crops mainly for consumption in the Gold Coast

Rice.—This crop would be grown by flood-irrigation. The chief requirements for this technique are land which is almost flat, a soil with an impervious substratum, and an abundant water supply. Since good yields depend on an even depth of flooding, it is essential that there should be no more than a fall of three inches in height between the upper and lower end of a paddy. A certain amount of levelling by heavy machinery might be required in the first stages to remove the major irregularities in surface relief. Thereafter, only the relatively minor operation of smoothing the paddy surface immediately prior to planting would be required, to ensure an even distribution of water to all parts of the paddy. Check banks and contour banks between paddies should be only as high as their function demands and should be broad-based, so that they can be over-ridden by mechanical implements during cultivation or harvesting, and so that their sides will not be trodden down by sheep grazing on them.

The irrigation régime in rice production varies according to whether the crop is cultivated by hand or by mechanical methods. In hand cultivation, the seed is sown in nursery plots from which the seedlings are transplanted to flooded paddies when they are four to six weeks old and about six to nine inches high. In mechanical cultivation, the seed can be drilled directly into the soil, as is the practice with other cereals ; or pre-germinated seed can be sown broadcast on already-flooded paddies.* After germination of the seed, the paddies are drained, and water is only applied in limited amounts for the next four to six weeks to encourage strong root development. Thereafter, in both mechanical and hand cultivation, the paddies are submerged for sixty to ninety days, the level of the water being gradually raised as the crop grows until a maximum depth of six to nine inches is reached. It has generally been considered essential to keep the water moving through the paddies during the period of submergence ; but experience on the Murrumbidgee Irrigation Areas in New South Wales, Australia (30), has shown that this practice is not required except in so far as water lost by evaporation, seepage and transpiration must be replaced. At the end of the growing period, the water is slowly withdrawn from the paddies to allow the crops to ripen and the ground to dry out for harvesting operations to be carried out.

One of the problems of mechanical cultivation of rice elsewhere has been that of weed control. Amongst the troublesome weeds are other species and varieties of rice. In the Gold Coast, besides the introduced *Oryza sativa* Linn. and the indigenous *O. glaberimma* Steud., both of which are cultivated, there also occur *O. Barthii* A. Chev. and *O. Stapfii* Roschev. The two latter, together with *O. glaberimma*, occur as weeds on rice plots or are found growing wild in grassy swamps, and are used for food in some districts in times of scarcity. These wild species, as well as certain red-grained varieties of *O. sativa*, are undesirable on cultivated paddies because of their habit of shedding the grain, their tendency to displace cultivated forms on continuously cultivated land, and, with some varieties, their objectionable awns or red colour. Red rices have a reputation as troublesome weeds on rice fields in the United States, Australia and British Guiana, and considerable effort is taken to eradicate them.

In hand cultivation weed control is achieved by transplanting seedlings from well-tended nursery plots to thoroughly-ploughed paddies. This gives the rice four to six weeks' advantage over weed growth on the paddies, and then, total submergence of the soil inhibits the growth of many types of weeds. Experience in British Guiana (31) and elsewhere has shown that mechanical cultivation can satisfactorily be carried out on flooded paddies and is an effective method

* In the United States, over ninety per cent. of the rice areas are now sown from aeroplanes : in this case, water-soaked seed is dropped into flooded paddies.

of checking weed growth. In the United States rice is reported often to be alternated with cattle in three-year rotations to limit infestation by undesirable weed rices, and a similar practice has been recommended for adoption on the Mahaicony/Abary Rice Development Scheme in British Guiana (32). Sheep are used for a similar purpose on the Murrumbidgee Irrigation Areas in Australia (33). It is recommended that stock might be used to aid weed control on the Accra plains, too. A further method of eliminating weed rices from cultivated fields is being attempted in the United States. Most red-grained varieties produce small grains, and so by selecting and growing long-grained varieties of white rice, it should be possible to separate mechanically the weed varieties from the grain set aside for seed (34).

The relative efficacy of hand and mechanical methods of cultivation should be investigated on the Pilot Area. It is pointed out, however, that hand cultivation demands a plentiful supply of cheap labour, so that if rice were to be grown on an extensive scale on the Accra plains, it would almost certainly be more economic to mechanize many of the cultural operations as has been done already on other large scale rice-producing areas in the United States, Australia and British Guiana (35). Conditions on the Accra plains can be considered particularly favourable for the mechanical cultivation of this crop, for apart from the suitability of the soils and topography, the seasonal distribution of rainfall would enable both the preparation of the soil and harvesting operations to be performed under dry conditions.

On the experimental station, small plots which formed part of manurial and varietal trials would have to be hand-reaped ; but experience would require to be gained with mechanical harvesting, as well as other operations, before extensive rice production could be engaged in on the Accra plains. Modern practice in harvesting is to use either combine-driers or ' headers ', although the use of both types of machinery must be regarded as being still in the process of investigation. It has been recommended on the Mahaicony/Abary Scheme that short-straw varieties of rice with little tendency to tiller should be selected and bred if combine harvesting is to be efficient (36).

Unlike some crops, it would be possible to grow rice continuously on the same land. Two crops could be produced in a year : the first, sown in March or early April, to be harvested in the short dry season from the middle of July to early September ; and a second, sown at the end of September or early in October, to be harvested in January or February. Alternatively, rice might be grown in rotation with one or more other crops. By preference, the crop grown in rotation should be one which improves the fertility and the structure of the soil. This factor is discussed below when crop rotation as a whole is dealt with. If rotation were practised, rice would be grown as the main crop, to be harvested in the main dry season, December to February.

The risk of increasing the incidence of malaria by the development of swamp rice production is not thought to be great, so long as proper precautions are taken. This matter has already been considered in an earlier section.

Sugarcane.—With the aid of irrigation and mechanical cultivation, first-class yields of sugarcane can confidently be expected on the Accra plains, for the

Black Clays are considered to be highly suitable for the production of this crop. Small amounts of inferior varieties, used for chewing, are, in fact, already grown by local farmers on soils liable to flooding.

Sugarcane varieties differ in the length of their growing period. So far as is known, the more-or-less recently-bred varieties obtained by the Department of Agriculture from the West Indies and Mauritius have an intermediate growing period of about eighteen months for plant canes, and twelve or thirteen months for ratoons. In Hawaii, where irrigation of sugarcane is practised, long-term canes, ripening after twenty-four months of growth, are employed. Importation and trial of the latter varieties is recommended. The length of the growing period determines the most suitable time for planting, since for maximum recovery of sugar it is necessary to reap the crop during a dry season. Except where unusual conditions prevail, it is customary to reap at least two ratoons before replanting, but it is thought very probable that, in the case of the soils of the Accra plains, many more than this number could profitably be reaped.

Sugarcane would be grown as a row crop. On the exceedingly heavy clays of the Accra plains it would be absolutely essential to provide means of drainage by a closely-spaced system of open field channels. Only on very porous soils is it possible with furrow irrigation to drain a field effectively by means of a single channel along its lower end.

The method which C. F. Charter has seen employed on heavy clays on Caroni Estate, Trinidad, and Vieux Fort Estate, St. Lucia, is to furrow and ridge the field across the slope and then to dig parallel canals down the slope at right angles to the furrows and ridges, at distances varying from ten to twenty-two feet apart. Irrigation is achieved by blocking the drains at their lower ends and then leading irrigation water into them. The water fills the drains and then overflows along the furrows. This is done during dry periods. During wet periods, these canals are left open at their lower ends and do duty as drains.

Although this system works with a certain degree of success, it would appear to have several serious drawbacks. Firstly, although the furrowing can be done mechanically, the dual-purpose canals have to be dug by hand. Secondly, these canals interfere with mechanical operations such as inter-row cultivation, distribution of fertilizers, and harvesting. Thirdly, it does not seem the best practice, at least in very impervious soils, to use the same canals for both distribution and drainage of water.

It is suggested that the method to be described below, or some modification of this, be given trial on the heavy Black Clays. The field should be laid out in slightly cambered beds separated by open field drains twenty-five feet apart from centre to centre, and approximately two feet wide and deep. Five furrows, five feet apart from centre to centre, should then be made along the length of the beds. The furrows should be between nine and eighteen inches in depth, the actual depth required on these soils being a matter for investigation on the experimental station. Sugarcane is then planted in the furrows which, at a later stage, are filled in and made into ridges by the opening out of the original ridges (Fig. 7). All these operations can be performed mechanically. Irrigation is effected by joining each group of five furrows—after ridging, four—to the irrigation ditch serving the field. The length of the furrow in this particular type of field layout will have to be determined by trial ; as, however, the soil is impervious, lengths of up to 400 feet may be found practicable. During rainfall, surface drainage is effected along the furrows, and subsurface drainage laterally through the cultivated layer into the drainage channel. With this method the irrigation and drainage channels are kept separate and the use of mechanical implements is made possible. Modifications which suggest themselves, besides furrow depth, are width of bed between the parallel drains, and the number of furrows to a bed. Similar provision for drainage would have to be made for other crops to be irrigated by furrows ; but whereas sugarcane furrows would need to be five feet apart, those for other crops could be more narrowly spaced.

