Tropical clay soils, their use and management

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Clay soils are widely distributed over enormous areas throughout the world and their successful cultivation presents problems wherever they are encountered. In tropical regions these problems are commonly aggravated by low rainfall, demanding water conservation and irrigation, and high temperatures, causing rapid drying of the surface soil. Nevertheless, by careful management and choice of suitable crops such tropical soils can be made very productive.

A soil is defined as a clay if it has > 40 per cent of the inorganic constituents of < 2μm in effective diameter. The field behaviour of such soils is dependent on the nature of the clay minerals, the amount of iron oxides and organic matter which they contain, the degree of cation saturation, and the nature of saturating cations. These properties are related to aggregation and aggregate stability of the soils. Oxisols could have over 90 per cent clay-size particles [1] but because of the nature of the clay minerals and the amount of iron oxide present, they are very strongly aggregated and behave in tillage and other physical properties as clay loams. Andisols are other examples of soils which could have clay texture but because of the high organic matter and iron oxide content and the nature and properties of the clay minerals, actually behave as loams and have extremely stable structure [2]. There are clay soils also whose field behaviour is affected by the degree of cation saturation and content of soluble salts. If sodium is an important saturating cation, the soils would at least be partly dispersed and in this condition their properties would be affected. Also, if the soluble salt content is high, the colloidal material is likely to be in a flocculated state, which would influence the physical behaviour of the soil.

There are large and important areas of clay soils in the world, and particularly in the tropics, which are extremely fine textured and in which the fine fraction is rich in smectite (montmorillonite) minerals. The majority of these soils have low organic matter and iron oxide contents and some of them may even be affected by high soluble salts annd exchangeable sodium. The combination of these properties confers on the soils very characteristic field behaviour which make their agricultural management a serious problem requiring considerable expertise, skill, and experience. All soils classified in the Order Vertisol (Black cotton soils, Black clay soils, etc.) [3, 4, 5] and many of the Inceptisols and Entisols (humic gleys, low humic gleys, other hydromorphic soils) are included in this category.

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The Vertisols are either developed on basic rocks yielding a clay residue and an abundance of cations on weathering, or on deposited partially pre-weathered materials. This Order probably occupies over three hundred million hectares of land in the world and it probably occurs in every tropical country. These are the most striking of the tropical clay soils in properties and management requirements. Prior to 1960, it was considered that the Vertisols were restricted to semi-arid and sub-humid areas of the tropics and that a dark surface horizon, high pH, and high cation saturation were essential aspects. Today, the concept of the order is based on many more soil properties and profile features associated with fine texture and high montmorillonite content. Soils classified within the Order are found in all rainfall regimes of the tropics except arid, and they do not all have dark surface horizons. Some members can be very acid—as low as pH 4.0—but do not necessarily have aluminium toxicity problems as do other soils with such low pH.

The Entisols and Inceptisols which are involved are commonly recent in age and occur on coastal fringes, river deltas and current flood plains of rivers, and in large inland basins. These soils could be extremely fine textured and may show little, if any, profile development. Depending on whether they have been influenced by fresh, brackish, or saline conditions at deposition and subsequently, and on present climatic conditions, extent of reclamation, and management history, their physical behaviour and chemical properties such as cation saturation and pH could vary widely.

Clay soils, whether Vertisols, Inceptisols, or Entisols, are for the most part encountered on land with a flat to only gently rolling topography. This is the case with such large areas as the Nile Valley in the Sudan, the Darling Downs of Australia, the Deccan Plateau of India, the alluvial plains of the southern USA, the coast of South America in the region of Guyana and Suriname, and large river deltas such as those of the Amazon, Orinoco, and Mississippi. Due to their gentle relief, often deep profiles and natural slow rate of erosion, they present great prospects for more extensive and successful agricultural utilisation.

Features related to management

Clay soils of the type discussed here have very slow internal drainage (infiltration rates of between 2.5–6 cm/24 hours) [3]. They also have high water-retaining capacities with wilting percentage of 25–30 and field capacity of 60–80 per cent water. With these characteristics, and a flat or nearly flat topography, adequate external and internal drainage is a very important aspect of management, particularly in wetter areas. Attention must be given to this problem at the time of reclamation and its solution could involve extensive and elaborate drainage installations.

