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THE SOILS OF WAMFIE COCOA STATION, BRONG AHAFO AREA

By

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C O N T E N T S

Figures

Tables

Appendices

SUMMARY

The station occupies some 240 acres in the drier more northern forest areas where annual rainfall is probably little more than 45 inches per year, and considerable areas of cocoa appear to suffer from dry season water shortages, especially in exceptionally dry years (page 8). The station is underlain by Lower Birrimian phyllites (page 10) and most of the upland sedentary soils consist of silty light clays containing abundant pea gravel in their subsoils. Almost flat upland areas occupy about 60% of the station, moderately steep valley sides about 30% and flattish valley bottom areas the remainder (page 11).

In addition to the extensive upland gravelly soils (Bekwai and Nzima) minor areas of non-gravelly soils developed in upland drift material and shallow soils over iron pan are found. The yellow brown light clays developed in a narrow band of colluvium on lower slopes merge into somewhat more extensive yellow brown to grey bottom soils developed in local alluvium.

Physically most of the upland soils suffer from the low fine earth fraction of the pea gravel subsoil where coarse material may exceed 70% by weight of the total soil. The most satisfactory water relationships are found in soils developed in colluvium of lower slopes and slight depressions. Valley bottom soils developed in silty or sandy alluvium have a low moisture storage capacity and a marked water regime, often being waterlogged in the rains but liable to dry season drought: for this reason cocoa seedling deaths on these soils have been high.

A number of profile analyses (Appendix 2) indicate a rapid falling off in nutrients below the topsoil, which is generally nearly base saturated and neutral to slightly acid in reaction. Analysis of bulk samples from the station and from nearby areas thought to be similar are discussed with particular reference to their organic matter content, cation exchange capacity, base saturation, content of individual bases and of phosphorus, and comparisons between upland and bottom soils show the latter to be distinctly poorer. The upland soils, however, appear to compare favourably as regards plant nutrients with the productive cocoa soils at WACRI, New

Tafo, thus reinforcing the view that the soils of the station are limited primarily by the well marked dry season and by their inability, in most cases, to store sufficient moisture, and not by their chemical characteristics.

Vegetation and current land-use on the station are mapped and described. Additional detailed soil descriptions, mechanical and chemical analyses and rainfall data are given in three appendices.

THE SOILS OF WAMFIE COCOA STATION, BRONG AHAFO AREA

INTRODUCTION

Wamfie cocoa station is situated in the more northern areas of the forest zone where the rainfall is probably not much more than 45 inches per annum and where the dry season is often severe. For this reason, mature successful cocoa in the area is often confined to soils with better-than-average dry season water relationships, particularly upland soils with a fairly high clay content and low lying soils near streams. The soils are generally limited agriculturally not by their nutrient status, which may be no worse (and is sometimes better) than many more productive soils of the forest zone, but by the effects of the dry season. These effects are aggravated by the poor physical properties of many of the soils, especially the extensive soils in which the subsoil is particularly gravelly and thus liable to dry out.

The station is of particular interest since it provides an opportunity of studying the soils of this drier, northern fringe of the forest zone and of the agricultural problems involved. This area is also one which has been subjected to fairly frequent cultivation in the past, and large areas are under thicket regrowth. Such soils can be expected to be somewhat degraded compared with otherwise similar soils under forest: they will be relatively low in organic matter and, particularly where the topsoil has suffered accelerated erosion, in nutrients.

With these facts in mind, it is not surprising that some of the cocoa on the station has died and much of what remains is not in particularly good condition. The station does, however, illustrate well the problems involved in the fairly extensive, drier, long cultivated areas of this type and information and results obtained on cocoa, oilpalm and other crops there will be of interest to considerable areas of similar soils developed over phyllite outside the station. For this reason the site has been well chosen.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
KUMASI	77.1	79.7	80.5	80.1	79.4	88.6	75.5	74.5	76.3	77.7	78.4	77.7
WENCHI	78.7	81.2	81.3	80.5	79.1	76.3	74.7	73.6	75.1	75.2	76.9	75.7

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Dormaa Ahenkro (5 year's)	0.28	2.35	5.73	5.27	5.47	7.79	4.36	1.70	5.60	7.87	1.74	0.75	48.91
Berekum (10 years)	0.70	2.12	3.79	5.63	5.82	6.63	2.84	2.07	5.97	6.11	2.65	1.12	45.45

Table 1. Average daily mean temperatures (degrees Fahrenheit) for Kumasi and Wenchi (from Walker, in press) and average monthly rainfall (in inches) for Dormaa Ahenkro and Berekum (based on information supplied by the Ghana Meteorological Department).

	1955	1956	1957	1958	1959
Jan.	Nil	Nil	Nil	1.13	0.75
Feb.	3.53	2.02	2.93	0.90	4.88
Mar.	3.48	3.22	7.24	5.09	7.71
Apr.	5.34	6.70	4.95	6.15	5.93
May	8.74	6.64	2.42	6.26	4.99
June	4.92	8.44	10.06	4.24	8.49
July	4.81	1.27	6.21	Nil	7.41
Aug.	1.75	1.26	1.66	0.80	1.38
Sept.	5.87	7.25	8.67	2.69	6.00
Oct.	11.40	3.91	9.86	1.75	9.05
Nov.	1.64	0.97	2.94	3.24	2.00
Dec.	0.41	1.04	1.60	2.99	Nil

Table 2. Monthly rainfall totals recorded at Dormaa Ahenkro preventive station, 1955-59. Daily totals are given in Appendix 3.

LOCATION AND AREA: TIME AND CONDUCT OF THE SURVEY

Wamfie cocoa station covers some 240 acres near the Bia-Tano watershed, on the Berekum-Dormaa Ahenkro road some 16 miles from Berekum to the east and 14 from Dormaa Ahenkro to the west. It is included within the Bia basin, the detailed-preliminary survey of which was carried out in the period November 1957 - March 1960 by a team led by the author (Ahn, in preparation*). The station itself was surveyed between November 1959 and March 1960. The method employed was a modification of that normally used on Branch sample strips: it involved digging a regular grid of chisel hole samples taken at 4 chain intervals on traverses 5 chains apart. The 155 chisel holes of the grid were supplemented by about another 80 chisel holes dug at much closer intervals wherever more information on the exact location of soil boundaries was required. Further accuracy was obtained by the use of a core auger at intervals of a few yards. In this way, for example, the narrow tongues of colluvial soils shown on the map were traced. Once the boundaries were established, a number of pits were dug to provide soil samples and profile diagrams of all the major soils on the association. Smallet pits, for inspection purposes, were also dug to check features, such as the presence or absence of indurated horizons, not readily observed from the smaller chisel holes.

The station was levelled with an abney level and the final soil and relief maps carefully checked in the field.

CLIMATE

Temperatures are uniformly high and show little variation throughout the year: they are similar to those of most of the forest zone. Figures in table 1 for Kumasi and Wenchi can be taken as being representative. Rainfall, on the other hand, is low for a forest area. No long-term records are available but short-term figures in table 1 for Dormaa Ahenkro (5 years) and Berekum (10 years) suggest that average totals are in the region of 45-50 inches per year. If this is so then there is little difference in total between this area, under forest, and others in the less dry savanna areas. The distribution of this rain is as important as the total amount and attention has to be given, in particular,

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*References in brackets refer to the list of references given on page 35.

to the length of the dry seasons. Not only the average, but the extremes of rainfall are important, for it is the unusually dry year (e.g. 1956-7) which is liable to damage valuable trees through drought and die-back. In 1957 the drought was such that parts of the forest in the area caught fire and cocoa farms near Dormaa were burned, events which normally never occur in most of the wetter areas of the forest zone. The attached tables for the 5 year period January 1955-December 1959 (Appendix 3, pages 54-8) show individual daily totals recorded at Dormaa Ahenkro, some 16 miles by road to the west of the station. In conjunction with the average monthly totals given in table 2 they indicate the range of variation that can be expected from the norm and the considerable periods that occur with little or no rain. There was not even a trace of rain between November 25, 1959 and January 10, 1960, a period of 45 days, and in the four month period November 1959-February 1960 inclusive, the total rainfall recorded was only 4.59 inches. During the same period evaporation from a free water surface, which gives some idea of potential evapo-transpiration rates, was probably of the order of 16-20 inches. The large deficit was more than most of the gravelly upland soils are capable of storing within the first few feet of the soil. Similar conditions explain the very dry condition and pale colour of these soils during the course of the survey. The stream beds were completely dry and the water level in valley bottom wells suggested a water table 25-30 feet below the surface.

These tables further suggest, what is not revealed in the average figures, the erratic nature of the amount of rainfall within the general seasonal pattern. In July-September 1958, for example, rainfall totalled 3.49 inches while in the same period of the following year the rainfall totalled 14.79 inches. Longer term figures would almost certainly show greater variations from the average than this. The importance to agriculture of year to year variations is particularly important in marginal areas such as this where the total approaches what appears to be the lower limit for forest, though rainfall distribution and soils are factors to be considered in addition to mere totals (there are in Ghana areas with higher rainfalls with savanna vegetation). Nevertheless, the dry dusty condition of the area during the major dry season is apparent to the most casual observer, while the expanding savanna patches between the station and

Sunyani and the increasing amounts of Pennisetum purpureum grass found in long cultivated local farms suggests that the dangers of over-cultivation, or careless cultivation, leading to an encroachment of grass should not be overlooked.

During the dry season, when the chisel holes were being dug on the station, the lack of soil moisture resulted in the soils being particularly hard and difficult to dig, as well as remarkably pale in colour. Soils normally yellow-brown to orange brown in the subsoil appeared greyish yellow or even yellowish grey. With the rains in March, this greyness disappeared.

From the point of view of soil genesis and fertility, the relatively low rainfall has resulted in topsoils with a neutral or near neutral reaction, since the leaching so characteristic of the wetter, acid forest soils has not taken place. This important fact is discussed further, below, under soils - (ii) chemical characteristics (pages 21-29)

GEOLOGY

The whole of the station is underlain by phyllites of the Lower Birrimian formations. These very ancient rocks were laid down in early geological times before fossils indicate life on the land. They consist of clay deposits subsequently hardened and altered by heat and pressure. The weathering of the rocks is, as in most of the forest zone, so deep however that no hard phyllite is usually ever seen: the weathered phyllite is soft and easily broken, recognisable pieces (showing the laminated structure) are typically found at 6-10 feet below the surface. From the plant point of view, clay deposits of this type are not particularly rich since they contain few minerals which release plant food on breaking down. However, not all the soils are derived directly from the phyllite: the area has been lifted up and dissected many times in past geological periods, sometimes under a different climate, and the soils have a long history: some of them are developed in older deposits, while others contain material (especially ironstone gravel) inherited from older soils. Most of the upland soils fall into this latter category: they go down directly to soft loam of weathered phyllite at 6-8 feet, but in their subsoils (particularly from 4 inches to 4 feet) they contain large quantities of accumulated and inherited gravel. Among this is quartz gravel and stones derived from the breaking up of the quartz veins in the phyllite. Quartz veins in the parent rock are numerous and widespread, but their distribution is uneven. For this reason patches are found where the soil contains very abundant quartz gravel and stones (e.g. in block U), while other small areas have relatively low amounts. When frequent, included stones and gravel seriously reduce the capacity of the subsoil to store moisture and plant nutrients.

RELIEF

The station is situated near the Tano-Bia watershed, a broad upland area, here at some 950-1050 feet above sea level, representing part of an old peneplain surface (Akumadan surface). This once fairly flat area has been relatively little dissected near the watershed, so that this is an area of broad summits divided by the upper headwaters of local streams which form valleys some 100 feet lower.

The station itself is typical of these moderately dissected upland areas: most of the area consists of nearly flat to very gently undulating broad summits at 1000 feet. Almost all the northern half of the station, near the main road, forms such a near flat upland area (plots A-H and L). The south-central areas of the station include a broad moderately steep sided valley, the floor of which is 930-950 feet above sea level. The valley-side gradients are of the order of 1 in 10 to 1 in 14, i.e. fairly steeply rolling. In the south-east the ground rises again to another, smaller, broad summit area (blocks S and V).

For agricultural purposes the relief of the station may be divided therefore as follows:-

A. Flattish to very gently undulating upland areas, occupying about 60% of the station (plots A-H and L, parts of plots I, J, K, P, S, and U and the area adjoining the road). Here gradients do not usually exceed 1 in 25 and there is little danger of accelerated sheet erosion if the ground is cleared.

B. Relatively steep valley side areas, occupying some 30% of the station (mainly in plots I, J, M, O, P, R, T, and V). Gradients are as much as 1 in 10 and these sloping areas should not be cleared completely of vegetation since accelerated sheet erosion, together with some gullying, would undoubtedly result in topsoil removal, thus seriously reducing the natural fertility of these soils and, in particular, the organic matter content.

C. Fairly flattish valley bottom areas where the gradient is low and there is little fear of erosion, though drainage in the wet season is slow. These areas occupy some 10% of the station, mainly in plots M, N, Q and R.

SOILS - (a) SOIL MORPHOLOGY AND DISTRIBUTION

A glance at the soil map will show at once a relationship between soils and relief.

The upland areas of most of the station are generally occupied by highly gravelly soils i.e. soils with very frequent to very abundant gravel immediately below the topsoil.

The valleys are occupied by non-gravelly yellow or yellowish grey to grey, light clay alluvial soils. The area of these alluvial soils and the width of the valley are both greater than would be expected from an area so near the watershed, associated with a stream which is small during the rains and non-existent in the latter part of the dry season. Even so, alluvial soils occupy only some 15% of the total area of the station, as compared with 80% occupied by upland soils.

Between the two groups is a band, usually relatively narrow, of yellow-brown colluvial soils. The colluvial material is a uniform, non-mottled, yellow brown clay, typically about 36 inches deep, overlying a slight stone line or, in the lower areas, a moderately indurated layer. Tongues of these soils often extend up some of the minor depressions; these tongues are rarely more than a chain wide, sometimes less than half a chain. The depressions are often very slight: very temporary streams occupy them immediately after a fall of rain. Such soils can easily be traced by augering or simply by pushing in a cutlass into the soil, since they are at once distinguished from surrounding upland "sedentary" (or residual) soils by the lack of included gravel.

