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SOME PHYSICAL PROPERTIES OF WETLAND SOILS WITH REFERENCE TO THE TROPICS *

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ABSTRACT

Some physical properties of wetland soils are reviewed with reference to the tropical regions. The soils have as common feature periodic flooding during the year. They exhibit wide variability in mechanical composition in accordance with their genesis and location. Bulk densities range from 1.0 to 1.9 Mg m^{-3} for mineral soils with moderate organic matter content and from about 0.02 to 0.2 Mg m^{-3} for organic soils. Total porosities are generally high with dominance of micropores in organic and clayey wetland soils. Shrink–swell potential is also generally high in many of these wetland types with consequent problems of crack formation. Anaerobiosis condition is common feature in wetland soils. Also carbon dioxide levels may be excessive for normal crop development. Water–retentivity has been found to be high to very high in a number of tropical wetland soils of medium to fine texture. In some organic soils values of over 100% (mass basis) are not uncommon. In particular, a value of up to 3000% has been reported. Water infiltration and percolation are highly variable. The heat capacities are generally high with resultant reduced temperatures. Land use and management strategies are proferred in the light of the properties.

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1. INTRODUCTION

Wetland soils are defined by Van Breemen [42] as soils that are ponded or water saturated during most of the time that they are, or could be used for crop production. They are similarly viewed as soils that are water saturated to such shallow depth and for such durations that they require for their agricultural use either critical drainage or the growing of adapted crops [12] or most simply as soils flooded for at least several weeks each year [28].

Pedologists associate wetlands with aquic moisture regime, the dominant soil conditions being gleyic and histic horizons. The major soil associations in wetlands are the aquic suborders of the Soil Taxonomy [35] or the Gleysols, Histosols and Fluvisols of the FAO [16]. They occur in most of the climatic zones from the tundra to the humid tropics constituting some estimated 66 million hectares of the latter [17]. The FAO/UNESCO estimates [16] place the land area with limitations due to water excess at approximately 9 percent of the total in Africa, 8 percent in Europe, 10 percent in North America and 19 percent in Southeast Asia.

Saturation with water which is a key feature of wetland soils may be traced to three major causes, namely, the presence of impervious layer in a soil, the impermeability of the soil body and the presence of a high water table [31]. Thus impedance to downward movement of rain water or the build up of ground water table would result in the development of temporary or prolonged water–logged soil environment.

For many years, the agricultural potential of wetlands such as bogs, marshes and swamps remained largely unexplored. In recent years, however, old fears and phobias are being gradually discarded. Agriculturists have been forced to pay greater attention to these areas in attempts to contain anticipated, if not impending food crises.

Whereas extensive research and documentation have already been carried out in respect of the genesis and chemistry of wetland soils, characterization with respect to physical properties has not received due attention. Humid tropical wetlands have to date remained poorly explored. This has meant considerable information gap that needs to be promptly bridged if appropriate resource management plans are to be developed for tapping the rich agricultural potentials of many of these soils.

The physical properties of wetland soils do not for most cases yield easily to generalization. Rather, many of these properties depend on the type of wetland soil and tend, quite often, to be site specific. Some consideration will be given to the important properties such as grain size distribution, structure, gaseous exchange, water retention and transmisison as well as soil thermal regime. The implications of these properties to soil management for increased crop production will be considered.

2. GRAIN SIZE DISTRIBUTION

The grain size distribution is a fundamental index soil physical property. Knowledge of this property allows prediction of many other soil properties. In general, the soils of the humid tropics are subject to intense rain storms which often cause clay eluviation with resultant tendency towards coarse texture in the surface horizons. In general, too, wetland soils display a wide complexity of textures depending primarily on their genesis and location. The textural profiles of a few selected wetland sites in West Africa and the United States are shown in Tables 1 to 4.

Flood plain soils show different textural patterns as a result of differences in parent materials and modes of deposition of the materials. A study by Valet [41] in the Sona area along the River Niger showed very heterogeneous alluvial materials deposited by the river. The examined profiles varied from silty to clayey textures in some cases and from sandy to clayey textures in others. Many inland valley soils in Sierra Leone and the neighbouring countries along the West Coast of Africa are composed mainly of sandy to coarse loamy materials whereas the more clayey soils are found on the wider flood plains of major rivers along the coast [28]. Textural stratifiction is evident in some soils of the Niger–Anambra flood plains of Southeastern Nigeria [29] and, in particular, the Niger–Ofu river flood plains near Idah, Nigeria (Table 4).

