Contribution to the agropedological knowledge of the Tropical Black Earths of Southern Ghana

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Summary

Approximately 1.000 square miles of calcareous montmorrillonitic black clays occur on the gently undulating coastal plains of south-eastern Ghana.

The earths overlying and being derived from basic gneisses and shists are related to the Indian regur, South African vlei and similar heavy-textured soils.

Rainfall varies with location between annual means of 30 and 50 inches. Distribution is double peaked with June as the wettest month and a less pronounced maximum in October. The dry season is severe though mean relative humidities remain fairly high, even during the driest period in January, February.

Vegetation changes from grassland in the driest parts to an open savannah with stunted trees in the higher rainfall areas.

The soils are not being cultivated due to their extreme deficiencies in nitrogen and phosphate. Agricultural development is subject in the first instance to applications of nitrogenous and phosphatic fertilizers. The choice of these is determined solely by the cost per applied unit of N and P_2O_5.

The heavy texture necessitates relatively large expenditure on land preparation. Crops to be considered foremost are rice and sugarcane. Successful production of these requires irrigation water to supplement the natural rainfall. Large-scale development is geared inevitable to the exploitation of water made available by the Volta river project.

1. Side details

In south-eastern Ghana dark coloured clays — resembling the Indian regur, "black cotton" and related soils — comprise an area of approximately 1.000 square miles (BRAMMER and DE ENDREDY, 1954). The soils overly precambrium basic gneisses and shists that belong to the Dahomeyan system (JUNNER and BATES, 1945; Gold Coast Geological Survey, 1955). Hornblende, pyroxenes, biotite and garnet are of common occurrence.

But for occasional solitary inselbergs (highest, Adaklu, 1.965 feet) and groups of such (Shai and Agbenu hills, to 1.000 feet) the clay areas lie well below the 250 feet contour. They appear as gently undulating plains intersected by mostly broad valleys in which intermittent streams provide drainage. Most slopes are less than two percent.

Precipitation is seasonal with maxima in June and October and minima in August and January (WALKER and SWAN, 1952; WALKER, 1957). Long-term means of yearly

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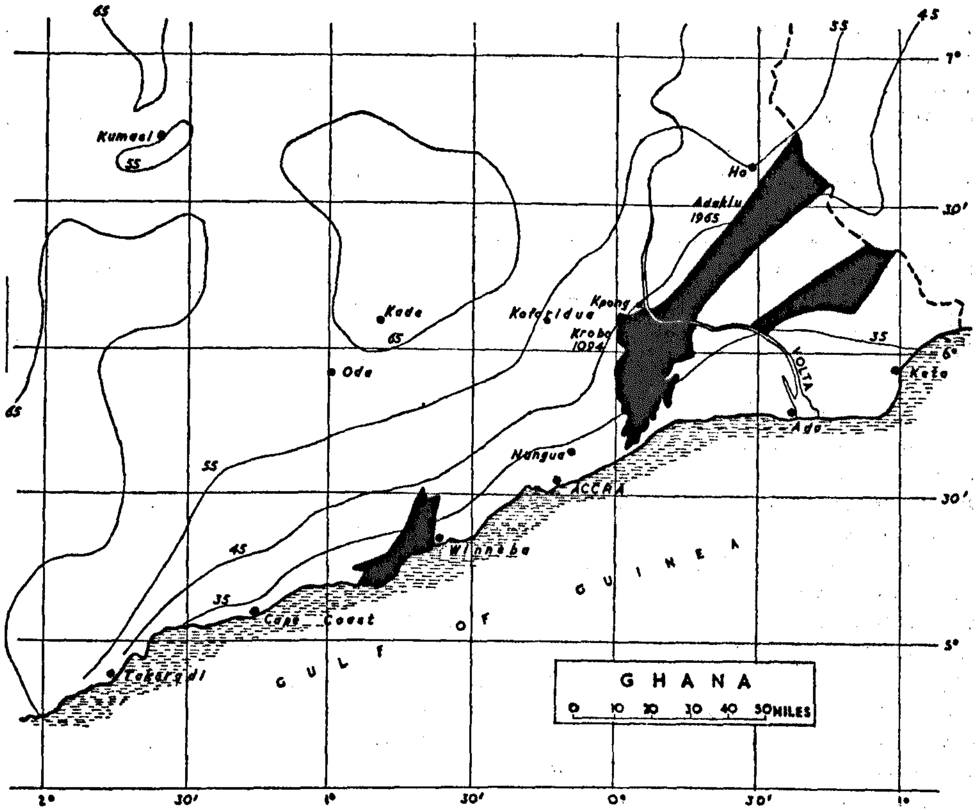