The upland soils, when examined more closely, are found to include minor patches of non-gravelly "drift" soils, while the much more extensive gravelly soils can be subdivided into those with ironpan or a moderately indurated layer in the subsoil and the larger areas of soils without induration. The latter can themselves be divided according to the colour of the gravelly subsoil i.e. into those with a distinctly red subsoil, suggesting good internal drainage and adequate aeration, and those with an orange-brown to dull brown or yellow-brown subsoil, not quite as well drained as the redder soils though nevertheless well drained by normal standards.

The soils of the station can therefore be simply classified and described, as follows:-

A. Upland soils

1. Normal gravelly "sedentary" soils
   - a. Reddish subsoil .... Bekwai series
   - b. Orange-brown to yellow-brown subsoil .... Nzima series

2. Gravelly soils with an indurated horizon
   - a. Gravelly soils over ironpan at 20-40 inches .... Nsuta series
   - b. Gravelly soils with a moderately indurated horizon at 20-40 inches .... Atonsu series

3. Non gravelly upland drift soils
   - a. Deep yellow to orange-brown light clay soils .... Afrancho series
   - b. Shallower examples with an indurated horizon at 15-40 inches....... Kawsan series

B. Colluvial soils of lower slopes and minor depressions

1. a. Yellow-brown clay to light clay, overlying a stone line and/or weathered parent rock (usually at 20-40 inches, typically at 25-36 inches)..... Kokofu series
   b. As above, but with a mottled and moderately indurated layer in the lower subsoil, usually at 30-36 inches..Sang series

C. Alluvial soils of valley bottoms

1. a. Yellow-brown to greyish yellow light clay, usually slightly mottled below the first 15-30 inches ....Kakum series

In practice this series grades into:-

b. Yellowish grey to grey light clay, (sometimes sandy light clay) often slightly mottled below the topsoil and more coarsely mottled at depth............ Oda series
c. Yellowish to greyish-yellow sand to fine sand .... Chichiwere series
d. White sand .... Srani series

Of the above (c) and (d) are rare on the station.

Brief descriptions of these soils follow. Detailed descriptions of examples of the more important series are given in Appendix 1, pages 41-44.

Bekwai series

Bekwai series is a well-drained gravelly upland soil developed over phyllite. It is widespread in the forest zone and is a typical ochrosol.

The dark greyish brown (7.5YR 4/3) humous upper topsoil is loam in texture and is crumbly, loose and well aerated. It has an average thickness of 2½ inches. The lower topsoil (to about 7½ inches) is less dark in colour (7.5YR 5/4), less humous, less crumbly and porous and may contain some gravel and quartz stones. The upper topsoil normally has a reaction of pH 6.0-7.0, i.e. neutral to slightly acid, the lower topsoil being a little more acid (averaging about half a pH unit lower).

The subsoil is normally a reddish brown (5YR 5/5 to 5YR 5/6) loam to light clay containing large quantities of pea gravel (i.e. ironstone concretions, ferruginised rock fragments, quartz gravel and stones). This coarse material may form 20-70% by weight of the soil: normally it is 25-50% with a maximum in the upper subsoil. The subsoil is more acid than the topsoil, usually being in the range pH 5.0-5.5 and showing a tendency to become more acid with depth (Table 3). The subsoil extends to 3-5 feet (occasionally more) before merging into the weathered substratum below.

The weathered substratum contains little or no coarse material and the texture, a loam to light loam, is lighter than in the subsoil. Mechanical analyses (Appendix 2) show a maximum of clay in the subsoil, with the silt increasing as the weathered rock is approached. The weathered substratum often consists of a silty loam derived from the soft weathered phyllite, traces and patches of which become more abundant with depth. This is the most acid part of the profile, typically being pH 5.0-5.2. In colour it is yellow-brown to orange-brown, often slightly mottled: weathered phyllite shows a range of colours.

Nzima series

Nzima series is a similar soil to Bekwai series, found on upper, middle, and sometimes lower slopes, below Bekwai series. It is slightly less well drained, internally, than Bekwai, and this gives it the somewhat browner (or more yellow-brown) subsoil colour which is the main characteristic used to separate it from Bekwai series. Whereas Bekwai is reddish brown in the subsoil, Nzima is brown to orange-brown (7.5YR 5/5 or thereabouts). Reaction is similar to, or very slightly more acid than, Bekwai series: the macro-morphology of the two series is very similar, as is their agricultural value. Together they occupy most of the uplands of the extensive forest ochrosol areas where the underlying rock is phyllite. Where dry seasons are not too long and severe these soils have been successfully planted to cocoa and they also support a range of forest food crops under the local land rotation cultivation system.

Kokofu series is a soil developed in local colluvium of lower slopes and depressions. The dark greyish brown loamy humous topsoil overlies two to three feet of yellow-brown light clay which in turn merges into a loam derived from weathered phyllite below. The transition between these two horizons is sometimes, but not always, marked by a layer of stones or gravel, referred to as the stone line, 2-3 to 12 inches thick, or by a slight mottling and partial induration. When this induration is sufficiently well developed to form a horizon dug with difficulty then the soil is Sang series. Sang series consists therefore of 2-3 feet (occasionally a little more) of yellow-brown light clay overlying an indurated mottled horizon. A detailed description of an example of this series dug on the station is given in Appendix 1, page 44.

Afrancho series is developed in patches of non-gravelly upland drift material, sometimes several feet thick. The origin of this material is not known with certainty but may be connected with termite activity over long periods in the past resulting in thick non-gravelly deposits of fine earth in which contemporary soils have been developed. Such deposits often occur on flattish upland sites but are characteristically irregular in distribution and patchy. On the station an irregular patch occurs in blocks G, H, C, and D and extends to the road. The soils developed in this material have a morphology somewhat similar to Kokofu series except that deeper examples also occur: a thin humous dark greyish brown topsoil merges into three to six or more feet of non-gravelly yellow-brown light clay: in some examples this shows a granular or fine sub-angular blocky structure. Towards its lower limit this material may be slightly mottled and the transition to the weathered substratum may be marked by a mottled and somewhat indurated layer. The example from the station (peg G/8, between blocks C and D) described in appendix 1, page 43, is an example in which this mottled indurated layer of the lower subsoil is particularly deep. Those examples of this series nearer the boundaries of the patch usually include shallow examples with only 1½-3 feet of non-gravelly yellow-brown drift material above the lower horizons derived from the weathered products of the underlying rock.

Kakum series is a well-drained yellow-brown soil developed in local light clay or fine sandy or silty light clay alluvium. A dark greyish brown loam topsoil, crumbly and up to 6-7 inches thick, overlies 2-4 feet (occasionally a little more) of silty to fine sandy yellow-brown light clay, with little obvious structure but occasionally containing water worn stones or gravel. The soil occurs on the better drained valley bottom and stream bank (levee) sites. On the levees it may grade into lighter textured soils developed in yellow brown sand to sandy loam known as Chichiwere series, though on the station this soil is thought to be uncommon. More frequent is a less well-drained light clay soil more or less grey in the subsoil, Oda series. Oda series consists of a dark greyish brown humous topsoil, often well developed, overlying a brownish grey to grey subsoil (occasionally greyish white, particular when very dry) of silty to sandy light clay. As with most soils developed in local alluvium, lighter textured more sandy horizons may occur, as may quartz gravel and stones, often slightly rounded by water. Slight mottles and stains are normal in the subsoil. An example from just outside the station, near block V, is described in appendix 1, page 45.

(b) AGRICULTURAL CHARACTERISTICS

(i) Physical characteristics

The topsoils of most non-eroded soils on the station consist of 4-5 inches of humous loam (occasionally light clay), free of stones and gravel and easy to work, though in the case of upland gravelly soils (Bekwai, Nzima, Atonsu, Nsuta series) cultivation may to a certain extent stir up the underlying gravel and mix it with the topsoil. The topsoils usually possess a fairly well-marked crumb structure and are porous and loose, so that they are well aerated.

Whereas topsoils are physically somewhat similar irrespective of series (though varying somewhat in their organic matter content with the vegetation phase or history of cultivation) the subsoils of the soils of the station show wide physical variations. Most of the upland soils contain abundant stones and gravel in their subsoils which contrast with the minor areas of non-gravelly upland soils and with soils developed in colluvium and alluvium in which a highly gravelly subsoil is also absent. These are dealt with in turn below.

(a) Upland soils

The most extensive upland soils, Bekwai and Nzima series (differing mainly in subsoil colour), are characterised by the presence in the subsoil of very frequent gravel i.e. of quartz gravel, quartz stones, ironstone concretions, ferruginised rock fragments and small pieces of fragmented ironpan.

This gravel is of no use to the plant. It reduces the fine earth fraction and hence the capacity of the subsoil to store nutrients and water. In view of the low total rainfall of the area and the occasionally very severe dry seasons, this reduction in water storing capacity is the more important of the two effects and merits close consideration. Measurements of the coarse material (i.e. material not passing through a 2 mm sieve) of typical upland soils were made, with the following results:-

SERIES	SAMPLING HORIZON		PERCENTAGE BY WEIGHT OF COARSE MATERIAL
1. BEKWAI	Topsoil	0-2"	12%
		2-5"	29%
(Sampled at peg A0 on the north-east corner of the station - plot A)	Subsoil	5-15"	57%
		15-28"	71%
		28-45"	71%
		45-60"	60%
	Weathered substratum	60-94-112-136"	5-6%
		below 136"	3%
2. NZIMA (Sampled at peg A16, plot E.)	Topsoil	0-2"	36%
		2-5"	64%
	Subsoil	5-10"	69%
		10-19"	66%
		19-38"	60%
		38-52"	49%
	Weathered substratum	52-68"	20%
		68-94"	64%
		94-104"	2%
3. NZIMA (Sampled at peg A60, plot S.)	Topsoil	0-2"	3.3%
		2-5"	16.9%
	Subsoil	5-10"	64%
		10-19"	75%
		19-34"	76%
		34-49"	67%
		49-64"	58%
	Weathered substratum	64-80"	5%
		80-99"	3%

Full profile descriptions of A/0 and A/60 are given below (appendix 1, pages 41-43). The Nzima on peg A/16 is eroded, as is shown by the shallow, gravelly topsoil. The other two profiles are on fairly flat to gently undulating sites. They have not been eroded but the Bekwai at A/0, now under thicket regrowth, has been cultivated fairly intensively in the past, hence the fairly large quantities, for a topsoil, of gravel in the 2-5 inch horizon.

The most important feature of these tables is however the very high quantity of coarse material in the subsoils, which is of the order of 60-70% by weight. The fine earth fraction - the part of the soil capable of storing water and nutrients - is therefore reduced to 25-40% by weight of the total soil, though by volume it forms a larger percentage of the soil (if the dry density of the total soil is assumed to be 2.0 and the specific gravity of the solid material 2.7, then 75% by weight of coarse material would be equivalent to 55% by volume of the total soil. The remaining 45% is fine earth, which would comprise about two fifths solid material and three fifths pore space).

No complete mechanical analyses are available for soils on the station but mechanical analyses of somewhat similar soils developed over phyllite elsewhere in the forest zone are given in Appendix 2.

Physically, upland soils (unless eroded) have an easily worked, well structured and well aerated topsoil which also, largely because of its organic matter content, has a fairly good moisture retention capacity. The topsoil is, however, often thin and the deep subsoil, on the other hand, is gravelly and, in the local severe dry seasons, may dry out more or less completely. In such a case plants will be largely dependent for their water supply on the weathered substratum which is usually a light clay to medium loam with little or no coarse material, though the silt content of the fine earth fraction increases as the parent material is approached.

b) Upland soils with indurated horizons

Where subsoil induration is slight to moderate (Atonsu series) there may be little influence on plant growth, but as the induration becomes more complete (Nsuta series) so is the downward penetration of roots and water increasingly held up. In extreme cases where a few feet of highly gravelly material overlie ironstone, then soil water relationships become particularly unsatisfactory since in times of rain the drainage tends to be impeded whereas, in dry spells, that part of the soil above the ironstone may dry out relatively rapidly. The gravel content of upland soils with indurated horizons is, in any case, often particularly high. The area of Nsuta series on the station is very small. Slightly indurated horizons, on the other hand, may dry out somewhat slowly, though considerable more study is required on their effects on soil moisture relationships and root development.

c) <u>Soils developed in local colluvium</u>

Colluvial soils of the area are often more productive than gravelly upland soils because:

(a) the fine earth fraction typically approaches 100% so that the moisture storage capacity is improved, and

(b) the position in relation to higher soils is such that there is a possibility of increased water supplies, particularly in shallow depressions.

A study of cocoa on the station does in fact suggest that the condition of cocoa on the tongues of colluvium mapped in block O for example, compares favourably with that on adjoining areas of Nzima series. The absence of gravel is a particular advantage in the cultivation of annual root or tuber crops.

The upland soils developed in minor areas of colluvium of shallow depressions are not indurated. The broader but nevertheless still fairly narrow band of these soils on the lower valley slopes includes non-indurated soils, generally in the upper part of the band, but also, particularly where this band widens (Blocks T and V) soils with a partially indurated horizon in the subsoil. There is often a slight break of slope, a step like drop of 1-2 feet, marking the point where this horizon comes to the surface at the side of the valley (Figs. 3 & 4). On these sloping sites internal drainage is not greatly impeded by these horizons and nowhere was the induration observed more than slight to moderate i.e. the indurated horizon can be dug through with only slight or moderate difficulty and pieces dug from these horizons can be broken in the hand.

(d) <u>Upland 'drift' soils</u>

The soils are characterised by a near-absence of gravel so that they are physically similar to colluvial soils, though the flat upland site is different. As in the case of colluvial soils some profiles include more or less indurated horizons.

(e) Soils developed in local alluvium

Soils developed in alluvium sometimes contain frequent quartz gravel and stones (but concretions are relatively rare) though most alluvial soils contain only a low percentage of coarse material. Topsoils are, as in the case of most soils of the area, easily worked, with a structure and porosity favourable to agriculture. The subsoil, usually a light clay or sandy light clay, is somewhat more compact, less well aerated, and has little obvious regular structure. Normally clay alluvial soils have relatively good dry season water relationships but the alluvial soils of the station, though fairly extensive, are associated with only a seasonal stream, have a low clay content and appear to suffer from a very marked moisture regime. In the wet season, internal drainage is slow. In the dry season, because of their low moisture retention capacity, the soils may dry out to a greater degree than their position would suggest. The cocoa in the valley bottom areas of block M is in poor condition with a large percentage of deaths at the seedling stage. This appears to be due to moisture relationships, and is more likely caused by dry season drought than wet season waterlogging, while the bad effects of either condition are aggravated by being succeeded by the other.