The suggestions made above apply more particularly to the plots located on Akuse (normal) soils. On the shallower (Prampram) soils, furrows no more than nine inches deep and running slightly off the contour should be used. Cambered beds would not be necessary, nor their construction practicable.

In formal field trials testing cultural methods, crop spacing, time of planting and application of fertilizers, reaping would have to be done by hand ; but it has to be borne in mind that if cane is later to be produced on an extensive scale on the Accra plains it might be essential to do as much of the harvesting as possible by mechanized methods. Mechanical cane-cutting, as well as mechanical methods of planting, weeding and applying fertilizers, should therefore be investigated at an early stage on the experimental station.

Tobacco.—The best known tobacco soils of the world are all light-textured, well-drained and acidic—very different in character from the Black Clays of the Accra plains. It seems, in fact, to be advantageous to grow the crop on infertile, sandy soils, for then the nutrient status of the soil can be artificially controlled by the addition of fertilizers, and a crop of standard quality produced. With one exception, ' bright ' tobacco—the type used in cigarette manufacture—is only produced on deep, light sands ; normally, the heavier textured the soil, then the darker and more aromatic is the tobacco produced. The exception noted is the tropical and subtropical Black Clays, light-coloured leaf being produced on these soils under irrigation in South Africa (23) and probably also in East Africa. As mentioned above, approximately 150 square miles of the Black Clays of the Guntur area in Madras Presidency, India, surveyed by Dr. Piekenbrock, are devoted to the production of Virginia tobacco. It is recommended, therefore, that two experimental plots should be sited on the Pilot Area, one each on Akuse (normal) and (Prampram) soils.

Since tobacco is not tolerant of waterlogged conditions, the crop should be grown on high ridges between furrows as deep as are practicable. Irrigation water should only be permitted to flow down the furrows at shallow depths. In this way, the soil in the ridges should dry out quickly and crumble to a granular structure giving good aeration to the roots. Tobacco is an exhausting crop, and would probably require relatively heavy applications of fertilizers.

The crop should be planted in nursery beds in late September and transplanted to the fields when four to six weeks old. Picking would commence in

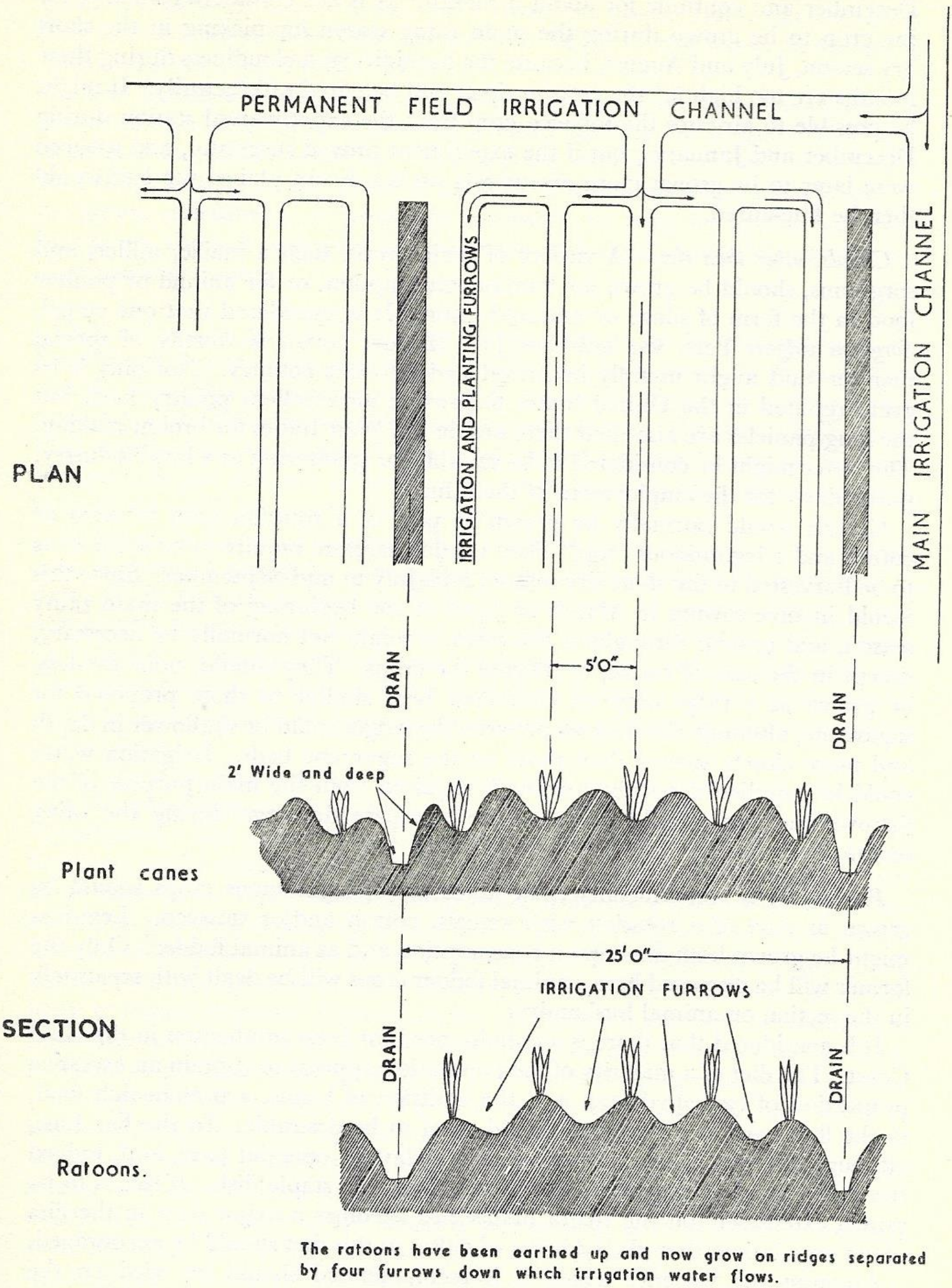


Fig. 7. The method of laying out ridges and irrigation furrows on beds separated by drains ; suitable for rowcrops such as sugarcane, etc.

December and continue for about a month. It is not considered suitable for the crop to be grown during the main rainy season for picking in the short dry season, July and August, because the humidity and cloudiness during these months are too high for the crop to ripen and be cured satisfactorily. It might be possible to air-cure the tobacco crop from the experimental station during December and January ; but if the experiment proved successful, and tobacco were later to be grown more extensively on the Accra plains, the leaf would then be flue-cured.

Cereals, other than rice.—A variety of grain crops, such a maize, millets and sorghums, should be grown for human consumption, or for animal or poultry food in the form of silage or matured grain. It is considered that one cereal, *Sorghum vulgare* Pers. var *technicum* Jav. (Broom corn), is worthy of special mention and might usefully be introduced into this country. Not only is its grain reputed in the United States to provide an excellent poultry food, but the long panicles are also used there and in the West Indies for broom-making. The latter might be considered to be suitable for sponsoring as a local industry, particularly for the employment of the blind.

Cereals would normally be grown as part of a rotation with tobacco or cotton and a leguminous crop. They would therefore require to be sown so as to be harvested in the short dry season, mid-July to mid-September. Since this would involve sowing in March or April at the beginning of the main rainy season, and growth throughout the rains, it might not normally be necessary, except in the case of maize, to irrigate the crops. They should, none-the-less, be grown as a ridge crop on cambered beds similar to those proposed for sugarcane, although the furrows between the ridges could be shallower in depth and more closely spaced than those on the sugarcane beds. Irrigation water could be supplied down the furrows if required ; but the main purpose of the furrows and beds would be to ensure adequate drainage during the rainy season.

Pulses.—It is recommended that a variety of leguminous crops should be grown as part of a rotation with cereals, cotton and/or tobacco. Legumes might be grown both for human consumption and as animal fodder. Only the former will be discussed here ; animal fodder crops will be dealt with separately in the section on animal husbandry.