In black: Tropical Black Earths
Curved lines: isohyets of mean annual rainfall in inches

totals vary from 30 to 50 inches. In the drier areas the June maximum is notably higher than the maximum occurring in October. As rainfall increases this distinction between the two maxima becomes less pronounced. Relatively little rain falls in August when the weather is dull with much overcast.

Contrasting sharply is the weather during the dry period around January when a maximum in the number of hours of bright sunshine occurs. The average duration of rain is two to three hours. On 65 to 75 % of the number of days that rain falls the daily total is less than 0,5 inch; lower day totals being more frequent near the coast than further inland. Variation in rainfall intensity is considerable. Rates of 5 inches per hour and more may last for short periods. Both diurnal and seasonal fluctuations in monthly means of vapour pressure are small. The yearly average lies between 25 and 30 millibar. During July, August the mean monthly maximum and minimum temperatures vary around 82° and 70° F. respectively. In January these values fluctuate around 75° and 88° F. Seasonal variation in monthly mean relative humidity measured at 06.00 hrs is negligeably slight. The means vary around 95 % and during many nights throughout the year dewpoint is reached. Taken at noon a maximum of monthly means of some 75 % occurs in June, July and a minimum of about 60 % in January, February.

As yet scant available data on evaporation from an open water surface suggest an annual mean in the order of 60 inches with a maximum of monthly means of about 6 inches in January, February and a minimum of some 4 inches in June, July. The conversion factor to potential evapotranspiration probably fluctuates around a mean of 0,75 whereas a factor unity is likely to be applicable for conversion to combined monthly and annual evaporation and transpiration losses (VAN WIJK and DE VRIES, 1954).

Daily and seasonal changes in atmospheric conditions are closely associated with movements of the Inter Tropical Convergence Zone, I.T.C.Z. (GARBELL, 1948). This is an area or belt into which flow airmasses coming from subtropical anticyclones on either side of the equator. The dry and hot "harmattan" is derived from an anticyclone that extends from the Azores to the Sahara. It reaches Ghana as a north easterly. The moist and cool "monsoon" originates in the South Atlantic. Approaching from the south-east it changes direction after crossing the equator and flows into Ghana from the south west. Contributing further are warm and moist equatorial air masses of doubtful origin. Moving southward at a speed of some 200 miles per month in January the I.T.C.Z. penetrates to its farthest mean southward position of 7° N. Returning at 100 miles per month the mean extreme northerly position of 17° N is reached in August. Irregularities in this oscillation pattern are common and daily advances and recessions take place. Rainfall occurs predominantly in areas where the "harmattan" and "monsoon" converge. Where the "harmattan" prevails skies are near to cloudless and visibilities are reduced by fine dust; days are dry and hot and nights are cool. The "monsoon" brings humid cloudy weather with little precipitation; both days and nights are cool. The relatively low rainfall of the plains directly east of Accra is explained by the direction of movement of the "monsoon" parallel to the coastline in June to August when the effect of this air mass is strongest and the presence at that time of the southerly born cold Benguela sea current. Thus before reaching the Accra plains the "monsoon" passing overland has gradually lost most of its moisture or has become more stable as a result of the cooling by the ocean.

The vegetation has been described as the coastal scrub and grassland zone (TAYLOR, 1952; BRAMMER and BRAND, 1956; BRAMMER, 1958). The distribution of the two physiognomic formations appears controlled by factors governing water relationships. But for riverine thickets most of the relatively dry clays of the Accra plains carry only grass; *Vetevaria fulfibaris* assuming dominance and other species contributing but slightly to this community.

Elsewhere, notably on the Ho-Keta plains east of the river Volta the cover is predominantly a tree savannah. Termite activity is governed by the genus *Nasutitermes* that builds small dome-shaped mounds, less than 2 feet high and no more than 3 feet in diameter at the base.