(ii) Chemical characteristics

Although chemical and physical soil characteristics are closely interlinked, it is convenient here to consider them apart. The physical characteristics discussed above govern by and large the supply of water and oxygen, essentials for growth, and planting failures (if not due to disease or physical damage) are more likely to be due to the physical limitations of the soil than the chemical i.e. to drought, or to excess of water, thus reducing the oxygen supply to roots. The supply of mineral nutrients in the soil influences the rate of growth and the size of yields, but is unlikely here to be so poor that a plant cannot survive for that reason alone. In the area represented by the station most upland soils are ochrosols (Fig.1) and leaching is, moreover, slight, since the rainfall is not heavy and the supply of mineral nutrients is probably better than for many wetter forest areas. This emphasises the importance, as a limiting factor to be overcome first, of the soil water relationships.

Mineral nutrients are stored in the soil by the clay fraction and by the organic matter, also responsible for storing water. Silt, sand, and coarse material have little or no capacity to store either, though they contribute to the building up of a soil structure that allows air and water to circulate. Since organic matter, weight for weight, can store far more nutrients and moisture than the predominately kaolinitic clays of the station, it is obvious that the fertility of any particular soil depends to a considerable degree on the thickness and organic matter content of the topsoil. The organic matter content is highest under original or secondary forest, least when the soil has been long cultivated or recently left to fallow after long cultivation. Erosion may also seriously reduce fertility by washing away into the drainage water the most valuable upper part of the topsoil - or even all of it - particularly on sloping areas.

The fact that most nutrients are stored in the topsoil while the nutrient content of the subsoil is relatively very low is brought out by the analyses given in Appendix 2, page 46. These show analyses of profiles thought similar to those of the station and illustrate the trends down the profile which are normal for soils of this type. For agricultural purposes, however, it is useful to examine larger areas than that covered by samples from a few pits, and to analyse bulk samples obtained by mixing samples from a larger area (e.g. a block, or field, or few hundred acres of one soil series). In this way the variations, which might be considerable, between a soil at one point and an outwardly similar soil a yard or two away, are averaged out, and it is possible to estimate the plant nutrient content of the area sampled with relative accuracy.

An examination of the analytical data obtained from 15 bulk sampples, representing several hundred individual samples, follows. These include six samples from the station itself, seven sets of samples from an apparently similar area near the village of Kawsan, north of Dormaa Ahenkro, and, for purposes of comparison, two bulk samples from the Asunso forest reserve taken at a point only 3 miles from the Kawsan area where soils and environment are assumed to be very similar. Each sample was obtained by thoroughly mixing 15-100 cores of a single series under a uniform vegetation cover, and subsampling.

(a) Effect of vegetation

10 samples were under thicket regrowth vegetation, three under cocoa, two under broken forest. The carbon, nitrogen and C/N ratio of these groups is summarised in the following table:

	Carbon	Nitrogen	C/N
Average of 10 bulk samples under thicket	2.66	.228	11.23
Average of 3 bulk samples under cocoa	1.88	1.80 (2 samples)	10.44
Average of 2 bulk samples (over 150 bulked samples) under broken forest	3.33	.305	10.91

As expected carbon and organic matter content under high (broken) forest was higher than the average for samples under thicket or cocoa. The forest soils showed 3.33% carbon (equivalent to 5.73% organic matter) in the top 6 inches, a not unusual figure. The bulk samples under thicket averaged 2.66% carbon (4.58% organic matter) but individual thicket bulk samples on the station itself (samples 1354/1 and 3) had about 4% carbon (or 6.9% organic matter) i.e. more than the average under forest. It seems therefore that organic matter content under thicket regrowth may sometimes reach relatively high levels. The thicket in question was estimated at 6-8 years old.

The carbon content of the three bulk samples under cocoa was relatively low, possibly reflecting the mediocre condition of the cocoa, which was medium to old-aged.

These figures are for the fine earth fractions of the top 6 inches. To compare them quantitatively it is necessary to take into account the fact that this fine earth fraction is sometimes as low as less than 60% of the total soil. Most of the gravel and stones of the coarse fraction are in the lower subsoil (3-6 inches) not in the top 3 inches where organic matter concentration is, of course, highest.

Nitrogen content parallels the carbon content fairly closely: C/N ratios (except for 1354/4, which is odd) range in individual bulk samples from 10.10 to 12.68, the minimum figure being for a sample under cocoa, the maximum for a bottom soil. The range is small however, and most upland soils appear to have ratios of about 11, a figure usually considered satisfactory.

If the carbon and nitrogen figures are considered in respect to soil type, then the lower figures for bottom soils stand out:

	Fine earth fraction	C	N	C/N
Upland sedentary soils (Bekwai and Nzima) - average of 8 bulk samples	68.3	3.11	302 (7 samples)	10.3
Upland drift soils (Afrancho and Atonsu series) - average of 4 bulk samples	95.3	1.94	183	10.6
Bottom soils (Kakum and Oda series) - average of 3 bulk samples.	95.9	2.08	136	15.3

These figures show totals for both the upland drift and the bottom soils which are lower than those for upland sedentary soils. To a great extent, however, this apparent difference is lessened by the lower fine earth fraction of the upland soils. The lower nitrogen average for bottom soils, however, increases the C/N ratio for this group.

(b) Cation Exchange Capacity

Cation exchange capacity for the 15 bulk samples shows a considerable range from 7.13, 6.94 and 7.38 m.e. for the three samples of bottom soils to a mazimum of 24.59 in a bulk sample of Bekwai series under thicket. Cation exchange capacity depends on the organic matter content, which is thought to have a capacity of 300-400 m.e., and on the content of clay, which is thought to be mainly kaolinitic. The following table compares C.E.C., O.M. and moisture percentage figures for the samples:

	Sample No.	C.E.C.	C	Moisture % air dry
(a) <u>Upland Sedentary Soils</u>	1354/1	24.59	3.96	5.15
	1354/2	18.14	3.34	3.93
	1354/3	23.13	4.07	4.11
	1354/6	11.73	1.94	2.53
	1355/1	14.40	2.44	3.23
	1355/2	14.42	2.43	2.86
	1356/1	17.62	3.34	4.21
	1356/2	16.68	3.33	3.58
Average, group (a):		17.59	3.11	3.7
(b) <u>Upland drift soils</u>	1354/5	12.08	1.88	2.81
	1355/3	12.08	2.20	2.81
	1355/6	10.87	1.68	2.10
	1355/7	12.94	2.01	3.06
Average, group (b):		11.99	1.94	3.06
(c) <u>Bottom soils</u>	1354/4	7.13	2.97	1.31
	1355/4	7.38	1.75	1.55
	1355/5	6.94	1.53	1.43
Average, group (c):		7.15	3.08	1.43

These figures show clearly the lower cation exchange capacity of the bottom soils, which appears to be due to their low clay content as well as to low organic matter totals.

(c) <u>Base saturation</u>

Reaction for the 6-inch layers sampled is usually between pH 6.0 and 7.0 i.e. neutral to slightly acid. This is to be expected from the rainfall totals of the area which, for the forest zone, are low. The following table compares pH, C.E.C., T.E.B. and base saturation figures for the 15 bulk samples:

		pH	T(CEC)	S(TEB)	S/T
(a) Upland sedentary soils	1354/1	6.40	24.59	23.80	96.8
	1354/2	6.32	18.14	18.36	101.2
	1354/3	6.82	23.13	26.76	115.7
	1354/6	5.95	11.73	10.15	86.5
	1355/1	6.10	14.40	11.99	83.3
	1355/2	6.80	14.42	16.20	112.2
	1356/1	5.95	17.62	15.65	88.8
	1356/2	5.60	16.68	12.30	73.7
Average, group (a):		6.24	17.49	16.88	96.5
(b) Upland drift soils	1354/5	6.10	12.08	10.79	89.3
	1355/3	6.50	12.08	12.18	100.8
	1355/6	6.20	10.87	10.52	96.78
	1355/7	5.90	12.94	9.69	74.9
Average, group (b):		6.18	11.99	10.80	90.1
(c) Bottom soils	1354/4	5.60	7.13	5.95	83.5
	1355/4	6.42	7.38	4.98	67.5
	1355/5	6.00	6.94	6.26	90.2
Average, group (c):		6.01	7.15	5.73	80.4

C.E.C. figures were obtained by the barium acetate method which has been found to give higher exchange capacity figures than ammonium acetate, and these higher figures agree better with the reaction (de Endredy & Quagraine 1960).

(d) Individual bases

Calcium is the dominant base, the Ca/Mg ratio in individual bulk samples ranging from 3.10 and 2.42 in two of the samples from bottom soils to 6.31 in a sample of Nzima series under thicket. There is a tendency for calcium to form a higher percentage of the total bases where this total is itself higher, i.e. variation between base totals in soils is more a difference in calcium content than in the content of Mg, Mn, or K, which vary somewhat less. In the following table, data for the 15 samples is arranged in descending order of total bases and the K as a percentage of the total is calculated.

Sample	Brief description	TEB	Ca	Mg	Mn	K	K/TEB	Ca/Mg
1354/3	Nzima/thicket	26.76	21.67	4.25	.034	0.55	2.06	5.10
1354/1	Bekwai/thicket	23.80	19.28	3.70	.041	0.64	2.69	5.21
1354/2	Nzima/thicket	18.36	14.56	3.18	.049	0.47	2.56	4.57
1355/2	Nzima/thicket	16.20	13.48	2.14	.024	0.40	2.47	6.31
1356/1	Bekwai/broken forest	15.65*	12.41	2.67	.096	0.41	2.62	4.64
1356/2	Nzima/broken forest	12.30*	9.43	2.43	.109	0.33	2.68	3.88
1355/3	Afrancho/thicket	12.18	9.66	2.14	.023	0.28	2.30	4.52
1355/1	Nzima/thicket	11.99	9.13	2.41	.070	0.35	2.91	3.79
1354/5	Afrancho/thicket	10.79	8.37	2.19	.072	0.23	2.13	3.83
1355/6	Afrancho/cocoa	10.52	8.57	1.68	.057	0.14	1.32	5.09
1354/6	Nzima/cocoa	10.15	7.94	1.96	.09	0.18	1.78	4.05
1555/7	Atonsu/cocoa	9.69	7.42	2.00	.062	0.20	2.06	3.71
1355/5	Kakum & Oda/thicket	6.26	4.97	0.96	.05	0.20	3.20	5.17
1354/4	Kakum & Oda/thicket	5.95	4.26	1.37	.047	0.19	3.19	3.10
1355/4	Kakum & Oda/thicket	4.98	3.30	1.36	.059	0.11	2.21	2.42

This table brings out clearly the dominance of calcium, totals of which closely parallel the total base figures. Manganese, distributed rather erratically in Ghana forest soils, is here low, being 0.1 or less of a millie-equivalent in all the samples. Potash in most samples is between 2 and 3% of the total exchangeable bases. Nye (1959) has considered 2% to be a critical level below which soils respond to manuring with this element. Only in two samples, both for soils under cocoa, is the percentage below this figure. The percentage which the potash represents of the total bases is probably a better indication of potassium availability than the absolute amounts, which here vary between 0.11 and 0.64 m.e. The Ca/Mg ratio is relatively high: generally speaking this ratio is higher in ochrosols than in the more leached and acid oxysols of the wetter part of the forest zone, and higher in the topsoil than in the subsoil.

(e) Phosphorus

The figures available are for total phosphorus. The figures do not appear to correlate with organic matter, though available phosphorus probably does. The total phosphorus figures given have a fairly wide range, from 265 to 1033 p.p.m., but since the available phosphorus this represents is not known they are difficult to interpret. Eleven of the 15 profiles have totals of over 500 p.p.m. and these figures are probably reasonably high by average forest

(*) includes 0.16 Na

(*) includes 0.11 Na.

zone standards. What is not known is how much of this is locked in insoluble or difficultly available compounds of aluminium, iron or calcium. Broadly speaking, less is locked up in this way in the less acid soils, such as those sampled, and in the horizons well supplied with organic matter.

Earlier analyses for 34 forest soils have shown (de Endredy and Quagraine, 1956) some correlation between total phosphorus and organic matter. These investigations are summarised in the following table:-

Horizon	1[1]	2	3	4[2]
Weighted averages, P p.p.m.	535	371	314	279
Organic matter (%)	10.9	3.3	1.5	1.0

(f) Moisture retention capacity

The moisture retention capacity of the top 6 inches sampled is due more to humus content than to clay. The low figures for bottom soils (group c) reflect both a low carbon content and a high percentage of silt and sand in these soils. In general, moisture figures for forest topsoils range from 2-7% of the air dry sample: 2-3% can be considered moderately low, 3-4% as average, 4-5% as moderately high and above 5% as high. In the subsoil there is a close correlation with clay content. In the bulk samples analysed the cation exchange capacity, in m.e., averages 4-5 times the moisture expressed as a percentage of the air-dry soil in both the upland and bottom soils. In the drift soils this factor falls to about 4.

It is probable that in many upland soils the gravelly subsoils dry out before the topsoils. An examination of the top 6 inches alone is insufficient to predict the moisture storage capacity of the soils of the station.

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[1] Horizons 1 and 2 represent the topsoil, 3 and 4 the upper subsoil.

[2] To an average depth of 34 inches.

(g) Comparison with cocoa soils elsewhere

For purposes of comparison, table 4 gives bulk sample analyses (from Burridge & Cunningham, 1960) for Wacri series, a productive cocoa soil occurring on the West African Cocoa Research Institutes station at New Tafo. Considered first by itself the table shows that soils with a high cocoa yield grading have a higher pH and considerably more calcium than those with a lower yield. O.M. and total P are slightly higher in the better soils though the difference in 'available' P is more marked. Cation exchange capacity is also higher in the better soils suggesting a higher clay as well as organic matter content.

These figures for what is known to be one of the more productive cocoa soils do not differ very much from some of the figures for bulk samples taken from the station. Both carbon and nitrogen in the soils under thicket and forest are considerably higher than in the W.A.C.R.I. samples and the samples from the station under cocoa have amounts very similar to the averages of the better W.A.C.R.I. soils.

As regards cation exchange capacity, the upland sedentary soils are similar to, or have a higher capacity than, the W.A.C.R.I. samples, though the drift and bottom soils are distinctly inferior in this respect. The position in regard to bases is somewhat similar though the average pH of soils from Wamfie and nearby areas is lower than that of the better W.A.C.R.I. samples. Total phosphorus, on the other hand, is higher.