It is considered that there is a definite need for bean production in the Gold Coast. The diet of a majority of the population appears to contain an excessive proportion of carbohydrates, and the addition of beans, a protein-rich food, to the foods customarily eaten would seem to be desirable. In the Far East, although the diet is based on rice, pulses play an essential part, and, indeed rice and beans are customarily eaten together as a staple dish. If rice is to be grown extensively on the Accra plains and becomes a major item in the diet of the population, then the addition of pulses to this diet should be encouraged.

Amongst the varieties which it is recommended should be tried on the experimental station are the following : pigeon peas (*Cajanus cajan* Millsp.) ; cow peas (*Vigna sinensis* Savi.) ; some of the tried, red, tropical varieties of kidney bean (*Phaseolus vulgaris* Linn.) ; black gram (*P. mungo* Linn.) ; green gram (*P. aureus* Roxb.) ; dwarf sieva bean (*P. lunatus* Linn. var. *lunonanus* Bailey) ; and sword bean (*Canavalia ensiformis* DC.). A trial might also be given to the soya bean (*Glycine Max* Merr.).

These legumes should be treated as row crops. They would normally be grown in the main rainy season and would need to be irrigated only if a deficiency in rainfall occurred. The spacing between the rows would vary with the character of the varieties grown. If leguminous crops were later to be grown extensively, it would be necessary to reap by special combine harvesters, and it is recommended that trials with these should be made on the experimental station.

Jute and similar fibres (37).—There would seem to be an advantage to the Gold Coast if cocoa bags, and sacks for other produce, could be made locally, and the possibility of growing jute or some equivalent fibre crop in the country to supply a local factory should be seriously entertained. If a fibre of sufficiently high quality could be produced, exports of the raw material might also be made to supply the jute industry in Britain or in other countries, although competition in this field might be expected to be intense.

Although in Eastern Pakistan, which produces by far the bulk of the world's jute, the crop is grown on alluvial loams containing little or no carbonate of lime, C. F. Charter is familiar with *Corchorus* spp. as a weed which grows abundantly on sugarcane fields on calcareous clays in Trinidad and Antigua. In Pakistan, *C. olitorius* is grown only on light-textured, well-drained soils, but *C. capsularis* is stated to be unaffected by shallow flooding. It would seem worth while to make trial of at least the latter species under the conditions which prevail here.

In Pakistan, jute is grown on the same land as, and in rotation with, rice, and the possibility of adopting this practice on the Accra plains should be investigated. The crop is stated to be exhausting on the soil, and the use of fertilizers would seem to be required if large scale commercial production were to be made here. The Pakistan jute-growing areas enjoy more than two inches of rainfall per week during the major part of the growing season, and a certain amount of irrigation would probably be required for production on the Accra plains. The crop is not tolerant of flooding to the same extent as rice, since this tends to induce stem-rot. If grown on the rice paddies, therefore, it would seem preferable to irrigate the crop by running small amounts of water over the fields at frequent intervals rather than by the continuous flooding practised with rice.

In Eastern Pakistan the crop is grown entirely by peasant farmers, but it is not considered that this method of production would be practicable in the Gold Coast where there is none of the traditional skill required in harvesting, retting and decortication of the fibre. If commercial production were to be undertaken here, many of the stages of production, such as drilling, weeding and thinning, manuring, reaping and decortication, might need to be mechanized. The use of chemical methods of retting the fibre might be investigated, although with irrigation water available, this operation could be simply performed in tanks built for the purpose on or near the fields. It is recommended that before large scale production might be attempted, advice on the growing, preparation and spinning of the fibre should be sought from an expert from the jute industry.

Since Egyptian cotton is recommended below as one of the main crops which it might be possible to grow on the Accra plains, it would not seem advisable to encourage the production of jute substitutes such as *Urena lobata* Linn. and *Hibiscus cannabinus* Linn. since these plants would provide alternative hosts for cotton pests and so increase the costs and difficulties of producing this crop.

Crops mainly for export

Cotton.—Although it might be possible on the Accra plains to produce food crops in excess of requirements in the Gold Coast and to sell the surplus outside the country, this would not be the chief aim in the production of these crops. It would be essential, however, to grow some crops for export in order to provide overseas currency for imports of machinery and fertilizers. It is considered that cotton would be the crop which could best be grown for this purpose, although it might take a considerable number of years of initial research before a saleable product could be marketed.

Cotton would be cultivated in fields irrigated by the furrow method. It would be planted in ridges, the height and spacing of which under local soil conditions will require to be determined. Climatic conditions necessary at the time of boll-formation determine the period of the year during which the crop might be grown. It would need to be planted in June and picked in January and February, the driest months of the year. Prior to the planting of the crop, the soil should be saturated with water, and then, during growth, irrigation should only be practised when signs of wilting become apparent. Excessive irrigation at this stage does not promote sturdy growth. Water should be added more liberally when blooming begins. Irrigation should be discontinued when boll-formation starts, because excess of water at this time delays the opening of the bolls and encourages premature shedding.

It is recommended that, with certain modifications, the proposals contained in paragraphs 25 to 31 and in paragraph 76 of the Cotton Mission's report (2) should be implemented. It was there suggested that trials should be made on the Accra plains with Egyptian long-staple varieties as well as a perennial variety, *marie-galante*,* already found growing locally ; and that it would be necessary to eradicate from the neighbourhood alternative plant hosts of cotton pests. This latter point will be discussed in a later section ; but it is necessary to state here that amongst the plants which it would seem desirable to eradicate are wild cotton plants, including *marie-galante*. It is considered that it would not be advisable therefore to cultivate a perennial cotton like *marie-galante* which might carry crop pests through from one season to another to affect not only its own production but also that from annual cottons.

Crops mainly for consumption by staff and labour on the irrigation and other regional development projects

No matter under what form of organization the Accra plains might eventually be developed, it would seem advisable, if not essential, to provide facilities for

* *Gossypium hirsutum* Linn. var. *marie-galante* Watt.

the labourers or farmers working the scheme to grow a certain amount of their own traditional food crops. It might also be necessary to grow similar crops to supply the large labour force which will be required in constructing the harbour, dam, factories, roads, railways and irrigation works in the locality. At an early stage, then, small scale trials should be made on the experimental station to discover how the production of these crops might best be fitted into the major programme, and how the benefits of mechanical cultivation and irrigation might be applied. The crops might best be produced by the labourers themselves ; or it might be found more economical to produce the crops by 'plantation' methods.

The crops which it is suggested might be tried are : plantains, cassava, yams, cocoyams, sweet potatoes, groundnuts, bambarra beans, tomatoes, okros, and peppers. Some of these crops could probably be fitted into rotations occasionally. They would not be fertilized directly but would exploit the residual fertility from previous manurings or from previous leguminous crops. The crops would normally rely upon rainfall, but arrangements could be made to provide irrigation in times of drought or if the production of any particular crop was thought to be sufficiently important to warrant the expense.

Not all the crops are suited to the heavy Black Clays, particularly where these are deep. Ground provisions such as yams, cassava and groundnuts, if grown at all, would require to be cultivated on high ridges similar to those already advised for the cultivation of tobacco. Plantains, however, could be grown by basin irrigation. It might be that the growing of these subsistence crops would provide a partial solution to the problem of using the shallower Prampram and Kloyo soils. On these soils, too, trials might usefully be made with pineapples, pawpaws, oranges and mangoes, as well as trees for the production of firewood and charcoal.

Crop rotation.—Rice and sugarcane could be produced continuously on the same land. The other major crops to be grown, cotton and tobacco, would only occupy the ground for half the year at the most, and it is considered that it would be advisable to occupy this in the meantime with other subsidiary crops. It will be the purpose of the experimental station to work out the most suitable systems of crop rotation.

It will later be recommended that animal husbandry should play a large part in the economy of the Accra plains, and it would be essential for the implementation of this scheme to produce large quantities of fodder crops by irrigation. Important amongst the fodder crops would be various legumes. Some of these, as well as the legumes grown for human nutrition, would be ideal plants to grow in rotation with the major crops because of their enrichment of the soil by the addition of nitrogen.

The possibilities of growing rice and jute in rotation has already been mentioned. Rice yields might also benefit from rotation with leguminous fodder crops, not only from the addition of nitrogen to the soil, but also because the growing of a 'dryland' crop would enable the soil to crack and moulder down, and so improve the soil structure as a preliminary to drilling and establishment. Cotton might benefit from a three-fold rotation : cotton planted in June and picked in January and February ; grains planted in March and April and harvested in August ; and legumes, planted in September, and reaped or grazed until the preparation of the land for another cotton crop in May. Certain subsistence crops might also occasionally be fitted into rotations with legumes and major crops.