Maintenance of the drainage works entails a high annual cost. In areas where there is the need to drain away excess water because of high rainfall and particular crop requirements, the drainage design must accommodate both external and internal drainage. Since internal drainage is very slow [3] in areas of heavy rainfall, there has to be much concentration on external drainage.

In drier areas, successful reclamation necessitates a satisfactory irrigation regime. Water often has to be transported for long distances, resulting in much loss. In the Sudan, it is estimated that 40 per cent of the water is lost in the course of transport from the source to where it is utilised and in other countries it could even be higher. The dangers of soil salinisation due to improper irrigation use is of great importance in these areas. There are many examples in the world where bad water use has salinised clay soils, and this is a potential hazard wherever irrigation is practised.

Clay soils have special tillage problems and requirements. The production of a tilth judged suitable for row crop cultivation in temperate agriculture is virtually impossible on most of these soils. Also, the soil moisture range within which any tillage should be carried out is specific, thus limiting greatly the opportunities for successful tillage in preparation for any planting season. Due to the fine texture and montmorillonite content, the soils become very hard and impenetrable in the dry season and they do not shatter easily in response to tillage. When too dry they do not shear when ploughed; instead, large blocks of soil are inverted. Reducing these blocks by subsequent harrowing is very difficult, as shown in figure 1, where the surface condition of a Vertisol in Antigua can be seen after four harrowings in preparing the land for sowing of maize. When the soil has imbibed too much water after heavy rainfall or excessive irrigation, it swells and becomes cohesive and plastic due to the properties of the montmorillonite and high clay content. In this condition, also, normal tillage is not possible. Effective seed bed preparation is, therefore, confined to a narrow moisture range during a period when the dry soil is rewetted by rainfall or irrigation but not to the point where it becomes cohesive.

On re-wetting of the dry soil, water is absorbed at different rates around the blocks (prisms) or units of soil. The resulting differential swelling sets up differential pressures within the soil units and at a certain stage of re-wetting these pressures result in shattering of the soil blocks into much smaller units, which may resemble normal soil aggregates with sub-angular shape [3]. However, for this to happen the soil has to be almost at an air-dry moisture condition before re-wetting. This must take place gradually, a situation normally achieved at the beginning of rainy seasons. If the soil was ploughed before drying commenced, the entire ploughed layer may shatter in this way on gradual re-wetting. If it is unploughed, up to 10 cm depth of surface soil can appear as though it has been ploughed and harrowed, providing an effective 'dust mulch'. This mulch is self-perpetuating and such soils are often described as 'self-mulching'; they are said to 'plough and harrow' themselves. In this state, the uninitiated could think that these are well structured soils!

This behaviour of such soils on wetting and drying is of much greater importance than any natural tendencies for the formation of stable aggregates. There are however, at least two exceptions to this general rule, one being soils which are not too eroded and where the organic matter content of the top layer is around three per cent or more. With this amount of organic matter, some ameliorative effect on soil structure could occur at least in the surface layer. This is commonly, but not unexceptionally the situation with calcium saturated clays. The other is where the clay soil is derived from parent materials relatively rich in iron oxide, which acts as fairly effective cement for aggregate stabilisation. Once again, only the surface soil is affected, because in the subsoil conditions are largely anaerobic and the iron is predominantly in the reduced state.

The ability of these soils to crack profusely on desiccation is another of their features that influence management. Figure 2 shows the surface condition of a soil in which such cracks have developed. Due to their fine texture and commonly high montmorillonite content, such soils are able to imbibe large quantities of water which is mainly held between micro-aggregates, absorbed on the surfaces of clay particles, and held within the clay structures. When saturated, the soils swell and become very cohesive, the false aggregates disrupt, and the soil becomes sticky. In the drying-out phase, with the loss of water, the soils shrink and this results in slight subsidence of the surface but, more spectacularly, cracks develop. It is commonly believed that the cracks are very important in the management of these soils.

For semi-permanent grass crops, such as sugar cane and improved grasses, the cracks form very important channels through which the soil becomes aerated and roots penetrate. The voids created by the cracks become filled again when the soil wets and swells but this process takes time, particularly in the subsoil. The surface soil wets first and as a result the openings of the cracks could be closed much sooner than those at depth: this is why they are so important as avenues for root proliferation. The soil mass between the cracks is very dense, with bulk density sometimes approaching 2. In such dense material, roots have little chance of making significant growth. Observations of the behaviour of root growth in clay soils has led to the comment that the management of clay soils is the management of soil cracks [6, 7]. In this connection, it is interesting that in the Gezira Project of the Sudan, the normal crop rotation includes a fourth year of fallow. Here the soil is cropped twice yearly with use of irrigation. Deterioration of the soil's physical condition could occur progressively during the three years of cropping, thus making a fourth year fallow essential. During this, the soil dries completely and cracks develop to the maximum capacity, leading in a sense to soil regeneration.