A more detailed comparison would have to take into account the fine earth percentages of the various samples and give some consideration to possible effects of subsoil differences, but a preliminary examination certainly tends to reinforce the impression received when examining the soils on the station, namely that the limiting factor in the area is not the nutrient status of the soils as much as the water relationships. The better upland soils are certainly not obviously inferior as regards nutrient status to cocoa soils giving high yields elsewhere: they appear to be limited by the effects of dry season drought and inability to store adequate moisture.

Yield grading according to maps	Pod yield per 100 trees	C	N	C/N	pH	Total P	'Available' P	C.E.C.	Exchangeable bases (m.e. per 100 gm.) Ca	Mg	K	I.O.N. nitric acid soluble potassium K
Low	86	1.70	0.156	10.90	6.1	310	5	13.7	9.46	2.14	0.29	1.10
Medium	297	1.82	0.170	10.71	6.8	331	7	15.7	12.71	1.58	0.29	0.81
High	504	2.10	0.187	11.22	6.9	379	10	18.2	18.45	1.61	0.38	2.07

Table 4. Bulk sample analyses (each an average of 3 samples of 20 cores each) for 0-6 inches for soils of Wacri series, New Tafo sampled according to cocoa yield category (columns 1 and 2). (From Burridge and Cunningham, 1960).

VEGETATION

The moist semi-deciduous forest of the area belongs to the relatively dry Antiaris-Chlorophora association (Taylor 1952, Lane, in press, Mooney, 1959) of which the indicator trees, Chlorophora excelsa and Antiaris africana, are associated with relatively dry forest areas and are, accordingly, found only in relatively small numbers to the south. Celtis mildbraedii, so common in the somewhat wetter forest areas, is here rather uncommon. On the station, however, little disturbed high forest has all but disappeared, and almost all of the station, apart from cultivated and built-up areas, is under regrowth vegetation.

Regrowth vegetation varies in character according to the soil, length of previous cultivation, supply of seed and other factors. A discussion of these factors, together with a detailed floristic analysis of the various succeeding stages, is given in Ahn, 1959. Forb regrowth (i.e. the weeds and shoots which quickly cover abandoned farms) is confined, on the station, to a few acres in block D. Most of the non cultivated area at the time of the survey was under poor thicket regrowth, 6-8 years old. Small patches of secondary forest (the succeeding formation) and what may be a small remnant of the original high forest are found in blocks Q and N.

LAND-USE

The station was acquired in 1954 when boundaries were demarcated and planting begun. In late 1956, however, work was abandoned because of a local political dispute sparked off by rival claims to the ownership of the land. At one point, only a single caretaker is said to have been left in charge. A W.A.C.R.I. cocoa uniformity trial begun in block G (now under thicket) had failed prior to this. The two major blocks of cocoa (A-10 and Am-6.8 on the land-use map, fig. 5) had been planted in 1954 and 1956 but suffered considerable neglect and numerous casualties during the caretaker period. Work on a larger scale was resumed in 1959.

A few old cocoa farms, totalling about 20 acres and planted 1930-40, were taken over with the station, of which one (plot CA1, blocks O, K, J) is said to yield 5 loads per acre and the remainder only 1-1½ loads. These low figures are probably fairly typical of much of the upland cocoa in the area.

Details of the present land-use are given in the map compiled by K.A. Asiedu (Fig. 5) and the full key on pages 33-34. Most of the station is under thicket, suggesting that cultivation of the area ceased in 1953-4, though the poor, thin nature of this thicket hints at a considerable period of cultivation prior to this, and consequent soil impoverishment. Considerable areas of cocoa had also been planted, but failed: occasional relics are seen amid the thicket. Apart from nurseries (including Dura x Dura oilpalm seedlings) and one acre of coconuts, the only trial begun since the early cocoa plots is one of 7 acres of coffee (block P). At the time of writing (mid 1960) work continues on offices, quarters and roads.

The condition of the amelonado cocoa is disappointing. The amazon cocoa, though slightly better, is poor compared with amazon cocoa on other stations. The long history of local cultivation and the chequered history of the station, including a period of neglect, may have contributed to this, but the major cause seems to be lack of water in the dry season. Cocoa seedlings planted to fill gaps in some of the old-aged plots were, at the time of the survey (early 1960) in very poor condition indeed. Despite improved agricultural methods employed on the station, it is questionable whether cocoa here will ever be particularly successful.

Small scale fertiliser trials were begun recently on six random ½ acre plots within the mature cocoa (5 in CA1, and one in CA3), in which half the plot is left as control and the other half given 5 cwts per acre of ready-mixed Albatross fertiliser (N, P, K and Mg in the ratios 10:10:7:5). After 2 years there has been little or no obvious response.

KEY TO VEGETATION AND LAND-USE MAP
(Surveyed early 1960)

1. Broken forest i.e. the original high forest of the Antiaris-Chlorophora association, somewhat disturbed by timber cutting.

2. Secondary forest, i.e. a mature forest regrowth about 20-25 years old.

3. Thicket regrowth, mostly 5-7 years old.

4. Thicket with relics of abandoned cocoa.

5. Forb regrowth, with relics of farm crops.

6. Built-over land (offices, quarters, bungalow, cocoa drying barn and adjacent non-agricultural land).

7. 7 acre robusta coffee plot, planted September 1957 and October 1958 at 8 x 8 feet.

8. 1 acre Ceylon coconut palms, planted October 1958.

Old cocoa i.e. cocoa planted by local farmers before the station was begun and now maintained by the Division of Agriculture.

CA1 11.8 acres old amelonado cocoa (planted circa 1930-40); irregularly spaced, in moderate condition, yielding a little over 300 lbs (5 loads) per acre. Small areas are receiving fertiliser.

CA2 4.4 acres of amelonado (planted circa 1940). Condition poor. Average yield now about 75 lbs per acre.

CA3 1.2 acres of amelonado (planted circa 1930-40) in poor condition, with an average annual yield of 125 lbs for the whole plot (or about 100 lbs per acre).

CA4 3.1 acres of amelonado (planted circa 1935) in poor condition. Average yield now about 75 lbs per acre.

C Minor plots, now neglected.

Young cocoa i.e. trial plants laid down by the Division of Agriculture after the station was acquired.

A-10 10 acres of Amazon cocoa planted June-September 1954, at 8 x 8 feet; in poor condition, with many casualties subsequently replaced by younger cocoa.

Am-6.8 6.8 acres of amelonado planted September 1956 at 5 x 5 feet: condition poor.

Am(s) Minor areas of CA1 and CA4 replanted with seedlings.

Nurseries

Nus Oil palm and cocoa nursery
Pcl Proposed site for clonal cutting material nursery
Pb Proposed site for propagation barn.

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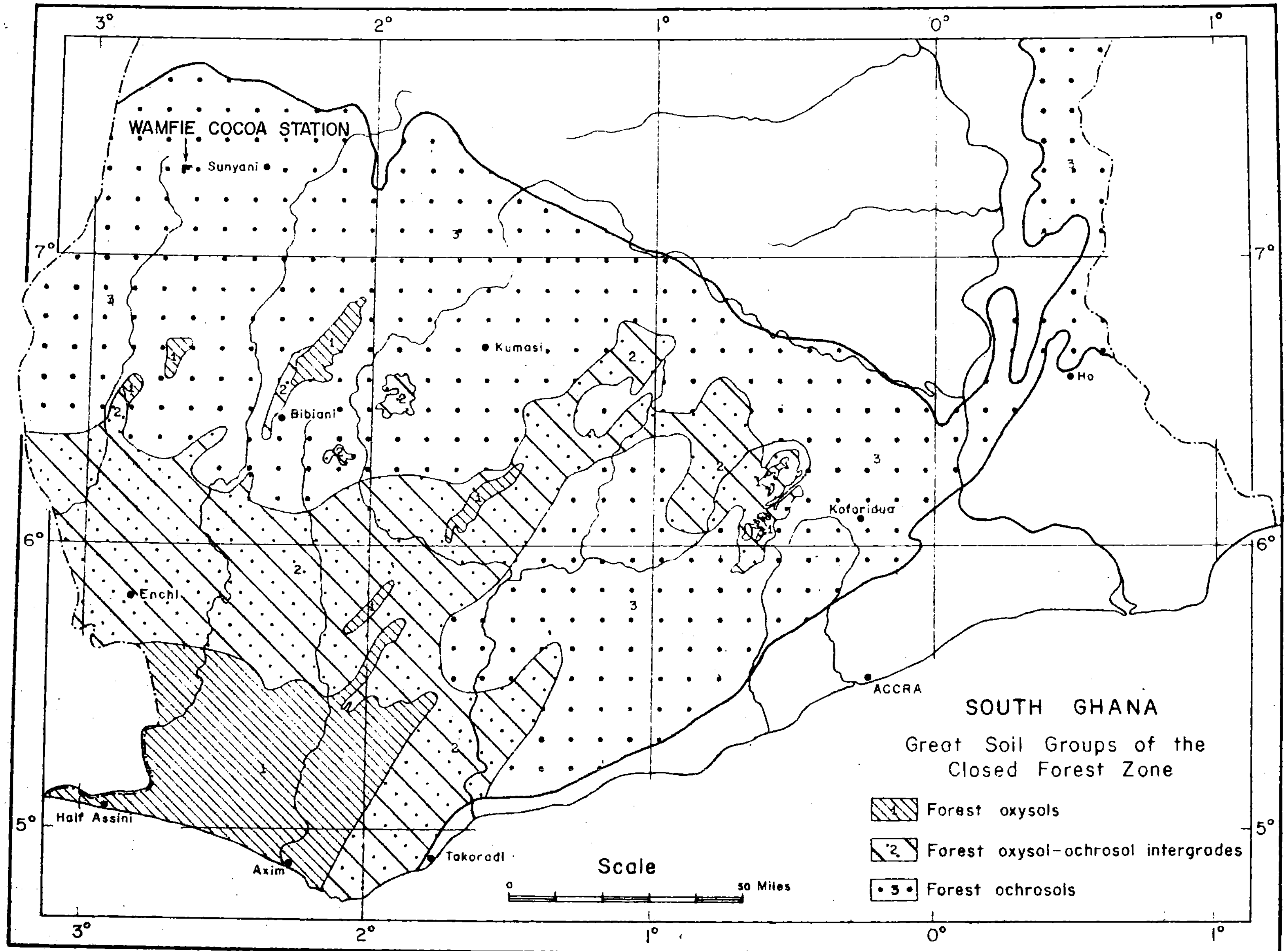

Ghana Ministry of Food and Agriculture, Scientific Services Division, Soil and Land-Use Survey Branch — Kumasi February, 1960

Fig. 1. Great soil groups of the closed forest zone, showing location of the station

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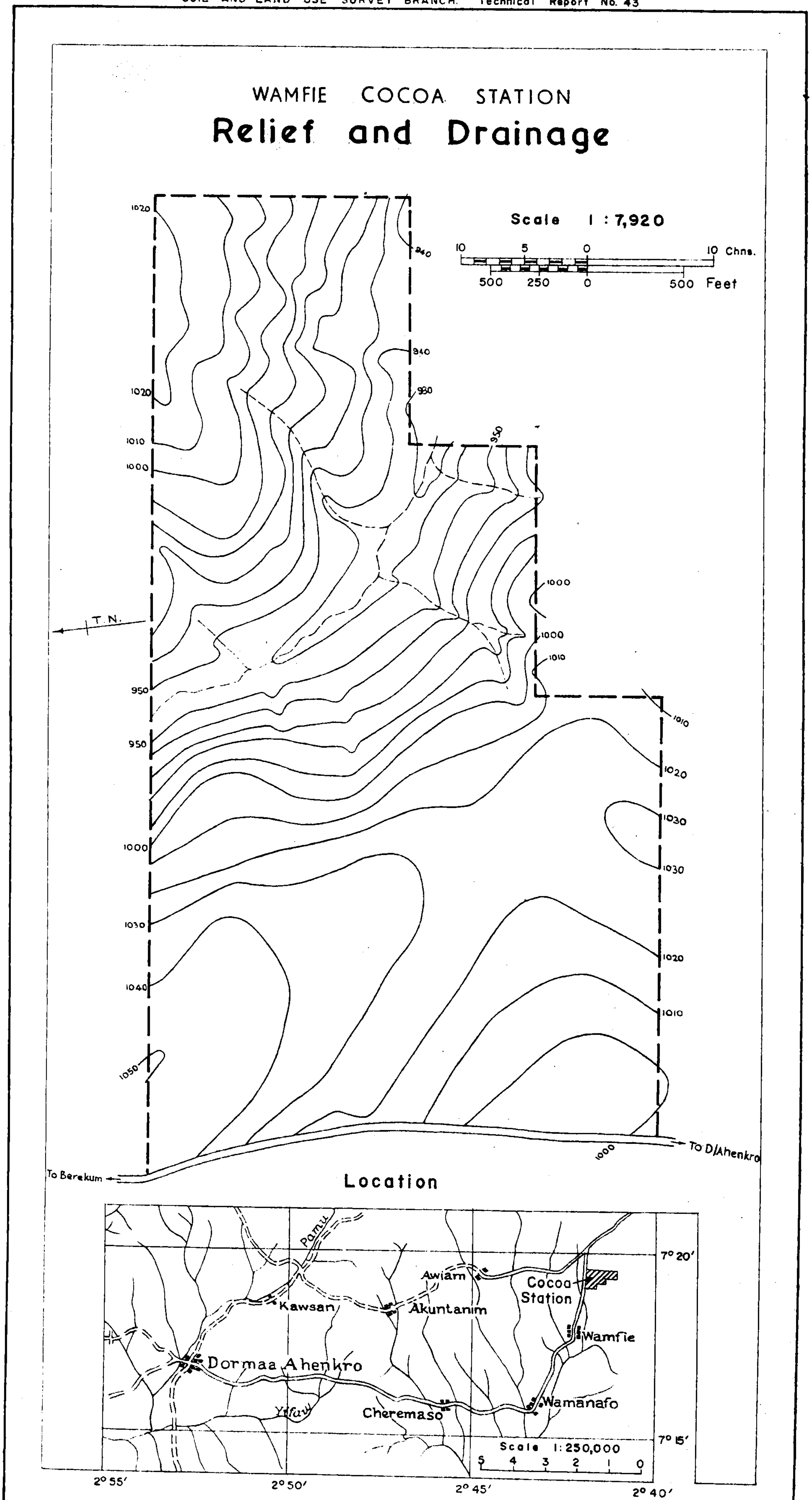