The clay areas are virtually uninhabited and not in use for cultivation or grazing grounds. Agricultural development using local irrigation schemes has been suggested (HUTCHINSON and PEARSON, 1947; CLARK and HUTCHINSON, 1948). Considerations for large-scale development are given in connection with the Volta River Project that entails the building of a dam, now under construction at Akosombo and the creation of a huge artificial lake (HALCROW, 1956). Experimental stations at Kpong and Nungua are run under the auspices of the University of Ghana and soil surveys have been carried out by the Ghana Department of Soil and Land Use Survey (BRAMMER, 1955, 1957).

Besides references quoted already, compiled monographs in "Agriculture and Land Use in Ghana" (WILLS, editor, 1962) and the "Atlas of the Gold Coast" (Survey Dept., 1949) may be consulted.

2. Description of the tropical black earths

Over large tracts the soil colour is black. A brown variant, apparently somewhat lighter in texture and with better internal drainage but otherwise showing identical profile characteristics only occurs on a limited scale in certain areas. Drainage channels in the brown clays are filled with black soil. When wet, the clays are plastic and slippery. On drying they compact when at the same time a network of cracks is formed. The cracks may be up to 2 inches wide. The soil surface is extremely uneven. Grass grows in raised tufts of approximately one foot in diameter. The tufts are separated from one another by bare patches of smaller surface area. Closer examination may reveal a second, less distinct form of micro relief. In places the soil surface shows undulations with a wavelength of some 12 feet and an amplitude of about 6 inches. The undulations run perpendicular to the contour lines.

These and similar forms of microrelief have been reported to occur in other countries. In the former Netherlands East Indies the phenomenon was known as "cauliflower structure" (MOHR, 1953).

The surface structures are particularly well developed in Australia where the relief has been named "gilgai", taken from the arboriginal for a small waterhole (HALLSWORTH *et al.*, 1955). The raised portion is referred to as "puff" and the depression has been called "shelf". Conditions necessary for the formation of "gilgai relief" are:

a. alternating wet and dry seasons,
b. montmorrillonitic clay,
c. an increase in the amount of adsorbed sodium with depth.

During dry seasons the combination of these factors results in the development of primary cracks that widen with depth. Secondary cracks cause the surface soil to break off into pieces that fall to the bottoms of the main cracks. Most of the early rainwater runs into the deep primary cracks, causing the surface material at the bottom to swell. This leads to the fracture of soil blocks that are forced upwards above the original surface. The volume of the so formed "puffs" is approximately equal to that of the swollen topsoil that fell to the bottom of the primary cracks. Subsequent drying and wetting leads to a repetition of the process as primary cracks tend to be formed along the same planes of weakness. Erosion of the uplifted soil blocks takes place and eventually "puffs" show the original subsoil on the surface.

Parts of "puffs" that are orientated across the lines of slope are most easily eroded while those running parallel to the contour lines tend to be preserved. This leads to the formation of gentle undulations arranged in regular patterns up and down slopes. When "puffs" and "shelves" are continuous the name "wavy gilgai" is used. The term "lattice gilgai" refers to patterns of continuous "shelves" and discontinuous "puffs" arranged in oblong strips across the contours. Though weakly developed both forms may be observed particularly in the drier parts of the Accra plains. They are distinguished most easily at the onset of the prime rainy season on land that had been burned. After the first showers the young grass flushes on the "puffs" before any growth on the "shelves" occurs, resulting in alternating green and dark strips. The effect is short lived and becomes obscured by regrowth of grass on the "shelves".