Fertilizers.—Since the land will be continuously cropped, it will almost certainly be necessary to apply complete fertilizers, the more so because of the reduced availability of certain essential nutrients in soils containing large amounts of calcium carbonate. Investigations should be made into the relative efficacy of various methods of applying fertilizers. In some cases it might be possible to distribute fertilizers by adding them to the irrigation water. There will also, at a later stage, be considerable scope for fertilizer trials on the Black Clays soils. It will be necessary to correlate these trials with soil analyses. Provision will also be required, in connection with fertility trials, for analyses to be made of irrigation water entering and drainage water leaving the irrigated areas to ensure both that there is economy in the use of fertilizers and, at the same time, that there is no undue accumulation of harmful salts in the irrigated soils.

Fertilizers would undoubtedly have to be imported into the country in large quantities. They would require to be paid for out of exports of the crops they would help to grow on the Accra plains. The possibility that the manufacture of fertilizers in this country might in the future be practicable with the aid of hydro-electric power from the Volta dam should be borne in mind. This would more particularly make possible the production of nitrogenous fertilizers by the fixation of atmospheric nitrogen. Local production of other fertilizers would depend upon the availability of suitable minerals within economic range of the manufacturing plant.

The practice of green manuring is not, on the whole, favoured, since to plough large quantities of undecomposed organic matter into these heavy clays might actually diminish the yields of the succeeding crop by inducing competition for nitrogen between the needs of growing plants and those of bacteria carrying on the decomposition processes. If leguminous cover crops were to be grown they should be close-grazed or reaped for fodder before the field was ploughed and prepared for the succeeding crop. The nitrogenous nodules and the roots themselves would, in decomposing, considerably enrich the soil. If the suggestions to be made later regarding animal husbandry were to be implemented there would also be abundant supplies of farmyard manure available.

Pest and weed control.—Considerable research will be required into means of controlling the numerous pests and diseases which are likely to affect the crops to be grown. In the particular case of cotton, it would be necessary to eradicate from the neighbourhood of the cultivated areas the alternative hosts of certain pests, particularly the cotton stainer. Plants serving as alternative hosts and found in the neighbourhood of the Pilot Area and locally throughout the Accra plains include the silk-cotton (*Ceiba pentandra* Gaertn.), bombax (*Bombax* *buonopozense* P. Beauv.) and baobab trees (*Adansonia digitata* Linn.), as well as certain smaller, wild cotton plants, amongst them *marie-galante*.

Protection might have to be afforded to trial plots on the Pilot Area against possible damage by baboons and monkeys which live on Krobo Hill, but carry out their depredations over a wide area. When the Accra plains as a whole is developed, it will be necessary to exterminate these animals from their refuges on the rocky inselbergs. Similarly, protection might be required against such rodents as the cutting grass or cane-rat (*Thryonomys swinderianus* Temm.), and a hare (? *Lepus zechi* Matschie.), both of which are found in the neighbourhood of the Pilot Area.

Local farmers who have attempted to grow rice on the Volta floodplain complain of the damage done to the crop by flocks of birds, presumably one of the weaver birds. This problem is commonly encountered when small isolated plots of a grain crop are cultivated. Protection would have to be sought on the experimental station by hiring small children to scare the birds away from the plots.

Weed control measures on cultivated plots have already been discussed when dealing with the crops to be grown. They include alternation of flood-irrigated and dry land crops on rice paddies, transplanting of rice or tobacco seedlings from nurseries onto prepared land, the promotion of a complete ground cover by the crop being grown and the grazing of sheep on ditch banks and bunds. The use of chemical and hormone weed killers might require to be investigated at some time in the future.

Weed control in irrigation and drainage canals presents a serious problem wherever open channels are used, and is responsible for a large part of the maintenance costs on an irrigation scheme. A variety of control measures are in use throughout the world ; but weed growth can perhaps most effectively be limited by the use of bituminous or concrete linings to canals. Although initial costs are high, the use of such lined canals effects considerable economies by reducing maintenance costs and the wastage of water by seepage.

Machinery.—It has already been advised when discussing the cultivation characteristics of Akuse (normal) and (Prampram) soils in Part II of this report that heavy mechanical equipment will be required to cultivate these soils successfully. Heavy equipment will be required in the first instance to prepare the land for cultivation : bulldozers will be needed to clear termite mounds and small trees, and to eliminate the minor irregularities in the ground surface, particularly on the future rice paddies ; heavy ' bush ' ploughs will be needed to deal with the wide-spreading surface roots of trees and coppice shoots ; and ditchers will be needed to excavate drainage channels, such as those which it has been recommended will be essential on the furrow-irrigated fields.

The Black Clays will demand the use of powerful tractors fitted with broad ' crawler ' tracks. High-clearance tractors will be required for cultural operations during crop growth, such as weeding and reshaping of the furrows. Implements should be attached directly to the tractor and raised or lowered by a hydraulic lift worked from the power take-off. By this means tractors could be given greater manoeuvrability in the irregular-shaped and small-sized fields probably demanded by irrigation. Only the heaviest equipment, such as sugar-discs, would require to be hauled by a draw-bar attachment. For the heavy ploughing required in the preparation of sugarcane fields it would probably be simpler to plough the whole sugarcane area as a unit, and erect the bunds and excavate the drainage channels afterwards. This operation, however, would only need to be carried out at relatively long intervals when replanting became necessary. A variety of combine harvesters for different crops should also be experimented with. The use of such heavy equipment as has been recommended will undoubtedly be uneconomic on the Pilot Area : but it is considered essential that various models should be tried there for their suitability under local conditions, for if the Accra plains are ever to be developed effectively, then machinery will require to be used on an extensive scale.

It is considered unlikely that, with a few exceptions, the equipment required will be obtainable from Britain. Although British agriculture is mechanized to a far greater extent than any in the world, research into design of implements has been largely to suit British conditions, vastly different from those met with in the tropics. A notable exception to this has been the production of sugar ploughs and gyro-tillers. Attention will require to be directed to the United States, particularly for implements designed for use in Hawaii, where modern mechanized agriculture, based on the crawler tractor, started. We particularly recommend investigating the possibilities of obtaining Killefer equipment and Athey trucks, the latter designed for, and used since before World War I, in sugarcane fields on heavy soils in Louisiana.

ANIMAL HUSBANDRY

Introduction

No scheme for agricultural development on the Accra plains should be concerned solely with crop production : an important contribution could, and should, be made by animal husbandry. Crop and animal husbandry should at all times be closely co-ordinated. Animals, besides themselves providing protein food for human consumption, could aid crop production by grazing fields and non-cultivated areas to control weed infestation, and by supplying farmyard manure. They could also effect economies in the costs of crop production by consuming waste products such as sugarcane tops, rice bran and the residues of sugar extraction and cotton-ginning, and by grazing leguminous cover crops.

It is the considered opinion of this Department that the stock-carrying capacity of the Accra plains could be greatly increased and that investigations to this end should be undertaken at an early date. As in the case with crop production, stock-farming would have to be carried out under the control of a development corporation if substantial progress were to be achieved. Both beef and dairy cattle could be kept. Beef cattle would graze extensively as at present, but a great deal of pasture improvement would be required for profitable returns to be obtained. Dairy cattle would be fed more particularly on artificial pastures and on fodder crops grown as part of a rotation system on the irrigated areas. Waste products from sugar production and cotton-ginning would provide useful concentrates. Allied with this improvement in quality of feeding stuffs there should go improvement in the quality of the beasts kept. With modern scientific methods of stock management, which control by a development corporation would permit, it should be possible to rear animals for meat and for milk production consisting of crosses between hardy indigenous stock and European breeds, as has been done elsewhere in the tropics.

Mutton could also be produced. Sheep can play an important part in irrigation agriculture by grazing fields, banks and ditches to control weed-growth (38). They could usefully be fattened by being allowed to close-graze leguminous cover crops before these were ploughed in. Here again, better feeding conditions and more scientific management should justify improvement of the local stock by crossing with selected introduced breeds.

The possibility of instituting large scale poultry farming should also be investigated : suitable grains for feeding-stuffs are included in the crops recommended for trial, and bran from the polishing of rice would also be available.

Sheep and poultry raising will not be considered further here, but extensive treatment is given below to ways of improving cattle feeding stuffs. It is recommended that investigatory work to this end should be carried out, or should at least be commenced, on the Pilot Area. Since few of the grasses and herbs growing on the Accra plains at present can be considered to be of great value for grazing or for fodder, it is recommended that proven grazing and fodder species should be introduced from other parts of the tropics where the climate and soil conditions are similar. A review of the principal grazing plants indigenous on the Accra plains and of those it is recommended should be introduced to the region is given below.