Fig. 2

Kumasi July, 1960

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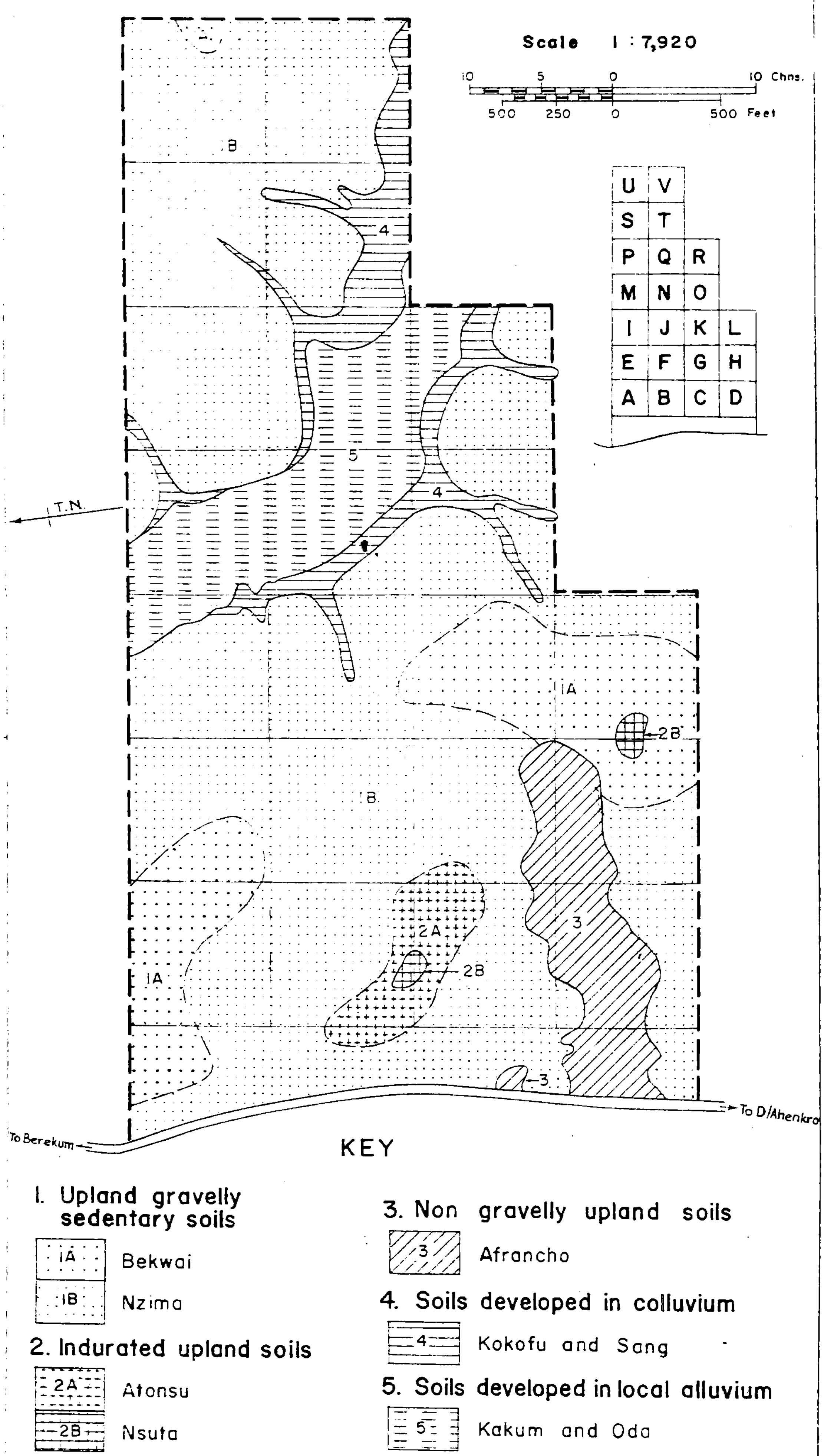
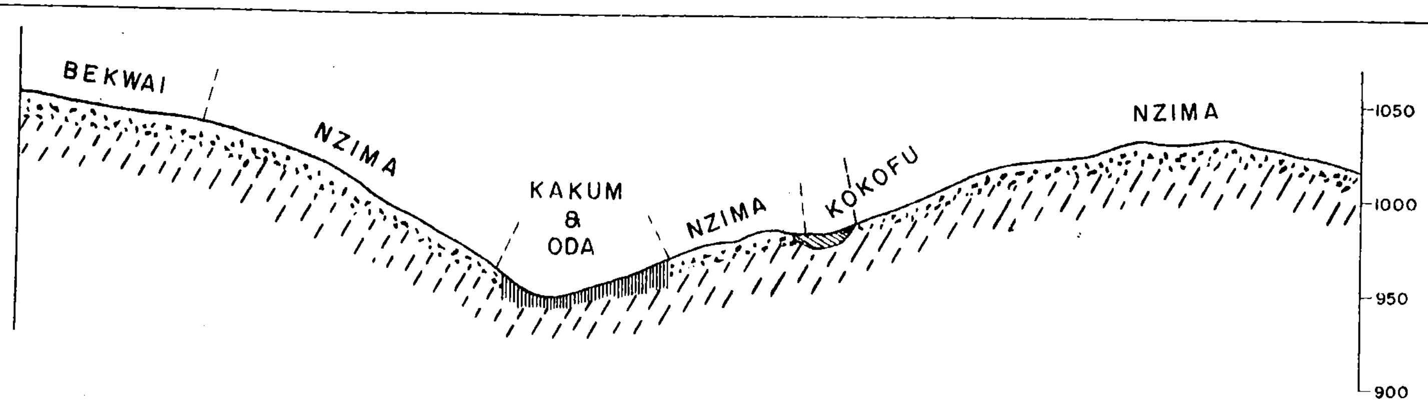
WAMFIE COCOA STATION
Soils

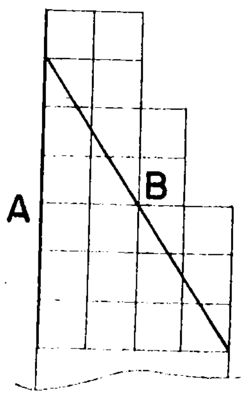


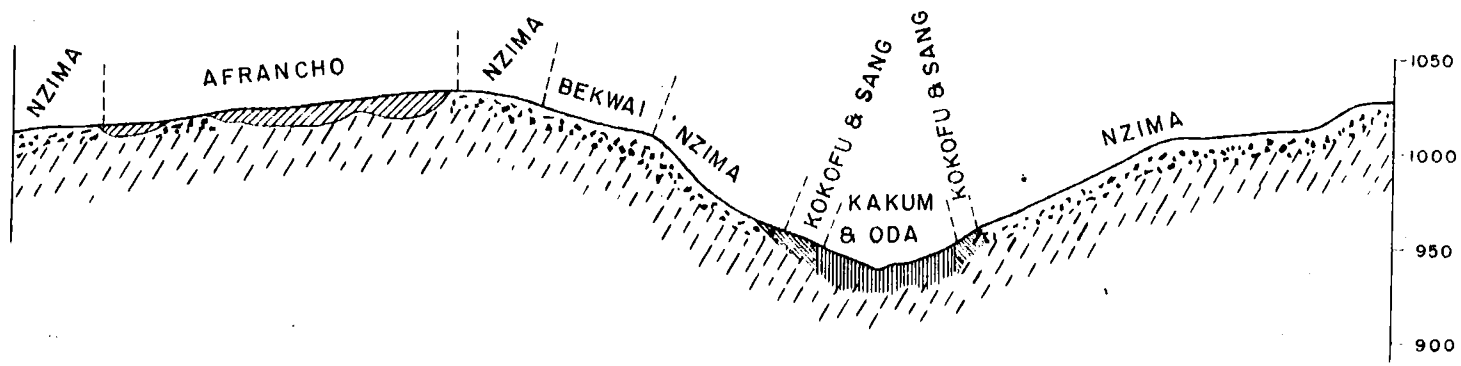
Kumasi. July, 1960

Fig. 3



A. CROSS SECTION OF WESTERN BOUNDARY OF STATION ALONG BLOCKS A. E. I. M. P. S. & U.





B. NW- SE CROSS SECTION OF STATION FROM BLOCK D TO BLOCK S

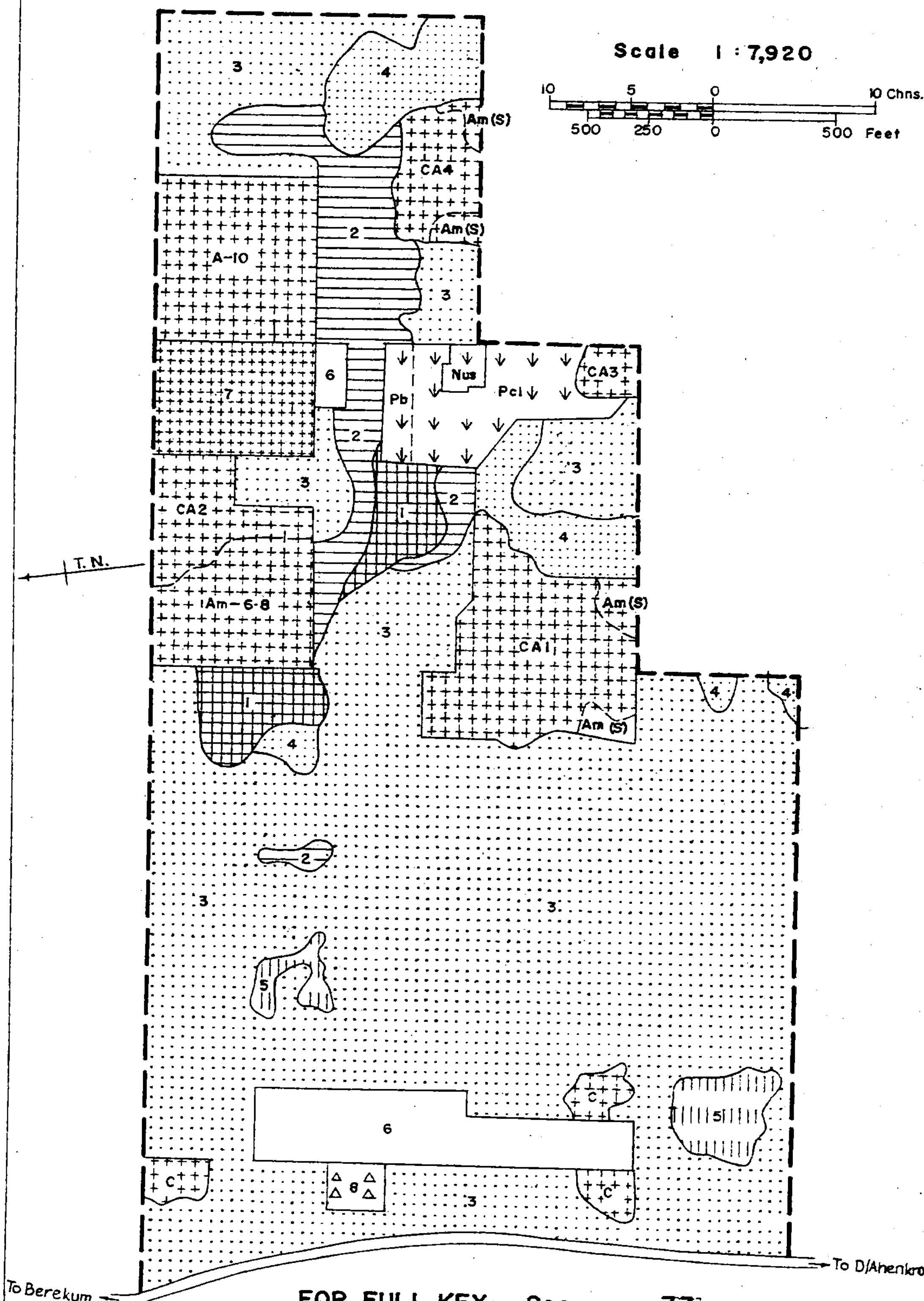
FIG. 4 CROSS SECTIONS OF THE STATION, SHOWING SOILS

GHANA MINISTRY OF FOOD AND AGRICULTURE, SCIENTIFIC SERVICES DIVISION,
SOIL AND LAND-USE SURVEY BRANCH Technical Report No. 43

WAMFIE COCOA STATION

Vegetation and Land Use

(January 1959)



FOR FULL KEY — See page 33

- 1 Broken forest
- 2 Secondary forest
- 3 Thicket regrowth
- 4 As 3, with crop relics
- 5 Forb regrowth
- 6 Built-over land
- 7 Coffee
- 8 Coconut palms
- Cocoa (see full key)
- Nurseries (see full key)

Fig. 5

APPENDIX 1 - DETAILED SOIL DESCRIPTIONS

(1) BEKWAI SERIES

Location : Peg A/O (block A).
Site : Upper slope to summit, gently undulating
Vegetation : Poor thicket regrowth, about six years old.

Detailed description

Topsoil 0-2 inches Dark brown (7.5YR 4/2) humous silty clay, crumbly and porous, with fairly frequent small roots and about 11% (by weight) of ironstone concretions and small fragments of ferruginised rock brash. pH 6.0

2-5 inches Brown (7.5YR 4/4) only slightly humous silty clay, crumbly and fairly porous, with occasional small roots and concretions, small rock brash and small quartz stones (some ironstained) totalling some 29% of the total soil. pH 5.8

Subsoil 5-15-28-45 inches Dull reddish brown to brown (7.5YR 5/4 to 5YR 5/8) silty clay, becoming light clay below 15 inches, with little visible structure, firm and highly gravelly. Coarse material increases from 57% (5-15 inches) to 70% (remainder of subsoil) and consists of occasional quartz stones and quartz gravel, frequent to abundant ferruginised rock fragments and abundant ironstone concretions, usually pea size or a little larger, and fairly smooth. pH 5.0-4.8

45-60 inches As above, but with slightly less gravel and stones (60%) and minor traces of soft decomposed phyllite. pH 4.8

Weathered substration

60-94-112 inches Brownish red loam, with feint yellow mottles becoming more marked with depth, and a decreasing content (37 to 17%) of ferruginised phyllite and quartz stones: ironstone concretions are infrequent in these horizons, but traces and small pieces of soft decomposed phyllite are fairly frequent.