Water infiltrates very slowly once the cracks are closed and, as stated above, actual measurements made in different parts of the world indicate that this can be less than 3 cm per 24 hours, the rate decreasing with time. Consequently, in India for example, many of the clay soils remain inundated during the monsoon and they are tilled only at the beginning of the dry season.

Many clay soils have an additional physical limitation due to the development of surface crusts. The contributing properties are lower clay content (40–50 per cent clay), high silt content, and commonly a fairly high degree of sodium saturation. As this crust prevents seedling emergence, reduces gaseous exchange, restricts infiltration, and increases run-off it could be a serious problem in crop establishment.

Clay soils display a wide range in levels of fertility depending on age, origin, and use. They can be extremely acid [8] to very alkaline [9, 4] even when exchangeable sodium is not important. Exchangeable aluminium does not play a dominant role in the infertility of acid soils. For instance, a clay soil with pH 4.5 could be only 25 per cent saturated with aluminium whereas other tropical soils (Oxisols, Ultisols, and Alfisols) at similar pH values could be at least 80 per cent saturated with exchangeable aluminium. In many of the acid soils, exchangeable magnesium is important in comparison with exchangeable calcium. It is believed that this is indicative of slow degradation of montmorillonite in these base-deficient environments, with resulting release of magnesium. It may also be taken as an indication of former marine influence. Further evidence of this is the presence of a montmorillonite kaolinite intergrade species, especially in the acid members [9]. In some cases the exchangeable magnesium is a contributory factor to the poor structure of these soils.

Available nitrogen is always deficient in tropical clay soils. Mineralisation of organic nitrogen takes place very slowly since the organic matter is extremely stable, in many cases being present in chemical combination with the clays. Clay soils also have the ability to fix ammonium in both exchangeable [10] and non-exchangeable [11] forms. Nitrification is always a slow process. Apparently, the redox status is hardly ever sufficient for the oxidation of ammonium to occur: this may be particularly so in low-lying areas where the rainfall is high. Soils with such serious drainage problems could be temporarily anaerobic following periods of heavy rainfall or irrigation and this condition could further influence transformations of nitrogen.

The available phosphorus status of tropical clay soils is highly variable. It is low in soils derived from fresh water sediments but not necessarily so for soils derived from marine sediments. In the Caribbean area, clay soils derived from calcareous materials have very satisfactory levels of available phosphorus [12, 9] while those derived from alluvial or volcanic materials are generally low [13]. In India, many clay soils derived from basic igneous and metamorphic rocks appear to be low in available phosphorus [14].

The potassium status of clay soils that are sediment-derived is usually quite good, especially if the sediments have a previous marine history [15, 16]. In the Caribbean, soils which are derived from calcareous materials are generally low in potassium. The clay soils derived from igneous and metamorphic rocks have variable available potassium content, depending on the mineral composition of the parent rock, the age of the soil, and its erosional history. In some of the soils, crop plants may experience difficulty in obtaining adequate supplies of potassium not due entirely to low levels but partly also because of an adverse balance of exchangeable calcium, magnesium, and potassium. These soils, especially the more acid and leached ones, have the ability chemically to fix potassium as well as ammonium and this could be another problem in availability of the nutrient [17, 18].

Clay soils are usually not deficient in minor elements. If derived from basic rocks or marine-derived sediments, the soils are adequately supplied with these nutrients. In island situations and in areas in close proximity to the ocean, there is also a continuing enrichment of minor elements through wind-blown salts, as observed in Barbados for instance. In situations where clay soils develop on transported weathered volcanic materials, toxicities due to some minor elements could result. A known case in the Caribbean is manganese toxicity in bananas growing on alluvial soils so derived. Since the majority of clay soils occur in areas where the climate is not very wet, the restricted leaching rate is another factor in trace element availability.

A chemical property of these soils which influences management is the high activity due to their high clay contents and montmorillonite mineralogy. Cation exchange capacities could range from about 25 to nearly 100 milli-equivalents per 100 g soil, and they adsorb divalent cations more tenaciously. It is also quite difficult, and in many cases impracticable, to ameliorate the pH by use of ground limestone due to the large amounts that are needed.