Profile characteristics are uniform over large areas. On the uplands "puffs" show a 4 to 6 inch surface horizon of plastic clay that desintegrates into hard clods and nuts on drying and that contains most of the grass roots. The horizon is less pronounced where distinct "shelves" occur. Underneath lies a heavy clay that is plastic and impervious when moist and that cracks into vertical columns of irregular shape on drying. This horizon usually varies between 3 and 6 feet but it may be less than 12 inches. Grass roots are sparse. The succeeding horizon is distinguished by the abundance of carbonate concretions and the absence of cracks. At the base the concretions may be sufficiently numerous to produce a greyish white soil colour. The horizon varies in thickness from one to 3 feet and is distinctly more friable than the overlying clay to which the transition is ill defined and shows wavy deformations.
A stone line consisting mostly of quartz fragments that not unfrequently are iron stained separates the carbonate horizon from solid or weathered bedrock. The depth of the weathered zone varies considerably depending on the mineralogical composition and structure of the fresh bedrock. Fresh pyroxenite gneiss has been observed without any weathered rock. In other cases where the bedrock was a basic shist containing an abundance of biotite the weathered zone of brownish plastic material was found to measure a thickness of 3 feet.
A well developed "puff" shows carbonate concretions throughout the profile. Their numbers commonly increase with depth. Cracks are near to absent and the soil colour varies from off-grey to greyish white depending on the amount of carbonate present. The soil is more friable than the adjoining "shelf" soil.
The predominatingly dark grey to black soil colour appears to be associated with a particular form of organic matter that may be reproduced in vitro under alkaline and anaerobic conditions (HESSAYON and HUTTON, 1954). Besides drainage channels also "shelves" of the brown clay variant show a dark grey to black colour through the whole profile. Above description holds good in particular for the more drier grass-covered areas. As rainfall increases and the grassland makes place for a tree savannah, "gilgai" relief becomes less pronounced and topsoils of 18 to 24 inches deep change into carbonate-free horizons that are more loamy in texture. Lower down the soil is more clayey and carbonate concretions are of frequent occurrence.
Base-exchange capacities vary between 80 and 100 milli equivalent per 100 grams clay. Actual exchange capacities are no more than half these values as the clay content seldon exceeds 50 %. Thermograms and X-ray photographs show the clay mineral to be montmorrillonite (STEPHENS, 1953; BRAMMER and DE ENDREDY, 1954).
Most prevalent and taking some 80 % of the adsorbtion complex are calcium and magnesium in ratios that vary from 4 : 1 to 1 : 1. Potassium figures are low; upper layers may be somewhat better supplied than the subsoil. Maximum values seldom exceed 1 % of the total bases present and averages are about half this value. Sodium contents increase with depth to more than 10 % of all exchangeable bases in the lowest layers. In the surface soil a maximum of 3 % of the total exchange capacity is accounted for by sodium. Specific conductivities indicate low contents of soluble salts and a relative increase with depth. Soil reaction increases gradually from pH 6,5 to 8,0 in the surface horizons to a maximum of pH 8,5 near weathered or fresh rock. Lowest pH-values of the surface soil occur in the higher rainfall areas.

With the exception of surface layers that may be sandier particularly in the wetter zones, the mechanical composition is fairly constant throughout the profile. Clay contents vary between 40 and 50 % and there is approximately 10 % silt. More than half the sand fraction consists of fine sand. Values for coarse sand may fall below 10 % and the ratio coarse to fine sand tends to remain constant down the profile until weathered rock is reached. Garnets are of common occurrence in the sand fraction.

Organic-carbon contents seldom exceed 2 % and are generally lower. The highest values occur in the rooted surface horizon. Decrease with depth is relatively slow. Immediately above the carbonate horizon, contents may be as high as 0,75 %. Further down in this horizon contents drop more abruptly to zero values. There is a slight tendency for C/N-ratios to decrease with depth. Values do not fall below 15 and are generally somewhat higher. The content of total phosphorus is low in all horizons and varies between 100 and 200 p.p.m. P.

Calcium-carbonate contents may increase to 50 % of the stratum in the calcium-carbonate horizon and are generally not less than 25 %. In the upper horizons contents vary from zero in the higher rainfall areas to 1,5 % in the drier zones.

3. Soil fertility

3.1. Experimental methods

Soil fertility has been studied exclusively by means of field experiments conducted from 1953 until 1957 on black cracking clays at the Agricultural Research Station Nungua in the south-west corner of the Accra plains. The number of plants per plot has been kept constant in each experiment. Rice and tobacco were transplanted from beds fertilized with sulphate of ammonia and superphosphate that were laid out on a sandy "grey earth" (HAGENZIEKER, 1961). The varieties were respectively *British Guiana 79* and *Yellow mammoth*. One node setts of the clone *P.O.J. 2878* were laid out in experiments on sugarcane. Bulrush or pearl millet (*Pennisetum typhoides*) of a non-descript type was sown thickly by seed drill and thinned out to constant spacing in the row, two weeks after emergence.