112-144 inches Reddish brown light loam with frequent yellowish mottles with very frequent pieces and large patches of decomposed phyllite, merging into multi-coloured decomposed phyllite, softened and easily crumbled, but showing the original laminated structure.

(2) NZIMA SERIES

Location : Peg A/60 (blocks S/U)
Site : Upper slope, gently undulating
Vegetation : Cocoa.

Detailed description

Topsoil (Under a thin layer of decaying cocoa leaves):-

0-2 inches Dark brown (10YR 4/2) slightly humous silty clay, crumbly moderately porous and firm, with frequent small roots. Rare concretions and quartz gravel form about 3% (by weight) of this horizon. pH 6.8

2-5 inches Brown (10YR 5/3) only very slightly humous stained, silty clay, crumbly and fairly firm. Occasional to fairly frequent quartz gravel and ironstone concretions amount to about 17% of this horizon. pH 6.6

Subsoil 5-10-19-34-49 inches Pale orange brown (10YR 6/4 to 5YR 6/6) silty lightly gravelly clay, containing 64-75% by weight of ironstone concretions, quartz gravel, ferruginised rock brash and quartz stones. No apparent structure. pH 5.4, 4.8 4.8, and 5.0 in the sampling horizons.

49-64 inches As above but with slightly less coarse material (58%) and traces of decomposing phyllite. pH 5.0

Weathered substratum
64-80 inches Reddish brown silty light clay, mottled red and yellow, with frequent traces of soft, decomposed multicoloured phyllite. Coarse material, comprising scattered concretions and quartz gravel and stones, amounts to 5%. pH 5.2

80-99 inches Light loam of soft, pale, decomposed phyllite, friable, though showing the original phyllite structure. pH 5.4

(3) AFRANCHO SERIES

Location : Peg G/8 (block D)
Site : Middle to upper slope, very gently undulating
Vegetation : Secondary forest.

Detailed description

Topsoil 0-2 inches — Dark greyish brown humous silty light clay (10YR 4/1) weakly crumbly and porous. pH 6.2, merging into:-

2-6 inches — Dull brown (5YR 5/2) silty light clay, only slightly humous, porous, fairly firm, and with a very weakly developed medium sub-angular blocky structure.

Subsoil 6-45 inches — Relatively uniform orange-brown (10YR 6/4) silty light clay, firm but moderately porous, with a weakly developed fine sub-angular blocky structure. In the lower few inches of the horizon rare concretions and fine quartz gravel occur. pH 4.8-4.6.

45-65 inches — As above, but with slight orange, grey and red mottles, and traces of induration.

65-160 inches and below. Deep, mottled, moderately indurated layer, predominantly orange-brown in colour, and very difficult to dig with a pick. Occasional embedded quartz stones. pH 4.8-5.0

(4) SANG SERIES

Location : Peg E/64 (block V).
Site : Lower slope, gently undulating
Vegetation : Thicket regrowth.

Detailed description

Topsoil 0-2 inches — Brownish grey (10YR 6/1) humous sandy clay, weakly crumbly and porous: frequent small roots: pH 5.8

2-6 inches — Pale greyish yellow (10YR 6/2) sandy clay, slightly humous, weakly crumbly and moderately porous. pH 5.0

Subsoil 6-11-20 inches — Pale yellowish brown to greyish yellow (10YR 7/2) sandy clay with little or no structure. The lower part is feintly mottled orange and includes fine to coarse quartz gravel and occasional stones (but only rare concretions) and this overlies:-

below 20 inches	Indurated iron-cemented material with occasional embedded quartz stones. Difficult to dig with a pick-axe.

(5) ODA SERIES

Location : Extension of base line 70 west to stream, 26 chains outside station boundary.
Site : Bottom, flat.
Vegetation : Secondary forest

Detailed description

Topsoil	0-3 inches	Dark greyish brown (10YR 4/1) humous sandy light loam, crumbly and porous: occasional to frequent roots. pH 6.2
	3-7 inches	Dull brownish grey (10YR 6/4) slightly humous sandy light clay, weakly crumbly to structureless. Rare quartz gravel and occasional roots. pH 5.6
Subsoil	7-12-24 inches	Brownish grey to grey sandy clay, prominently mottled yellow and orange, structureless and fairly firm. Rare to occasional roots, scattered quartz stones and gravel. pH 5.4 to 4.8
	24-36 inches	Sandy light loam prominently mottled yellow, orange, grey and white, structureless and firm. Rare roots, occasional quartz stones and gravel. pH 4.6

APPENDIX 2: Soil Analyses of comparable soils outside the station

Lower Depth of Horizon in inches	Gross Mechanical Analysis per cent. Air-Dry: Stones 20mm.	Coarse Gravel 20-6.25mm.	Fine Gravel 6.26-2mm.	Fine Earth 2mm.	Mechanical Analysis of Fine Earth per cent. Oven-Dry: Very Coarse Sand 2-.625mm.	Coarse Sand .625-.2mm.	Fine Sand .2-.02mm.	Silt .02-.002mm.	Clay .002mm.	CaCO3	Loss on Solution	Total	Per cent. Oven-Dry: Ignition Loss	Corr. Ignition Loss	Moisture per cent.
2½					1.66	5.08	20.33	22.56	40.09	NIL	10.42	100.14			3.93
7					1.33	7.26	22.39	23.82	41.87	NIL	4.11	100.78			2.45
15					20.56	4.44	15.82	17.35	39.54	NIL	2.35	100.06			2.31
31					21.92	3.43	9.84	12.12	51.08	NIL	2.09	100.48			2.81
41					7.39	2.24	11.45	19.89	57.11	NIL	2.31	100.39			
52					2.57	1.85	12.32	25.98	56.26	NIL	1.38	100.36			
72					.97	1.63	15.44	39.66	41.39	NIL	1.04	100.13			
95					1.09	3.29	18.02	49.60	27.43	NIL	.81	100.24			
2					.66	1.37	22.33	28.67	35.85	.03	11.09	100.00			4.30
11					3.24	4.19	21.27	28.87	39.80	.002	2.63	100.00			2.30
21					6.46	3.81	16.38	25.41	45.60	.002	2.34	100.00			2.12
33					9.47	4.03	14.21	23.96	46.25	.002	2.08	100.00			2.02
46					3.71	2.89	15.81	33.08	43.67	.002	.84	100.00			2.07
64					1.56	2.61	11.81	59.50	24.13	.002	.39	100.00			1.15

Mechanical Analyses of Bekwai series (B.231 - PKR 8 above, and B.704-PKR 74, below).

Lower Depth of Horizon in inches		Gross Mechanical Analysis per cent. Air-Dry				Mechanical Analysis of Fine Earth per cent. Oven-Dry								Per cent. Oven-Dry		Moisture per cent.
		Stones 20mm.	Coarse Gravel 20-6.25mm.	Fine Gravel 6.26-2mm.	Fine Earth 2mm.	Very Coarse Sand 2-.625mm.	Coarse Sand .625-.2mm	Fine Sand .2-.02mm.	Silt .02-.002mm.	Clay .002mm.	CaCO3	Loss on Solution	Total	Ignition Loss	Corr. Ignition Loss	
1.	3	NIL	9.9	5.1	85.0	.41	3.49	20.28	15.30	45.80	.06	14.24	99.58			4.50
2.	9	2.2	30.5	6.3	61.0	2.96	6.35	28.34	10.67	47.11	.01	4.38	99.82			2.40
3.	25	NIL	63.1	6.4	30.5	5.82	4.06	19.69	9.45	58.44	.02	3.19	100.67			2.70
4.	37	NIL	15.3	4.1	80.6	1.81	3.57	17.56	13.52	61.68	.02	1.83	100.04			2.77
5.	56	NIL	2.0	1.4	96.6	.56	1.94	19.15	21.75	55.21	NIL	1.31	99.92			2.40
6.	69	NIL	NIL	NIL	100.0	.52	3.74	25.19	21.63	47.31	NIL	1.12	99.51			1.72
7.	95	NIL	1.0	.9	98.1	.30	2.40	24.30	25.33	46.43	NIL	.96	99.72			1.70
1.	3	NIL	NIL	NIL	100.0	1.66	6.59	31.99	25.77	22.74	NIL	10.97	99.72			2.96
2.	5	NIL	3.8	6.9	89.3	7.66	21.38	26.58	21.19	18.73	NIL	4.65	100.19			1.40
3.	15	42.6	27.2	10.1	20.1	13.77	18.66	24.21	21.76	19.69	NIL	2.09	100.18			1.16
4.	24	48.0	34.4	1.6	16.0	16.84	10.10	11.91	11.54	47.99	NIL	2.35	100.73			2.06
5.	33	NIL	33.8	19.5	46.7	11.98	7.25	9.00	9.31	61.85	NIL	1.46	100.85			2.52
6.	42	NIL	28.3	9.4	62.3	4.98	5.58	7.58	10.22	70.91	NIL	1.15	100.41			2.72
7.	60	NIL	27.0	13.8	59.2	2.61	6.65	8.55	15.46	66.43	NIL	.92	100.62			2.20
8.		13.4	23.1	15.2	48.3	1.94	4.37	6.14	16.81	70.30	NIL	.55	100.11			2.50
1.	4	NIL	0.1	0.3	99.6	3.25	23.17	26.45	7.47	28.03	NIL	12.24	100.61			4.14
2.	11	16.0	7.9	4.1	72.0	11.86	28.68	22.55	7.18	26.64	NIL	3.21	100.12			2.16
3.	20	26.1	9.1	6.6	58.2	10.81	23.00	20.93	7.91	35.01	NIL	2.62	100.28			2.44
4.	28	3.4	1.0	1.1	95.5	14.55	9.15	10.83	5.26	57.90	NIL	3.10	100.79			3.98
5.	41	NIL	3.2	8.6	88.2	6.31	12.15	15.21	8.36	55.85	NIL	2.24	100.12			3.68
6.	52	NIL	0.9	3.7	95.4	3.59	8.74	10.44	10.58	64.02	NIL	1.69	99.06			3.90
7.	74	NIL	NIL	1.6	98.4	5.82	8.20	13.46	22.41	49.71	NIL	0.80	99.60			3.02

Mechanical analyses of Nzima series (B.707, PKR 126 above; B.709, DKR 61 centre; B.334, PSPCA 4 below).

Series	Vegetation	Lower horizon depth inches	pH	% fine earth	T (CEC)	Exchangeable bases (m.e./100gm) Ca	Mg	Mn	Na	K	S (TEB)	S/T x100	Ca/Mg	Mg/K	% C	% N	C/N	% O.M.	P. p.p.m.	Moisture air dry %
BEKWAI B 251	COCOA	2½	6.25		31.98	18.18	3.63	.50	.33	.24	22.88	72.2	5.01	15.13	4.19	.412	9.76	6.91		3.70
		7	5.0		13.39	2.54	1.21	.43	.15	.10	4.43	33.1	2.10	12.10	1.10	.139	7.99	1.91		2.44
		15	4.6		11.36	.90	.54	.02	.11	.08	1.65	14.5	1.67	6.75	.77	.094	8.08	1.31		2.20
		31	4.7		11.41	.66	.40	.02	.17	.07	1.32	11.6	1.65	5.72	.52	.077	6.75	.89		2.76
		41	5.0		11.79	.99	.98	.04	.12	.07	2.20	18.7	1.01	14.00	.32	.045	7.11	.55		3.15
		52	5.05		11.05	.62	.94	.04	.13	.04	1.77	16.0	.66	12.30	.22	.044	5.00	.38		3.08
		72	4.90		9.18	.35	.63	.02	.21	.02	1.23	13.4	.56	31.50	.09	.036	2.50	.15		2.32
		95	5.0		8.10	.25	.35	.08	.21	.05	.94	12.2	.71	7.00	.08	.034	2.35	.14		1.85
BEKWAI B 392 DKR 9	COCOA (neglected in Forb regrowth)	3	6.95		30.36	37.64	4.40			.44	42.48	139.92	8.55	10.00	7.08	.714	9.92	12.18		5.16
		6	5.8		10.03	6.52	1.77			.21	8.50	84.75	3.68	8.43	1.27	.154	8.25	2.18		2.70
		18	5.0		9.25	2.43	1.93			.24	4.60	49.73	1.26	8.13	.74	.089	8.31	2.17		3.18
		32	4.65		10.09	1.24	1.47			.23	2.94	29.28	.84	5.88	.53	.069	7.68	.91		3.60
BEKWAI B 441 FTB 39	COCOA	2	7.2		21.12	14.60	5.26			1.03	20.89	98.91	2.78	5.11	3.58	.358	10.00	6.16		3.28
		6	6.5		12.56	6.52	2.46			.61	9.59	76.35	2.65	6.98	1.42	.164	8.66	2.44		2.48
		12	5.4		9.35	2.33	1.31			.40	4.04	43.21	1.78	3.28	.60	.075	8.0	1.03		2.38
		22	5.5		9.19	2.28	1.21			.33	3.82	41.57	1.88	3.67						2.54
BEKWAI B 443 FTB 41	COCOA	2	6.5		17.46	11.47	3.29			.76	15.52	88.89	3.49	4.33	2.52	.184	13.70	4.33		2.58
		6	5.8		13.34	6.63	1.21			.45	8.29	62.14	5.48	2.69	1.40	.104	13.46	2.41		2.50
		12	6.1		11.35	6.27	.93			.27	7.47	65.81	6.40	3.44	.89	.084	10.59	1.53		2.30
		24	6.6		10.75	6.25	.90			.22	7.37	68.56	6.94	4.09						6.52
BEKWAI B 462 DKR 168	COCOA	3	7.2		38.63	42.88	7.26			.41	50.55	130.87	5.90	17.71	8.26			14.21		5.50
		8	6.95		10.72	9.85	3.90			.22	14.07	131.50	2.53	17.73	1.43			2.46		2.20
		18	5.1		6.96	2.55	1.04			.13	3.72	53.46	2.45	8.00	.70			1.20		2.10
		26	4.5		7.40	1.03	1.76			.18	3.67	49.58	0.59	9.78	.56			0.96		2.50

Appendix 2 - continued. Chemical analyses of soils comparable to those on the station.