Some young alluvial soils may show a dominance of medium to fine textures in the topsoils. This is the case with some soils of rice lands in tropical Asia [28]. Seasonally wet soils in the Ganges flood plains of India showed finer textures in the topsoils. They were developed in originally calcareous sediments [6]. The older flood plains soils showed gradation from fine–textured topsoils to sandy bottom layers. Many of the young alluvial soils of tropical Asia studied by Moorman and Van Breemen [28] showed surface textures of loamy to clayey materials. In Thailand, however, coarse textures dominated on the surface of some young alluvial soils. Further examination showed that these soils were formed on sandy sediments derived predominantly from sandstone. Most of the surface soils had apparently lost a great deal of their clay owing to pedogenic processes. The subsoils were clayey. Also in some inland valleys of Sri Lanka, the topsoil had high coarse sand contents and low silt contents. The parent material was found to be gneiss.

A general survey of the hydromorphic soils of Nigeria, Sierra Leone and Liberia showed that approximately 80 percent of the topsoils were coarse textured [20]. In central Nigeria, however, a wide variability in texture was found with some extensive area in some river basins showing clayey and silty topsoils. Some hydromorphic soils of Southeastern Nigeria which are known to have shale parent material within about two metres from the surface have topsoils of medium texture overlying clayey subsoils (Table 3).

Soils along the coastal areas are subject to inundation by tidal action. Deltaic sediments give rise to soils of varying texture. An outstanding feature of tidal marsh soils is the accumulation of plant resudue in the surface horizon. Also the mineral portion of the tidal marshes may show textural stratification. The particle size distribution data of the mineral portion of a tidal marsh soil are included in Table 4.

Saline swamps in Sierra Leone show wide variation in mechanical composition of the soils. The clay contents of the topsoils were in the range of 4 to 30 percent. In one soil examined, distinct gravelly texture was noted at the 44–78 cm depth. Many of the soils, however, were sandy at depth [40].

Organic soils are found scattered among othe soils in some swampy areas. They result from accumulation of plant remains in bogs. They contain 15 percent or more organic matter throughout the upper portion of the weathered profile - the A and B horizons [34]. Two "textures" (peat and muck) can be described. In peats, the original plant remains are readily recognized whereas in mucks they are not.

3. SOIL STRUCTURE

Soil structure controls many aspects of productive potential like air and heat flow into and out of the soil, water retention and movement as well as ease of root penetration and nutrient uptake. Small changes in bulk density have been found to cause some roots to flatten. High densities will cause actual root restriction. Whereas soil texture may not be changed economically over a short period of time, soil structure can be easily changed to advantage by proper management. Indices of soil structure include bulk density, porosity and soil aggregate stability.

3.1 Bulk density

The bulk density of a soil depends on the type, nature and the packing pattern of the mineral and organic constituents. Typical values for some tropical wetland soils are shown in Tables 5 and 6. For most mineral soils bulk density values range from 1.0 to 1.9 Mgm^{-3}. Some humose topsoils may show values slightly less than 1.0 Mgm^{-3}. The bulk density of most peats is considerably less than 1.0 Mgm^{-3}. Furthermore up to tenfold difference may be found among different peats. The range in weight of a hectare of top 15 cm of organic soil may be between one twentieth to three tenths the weight of equivalent mineral soil [11].

The bulk densities of some selected peat types were reported by Farnham and Finney [15]. These ranged from 0.02 to 0.2 Mgm^{-3} compared to 1.27 Mgm^{-3} for a mineral soil. Among the peats, loose and fluffy types like sphagnum and hypnum moss have been shown to have low bulk density values in the range of 0.05 to 0.1 Mgm^{-3} whereas finely divided sapric types have highest values [15]. Table 6 shows the bulk density of peats as related to the degree of decomposition [5]. Sapric peat has the highest and fibric the lowest bulk density.

The bulk density of alluvial soils will be expected to vary in accordance with the nature of the deposited materials. For sixty eight textural layers of alluvial soil examined by Lund [26] bulk densities ranged from 1.04–1.69 Mgm^{-3}. The flood plain soils of the Niger–Anambra rivers of Nigeria had values in the range of 0.79 Mgm^{-3} for a humose top layer to 1.5 Mgm^{-3} for a mineral subsoil [30]. Some of the terrace soils of the Niger at Sona exhibited high bulk densities of 1.7 to 1.8 Mgm^{-3} [41]. Similar high average value of 1.67 Mgm^{-3} was noted for some Fragiaqualfs [33]. Finally, the bulk density values of some surface water gleys were found to be in the range of 1.30 to 1.59 Mgm^{-3} [39].