Irrigation water was supplied by pumping from a reservoir created by damming a perennial stream. Attempting to avoid fertilizer wash plots were irrigated independently from main furrows. Rice bunds of 12 × 12 feet were separated by small dams. Tobacco was planted on ridges and for the cultivation of sugarcane the "Reynoso" system was adopted (VAN HALL and VAN DE KOPPEL, editors, 1948). With this method cane cuttings are laid out in furrows. After sufficient growth has been made the relief is inversed by splitting ridges back into furrows. At a later date plants are ridged up further with soil from the newly created furrows.

The principal fertilizers used were sulphate of ammonia (20 to 21 % N), granulated single superphosphate (18 % P_2O_5), granulated triple superphosphate (45 % P_2O_5) and sulphate of potash (45 % K_2O). Used on a limited scale were Morocco ground rock phosphate (31—32 % P_2O_5), basic slag (17—18 % P_2O_5) and "Fertiphos" (dicalcium phosphate, 40 % P_2O_5). On rice, fertilizers were broadcast in the flooded bunds. Applications on millet and tobacco were made by broadcasting the artificials over ploughed land before respectively discing as a final seedbed preparation or ridging. In the case of sugarcane fertilizers were placed near the young plants in the furrows six weeks after the cuttings had been laid out and shortly before the ridges were split back into the furrows. Broadcast as such or followed by discing as a treatment took place on natural grassland. Despite precautions taken, fertilizer wash proved unavoidable when irrigation was practised, thus partly obscuring some of the current effects and causing the study of residual responses to fail.

In the TABLES small letters are used to denote treatments and capitals are employed to indicate factorial effects and interactions. Subscript numbers are used to denote the degrees of freedom associated with standard errors (S) and mean square ratio's (F). Thus $F_{4/78}$ indicates a ratio with mean squares as numerator and denominator associated with respectively 4 and 78 degrees of freedom. Calculated F-values larger than corresponding theoretical values at a probability level (P) of 1 % have been given a double asterisk. Least significance differences (l.s.d.) and levels of significance (s.l.) are given at P levels of 1 and 5 %. Only differences larger than calculated values at P: 5 % are considered "statistically significant".
All experiments were laid out on virgin soil. The grass sod had been ploughed under at least twelve months before and repeated ploughing and discing had "weathered down" the surface 12 inches to a condition that made the preparation of seed and planting beds possible.

3.2. General

Striking responses to fertilizer dressings were obtained on rice. The experiment was of a 3^3-factorial design and incorporated different application rates of sulphate of ammonia, single superphosphate and sulphate of potash. The second order interaction was fully confounded. Results are given in TABLE 1.

TABLE 1. Responses of rice to application rates of sulphate of ammonia (n) single superphosphate (p) and sulphate of potash (k); yields of grain in lbs per acre; fertilizer rates in cwts per acre

	k			Mean	p		
	nil	0,5	1,0		nil	1,0	2,0
n		S_{78} 130		S_{78} 75		S_{78} 130	
nil	1480	1510	1340	1440	780	1820	1730
2	2820	2630	2660	2700	930	3570	3610
4	2590	2590	2690	2620	1010	3390	3450
		S_{78} 75				S_{78} 75	
Mean	2300	2240	2230		910	2930	2930
p		S_{78} 130					
nil	960	870	890				
1	2950	2940	2890				
2	2980	2900	2910				
		l.s.d.		$F_{2/78}$		$F_{4/78}$	
	S_{78}	P 0,01	P 0,05	N : 28,58**		NP : 5,20**	
	130	480	360	P : 78,60**		NK : 0,18	
	75	270	210	K : 0,08		PK : 0,01	
				NPK : fully confounded with blocks			

Applications of sulphate of potash had no effect.
Substantial yield increases were obtained from dressings of superphosphate alone and this effect was accentuated by additional supplies of sulphate of ammonia. The latter

fertilizer given solely resulted in non significant yield increases. It is considered likely that fertilizer wash has somewhat obscured results and that in particular yields of plots that received neither superphosphate nor sulphate of ammonia would have been lower had such disturbance not occurred.
A prime contributing factor to higher yields was the increased rate of tillering which was a most noticeable effect of superphosphate applications.