A review of indigenous and exotic fodder and grazing plants

Grasses.—The dominant grasses occurring on the Accra plains in the areas of heavy soils with impeded surface and/or internal drainage comprise : *Vetiveria fulvibarbis* Stapf, *Brachiaria falcifera* Stapf, *Monocymbium ceresiiforme* Stapf, *Andropogon canaliculatus* Schum. and, less prominently, *Schizachyrium semiberbe* Nees, *Cymbopogon giganteus* Chiov. and *Sporobolus pyramidalis* P. Beauv.

Vetiveria fulvibarbis appears not to be relished by stock at any stage of its growth and generally remains ungrazed except in times of emergency. *Monocymbium ceresiiforme* is stated in some parts of Africa to provide good hay. Its nutrient value is not known and it produces very little bulk. Much the same can be stated of *Brachiaria falcifera*. The two grasses *Schizachyrium semiberbe* and *Sporobolus pyramidalis* are not considered as amongst the best fodder and grazing plants since they too easily become tough with age. *Sporobolus indicus* R. Br., which closely resembles *S. pyramidalis*, is a dry-rangeland grazing plant of some value, but, again, mainly in its young stages before flowering. *Cymbopogon* *giganteus* is a bulky ' sourgrass ' containing a bitter, aromatic, essential oil. Such grasses elsewhere in the neo-tropics, e.g. *Andropogon pertusus* (Linn.) Willd. and *A. saccharoides* Swartz, are not relished by stock, and are usually only eaten when more palatable fodder is scarce.

The dominant grasses on the Volta floodplain comprise species of *Panicum* and *Andropogon* as yet unidentified, and *Echinochloa pyramidalis* Hitchc. and Chase. All of these produce excellent fodder when young.

The well-known fodder grasses, *Panicum maximum* Jacq. and *Andropogon Gayanus* Kunth, typically grow on well-drained, light-textured soils. The former is frequently seen growing on the disturbed soils along the sides of roads and the latter on abandoned farmland in savannah areas.

Amongst the species which it is considered should be introduced are : *Andropogon caricosus* Linn. and *A. nodosus* (Willem.) Nash, both producing a sward ; *Panicum purpurascens* Raddi (previously—and better—known as *P. barbinode* Trin.) ; and, possibly, *Paspalum fasciculatum* Willd. All these species grow well on heavy, ill-drained soils with good lime-status such as occur on the Accra plains. (These soils comprise not only the Black Clays, but others, too : together, they cover almost half the total area of the Accra plains.) *Panicum purpurascens* is actually an African grass which has made its reputation in the New World tropics : it is probably amongst the unidentified species of *Panicum* collected on the Volta floodplain.

Legumes.—So far as indigenous legumes are concerned the picture is disappointing, although as many as 45 different species of papilionaceous herbs have been collected during the Reconnaissance Soil Survey of the Accra Plains. It is unfortunate that the dominant genera amongst these are *Crotalaria, Tephrosia* and *Indigofera*. Species of the first one are not eaten by stock at all, and may be poisonous, although many form some of the best tropical cover crops. Some of the species of *Tephrosia* are well known to be poisonous, and the remainder, as well as the species of *Indigofera*, are not placed amongst the major leguminous fodders of the tropics.

Amongst the Papilionaceae found growing locally on the Accra plains which it is considered should be encouraged, are the following : *Alysicarpus* spp., *Stylosanthes erecta* P. de Beauv., *Zornia diphylla* Pers., *Rhynchosia minima* DC., *Desmodium triflorum* DC., *Teramnus labialis* Spreng., and *Centrosema pubescens* Benth. The latter (or ? *C. virginianum* Benth.) has already proved its value in experiments at Asuansi Agricultural Station where, under forest conditions, it grew so vigorously that eighty head of sheep, grazing eight acres of it continuously, were unable to check its growth (39).

Amongst the exotic fodder legumes which could be introduced with advantage are the upright *Phaseolus semierectus* Linn. and *Stylosanthes mucronata* Bak., and the following twiners : *Dolichos hosei* Craib., *D. biflorus* Linn., *D. Lablab* Linn., *Clitoria Ternatea* Linn., and *Centrosema virginianum* Benth. (often confused with *C. pubescens* Benth.). Soil conditions are not suitable for the production of *Medicago sativa* Linn. (lucerne or alfalfa).

Browse-shrubs.—Again, very little is known in the Gold Coast of the value to stock of the foliage of indigenous trees and shrubs, only *Afzelia africana* Smith being mentioned in the literature in this respect. Amongst browse-shrubs that should prove useful is *Leucaena glauca* Benth.* already introduced for cocoa shade. It makes a valuable fodder, and its seeds—copiously produced—a protein-rich concentrate. Another drought-resistant browse-shrub well worthy of introduction and suited to the conditions is *Prosopis juliflora* DC., the foliage and pods of which provide valuable cattle fodder.

Fodder production, pasture improvement and management of rough-grazing

Stock could be raised by being fed on fodder crops, by grazing artificial pastures, or by extensive grazing of rough pasture ('rangeland' in the American terminology). Since these demand rather different techniques of management, they will be treated under separate headings below. Normally, of course, stock would feed on all three from time to time. Beef cattle would depend more particularly on extensive grazing of rough pasture, but might be fattened for sale by being grazed on improved pastures and by being supplied with fodder. They would rely on the latter during dry seasons, too, when rough-grazing would be scanty. Dairy cattle, on the other hand, would probably depend almost entirely on fodder and on the grazing of improved pastures.

Fodder crops.—The production techniques for these would have much in common with those for other cultivated crops. Fodder crops would normally be grown as part of a rotation system with one or more other crops, and would be irrigated either by flood or furrow methods. They might be required to rely on the residual fertility in the soil from previous manurings ; but the response to fertilizers should also be investigated.

Fodder crops in the tropics appear usually to be grown in pure stands of one species. It is considered, however, that it would be better to follow the British practice of growing a balanced mixture of grasses, legumes and herbs together. Grasses provide proteins and carbohydrates, the former mainly in the young growing-points, but they are deficient in mineral bases : the latter can be supplied by legumes and herbs. By growing a suitable mixture of fodder plants, a balanced diet can be arranged. Moreover, it is considered sound tropical practice to interplant legumes with subsistence crops, since the former are able to exploit and render available soil nutrients otherwise almost or completely inaccessible to the other plants. Similarly, in fodder production, the inclusion of legumes would make available to grasses and herbs nutrients which might otherwise need to be supplied as fertilizers. The mixture of plants grown could be arranged in two ways : short or medium-height grasses could be interplanted with erect legumes and herbs ; or tall grasses could be planted which would support leguminous and other herbaceous twiners.

Investigations will be required on the Pilot Area to devise suitably balanced mixtures of fodder crops. It will also be necessary to discover the time of

* All literature dealing with this plant mentions the extraordinary depilatory effect this has on the *Equidae*. This is probably merely an oft-quoted tale, for this effect has never been observed by C. F. Charter in territory where both *Leucaena glauca* and horses, mules and donkeys were abundant.

sowing, and the place of fodder crops in various rotation systems ; their fertilizer and water requirements ; the time and number of reapings possible ; methods of applying irrigation water ; and methods of mechanized cultivation and reaping.

Artificial pastures.—It should be the aim in creating pastures for intensive grazing to provide, by the introduction of suitable species, a complete sward in place of the sparse, tussocky cover which exists on the plains at present. As with the growing of fodder crops, too, it would be advantageous to provide a balanced feed by interplanting grasses, legumes and herbs. Investigations are required to discover the species most tolerant of intensive grazing.

The need for irrigation and the most suitable methods of effecting it should be determined. Water can safely be allowed to run over the ground-surface, as in flood- (or border-) irrigation, even on relatively steep slopes, if a complete sward is achieved. It would be necessary only to provide occasional contour check banks to control the flow of the water and to encourage its absorption into the soil. Such banks might very well be combined with interceptor drains, the need for which has already been expressed.

Investigations are also required to discover the need for fertilizers, for cultivation of the surface soil, and for weed control, and to discover the relative practicability of permanent pastures and of temporary pastures sown as part of a rotation system.

Rough-grazing.—There is scope for a considerable amount of research into the management of rough-grazing land. This is a technique which appears to have been almost completely ignored in British colonies, but the importance of which has been recognized in America and some of the Dominions.