3.2 Porosity and Pore Size Distribution

The total pore volume, distribution and stability of pores are important considerations relating to soil structure. In general organic soils have high total porosity, the values for several peats ranging from about 80 to 100 percent compared with 30 to above 50 percent for many mineral soils (Tables 5 and 6).

The pore size distribution expectedly varies with peat types. A decomposed herbaceous peat, for example, was found to have high total porosity but with a preponderance of macropores whereas undecomposed surface peats had a dominance of macropores.

Alluvial soils do not exhibit any definite pattern with regard to porosity. Where sandy deposits dominate macropores would expectedly dominate. On the other hand, where the deposited material is of high clay and organic matter content, water–logging may be expected to cause pore instability with resultant tendency towards the formation of smaller pores. In the soils examined by Lund [26], the percentages of large pores were found to be very low. They ranged from 1.7 to 10.7 percent. The picture of low macroporosity was also shown in some soils of the Niger-Anambra and Niger-Ofu flood plains of Nigeria (Table 5).

Surface water gleys of Bangladesh had total porosities of 38–52 percent and microporosities of the order of 10 percent [6].

3.3 Soil aggregate stability

Soil aggregate stability is expected to decrease with flooding because of the processes of hydration, swelling and solubilization of some cementing agents [32]. Leyton and Yadav [25] found higher percentage of water-stable aggregates in a drained soil compared to undrained soil. The effects of upward movement of gases as well as the reduction of iron, due to anaerobic decomposition on soil structural stability were studied by Ahmad [1]. The two factors combined to give an increase in wet aggregate stability. It was postulated that on drying out the iron was oxidized and deposited around the channels making the aggregates formed to be of increased stability. Aggregate stability of a wetland soil was found to decline under continuous arable cropping owing to a decline in organic matter content.

3.4 Swelling and Shrinking

The swellling and shrinking properties are intimately associated with soil organic fraction and the clays. Swelling is principally due to the colloidal content of the soil. Organic soils swell

upon wetting and shrink on drying to a degree dependent on the types. Shrinkage calculated as a percentage of the original volume may vary between 90 percent for some aquatic peats, 40 percent for matted fibrous peats and 19 percent for some mucks [11].

Clayey soils are expected to exibit swelling tendency under condition of water–logging or high water table and shrinking tendency with periodic drying. The shrink–swell characteristics are important management factors with particular reference to soil internal drainage.

4. GASEOUS EXCHANGE

An important aspect of soil aeration is the supply of oxygen to the roots and the micro–organisms. Under condition of proper aeration oxygen content of a soil is close to that of the atmosphere (about 21 percent) the oxygen removed being readily replaced by diffusion from the atmosphere [19]. In soils with excessive water stemming from surface ponding or a stagnating water table, pores are closed and oxygen availability is restricted to that dissolved in soil water and entrapped soil air.

The degree of availability of oxygen in the soil may be expressed in terms of its concentration or in terms of its rate of supply. A widely used index is the oxygen diffusion rate (ODR). For many crops ODR values of about 0.20 $g\ cm^{-2}\ min^{-1}$ will arrest root growth [37]. Roots rot at values less than this. Some factors influencing the ODR include water content, soil texture and temperature. Oxygen diffuses in water ten thousand times more slowly than in the air [7]. This means that only a thin layer of surface water is necessary to form an effective barrier against gaseous interchange between the soil and the atmosphere. Investigations show that ODR is positively correlated with distance to a water table [44].

For three soils studied by Kristensen and Enoch [21] oxygen content decreased to zero before the water table was reached. A clayey soil showed drastic change at about 25–30 cm from the water table in comparison with a sandy soil with no appreciable reduction before a distance of about 15 cm from the water table [21]. The ODR decreased rapidly with increasing soil depth. Another study of two drained wetland soils of clay loam and sandy texture showed that as the water table dropped, oxygen diffusion rates increased at greater rate in clay loam soil than in sandy soil [44].

Moderate to high ODR values are generally to be expected in soils with high air space porosities. With regard to temperature, decreased solubility of oxygen in soil solution with increased temperature has been noted [24]. Thus, the relatively higher temperatures expected in tropical compared to temperate wetlands would tend to accentuate the problem of oxygen availability.

Under flooded conditions, large amounts of carbon dioxide in the trapped soil air (1.3 to 6 percent) have been noted. Some workers have observed that the restrictive effect on growth could be due not only to the lack of oxygen but also to the high carbon dioxide content.