Series	vegetation	Lower horizon depth inches	pH	% fine earth	T (CEC)	Exchangeable bases (m.e./100gm) Ca	Mg	Mn	Na	K	S (TEB)	$\frac{S}{T}$x100	$\frac{Ca}{Mg}$	$\frac{Mg}{K}$	% C	% N	C/N	% O.M.	P. p.p.m.	Moisture air dry %
BEKWAI B 546 PTBA 328	COCOA	2	5.6		26.16	13.06	4.48			.56	18.12	69.27	2.91	8.00	4.81	.475	10.17	8.27		4.64
		6	5.4		17.41	5.39	1.94			.25	7.58	43.54	2.78	7.76	2.45	.276	8.88	4.21		3.70
		15	5.1		8.86	.85	.24			.15	1.24	14.00	3.54	1.60	.71	.088	8.07			2.58
		29	5.1		10.83	1.60	.42			.10	2.12	19.58	3.31	42.00	-					3.40
BEKWAI B 627 PTBA 324	THICKET	2	7.0	90	26.30	21.62	5.25	.17		.68	27.72	105.39	4.12	7.72	4.56	.448	10.18	7.84		4.12
		4	7.0	90	15.98	10.78	2.30	.04		.42	13.54	84.71	4.69	5.48	1.71	.218	7.84	2.94		3.08
		10	7.0	85	11.77	7.02	1.29	.02		.17	8.50	49.27	5.44	7.59	1.04	.127	8.19	1.79		2.52
		18	6.8	72	10.28	5.29	1.27	.01		.17	6.74	65.67	4.17	7.47						2.82
BEKWAI B 628 PTBA 330	COCOA	2	5.8	86	18.39	6.51	2.87			.42	9.80	55.13	2.27	6.83	3.29	.319	10.31	5.66		
		4	5.9	93	14.51	4.18	1.76			0.20	6.14	42.32	2.38	8.80	1.91	.214	8.93	3.29		
		9	5.9	51	10.34	2.37	0.62			.16	3.15	30.46	3.82	3.88	.87	.112	7.77	1.50		
		18	5.9	28	11.22	3.31	1.09			.24	4.64	41.35	3.04	4.54						
BEKWAI B 629 PTBA 265	CULTIVATION WITH COCOA SEEDLINGS	2	5.9	96	21.44	10.41	2.81			.39	14.12	65.86	3.70	7.20	4.68	.399	11.73	8.05		
		7	5.32	96	10.32	1.83	.59			.03	2.68	25.97	3.10	19.66	1.57	.160	9.81	2.70		
		15	5.2	50	6.95	.51	.32			-	0.97	13.96	1.60	-	.72	.073	9.86	1.24		
		39	5.5	50	8.30	.31	.53			.02	1.02	12.29	.58	26.50						
BEKWAI B 630 PTBA 384	SECONDARY FOREST	2	5.9	99	16.06	6.92	2.43			.23	9.58	59.65	2.85	10.57	2.81	.284	9.89	4.83		3.34
		4	6.05	82	13.29	5.53	1.41			.12	7.06	53.12	3.92	11.75	1.52	.188	8.09	2.61		3.22
		12	5.7	47	11.69	3.18	1.20			.13	4.51	38.58	2.65	9.23	.85	.105	8.09	1.46		3.48
		30	5.65	65	12.96	1.51	3.03			-	4.54	35.03	.50	-	-	-	-	-		4.74
BEKWAI B 702 DER 66	THICKET	2	6.5	93	35.73	28.68	2.81	.11		.47	32.07	89.76	10.21	5.98	5.45	.430	12.67	9.37		4.77
		4	6.5	86	17.26	11.46	1.16	.03		.15	12.80	74.16	9.88	7.73	2.12	.205	10.34	3.65		3.07
		6	5.2	70	12.12	2.68	.73	.01		.16	3.55	29.29	3.63	4.56	1.25	.123	10.16	2.15		2.69
		18	5.1	56	11.79	1.63	.50	.01		.07	2.21	18.74	3.26	7.01	1.02	.103	9.90	1.75		2.73

Appendix 2 - continued.

Series	Vegetation	Lower horizon depth inches	pH	% fine earth	T (CEC)	Exchangeable bases (m.e./100gm) Ca	Mg	Mn	Na	K	S (TEB)	$\frac{S}{T}$x100	$\frac{Ca}{Mg}$	$\frac{Mg}{K}$	% C	% N	C/N	% O.M.	P. p.p.m.	Moisture air dry %
BEKWAI B 704 PKR. 74	COCOA	2	6.4	100	43.13	24.91	7.79	.39		.29	33.38	77.39	3.20	26.86	6.11	0.454	13.46	10.57	556	
		11	5.1	94	16.00	1.74	1.30	.05		.08	3.17	19.81	1.34	16.25	1.28	0.137	9.34	2.20	424	
		21	5.0	42	13.20	.48	.31	.02		.07	.88	6.67	1.55	4.43	0.71	0.085	8.35	1.22	436	
		33	5.1	31	10.95	.44	.30	.02		.08	.84	7.67	1.47	3.75	0.40	0.061	6.56	0.69	453	
		46	4.9	79	9.99	.33	.49	.03		.02	.87	8.71	.67	24.50	0.31	0.069	4.49	0.53	395	
		64	5.5	100	6.93	.25	.40	.01		.02	.68	8.91	.63	20.00	0.28	0.057	4.91	0.48	402	
		79	5.4	100	6.55	.31	.30	.01		.08	.70	12.61	1.03	3.75	0.07	0.047	1.49	0.12	-	
BEKWAI B 1060 BFRS 59	BROKEN FOREST	2	7.0			27.52	5.66	.071		0.84			4.86	6.74	6.01	.624	9.63	10.34		4.54
		8	5.35			2.74	1.25	.122		0.32			2.19	3.91	.75	.103	7.28	1.29		2.18
		18	4.90			1.95	1.10	.129		0.37			1.77	2.97	.54	.077	7.01	0.93		2.86
		35	5.00			1.79	1.22	.099		0.19			1.47	6.42	.44	.065	6.77	0.76		3.01
		57	5.15			1.61	1.38	.049		0.08			1.17	17.25						2.97
		77	5.00			.92	1.22	.012		0.07			0.75	17.43						3.19
		90	5.0			.97	.96	.008		0.11			1.01	8.73						3.07
		96	5.15			.80	.79	.009		0.09			1.01	8.78						1.66
BEKWAI B 1169 BIA 195	THICKET	2	5.5		15.64	9.87	2.66	.43	.21	.57	13.74	87.9	3.71	4.67		.325			602	2.77
		5	5.4		6.62	2.57	1.10	.22	.08	.22	4.19	63.3	2.34	5.00		.123			437	1.70
		12	5.15		5.96	1.31	.80	.12	.17	.15	2.55	42.8	1.64	6.67		.061			402	1.79
		23	4.35		9.89	2.36	1.05	.09	.20	.28	3.98	40.2	2.25	3.75					463	3.84
		40	5.0		10.40	1.86	.69	.04	.10	.17	2.86	27.5	2.70	4.06					500	4.01
		75	5.2		9.37	.62	.42	.001	.09	.06	1.19	12.7	1.48	7.00					346	3.68
		93	5.35		8.72	.41	.41	.001	.09	.04	.95	10.9	1.00	10.3					336	3.42
		105	5.35		8.23	.31	.57	.001	.09	.04	1.01	18.9	.54	14.3					335	3.09

EKA+

Appendix 2 - continued.

Series	Vegn.	Lower horizon depth inches	pH	% fine earth	T (CEC)	Exchangeable bases (m.e./100 gm) Ca	Mg	Mn	Na	K	S (TEB)	$\frac{S}{T}$ x 100	$\frac{Ca}{Mg}$	$\frac{Mg}{K}$	% C	% N	C/N	% O.M.	Moisture Air dry %
NZIMA B 333 PSPCA 2	Coffee Plantation	2	5.3		18.18	4.71				0.19					2.04	0.217	9.43	3.51	
		11	5.1		13.79	1.39				0.12					0.64	0.091	7.03	1.10	
		28	5.3		13.14	1.10				0.11					0.43	0.063	6.82	0.74	
		39	5.8		10.64	1.04				0.11					0.22	0.037	5.95	0.38	
		92	5.9		8.08	0.90		-		0.09					0.14	0.016	8.75	0.24	
		92	6.2		6.97	0.83				0.12					0.04	0.014	2.86	0.07	
NZIMA B 334 PSPCA 4	Secondary forest	4	5.3	26.45	25.74	12.40	3.84	0.23	0.25	0.69	17.41	67.6	3.23	5.56	5.91	0.503	11.75	10.17	
		11	4.7	22.55	11.09	1.44	1.02	0.02	0.34	0.34	3.16	28.5	1.41	3.00	1.31	0.138	9.49	2.25	
		20	4.7	20.93	10.94	1.11	0.94	-	0.26	0.27	2.58	23.6	1.18	3.48	0.82	0.087	9.43	1.41	
		28	4.9	10.83	15.91	1.17	1.35	-	0.26	0.28	3.06	19.2	0.87	4.82	0.73	0.081	9.01	1.26	
		41	5.0	15.21	14.58	1.09	0.86	-	0.13	0.36	2.44	16.7	1.27	2.39	0.41	0.061	6.72	0.71	
		52	5.1	10.44	15.72	1.25	0.87	-	0.16	0.25	2.53	16.1	1.44	3.48	0.35	0.049	7.14	0.60	
		74	5.2	13.46	13.57	0.98	0.39	-	-	0.23	1.60	11.8	2.51	1.70	0.91	0.043	4.42	0.33	
NZIMA B 545 PTBA 326	Cocoa	2	5.5		23.18	12.92	1.83			0.57					4.97	0.436	11.40		
		4	5.6		10.76	3.88	0.71			0.17					1.44	0.164	6.78		
		19	5.6		9.24	3.01	0.73			0.16					1.06	0.130	8.15		
		15	5.7		7.91	1.99	0.75			0.16					-	-	-		
NZIMA B 549 PTBA 98	Cocoa	2	6.68		27.94	19.01	8.47			1.04					5.66	0.452.447	12.52		
		10	6.48		24.62	2.24	1.91			.35					0.40	0.050.048	8.00		
		18	5.3		13.17	2.15	1.11			.43					0.35	0.042.048	8.33		
		45	5.4		11.51	1.18	.59			.24									
NZIMA B 631 PTBA 376	Broken forest	2	6.7		31.035	23.24	6.42			0.99					7.17	0.631	11.36	12.33	
		4	6.1		9.08	2.55	1.49			0.34					1.41	.170	8.29	2.43	
		10	6.2		6.62	1.11	1.08			0.39					0.63	.077	8.18	1.08	
		19	5.5		10.88	1.33	1.14			0.33									
		33	5.5																
		48	5.5																
		66	5.6																
		76	5.7																
NZIMA B 632 PTBA 385	Cocoa	2	6.2		21.17	8.73	6.55			0.36					4.25	0.366	11.61	7.31	
		5	5.4		13.42	2.33	1.70			0.21					1.91	.174	10.98	3.29	
		12	5.9		6.24	0.94	0.28			0.13					0.60	.064	9.37	1.03	
		22	5.95		7.69	1.59	0.79			0.12									
		32	6.0																
		44	5.8																
		62	6.0																
		88	6.15																
		104	6.2																

Appendix 2 - continued.

Series	Vegn.	Lower horizon depth inches	pH	% fine earth	T (CEC)	Exchangeable bases (m.e./100gm) Ca	Mg	Mn	Na	K	S (TEB)	$\frac{S}{T}$ x 100	$\frac{Ca}{Mg}$	$\frac{Mg}{K}$	% C	% N	C/N	% O.M.	Moisture Air dry %
NZIMA PTBA 342 B 633	Broken forest	2 6 15 24	6.55 6.4 6.85 6.2		15.93 11.75 8.09 15.26	10.78 5.94 4.13 4.99	2.80 1.16 0.68 2.35			0.41 0.26 0.14 0.12					3.22 1.41 0.59	0.328 .170 .067	9.82 8.29 8.81	5.54 2.43 1.01	
NZIMA B 705 PKR 10	Cocoa	3 8½ 20 34	6.50 6.50 6.70 6.00		16.06 9.22 7.32 8.65	15.32 6.91 4.16 3.79	3.46 2.26 3.26 3.29			.12 .12 .20 .08					2.96 1.07 .58 .47	.296 .135 .067 .059	10.00 7.93 8.66 7.97	5.09 1.84 1.00 .81	
NZIMA B 706 PKR 75	Cocoa	3 10 20 34	6.20 5.50 5.60 5.40		16.93 6.31 6.21 6.87	11.56 2.34 1.63 1.74	5.40 2.34 2.36 3.60			.08 .12 .18 .03					4.02 .77 .46 .50	.335 .087 .064 .077	12.00 8.85 7.19 6.19	6.91 1.32 .79 .86	
NZIMA B 707 PKR 126	Broken forest	3 9 25 37 56 69 95	9.80 4.5 4.55 4.9 4.9 4.90 5.05	85 61 30 81 97 100 98	37.86* 13.82 12.99 9.08 9.23 6.72 5.98	20.74 .77 .58 .68 .70 .49 .26	7.14 .72 .72 .76 .56 .49 .38	1.33 .09 .01 .02	- - - -	.80 .12 .16 .08	30.01 1.70 1.47 1.54	79.27 12.30 11.32 16.92	2.90 1.07 .81 .89 1.25 1.00 .68		7.40 1.81 1.02 .56	.590 .164 .105 .064	12.54 11.04 9.71 8.75	12.73 3.11 1.75 .96	4.71 2.46 2.78 2.85 2.46 1.72 1.70
NZIMA B 709 DKR 61	Thicket	3 5 15 24	5.20 4.80 5.50 5.30		16.97 7.13 4.41 6.96	9.63 10.52 2.58 2.46 2.32 2.16 2.76 3.02	3.04 1.05 .82 .19			.58 .68 .25 .27 .22 .30 .26					6.00 1.86 .80 .71	.527 .197 .084 .089		10.32 3.10 1.44 1.53	
NZIMA B 1063 BFRS 77	Broken forest	2 6 15 24 31 50 55	5.50 5.25 4.90 4.90 4.95 5.00 5.00			9.87 1.92 1.58 1.80 1.48 1.18 0.72	3.32 1.17 1.05 0.99 1.00 0.82 0.36	0.41 0.09 0.07 0.03 0.01 0.01 0.01		0.46 0.11 0.32 0.17 0.08 0.06 0.14					4.91 0.61 0.53 0.52	.415 .100 .094 .086			
NZIMA B 1067 BFRS 83	Secondary forest	2 4 14 22 34 52 60	6.35 6.00 4.70 4.90 4.55 4.90 5.15			18.99 4.40 1.49 2.04 .55 .38 .26	3.17 1.42 1.07 1.33 .61 .52 .31	.178 .051 .011 .047 .006 .011 .008	.37 .08 .08 .08 .08 .12 .10	.51 .051 .011 .047 .006 .011 .008						.430 .157 .118 .105			