The relationship between the characteristic water relations, shrink-swell properties, tillage features, crusting behaviour, and fertility of these unique soils and their management and use is of special interest, and will be considered next.

Soil management

Due to the properties outlined above, clay soils severely restrict the range of crops for which they are naturally suited. The texture, structure, and cracking ability make them unsuitable for tree-crop cultivation. The root intensity of many tree crops is too sparse for them not to be seriously affected when the soil cracks each year and roots are sheared. Palms—that is coconut (*Cocos nucifera*) and oil palm (*Elaeis guineensis*) are the best suited, due to their very prolific root systems; figure 8 shows the exposed proliferating root system of a palm on a clay soil. In preparing the planting hole, another soil mixed with compost, could be used to give the young plants a good start. From observations with coconut, the young trees develop rather slowly but they eventually achieve

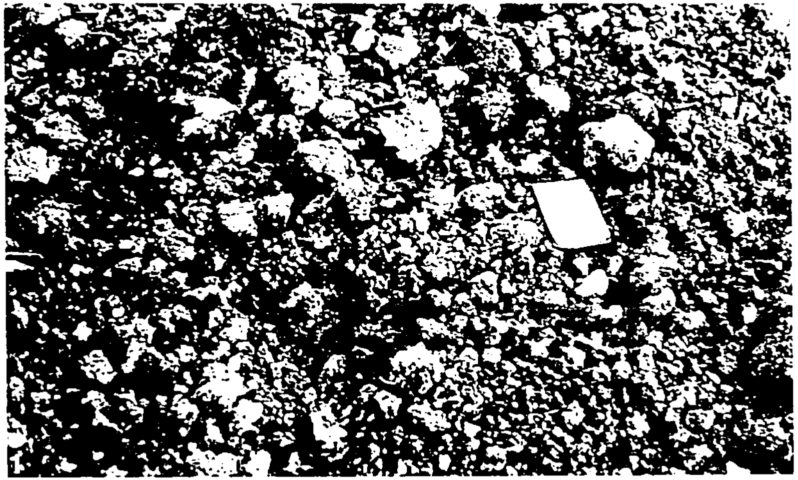

Figure 1 Condition of soil after disc ploughing and harrowing four or more times in Antigua. (Notebook is 11.5 × 7.5 cm).

Figure 2 A Trinidad Vertisol with cracks after a rice crop has been harvested. Over 35 per cent of the land surface could be taken up by cracks when these have fully developed.

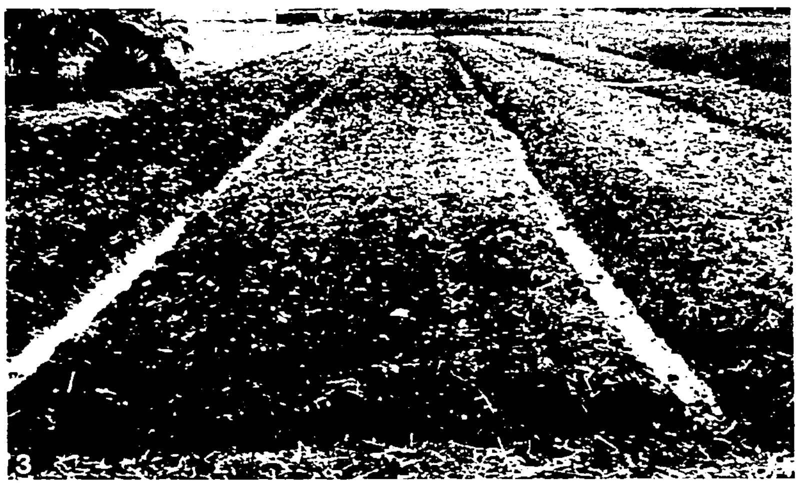

Figure 3 A Vertisol in Trinidad with greater than three per cent organic matter in the top layer recently tilled and planted with eddo (*Colocasia esculenta*). This soil could be tilled more easily than that shown in figure 1, due to the higher organic matter.

Figure 4 Clay soil with peanut (*Arachis hypogoea*) in the Sudan. The crop is grown on ridges. Note deep crack along the drain between ridges and surface cracking of a crust which develops on irrigation. (The blue object in the drain is 16 cm × 7 cm).

a good level of establishment and production. On essentially flat topography in areas of high rainfall even coconut cannot be considered suitable, since it develops physiological disorders or diseases associated with the water-logged environment.