As with fodder crops and artificial pastures, so with rough-grazing : the most desirable aim in management should be to produce a balanced feed for stock. Investigations are needed to discover which browse-plants are used by animals. These plants could be encouraged in rough-grazing, whereas this would be impractical in the case of artificial pastures, unless the shrubs or trees were grown as a hedge to provide, at the same time, food, shade to the animals and protection to banks or drains against trampling. The possibility of artificially seeding and manuring rough-grazing, which might in the future be desirable, should receive investigation, as should also the value and practicability of providing contour check banks and/or interceptor drains to improve the effectiveness of rainfall. Rough-grazing would seem to be a suitable form of utilization for some of the less easily cultivable Prampram and Kloyo soils.

The value of burning in rangeland management is a matter of controversy. This is a matter, too, which should receive attention on the Pilot Area. It can be argued that burning is wasteful in that the ash of the burnt vegetation, with such mineral nutrients as it contains, is washed away in the drainage water during the first succeeding rainstorm so that the soil is constantly being depleted of its bases. Burning, too, leaves the ground surface bare for quite a considerable period, which results in unnecessary drying out of the soil and may encourage accelerated soil erosion. There may be danger, also, of uncontrolled fire spreading to cultivated cropland and to settlements.

On the other hand, it can be said in favour of burning that it is a simple method of preventing the growth of trees in grazing areas. It is also efficaceous in clearing old flowering stems and leaves of grasses and herbs, and in stimulating new growth ; for, despite continuous grazing, all grasses and herbs reach a stage in the year when they become tough, unpalatable and probably of little nutritional value to stock. The influence of burning on the floristic composition of savannah is not known, except in so far as it tends to inhibit the growth of trees.

Further considerations

Such investigations as have been recommended could very suitably be carried out on the Pilot Area. A large part of the square mile would not be used for cultivation, and could be devoted to this work. It would be necessary in the first instance to grow suitable indigenous and exotic fodder and grazing plants solely for the multiplication of seed. When sufficient of this was available, grassland investigations could begin. Plots for pasture experiments need only be small. In Hawaii such experiments are carried out on plots of one two-hundredth or one two-hundred-and-fiftieth of an acre. Somewhat larger plots would probably be required for experiments with fodder crops and the taller grasses.

The aim in fodder production and pasture improvement must be to provide quality rather than quantity. Many of the indigenous fodder grasses at present considered to be ' excellent ' are far too bulky and fibrous. In conjunction with investigations into methods of production of fodder crops and improvement of grazing, therefore, it will be essential to carry out stock feeding trials and chemical analysis of the nutritional value of the plants grown. It is pointed out that there is in the tropics an almost complete dearth of quantitative data on the nutritional value of fodder and grazing plants, and their provision would be a major contribution to the development and improvement of stock-raising in other regions besides the Accra plains.

The possibility of using natural supplies of water for flood irrigation of pastures and fodder crops should be investigated. This work could be carried out on the Okwe-Volta floodplain in the north of the Pilot Area, utilizing not only water from the two rivers when in flood, but also sheetflood water coming down from the slopes to the south during rainstorms.

These grassland investigations are regarded as of the highest importance. Whether the major scheme for the irrigation of the Accra plains goes ahead or not, a great improvement in the productivity of the region could be achieved by more rational methods of stock farming. Ways should be studied of applying techniques of improving pastures and producing fodder crops to large areas of the Accra plains. If the results of investigations with the use of natural water supplies for irrigation of pastures and fodder crops on the Pilot Area were encouraging, similar techniques might be applied at a relatively early date to other valleys on the Accra plains. It might be necessary in these valleys to impound water for irrigation and stock behind small earth dams. Such development would provide a useful prelude to the opening up of the whole region by irrigation.

It is essential that work on the Pilot Area should be co-ordinated with that being undertaken at present by the Department of Animal Health on their Nungwa stock farm.

STAFF

The Kpong Pilot Irrigation Area presents opportunities for investigations into irrigated and mechanized agriculture of the greatest importance. Not only can these provide information on which the future development of the Black Clays and, indeed, of the whole of the Accra plains will depend, but the results will be applicable in greater or lesser degree to other areas throughout the Gold Coast where irrigated agriculture might be commenced at a later date. This being so, it is highly important that the staff working on the experimental station should include suitably qualified and experienced specialists who would be sufficiently numerous to tackle the investigations needed.

The staff suggested is as follows* :—

Senior Officers

Officer in Charge.
Agricultural Engineer (Land).
Agricultural Engineer (Machinery and farm structures).
Agricultural Chemist.
Officer in Charge, Plant Husbandry.
Officer in Charge, Animal Husbandry.
Officer in Charge, Agricultural Hydrology.

Junior Officers

There should be an adequate supporting staff of junior agricultural officers, including a First or Second Division Surveyor who would assist in the layout of fields, irrigation channels, drains, etc.

The Officer in Charge should be an all-round agriculturalist with experience of industrial agriculture, but with professional qualifications in agriculture as well. His experience should include that of mechanized agriculture and, if possible, irrigation agriculture. The requirement of industrial agricultural experience is important as the investigations proposed are not merely research *per se*, but research with the object of bringing extensive areas under mechanized and irrigated agriculture by economic means. The sort of officer which it is considered would fit the requirements would be a good cultivation manager of a tropical or subtropical plantation concerned with arable agriculture.

The post of Agricultural Engineer (Land) is regarded as particularly important. This officer would be responsible for the laying out of irrigation channels and drains, and for investigations to discover the most appropriate forms of field layout for the various crops under mechanized irrigation agriculture and on different soils and slopes. It is suggested that he might usefully be recruited from South Africa from amongst irrigation officers with practical experience on the Black Clays of that Dominion.

* The staff at present (1954) approved for the Kpong Irrigation Research Station comprises : an Agronomist, in overall charge of investigatory work, an Irrigation Engineer and a Soil Physicist. These officers are being contributed initially by F.A.O. but the Gold Coast Government intends to engage staff to understudy them and continue their work. A Senior Agricultural Officer (Irrigation) has been appointed to take charge of all agricultural operations on the Station.

The Agricultural Engineer (Machinery and farm structures) would have charge of tractors and machinery, and be responsible for trials to discover the equipment and techniques demanded by the soils, field layout and irrigation. He could be recruited from the United Kingdom. Some experience of the work would be desirable.

The duties of the Agricultural Chemist would include the determination of soil nutrient status, the conduct of fertilizer experiments, and the analysis of pasturage, fodders and other stock foods. He would be required to know something about the statistical analysis of field trials. He would not need an elaborate laboratory, but one mainly equipped to carry out soil nutrient determinations by some of the recently-elaborated rapid chemical methods. This officer could be recruited from the United Kingdom. It would be desirable that he should have had some post-graduate experience of soil fertility analysis and the conduct of fertilizer trials.

The Officer in Charge, Plant Husbandry would be required to carry out field trials on the various crops being grown, such as time of planting, spacing, time of reaping, as well as variety trials, for which it would also be necessary to have a knowledge of the statistical treatment of results. This officer could be recruited from the United Kingdom ; but one from South Africa with experience of tobacco culture would be preferable, especially if he was familiar with the cultivation of the Black Clays, too.

The Officer in Charge, Animal Husbandry would be responsible for the stock on the station. He would be required to make studies of extensive grazing on the Accra plains as a whole, as well as more intensive work on the experimental station on pastures, fodders, etc. He should be as much a range officer as a livestock officer in the British tradition. This officer, too, would probably have to be recruited from one of the Dominions, since livestock officers from Britain are likely to have little or no knowledge of range work unless they have had overseas experience.

The Agricultural Hydrologist would be responsible for studying all aspects of soil-moisture relationships. He would collect and treat the necessary data for the determination of water losses through evaporation and drainage. Laboratory space would be required for soil-moisture determinations. It would possibly be necessary to recruit an officer from the U.S.A. for this post : similar posts exist in the Department of Public Works, California.