Temperature and soil water content affect carbon dioxide concentration. In a warm soil, carbon dioxide has been noted to increase more rapidly in comparison to a cool soil. This has been attributed to increased microbial activity [43]. Carbon dioxide concentration exceeding 40 percent by volume was found above the "capillary fringe" in soil columns with stagnating water table. The high microbial activity and the high solubility of the carbon dioxide in water were advanced as probable explanations for the observed result [14].

In anaerobic soil, nitrification is almost completely inhibited. Denitrification process dominates. Investigations revealed nitrous oxide even in well drained soils in Western Nigeria [7] indicating denitrification at the anaeoribic microsities.

The composition of soil atmosphere sample collected at 12 cm depth in lysimeters with varying water table depths was examined by Lal and Taylor [23]. There were generally high CO_2 and low 0_2 in lysimeters with high water table. The CO_2 contents were consistently high at 15 cm water table. Whereas the 0_2 content was 7.4 percent the highest CO_2 content was 8.6 percent. High N_2 content was thought to be due to the release of elemental soil nitrogen resulting from nitrification.

5. SOIL WATER RETENTION

Soil water and physical properties related to its storage play significant role in determining how a soil should be managed for optimum productivity. Water retentivity varies widely in wetland soils as it depends very much on soil porosity and particularly on the pore size distribution. In organic soils, the type of organic matter and the stage of decomposition would largely determine the pore charactersitics. In mineral soils, clay content, mineralogy and organic matter content are the key determinants.

An organic soil will usually hold several times the amount of water retained by equivalent mass of mineral soil. A study showed that the water content of a peat ranged from 300 to 3200 percent on mass basis in comparison to about 31 percent for a selected mineral soil [11]. It has been established that at saturation all peats could hold up to, if not more than 80 percent water by volume [4]. Undecomposed moss peats have been reported to retain up to 95 to 100 percent water by volume attesting to their high total porosity [2]. Usually much of their retained water is lost at low tension range of 0–15 mb indicating the dominance of macropores. Partially decomposed peats tend to be "denser" and have been reported to hold between 80 and 90 percent water by volume at saturation. They have been noted to release least water with increasing tension. Apparently, much of the water is retained in micropores and, therefore, not easily drained. A separate study by Boelter [5] showed that at very low tension of say , 5 mbar, the water retention of peat materials increased with decomposition because of increased microporosity. However, saturation water content decreased with decomposition. The least decomposed peat retained nearly 100 percent water by volume whereas the most decomposed retained 82 percent.

At wilting point, peats may contain about 24 to 80 percent water depending on composition. One aspect of organic soils which must be noted is that when air–dried, they usually cannot be rewetted to their original maximum water holding capacity. This resistance to rewetting is important in the agricultural utilization of the soils.

Sanchez [32] reported an average of 51.5 percent water content at 0.3 bar in the 0-58cm depth zone of a tropical soil of the Aquept suborder and an average of 33.5 percent water content at 15 bars (Table 8). The soil had an average clay content of 56 percent. Drover [13] reported values for a "gerf soil" in Sudan (Table 8).

For flood plain mineral soils, water retention, like a number of other properties should depend on the nature of the deposited materials. The retention characteristics for a number of these soils are shown in Table 8. The soils of the Niger–Anambra and Niger–Ofu River foodplains of Nigeria have generally high available water capacities of up to 29.4 cm per metre of soil. In the former it was shown that very little water was lost between saturation and very low tension of 0.01 bar [30]. The same would be true for the latter (Table 8) thus indicating, in both cases, few macropores in terms of total soil volume.

6. WATER INFILTRATION

Water infiltration into a soil is a highly variable process greatly influenced by the soil water content and by the surface conditions, particularly texture, structure, and the degree of vegetative or soil protective cover.

Many flood plain soils under forest or grass vegetation in southern Nigeria have high to excessive infiltration rates. In the Niger–Anambra flood plains the values ranged from 56 to 1000 mmh^{-1} whereas in the Niger–Ofu River flood plains the range was 30 to 1200 mmh^{-1}.

In some other tropical wetland soils however, very low to moderate infiltration rates have been recorded. The investigation carried out in the Niger flood plain at Sona showed a rate of 0.04 cm h^{-1} at twelve hours for one of the hydromorphic soils [41].

The hydromorphic soils of Ikem, Ehamufu and Ezilo in Southeastern Nigeria had infiltration rates of 180, 288 and 47 mm h^{-1} at three hours [29].

7. HYDRAULIC CONDUCTIVITY

The hydraulic conductivity is intricately connected with water availability to plants, the soil trafficability as well as drainability.