* With barium acetate

Series	Vegn.	Lower horizon depth inches	pH	% fine earth	T (CEC)	Exchangeable bases (m.e./100gm) Ca	Mg	Mn	Na	K	S (TEB)	$\frac{S}{T}$ x 100	$\frac{Ca}{Mg}$	$\frac{Mg}{K}$	% C	% N	C/N	% O.M.	Acid soluble P
Afrancho B 429 FTB 28	Cocoa	2 6 10 20	6.5 5.6 5.4 5.3		14.18 7.63 6.15 5.38	10.89 3.48 2.45 2.36	3.25 0.73 0.03 0.29			0.29 0.24 0.21 0.09					2.87 1.07 0.75	0.276 0.084 0.065 0.050	10.40 12.74 11.54		
Afrancho B 661 PTBA 19	Thicket	3 11 18 26	6.8 5.3 5.2 5.25		21.40 7.44 7.89 7.32	13.64 1.21 0.76 0.76	5.37 0.38 0.13 0.13			0.77 0.13 0.09 0.10					4.33 0.86 0.55	0.418 .074 .064	10.36 11.62 8.59		
Afrancho B 54 TBA 170	Young Cocoa	3 9 18 31 45 73	6.3 6.2 5.3 5.4 4.9 5.3		22.48 7.37 5.41 6.64	19.73 4.11 1.81 1.87	4.56 2.03 1.23 1.03			0.48 0.11 0.12 0.11					4.46 0.99 0.45 0.44 0.36 0.14			7.7 1.7 0.8	5.6 2.2 1.7
Afrancho B 55 TBA 173	Cocoa	3 9 22 39 57 77	6.3 6.9 5.7 5.2 5.0 5.1		23.38 7.29 8.41 8.13	18.51 6.40 3.81 2.16	2.89 0.49 0.39 0.30			0.32 0.14 0.11 0.12			6.40 13.06 9.77 5.54	9.03 3.50 3.55 3.25	4.55 0.96 0.57 0.44 0.22 0.20				
Afrancho B 1110 ARSK 2	Broken forest	1½ 4 15 25	5.60 4.70 4.85 4.85			5.91 2.07 .96 .81	1.01 1.21 .76 .71	.228 .163 .027 .016	.18 .18 .12 .12	.49 .36 .12 .09					0.27 0.97 0.74	0.253 0.128 0.076 0.066			2.08 1.96 2.41 2.61
Kakum B 208 RBAN 2	Thicket	2 7 12 20 34 45 53	5.1 4.8 4.8 5.0 5.5 6.1 4.9		17.0 4.2 2.9 8.8 1.0 3.9 8.7	9.4 0.5 0.5 0.5 0.9 0.6 0.5				0.52 0.09 0.04 0.01 NIL 0.07 NIL					5.72 0.58 0.26	.407 .066 .031	14.0 8.8 8.3	9.8 1.0 0.4	29.6 1.3 NIL
Kakum B 245 DPA 10	Forb regrowth	3 9 20 36 60 74	6.0 4.9 5.0 5.5 6.8 5.9		35.16 20.37 22.53 18.35 7.08 18.85	19.70 8.66 8.27 7.53 3.32 7.53				0.92 0.14 0.17 0.13 0.05 0.09					6.45 0.71 0.53	0.433 0.064 0.083	14.9 11.1 6.4	11.1 1.2 0.9	68.4 8.8 3.0

Series	Vegn.	Lower horizon depth inches	pH	% fine earth	T (CEC)	Exchangeable bases (m.e./100 gm) Ca	Mg	Mn	Na	K	S (TEB)	$\frac{S}{T}$ x 100	$\frac{Ca}{Mg}$	$\frac{Mg}{K}$	% C	% N	C/N	% O.M.	Acid soluble P
Kakum B 607 PTBA 84	Cocoa	3	7.22		8.49	8.02	3.22			.25					2.03	0.163	12.45	3.49	
		6	7.2		5.92	6.28	.95			.14					1.19	0.102	11.67	2.05	
		18	6.4		2.96	1.94	.29			.10					0.38	0.041	9.27	0.65	
		24	6.14		2.52	.98	.24			.11									
Kakum B 640 PTBA 155	Savannah thicket	2	5.0		26.27	10.90	4.02			0.45					4.66	0.462	10.09	8.02	
		10	5.1		18.27	6.41	3.08			0.18					1.16	.163	7.12	2.00	
		50	4.6		15.26	1.82	.88			0.11					0.28	.050	5.60	0.48	
		65	4.7		13.88	1.25	.68			0.06									
Oda B 1072 BFRS 3	Broken forest	3				7.15	1.51	.038	.19	.40	9.28								
		8				3.20	.80	.034	.14	.11	4.28								
		20				3.32	1.31	.012	.78	.06	5.48								
		38				4.98	2.39	.005	2.01	.05	9.53								
		44				4.57	2.64	.006	2.41	.08	9.62								
		53				8.70	5.64	.008	2.33	.14	16.81								
		72				9.71	6.53	.006	4.84	.13	21.21								
		108				10.18	7.10	.005	5.26	.14	22.68								
Oda B 1348 CAS	Thicket	3	4.75		3.72	0.50	0.443	0.037	2.42	0.08	3.4484	92.47	1.13	5.54	0.91	0.089	10.22	1.57	
		7	4.70		6.44	0.90	0.871	0.089	0.04	0.08	1.8998	29.35	1.03	10.89	1.65	0.162	10.18	2.84	
		15	4.75		2.89	0.55	0.159	0.041	0.10	0.19	1.004	34.60	3.46		0.57	0.053	1.76	0.98	
		30	4.90		2.84	0.25	0.271	0.029	0.10	0.04	.669	23.24	0.92		0.23	0.029	7.93	0.40	
		44	4.70		2.84	0.30	0.604	0.006	0.09	0.02	1.01	24.16	0.50		0.22	0.019	11.58	0.38	
		52	4.30		4.18	0.20	1.414	0.006	0.33	0.02	1.967	46.89	0.49		0.19	0.019	10.0	0.33	
		66	4.30		10.46	0.50	3.923	0.007	0.89	0.05	5.367	51.24	0.54		0.21	0.016	13.13	0.36	
															0.20	0.015	13.33	0.34	
Oda B 633 PTBA 379	Broken forest	3			20.53	9.60	4.09			0.70					6.19	0.438	14.13	10.65	
		6			7.82	1.52	1.30			0.19					1.03	.122	8.44	1.77	
		12			4.75	0.96	0.47			0.05					0.28	.046	6.09	0.48	
		22			4.04	1.11	0.40			0.11									
Oda B 605 PTBA 81	Cultivation	4	6.10		11.89	6.70	1.16			0.27					3.03	0.244	12.42	5.22	
		10	6.0		5.49	2.76	0.83			0.09					0.66	0.074	9.19	1.17	
		17	6.5		5.11	2.52	0.63			0.11					0.53	0.062	8.55	0.91	
		35	6.1		4.74, 5.51	2.02, 2.15	1.42, 1.70			0.20 .14									
Oda B 395 DKR 13	Forb regrowth	4	7.00		22.35	21.57	4.66			.14						0.315			
		16	6.80		11.84	9.69	2.87			.12						.091			
		30	6.40		10.47	6.51	3.79			.08						.041			
		54	5.90		10.25	7.32	2.57			.10									

APPENDIX 3: DAY BY DAY RAINFALL RECORDS, DORMAA-AHENKRO PREVENTIVE STATION, 1955-9

(a) REGISTER OF RAINFALL IN 1955

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
1						0.24				0.20		
2			0.56	1.44						2.18		
3						0.58						
4				0.63	1.60					0.27		0.41
5									0.14			
6		1.40					0.73	0.22	0.16		0.40	
7		1.00				0.32				0.36	0.16	
8			0.03	0.18	2.22							
9						0.45				0.53		
10			0.27				0.35	0.48	0.16	1.01		
11								0.15				
12			0.32		0.16	0.63		0.17	0.21	0.75		
13										0.16		
14			0.33			0.52			0.02			
15				0.83	0.34	0.50	2.20	0.17	0.41			
16			0.70				0.38		0.02	0.04		
17					1.08	0.11			1.46			
18		0.46	0.46						0.03	0.04	0.43	
19		0.26		0.40			0.03			0.50	0.65	
20			0.62		0.56		0.01		0.21			
21				0.08		1.00			0.03			
22					1.57		0.13		2.25	0.46		
23				1.03			0.86			1.43		
24			0.07	0.15		0.10		0.04				
25				0.48			0.12			0.17		
26					1.01				0.08	1.89		
27		0.41	0.08	0.12		0.25						
28			0.10			0.06		0.39	0.43	0.96		
29					0.20					0.45		
30						0.16		0.12	0.26			
31								0.01				
Total	NIL	3.53	3.48	5.34	8.74	4.92	4.81	1.75	5.87	11.40	1.64	0.41

Annual total: 51.89"

(b) REGISTER OF RAINFALL IN 1956

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
1						2.95						
2												
3				0.79	0.07				0.02			
4						2.46					0.06	
5										0.39		0.85
6						0.40	.12			0.05		
7				0.12	0.90	0.09	.27		0.25			
8					0.09					0.25		
9				0.87	0.39						0.91	
10		0.35			0.22	0.44			0.05			0.19
11				0.40		1.00			0.60	0.55		
12		0.45					.25			0.35		
13			0.48						0.25			
14				0.52	0.63		.50		0.19			
15			1.01							0.12		
16						0.79				0.17		
17		0.26			1.24		.13		0.03	0.56		
18		0.26		0.15					0.05			
19								.21	0.02			
20						0.22						
21		0.29			2.22				2.25			
22			0.06	0.98					0.06			
23				0.72					0.49			
24			1.40						0.17			
25									0.30			
26					0.25				0.15	0.92		
27		0.41		0.05				0.20				
28				0.66					1.47	0.55		
29								0.80				
30			0.27	1.44	0.33	0.09		0.05				
31					0.30							
Total	NIL	2.02	3.22	6.70	6.64	8.44	1.27	1.26	7.25	3.91	0.97	1.04

Annual total: 42.72"

(C) REGISTER OF RAINFALL IN 1957

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
1				0.49								0.38
2												
3				1.00		1.36				0.51	0.66	
4								0.33		0.08	0.05	0.50
5				0.45			0.20					
6							0.85	0.43			0.41	
7				0.37	0.44	1.82	1.32	0.02				
8						2.31				2.60		
9								0.32	0.30			
10			1.38			1.32				2.38	0.70	
11							0.40	0.14	0.58		0.08	
12				1.41	0.41	0.28	1.18		0.06			
13						0.66				0.75		
14				0.34	0.34	0.33				0.78		
15							0.04			0.18		
16							0.40					0.72
17						0.83			1.28	0.08		
18						0.30			1.35			
19			2.34			0.05			1.02			
20			0.38				0.40		0.30			
21				0.10		0.80		0.70		0.65	0.10	
22		1.42				0.01	2.27		1.60			
23		0.12		0.34					0.35		0.05	
24								0.32	0.17	0.42		
25					0.33			0.40		1.07	0.82	
26				0.29					1.66	0.46	0.77	
27				0.45			0.08					
28		1.39			0.16	0.02	0.07					
29					0.74							
30												
31			3.14									
Total	NIL	2.93	7.24	4.95	2.42	10.06	6.21	1.66	8.67	9.86	2.94	1.60

Annual total: 58.54"

(d) REGISTER OF RAINFALL IN 1958

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
1				0.49							0.26	
2						0.24				0.22		
3				0.87	0.93					0.44	0.65	
4					0.11						0.27	
5			0.25	0.50								
6												
7				0.16	0.21	0.27						
8						0.40						0.42
9					0.44							
10				0.84	1.05					0.32		1.15
11										0.32		
12											0.48	
13						0.50			0.30			
14	0.23			0.10		0.40			0.06			
15	0.31		1.49			0.49				1.28		
16			0.08			0.55					0.69	
17						2.10					0.27	
18				1.00	0.94	0.48		0.40			0.28	0.32
19				0.63	0.10							0.30
20										0.32		
21			0.31	0.33					0.73			0.80
22			1.01									
23		0.10	1.60	0.08	0.31	0.51						
24												
25		0.80		0.83					0.20			
26						0.13				0.78	0.34	
27	0.05			0.32				0.35		0.16		
28	0.48								0.50			
29					1.57	0.09			0.87			
30			0.36		0.05	0.08		0.05	0.03			
31	0.06				0.5							
Total	1.13 5	0.90 2	5.09	6.15 12	6.26 11	4.24 13	NIL NIL	0.80 3	2.69 7	1.75 8	3.24	2.99

Annual total: 35.24"

(e) REGISTER OF RAINFALL IN 1959

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
1					0.14		1.30		1.50			
2			0.55				0.12		0.16			
3			0.60			0.44	0.32	1.05		0.22		
4							0.04			0.34		
5					0.50	0.35	0.24			0.29	0.50	
6				0.38						0.87		
7					0.44			0.97		0.35		
8					0.04					0.70		
9	0.37	1.72		0.10	2.30					1.17		
10	0.38			0.60		0.65						
11							1.95			1.70		
12		0.10	0.51	0.39		0.65				0.21		
13									0.30	0.46		
14				0.75			0.65		0.10			
15			2.06	0.05			0.14		0.20		.50	
16				0.28			0.02			0.32	1.00	
17							1.48					
18			1.36	0.40			0.06		0.25	0.49		
19			0.87		0.12	0.69						
20				0.70		0.05				1.37		
21			0.66		0.37							
22					0.98				0.25			
23						2.23		0.16				
24						0.47		0.17				
25												
26		2.04	1.56	0.75			0.43			0.70		
27						1.76	0.11		0.50			
28		1.02	0.09	1.26					0.80			
29							0.55			0.86		
30				0.27		1.20			1.31			
31												
Total	0.79	4.88	7.71	5.93	4.99	8.49	7.41	1.38	6.00	9.05	2.00	NIL

Annual total: 58.59"

/FMA/AO+ /