These officers would not all be required from the beginning. The Officer in Charge, the Agricultural Engineer (Land), the Agricultural Chemist, the Agricultural Hydrologist and the First or Second Division Surveyor together with other junior personnel would form the initial staff. The remaining senior staff would not be required until the second year of work.*

In addition to their investigations on the Pilot Area, it is envisaged that these officers would carry out suitable exploratory investigations throughout the

* Since the first manuscript edition of this report was prepared (June, 1952), the Food and Agriculture Organization of the United Nations has been approached regarding the provision of suitable technical experts for the Kpong Pilot Irrigation Scheme, and arrangements have been made for three men—an agronomist, an irrigation engineer and a soil physicist—to come out for a period of two years commencing from the second half of 1954. In addition, the Department of Agriculture has provided a Development Officer who will act as farm manager when the experts assume duty : at present he is supervising the laying of the delivery pipeline and the construction of buildings.

extent of the Accra plains to collect, *inter alia*, appropriate data on evaporation, drainage and soils, and to conduct grazing trials on the grassland developed over the various soils. They could, with this experience, form a scientific advance-party for the development of the Accra plains as a whole ; for, if large scale mechanized, irrigation agriculture is to be developed in this region, a permanent research staff will be required to deal with the numerous technical problems which will continually arise. This staff could suitably be employed by the Gold Coast Agricultural and Fisheries Development Corporation and, for technical control, be placed under the Director of Agriculture. Advice on pests and diseases could, as appropriate, be provided by the present staffs of the Department of Agriculture and the Department of Animal Health.

PHASES OF DEVELOPMENT ON THE KPONG PILOT EXPERIMENTAL STATION

Although a great deal of the experimental and investigational work on the Pilot Area could very well run concurrently, priority of attention should be given to certain factors which are of more immediate importance than others. The primary purposes of the Pilot Scheme are to learn how to handle the Black Clays under combined mechanized and irrigation agriculture, and to discover which crops can economically be produced on them by these methods. When this information has been gained, then more detailed experimental work such as manurial and varietal trials could proceed.

The suggested phasing of development and investigations on the Pilot Area is given below.

Phase I. Layout of Area (First 12 months)

General

(*a*) Initiation of a meteorological station for collection of evaporation data.
(*b*) Improvement of drainage outlet.
(*c*) Siting of interceptor drains.
(*d*) Construction of field access roads.

Crop husbandry

(*a*) Layout of distribution and drainage channels.
(*b*) Siting of fields to be cultivated, and clearance of obstructions on them.

Animal husbandry

(*a*) Siting of pastures.
(*b*) Introduction of exotic pasture and fodder plants for multiplication of seed.

Phase II. Field layout (Second and third years)

Crop husbandry

(*a*) Layout of field distribution channels.
(*b*) Construction of bunds, check banks, furrows and ridges, etc.

(c) Methods of tillage in preparation of fields for irrigation and planting.
(d) Methods of application of water.

Animal husbandry

(a) Layout of pastures for irrigation.
(b) Continuation of multiplication of seed.

Phase III. Determination of crops it is profitable to grow (To run more or less concurrently with Phase II)

Crop husbandry

(a) Field trials of crops proposed.
(b) Trials with cultivation machinery.

Animal husbandry

(a) Selection of main grasses and fodders.
(b) Continuation of multiplication of seed.
(c) Initiation of stock feeding trials.

Phase IV. Agronomy of selected crops (Fourth year onwards)

Crop husbandry

Experimental work to determine times of planting, crop-spacing, water requirements, manurial requirements, most suitable varieties, rotations, etc.

Animal husbandry

(a) Improvement of natural grazing by investigating :—
  (i) Methods of irrigation.
  (ii) Value of surface cultivation.
  (iii) Degree of grazing.
  (iv) Manuring.
(b) Development of artificial pastures by ' seeding-down ' with introduced grasses and legumes ; trials (i), (ii), (iii) and (iv), as in (a) above.
(c) Fodder production by :—
  (i) Improvement of natural grassland.
  (ii) Growth of special fodder varieties for hay, silage or direct feeding.
  (iii) Trials (i), (ii), (iii) and (iv), as in (a) above.
(d) Continuation of feeding trials.

APPLICATION OF THE RESULTS OF THE INVESTIGATIONS ON THE KPONG PILOT AREA TO THE FURTHER DEVELOPMENT OF THE ACCRA PLAINS

Under present conditions, the Pilot Area can be regarded as no more than an Irrigation Research Station. Extension of the findings of this research will depend on the future financial status of the country and on whether or not a high-level dam is constructed in the Volta gorge. Development on the Accra plains is in any case likely to be slow so long as cocoa farming gives such high returns for so little effort, and/or until there is greater pressure of population on the land than exists at present.

When extension from the Pilot Area becomes practicable, the Accra plains must be developed on a basis of small natural regions having adequate control over local drainage. These units should normally be complete drainage basins. Where the upper part of a drainage basin is outside the irrigated area, such as will be the case with the Okwe and Dodowa systems, development must proceed on a basis of tributary valleys within the area to be irrigated unless complete control of the drainage of the major valley can be effected from the point at which it enters the area to be developed. If the extensions to be made are small, then development should be made from the head of a drainage unit downstream so that control of drainage within the developed area is maintained at all stages.

Before any such extensions are made, detailed soil and topographical surveys will be required so that field layout and crop distribution can be efficiently planned. It is considered that the need for detailed soil surveys before further development is undertaken is amply demonstrated by the complex pattern of soils revealed by the survey made on the Pilot Area. In the case of the need for detailed topographical surveys, it is pointed out that there is evidence that in the United States of America and in Ceylon, before irrigation work in certain areas is undertaken, maps contoured at 1-foot or even 6-inch intervals are produced (40, 41).

In their final report (August 1951), the Consultants, Sir William Halcrow and Partners, tentatively proposed what they named a ' combined scheme ' to pipe water from the Volta to the new harbour town at Tema, and, at the same time, to irrigate land *en route* in order to produce food for the large numbers of workers required during the construction of the harbour (42). Suitable soils exist almost throughout the whole length of the route ; but it is considered that it would be highly inadvisable to proceed with such a scheme until sufficient knowledge of cultivation and irrigation techniques for the Black Clays had been gained on the Pilot Area to warrant a large scale extension of agriculture on these soils. It is impossible to predict what length of time will be required to collect this essential information, but much will depend on the numbers, quality and experience of the staff recruited for the task. It may be recalled, however, that the British West African Rice Mission (1948) considered that it might require 10 years' investigations on an experimental station before any larger project could be launched (43).

There is no reason why the ' combined scheme ' should not be the first step in the development of the Accra plains ; but, unless this scheme shows that it is economic to pump irrigation water from the Volta, it is likely that further development of crop production must await the building of the dam in the Volta gorge. Until this stage is reached, the most suitable line of development would appear to be that of stock raising. For this, controlled extensive grazing might be supplemented by the production of fodder crops in the valleys, probably with the aid of floodwater irrigation and mechanical cultivation if the investigations on the Pilot Area show this to be practicable.

If and when the high-level dam is built, the Black Clays belt should first be systematically developed before extension is made onto other soils of the Accra plains. Before such latter extension takes place, small experimental stations will require to be set up on the different soils to discover how far they demand new techniques. Generally speaking, extensive stock raising would normally precede irrigated crop production in any part of the region, and would diminish in relative importance as more and more land was brought under intensive agricultural development. This does not imply that crop husbandry would eventually supersede animal husbandry. It should not. Crop and animal husbandry would require at all times to be closely integrated if the scheme were to be run efficiently.

Development at all stages, from the initial investigations on the Kpong Irrigation Research Station onwards, should be directed, as has already been stated, by an Agricultural Development Corporation. This body would have absolute control over technical, financial and administrative affairs, and would run the scheme on industrial lines.

As development extended, however, a great deal of local autonomy could be given to subregional boards. Such boards would organize farming operations within, ideally, the whole of a natural drainage unit. The subregion would be subdivided into smaller areas in which farming would be the responsibility of local managers. The size of a local unit would depend on, *inter alia*, the amount of rough-grazing land included, but might normally be from two thousand to five thousand acres in extent. Such a unit, or ' estate ', would in effect comprise the area of land which could efficiently be organized by a local manager. These ' estates ', too, should so far as is possible be designed to have complete control over local drainage.

The subregion would be organized from a convenient town enjoying good communications internally with all parts of the area it commanded and, externally, with the region as a whole. This town would be the administrative, social and market centre of the subregion and might contain one or other of the sugar factories, cotton ginneries, etc., for the region as a whole, as well as smaller local industries. The ' estates ' would, in effect, be village settlements where the staff and labourers working the surrounding land would live.

The rôle of the development corporation would gradually change as development extended. It would still be entirely responsible for opening up new areas ; but in the areas already developed, it would only retain charge of the major irrigation structures, allocate irrigation water, direct research stations and perhaps still organize the marketing of produce.

The agricultural development scheme should at all stages be fully integrated with other development projects in the region, such as the construction and working of the harbour town at Tema, factory development at Kpong, and, particularly, with road and rail construction. Equally important, the latter must be planned from the beginning to serve the needs of agricultural development as well as those of industry.