Graminaceous crops — such as cereals, sugar cane, and pasture grasses — are best suited for these soils. Their root systems are so extensive that the crops can better withstand root damage due to soil cracking. In the normal cycle of cultivation the crop is usually at its maturation phase when extensive soil cracking occurs, except for improved pasture. For sugar cane, which may occupy the land for several years before re-planting, a combination of factors such as mulching by the leaves of the crop, irrigation, or rainfall could prevent excessive soil desiccation and as a result the soil does not crack to a maximum extent at any time.

Cotton (figure 5) is well adapted to these soils and the semi-humid climatic conditions which is often associated with them. The cotton plant is deep rooted, so that an appreciable amount of the roots grow in the soil layers where cracking never occurs to the extreme. The crop is usually planted towards the end of the wet season, and it develops through its vegetative actively growing phase when the soil is still moist and cracking not fully developed. In very dry climates or in irrigated conditions as in the Sudan [8], the soil moisture levels through the various stages of the crop are regulated. The same consideration applies to cereal with or without irrigation.

Many clay soils are successfully used for small root crops. In Trinidad, aroids (*Colocasia* and *Xanthosoma* spp.) are commonly grown on these soils but farmers select those areas where the organic matter content is over 3 per cent in the surface layer; on such soils the physical behaviour is not so extreme (figure 3). In Barbados, on similar soils, sweet potato (*Ipomea batatas*) and yam (*Dioscorea* spp.) are successfully grown.

Clay soils are not among the most suitable for grain legumes, although some success is achieved by ridging. In India, common grain legume crops such as pigeon pea (*Cajanus cajan*), mung bean (*Phaseolus mungo*) and chick pea (*Cicer arientinum*) are grown on these soils. Groundnut (*Arachis hypogoea*) is a rapidly expanding crop in the Sudan on clay soils (figure 4). This crop needs only a shallow depth of soil for the redevelopment of the nut, and this is achieved by planting the crop on ridges where the top soil is concentrated.

Vegetable crops can be grown on clay soils with some measure of success, although there are problems. Experience in Barbados and Martinique in the Caribbean has shown that land preparation, land layout and water management are the most important factors in this culture.

Tillage and land layout

In order successfully to plant the crops normally grown on clay soils, some form of tillage is necessary: the problem is to determine the type of tillage needed and the extent to which it should be done. Tillage could best be carried out taking advantage of the natural behaviour of these soils during their drying and wetting cycles. For field-crop cultivation in mechanised systems in rainfed or irrigated conditions, initial ploughing should be done to allow the ploughed layer to become desiccated, thus facilitating the self-shattering effect on initial re-wetting; at this time the rest of the land preparation could be carried out. As a means of extending the period during which tillage can be done, encouraging results have been obtained by using ploughs coated with teflon or lubricated with a plastic emulsion to reduce adhesion of a wet clay soil to the plough share [19].

Tillage operations in clay soils require a higher energy input than for most other soils. This author has seen, both in Ghana and in the southern USA, places where a tractor capable of pulling four ploughs in other soils could manage only two in these soils. Experiments are in progress in several centres in the world to determine the minimum tillage needed for these soils. Theoretically, deep tillage (sub-soiling) ought to be effective in shattering the soils to depth and so temporarily improving their physical condition. However, tangible benefits of this practice have not yet been demonstrated. One study [20] shows a progressive deterioration of the soil's physical properties, with decreasing root growth following repeated sub-soiling. In order to give deep tillage a chance of success, the physical condition of the soil at the required depth must be such that it will shatter and not smear when the operation is being carried out [21]. For these soils this effect might be achieved over only a very limited moisture range, making it impractical to carry it out in association with other forms of tillage. The high energy requirements and heavy equipment needed are also important considerations. In spite of these points, deep tillage is done routinely in Trinidad on sugar cane soils but the operation is limited to one out of four to five years, when the crop is being replanted.

Layout of the land for crop planting is another aspect of land preparation that varies very much from one area to another. The important considerations are to enhance surface drainage where the topography is flat, to concentrate the top soil where the crop is actually being planted, and to facilitate irrigation. Patterns of land layout include preparing a seed bed on flat land for non-cereal crops on cambered beds and on ridges (figures 3, 4, 5). The width of the cambered beds may vary from 4 metres to as much as 20 metres, and they could be up to 200 metres long. Drainage is accomplished by allowing water to run off the sides of the beds into drains connected to drainage ditches at the ends of the beds [22].