Responses of tobacco to applications of sulphate of ammonia, single superphosphate and sulphate of potash were tested in a single replicated experiment of factorial design, laid out in two blocks. Four pickings were made of leaf that was cured in a small experimental barn. Results are given in TABLE 2.

TABLE 2. Responses of tobacco to application rates of sulphate of ammonia (n) single superphosphate (p) and sulphate of potash (k); yields of flue cured leaf in lbs per acre; fertilizer rates in cwts per acre

	k		Mean	p	
	nil	1,0		0,5	1,0
n	S_4 113		S_4 80	S_4 113	
0,5	763	678	720	698	743
1,0	885	889	887	873	902
2,0	885	941	913	792	1034
	S_4 65			S_4 65	
Mean	884	836		788	893
p	S_4 92				
0,5	800	775			
1,0	887	898			

	l.s.d.		$F_{2/4}$	$F_{1/4}$
S_4	P 0,10	P 0,20	N : 1,71	K : 0,01
65	197	141	NP : 0,55	P : 0,30
80	242	174		
92	278	200		
113	342	246		

PK and NPK : Confounded with blocks. The sum of squares (SS) for the NK interaction has been pooled with the remainder SS for the estimation of the error SS.

Despite the relatively large error mean square resulting in effects none of which proved "statistically significant" it appears evident that no response was obtained to a dressing of sulphate of potash and that applications of nitrogenous and phosphatic fertilizers are required to obtain optimum yields. The general grade of cured leaf was fair having reasonable burning qualities. The lower dressings of sulphate of ammonia produced a light bodied leaf.
Positive responses to applications of sulphate of ammonia and superphosphate similar to those described were obtained also on sugarcane, on sorghum and millet (*Pennisetum typhoides*) and on the natural grassland. In no instance were positive responses to dressings of sulphate or muriate of potash recorded. The absence of responses to foliar and soil applications of ammonium molybdate, borax and the sulphates of iron, magnesium, manganese and zinc make the prevelance of other than acute nitrogen and phosphate shortages highly improbable.

3.3. Types of fertilizers, rates and residual effects

Urea proved equally effective as sulphate of ammonia. In the prilled form no application difficulties were encountered. Packed in bags with air-tight polythene liners the fertilizer was stored for well over a year without any trouble due to hygroscopicity occurring. There is no reason to presume that results from applications of nitrate-containing materials will differ from those obtained with ammoniacal fertilizers.

It appeared immaterial which type of phosphatic fertilizer was used. Equally good responses were obtained in an experiment on rice to applications of single superphosphate, Morocco ground rock phosphate, basic slag and "Fertiphos" (dicalcium phosphate). A basic dressing of sulphate of ammonia at a rate of 2 cwts per acre was given. Results are presented in TABLE 3.

TABLE 3. Responses of rice to applications of different phosphatic fertilizers; yields of grain in lbs per acre; rates of fertilizers and P_2O_5 in cwts per acre

Fertilizer		P_2O_5	S_{30} 115	Fertilizer		P_2O_5	S_{30} 230
none	nil	nil	1200	m	1,0	0,32	3680
			S_{30} 230		3,0	0,96	3650
				b	1,0	0,18	3590
ss	0,5	0,09	2430		3,0	0,54	3710
	1,5	0,27	3620	f	0,5	0,20	3700
	3,0	0,54	3590		1,5	0,60	3640
	5,0	0,90	3710	x	3,0	0,89	3580
				y	3,0	0,54	3660

S_{30}	l.s.d. P 0,01	l.s.d. P 0,05	
230	900	670	$F_{15/30}$: 22,58**

ss = Single superphosphate (18 % P_2O_5)
m = Morocco ground rock phosphate (31—32 % P_2O_5)
b = Basic slag (17—18 % P_2O_5)
f = "Fertiphos" (dicalcium phosphate — 40 % P_2O_5)
x = A mixture of 5 parts m to 1 part ss
y = A mixture of 5 parts b to 1 part ss

As outlined before, studies on residual effects of fertilizers failed in most cases due to wash. However, the general impression was gained that substantial residual responses may be expected from dressings of phosphatic materials in the previous season and that such responses to nitrogenous fertilizers if present are small and of little practical importance. Responses of the natural grassland to applications of sulphate of ammonia (N) and single superphosphate (P) lasted for at least one year. Results to these effects are given in TABLE 4. The 2^3-factorial experiment with 4 replications incorporated a disc-harrowing treatment carried out shortly after broadcast of the fertilizers and intended to "open up the soil" in order to facilitate penetration of the artificials.