There is the opportunity in this largely uninhabited and undeveloped region to practise rational land utilization from the outset. This principle should be firmly adhered to, for in so far as piecemeal and *ad hoc* schemes are allowed to interfere with planned development, by so much will the ultimate achievement fall short of the potentialities.

SUMMARY OF RECOMMENDATIONS

1. The Kpong Pilot Area should be regarded as an Agricultural Irrigation Research Station where techniques of cultivation and irrigation of the Black Clays unknown in this country at present, can be investigated. Many of the results of this work would be applicable to irrigation and development work elsewhere in the Gold Coast.

2. Agricultural development on the Accra plains should be by comprehensive, fully-integrated farming, organized from the beginning by an Agricultural Development Corporation.

3. The staff on the Irrigation Research Station should comprise a sufficient number of qualified and experienced officers of the correct categories to tackle the investigations needed. They should form a scientific advance-party for the development of the entire Accra plains.

4. Meteorological data should be collected both on the Pilot Area and at suitable places elsewhere on the Accra plains to provide information on evaporation which will be essential for the planning of agricultural and irrigational development.

5. Effective measures for control of surface drainage should be provided. Improvements to the drainage outlet of the Okwe stream should be made.

6. Priority of attention in investigational work on the Pilot Area should be given to elaborating suitable forms of field layout for mechanical cultivation and irrigation on different soils and slopes. Serious attention should be given to discovering means of utilizing Prampram soils, since these soils are intimately associated with deep Akuse soils throughout an important part of the Black Clays belt.

7. Attention should then be given to elaborating cultivation and irrigation techniques for the Black Clays.

8. One of the important functions of the Pilot Scheme will be to discover which crops could economically be produced on the Black Clays. Experimental crops of rice, sugarcane, cotton, jute, tobacco, grains, pulses and a variety of local subsistence crops should be tried.

9. Suitable exotic and indigenous grasses, legumes, herbs and browse-shrubs should be introduced for investigational work designed to improve pasturage and fodder.

10. Cattle and sheep would require to be kept in connection with feeding trials ; they would also serve to graze non-cultivated areas to control weed growth.

11. A variety of models of heavy tractors, cultivation implements, harvesters, ditchers, etc., should be tried out.

12. There should be no extension of development from the Pilot Area until cultivation and irrigation techniques for the Black Clays have been mastered. When extension is possible, it should be carried out by the systematic development of natural drainage units, which must first be the subject of detailed soil and topographical surveys.

REFERENCES

1. Vine, H. 1950 Soil Studies on the Accra Plains, March-April, 1950. MS. report to the Director of Agriculture, Accra.
2. Hutchinson, J. B. and Pearson, E. O. 1947 Report on a visit to the Gold Coast. Mimeo. report to the Empire Cotton Growing Association, London.
3. Clark, W. M. and Hutchinson, F. H. 1948 British West African Rice Mission's report on the possibilities of expanding the production of rice in the British West African Colonies. Mimeo. report to the Secretary of State for the Colonies, London.
4. Akenhead, M. 1948 Reports on Rice Soil Surveys of (i) Prampram-Nugo-Shai area and (ii) Akuse area. MS. reports to the Director of Agriculture, Accra.
5. Mason, W. B. 1949 Report on Kpong Agricultural Station. (Includes an interim report on its soils, by C. F. Charter.) MS. report to the Director of Agriculture, Accra.
6. Sir William Halcrow and Partners, London 1950 Preliminary Report on Development of the River Volta Basin. Printed report to the Crown Agents for the Colonies, London.
7. Kitson, Sir A. E. 1928 Provisional Geological Map of the Gold Coast and Western Togoland. Gold Coast Geological Survey Department, Bulletin No. 2. Govt. Printer, Accra : p. 6.
8. Annett, H. E. 1909 The Nature of the Colour of Black Cotton Soil. Mem. Dept. Agric. India, Chem. Series 1 : pp. 185-203.
9. van der Merwe, C. R. 1941 Soil Groups and Sub-Groups of South Africa. Govt. Printer, Pretoria : p. 96.
10. Hosking, J. S. 1935 A comparative study of the Black Earths of Australia and the Regur of India. *Transactions of the Royal Society of South Australia* LIX : p. 172.
11. van der Merwe, C. R. 1941 Soil Groups and Sub-Groups of South Africa : p. 73.
12. Robinson, G. W. 1949 Soils, Their Origin, Constitution and Classification. Thomas Murby & Co., London : p. 343.
13. van der Merwe, C. R. 1948 The Sub-Tropical Black Clays Soils. *Proceedings of the First Commonwealth Conference on Tropical and Sub-Tropical Soils.* Commonwealth Bureau of Soil Science, Harpenden, England. Technical Communication No. 46 : p. 45.
14. Gold Coast Geological Survey 1947 Bulletin No. 15. Govt. Printer, Accra : p. 20.
15. Truog, E. 1948 Lime in relation to plant nutrients. *Soil Science* 65 : p. 3.
16. van der Merwe, C. R. 1941 Soil Groups and Sub-Groups of South Africa : pp. 75-77.
17. —— 1941 *Op. cit.* : p. 88.
18. Piper, C. S. 1950 Soil and Plant Analysis. University of Adelaide, Adelaide : pp. 4-6.
19. —— 1950 *Op. cit.* : pp. 75-77.
20. —— 1950 *Op. cit.* : pp. 223-227.
21. Peech, M. *et al.* 1947 Methods of Soil Analysis for Soil Fertility Investigations. U.S. Department of Agriculture, Washington. Circular 757 : p. 7.
22. —— 1947 *Op. cit.* : p. 3.
23. van der Merwe, C. R. 1941 Soil Groups and Sub-Groups of South Africa : p. 82.
24. Sir William Halcrow and Partners, London 1951 Report on Development of the River Volta Basin. Printed report to the Crown Agents for the Colonies, London : p. 31.
25. Priestley, C. H. B. 1951 Meteorological aspects of soil and crop evaporation. *Proceedings of British Commonwealth Scientific Official Conference : " Plant and Animal Nutrition in Relation to Soil and Climatic Factors," Australia,* 1949. H.M. Stationery Office, London : p. 38.
26. Report on the Mahaicony/Abary Rice Development Scheme to 31st December, 1948 1950 The Daily Chronicle Ltd., Georgetown, British Guiana : p. 5.
27. Israelsen, O. W. 1952 Irrigation Principles and Practices. 2nd Edition. John Wiley & Sons, Inc., New York : p. 136.
28. Report on the Geological Survey Department, 1940-41 to 1945-46. Govt. Printer, Accra : p. 16.

29. Pelzer, K. J. 1951 Geography and the Tropics, *in* Geography in the Twentieth Century (Taylor, G., ed.). Methuen & Co., London : p. 337.
30. Clair Potts, C. K. H. 1929 Rice Growing on the Murrumbidgee Irrigation Areas, New South Wales, Australia. *Proceedings of the Fourth Pacific Science Congress, Java,* 1929, *IV—Agricultural Papers :* p. 432.
31. Report on the Mahaicony/Abary Rice Development Scheme 1950 : p. 15.
32. *Ibid. :* p. 9.
33. Clair Potts, C. K. H. 1929 Rice Growing on the Murrumbidgee Irrigation Areas : p. 433.
34. Report on the Mahaicony/Abary Rice Development Scheme 1950 : p. 9.
35. Hartley, C. W. S. 1951 The mechanization of rice cultivation. *Soils and Fertilizers* XIV : pp. 267-270.
36. Report on the Mahaicony/Abary Rice Development Scheme 1950 : p. 16.
37. Kirby, R. H. 1947 Jute and its substitutes : possibilities of production in the British Empire. *Bulletin of the Imperial Institute* XLV : pp. 97-131.
38. Clair Potts, C. K. H. 1929 Rice Growing on the Murrumbidgee Irrigation Areas : p. 435.
39. Stewart, J. L. 1938 The cattle of the Gold Coast. *Empire Journal of Experimental Agriculture* VI : pp. 85-94.
40. Etchevery, B. A. and Harding, S. T. 1933 Irrigation Practice and Engineering Vol. I. 2nd edition. McGraw-Hill Book Co., New York : p. 124.
41. Kahawita, R. 1939 Preparation of lands under major irrigation works for paddy cultivation. *The Tropical Agriculturist* XCIII : p. 135.
42. Sir William Halcrow and Partners, London 1951 Report on the Development of the River Volta Basin : p. 31.
43. Clark, W. M. and Hutchinson, F. H. 1948 The British West African Rice Mission's Report : p. 28.