The cambered bed layout is fairly satisfactory for drainage purposes for some crops, particularly sugar cane, but it is not satisfactory for crops more sensitive to water-logging such as some cereals, grain legumes, and other food crops. Another factor affecting growth and production of crops in this system of land layout is a soil fertility gradient from the top of the beds to the drains. The gradient across the bed is formed by scraping up the top soil and piling it on top of the bed, so that the closer to the drain the more likely it is that essentially sub-soil will be exposed. Many crops show a marked difference in response from the top of the bed to the drain, as one gets to less fertile soils and more waterlogged conditions. Figure 6 show the

Figure 5 Growing crops on ridges is universal on clay soils. In the Sudan this is the most practised land layout for cotton and other crops to facilitate irrigation, along with other benefits

Figure 6 In Trinidad, the cambered bed shown here would be adequate for sugar cane but quite unsatisfactory for maize. The rows of maize closest to the drains fail completely. A reasonable crop is obtained on only about one-third of the bed at the crest

Figure 7 Land slipping is an important form of erosion in the clay soils where there is some relief. The slip shown here was caused by underground seepage from a septic tank. Similar slips could be caused by runoff water from paved areas, houses, farm sheds, etc. entering cracks.

Figure 8 As seen in Belize, gullying is not halted even by the extensive root system of a cohune palm (*Maximiliana* sp.).

Similar generalisations cannot be made for phosphorus and potassium.

Nitrogen use presents some hazards. If the soil pH is high and the soil moist with high windspeed, volatilisation losses could be very high from surface-applied ammoniacal fertilizers. If short periods of high rainfall or irrigation precede nitrogen application, denitrification could be severe due to temporary anaerobic soil conditions. When high levels of nitrogen are applied, chemical fixation by the clays may also be important [18]. On the other hand, both ammoniacal and urea fertilizers are actively adsorbed by these soils, and therefore leaching losses are at a minimum. For this reason, urea can be expected to be quite efficient. Considering all the possible sources of losses of applied nitrogen, low levels of recovery of nitrogen, probably not exceeding 40 per cent, is to be expected, but this must be confirmed by experiment.

Among tropical soils the types of clay soils being considered here do not normally have great capacity to fix added phosphorus, except where the soils are derived from marl or coral and have free lime in the solum. Since most non-graminaceous crops are likely to have restricted root systems, the fertiliser should be placed as close as possible to the crop and not broadcast. Surface applications may not be very beneficial under field conditions, since phosphorus is not likely to move very much from where it makes contact with the soil. Due to the extremes in soil moisture conditions on the surface, plant roots would tend to avoid this part of the profile; consequently significant uptake of surface-applied phosphorus would not occur. Providing the surface soil to which phosphorus is applied is not eroded, mulching of it would allow better utilisation of added phosphorus through its effect on soil water. Objections to surface applications would not apply to crops where the ground surface is covered, such as in pasture and sugar cane cultivation. Each year this part of the profile is mixed with the cultivated layer; in this way the whole soil becomes increasingly enriched in available phosphorus, providing surface erosion is controlled. This is clearly demonstrated in the clay soils of Barbados where after 300 years of applying phosphorus-containing fertilizers and manures, the nutrient is now highly available in the surface cultivated layer [12]. Clearly, as a prelude to more efficient management, research should be concentrated on the behaviour of added phosphorus on these soils, using labelled materials.

As stated above, often there is no response to potassium fertilizers in clay soils and where it is needed, the considerations stated above for phosphorus would apply.

Crusting of clay soils poses an additional constraint to their management. In the Sudan, growing crops on ridges is considered advantageous in overcoming the effects of crusting. Surface protection in the form of mulches or chemical soil aggregators are effective, but impractical and expensive. If there is a choice, it is better to use crusting soils for crops such as pasture, sugar cane, and rice and not for cereals, other food crops, and cotton. Additives such as farmyard manure and incorporation of crop residues would increase the capability of these soils as would the use of mulches.