Application rates of fertilizers required for optimum production, besides being subject to strongly variable climatic conditions differ with the type of crop. Nitrogen supply appears the foremost factor in the control of both quantity and quality of produce. Dressings in excess may result in uncurable heavy-bodied tobacco leaf or in the lodging of weak-strawed rice with little grain; fungus attack on leaves may

TABLE 4. Responses of the natural grassland to applications of sulphate of ammonia (n), single superphosphate (p) and disc harrowing (h); yields of green grass and fertilizer rates in cwts per acre

	First cut 9 weeks after application of treatments			*Second cut* 59 weeks after application of treatments		
	S_{21} 1,2	P	s.l.	S_{21} 2,8	P	s.l.
		0,01	4		0,01	8
N	9**	0,05	3	10**	0,05	6
P	1			10**		
H	9**			5		
NP	2			1		
NH	nil			nil		
PH	2			nil		
NPH	—2			—4		
Standard deviation	3,6			8,0		
Mean	20			61		

be more prevalent and although juice contents of sugarcane may be raised, there is the tendency to lower sugar contents. No such dangers accompany excessive application rates of phosphate.

It will be appreciated that only very approximate optimum rates of general validity can be laid down and that more detailed information must await the results of investigations on specific crops in an established pattern of farming. For most crops it appears unlikely that in the first years following clearing these rates will exceed some 2 cwts per acre of sulphate of ammonia and 1 to 2 cwts of single superphosphate or the equivalent thereof in other forms of nitrogenous and phosphatic fertilizers. A build up of the soil-phosphate status resulting from successive dressings of phosphatic materials is to be expected.

No predictions can be made in respect of the need of other nutrients but nitrogen and phosphate following a number of harvests.

4. Soil and land evaluation

There is no doubt that the Black Earths of Ghana could be developed into some of the most productive soils of the country. Elsewhere, in Australia, India and South Africa similar soils have been cultivated for some considerable time. Unacceptable is the often heard explanation for the absence of farming on the Black Earths that these soils should be too difficult to be worked by primitive peasant methods. The local population is prepared to spare neither trouble nor physical effort if it comes to the preparation of land that is known from experience to produce acceptable yields. Furthermore, remains of small-scale abortive attempts by nearby farming communities to grow crops on the black clays adds further weight to the incorrectness of such statements. Also, insufficient rainfall cannot be regarded a main factor preventing crop production. Any form of agricultural development on the Black Earths is subject in the first instance to correcting the deficient nitrogen and phosphate status of these soils. In doing so it leaves no question that artificials will have to play a decisive role.

Relatively cheap supplies of nitrogenous and phosphatic fertilizers are desirable. As for the latter, deposits of high-grade tricalcium phosphate being mined near Lome in the adjoining Republic of Togo demand attention. Taking into consideration the heavy texture of these soils which must involve relatively large capital expenditure on initial land preparation, crops that suggest themselves to be cultivated foremost are rice and sugarcane.

For the successful production of both, irrigation water supplementing the natural rainfall will be imperative. The cost of supply of such water greatly determines the economic feasibility of agricultural enterprises. Only in isolated places do topographical features favour the storage of run-off water by means of small dams. Development of large areas is geared inevitably to the exploitation of water made available by the Volta river project.

The choice of irrigation system depends upon costs. There are no soil-inherent or other foreseeable objections to furrow irrigation. In fact at optimum moisture contents excellent soil structures could be maintained by such method. However, difficulties in distribution by means of furrows may prove a sprinkler system economically better justified. As an exception, here and there gravity irrigation may be possible on a very limited scale. Pumping will be necessary to distribute the bulk of all water.

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