Erosion control and engineering aspects

Where clay soils develop on recent alluvial deposits the topography is essentially flat and surface erosion is not a problem except where some relief is imposed, as in land grading. In areas with more relief, all forms of erosion are a serious problem in management. This is well exemplified by experience in Barbados, where during the mid-1970s it was possible to burn the sugar cane crop prior to harvest as is normally done elsewhere. The fire destroyed the natural mulch formed by the trash which had been a feature of sugar cane cultivation on this island for centuries. Following burning and harvest of the crop, the soil remained exposed for several months until the new crop could offer protection. During this period the annual soil loss was very obvious. The average decrease in yield was estimated at 4 tons per hectare during the period when burning was allowed, and this was enough to convince the authorities that the practice should be banned. There were, of course, other effects of burning which contributed to the yield decrease.

Land-slipping is a very important aspect of soil erosion on clay soils where there is some relief. This is a serious problem in Trinidad, and leads to dislocations and expensive maintenance of highways, buildings, and agriculture (figure 7). The problem is aggravated by cracking of the soil, which allows easy access of water into the sub-soil in the wet seasons. This form of erosion is also aided by the occurrence of natural shear planes or slip faces in the substratum. The water eventually finds its way between these faces and forms a lubricant on which the material above may slip. In management of clay soils prone to land-slipping, excessive desiccation should be avoided, so that cracks will not develop to a maximum extent in the dry seasons; additionally, disposal of waste water from houses, dairy pens, roadways, soak-aways, etc. should be well planned and executed. In reclaiming areas subject to slipping, this problem should be recognised and the hydrological conditions of the area should not be disturbed in the process. Failure to do this could lead to catastrophic land slips on land that has been reclaimed. Agriculture should also be very intensive, using irrigation to avoid the excessive annual variation of soil moisture which is naturally characteristic of these soils.

Another form of erosion which is serious on clay soils is gulleying on banks of river and water ways (figure 8). Cracking of the soil on the banks occurs during the dry season, and with the onset of rain it collapses, leading to gulleying. If this problem is recognized at the time of reclamation, the natural vegetation can be left along river banks for protection. Erosion also occurs along irrigation canals, leading to expensive maintenance. The only practical way of dealing with this problem is to keep canals filled with water to avoid drying out of the banks and to allow growth of vegetation that will not hinder the flow of water. Once extensive cracking develops on the banks of irrigation channels, the loss of water through these cracks would also be a problem and could lead to inefficient water use.

As a result of the collapse of the soil along drainage courses, very rapid deterioration of these installations occurs, requiring constant maintenance. Due to

TABLE 1: CHEMICAL PROPERTIES OF THE IRRIGATION WATER IN THE GEZIRA AND MANAGIL CANALS AND OF THE WATER IN THE BLUE NILE†

	El Gezira		Managil		Nile	
	June*	October*	June	October	June	October
Total salts (ppm)	196	100	199	87	198	87
pH	8.1	7.9	8.2	7.8	8.2	7.9
Na (m.e/100 gm)	0.58	0.17	0.58	0.19	0.58	0.19
Mg (m.e/100 gm)	0.74	0.43	0.75	0.38	0.75	0.39
Ca (m.e/100 gm)	1.66	0.88	1.68	0.90	1.68	0.90
Sodium adsorption ratio	0.53	0.21	0.52	0.24	0.53	0.24

† Source of data is the Soils Section of the Ministry of Agriculture, Republic of the Sudan
* June represents conditions in the dry season, and October the cool season

differential performance of maize across the camber in response to these factors. The beds are also an impediment to mechanisation. In Guyana, in order to provide a satisfactory layout to allow for effective water management for sugar cane cultivation, it is estimated that 20 per cent of the land surface is occupied by water courses of all categories and the installation costs exceed US$1000 per hectare.

Ridges (figures 4 and 5) are widely used for planting field crops. Sometimes the ridges are formed on cambered beds, but they are also made on flat or graded land. The spacing is determined by the crop requirements. The further apart the ridges can be, the higher they are, since they are formed by heaping up the soil in between. In this system top soil is concentrated where the crop is actually planted. Irrigation water is applied through drains between the ridges (figures 4 and 5) and these also serve as drainage channels when necessary. In order to function successfully, if the land is essentially flat, grading may be required to impose an even gradient to allow for satisfactory flow of water. This layout is less of a problem to mechanisation than is the cambered bed. The agriculture in the Gezira Project of the Sudan, for example, is based on planting on ridges. Flat planting is normal for small cereals and oil seeds such as at the Darling Downs of Australia and for rice cultivation, which will be considered later.

Water management

One of the most difficult problems in the management of clay soils is achieving satisfactory external and internal drainage. External drainage is obtained through land layout as mentioned above. However, this is not enough, because due to slow water transmission through the soils, aeration could be inadequate for long periods following heavy rainfall or irrigation. In Belize, mole drainage is successfully used in association with cambered beds by some farmers, the moles running across the camber. This combination provides adequate drainage for maize, beans, and other field crops. Encouraging results have also been obtained in Guyana where mole drainage is being used experimentally for sugar cane cultivation; here moles are made after the land has been graded to a pre-determined slope. The combination of land grading and mole drainage is apparently satisfactory in providing adequate drainage. In India experiments are being carried out using tile drainage [10]. However, it has been pointed out that the cost could be prohibitive for field crops, though if cropping is made really intensive by improving the drainage this may go a long way to off-set the cost. Also, the long-term benefit of such expenditure has to be considered.

Where clay soils are to be irrigated, great care should be exercised in effecting salinity control. Salinisation of these soils by faulty irrigation is a world-wide problem, and the effects can be catastrophic. Large areas of land for which costly reclamation has been carried out could be made uncultivatable in a short time. Commonly, the water available to irrigate clay soils has high salt content and particularly high sodium absorption ratios. There are exceptions, however, a notable one being the water of the Blue Nile used for irrigation in the Gezira scheme in the Sudan. Since this is one of the largest and most successful irrigation projects in the world, the quality of the irrigation water as a factor in its success is significant. Table 1 shows some of the properties of the water in the main irrigation canals of the El Managil and El Gezira parts of the area, as well as the water of the Blue Nile at the intake (Sennar Dam) for June (hot and dry) and October (cooler). In this case, there is little danger of soil salinisation and therefore the water is used almost without precaution. The same is true for low-lying areas of high rainfall such as Guyana and Suriname, where water of excellent quality is available.

It has been suggested that when applying irrigation water to clay soils, this should be done rapidly in an attempt to overcome slow and complete wetting of the soils which could result in total disruption of any soil aggregates, causing severe deterioration in physical condition [13]. For this reason, furrow irrigation is preferred to sprinkler irrigation. This method also avoids the deleterious effect of water falling on the soil surface.

Fertility maintenance

Depending on their origin and degree of development, clay soils can be quite fertile. Examples of this are the Darling Downs of Australia, where high yields of cereal crops and oil seeds have been obtained over a long period without addition of fertilisers. Also, on soils derived from recent marine sediments in Guyana and Suriname, nitrogen is often the only limiting nutrient. Taken as a whole, responses to added nitrogen could be obtained from almost any clay soil.

shrink-swell properties, maintenance of farm roads, farm buildings, water mains, and fences creates very serious problems requiring expert engineering inputs.

Pasture use

Probably the most important use of tropical clay soils world-wide is as unimproved pasture, providing seasonal grazing with low overall productivity. The native grass species which form the pasture seed and die or go dormant as the dry season advances. The challenge is to find pasture grasses and legumes which can remain productive throughout the year, thus improving the carrying capacity of these pastures. It is surprising how little is at present known about the adaptability of forage plants to soil and climatic conditions associated with the clays. The Tropical Crops and Pasture Division of the CSIRO in Australia has a research programme to assess the suitability of forage plants for clay soils; similar work is being done in Belize and other centres in Central America.

Rice cultivation

Clay soils are used all over the world for the cultivation of rice and in many countries, especially in the Far East, soil management for this crop is traditional and allows for fertility maintenance mainly through the use of organic manures. More recently, the use of fertilizers is becoming widespread, coincidental with the availability of high yielding varieties demanding more nutrients. In the tropics, mechanization of rice cultivation has posed special problems due to excessive weed growth, greater demands in water control and other agronomic factors, and difficult field conditions. Work done in Guyana [23] and Suriname [24] on soil management for continuous mechanized rice culture on clay soils has been of a pioneering nature. The system involves tillage of the land in a submerged condition, ending with the preparation of a satisfactory seedbed for the sowing of pre-germinated seed either manually or mechanically. Harvesting of the grain often has to be done when the field is still wet. These extreme conditions require special modifications to custom-built machinery and high operation costs. However, it is effective in weed control and allows the sowing of pre-germinated seed for early and satisfactory crop establishment. At present, rice cultivation on clay soils is expanding rapidly in the tropics, particularly in Africa and Central and South America.

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