In organic soils conductivity is dependent on the character of the organic components of the various horizons. The less decomposed peats generally have a dominance of larger pores which permit rapid water movement. Measurements showed saturated hydraulic conductivity of more than 137.2 cmh^{-1} for undecomposed peat near the surface and less than 0.04 cm h^{-1} for dense decomposed herbaceous peats [3]. Another study showed that undecomposed moss peat had conductivity of 152.4 cm h^{-1} whereas well decomposed herbaceous peat had very low conductivity of 0.003 cm h^{-1} [4].

For a given organic soil, conductivity may be expected to vary with soil depth. Undecomposed moss peat near the surface had values as high as 3290 cm day^{-1} but at the lower depths where the peats were well decomposed, very low value of 0.959 cm day $^{-1}$ was obtained [3]. Measurements in a bog showed very low conductivity values of 23.9×10^{-3} and 16.1×10^{-3} cm day^{-1} at the 46 and 91 cm depths respectively [38]. For a muck soil conductivity values were 30.7 , 18.5 and 8.9 cmh^{-1} for 0–3, 9–12, and 18–21 cm depth zones respectively [38]. In more recent works Chason and Siegel [8] found field conductivity ranges from 5.6×10^{-3} cm s^{-1} on the bog; from 2.5×10^{-4} to 5.6×10^{-3} cm s^{-1} at the fern margin and from 6.7×10^{-4} to $1.6 \times 10^{2} cms^{-1}$ on the spring fern. The conductivity determined for partially decomposed peat deeper than 1 metre was much higher than previously reported. There appeared to be little correlation of conductivity with depth. Finally, laboratory analysis showed that horizontal hydraulic conductivity was much higher than the vertical conductivity. Humified peats, they observed, could transmit ground water very rapidly.

In the case of wetland mineral soils, wide variation in conductivity values would also be expected. There is the added tendency for conductivity to decrease with soil depth although, in some cases, it may actually increase as a result of coarse texture or strongly developed structure which may be found at a lower depth.

Table 9 shows some hydraulic conductivity values obtained for the mineral portion of some tidal marsh soils. They ranged from low value of 0.2 cm h^{-1} to a very high value of 149 cm h^{-1} [9]. For some surface water gleys values of 2 to 5 cm day $^{-1}$ were obtained [39]. For another surface water gley, the values ranged from less than 0.1 cm day $^{-1}$ to up to 1400 cm day $^{-1}$ [6]. In "rice soils" puddling and traffic pan formation are common features. These cause great reduction in conductivity. Some measurements have shown values ranging from 1 mm to several centimetres per day depending on soil texture [28]. A conductivity of about 20 mm day $^{-1}$ is considered optimum in the "rice soils" of Japan [28].

Flood plain soils with wide complexity in texture and structure expectedly show wide ranging conductivity values. For sixty eight textural layers examined by Lund [26], the saturated hydraulic conductivities were generally low. Some had no measurable values at all. Texture contributed much to the observed results. One of the profiles was found to have up to 93 per cent clay content.

Many subsoils of the Niger–Anambra and the Niger-Ofu River flood plains had low conductivities (< 0.11 cm h^{-1}). This was attributed to the massive structure of the clayey subsoils. In some cases, however stratification resulted in coarser soil texture at some lower depths and therefore in higher conductivity at these depths.

The hydromorphic soils of southeastern Nigeria were found to have conductivity values of 2.8 to 6.1 cm h^{-1} in the top layers whereas in the subsoils values less than 0.11 cm h^{-1} were obtained (Table 9).

The importance of cracking which follows the drying of many wetland soils cannot be overemphasized. It may result in unanticipated increase in conductivity which will affect the water economy of the wetland soil.

8. SOIL THERMAL REGIME

Soil temperature is an important physical factor affecting crop growth and development. Sub-optimal and supra-optimal soil temperatures are known to have adverse effects. The optimum temperatures for such crops as cowpea, pigeon pea, cassava and upland rice are in the range of 30–35°C. For maize and soybean the optimum range is 25 to 30°C [22].

Preliminary investigation (unpublished) showed that the 1.30 p.m. temperatures of the top 1 cm depth zone of a ponded sandy loam soil in southeastern Nigeria were generally lower by 3–8°C when compared with a similar well drained soil with no water table. Also the temperatures of the ponded soil were about 2–4°C lower than air temperatures. The highest temperatures during a ten–day period of observation in March were 27, 34 and 30°C for the wet soil, well drained soil and air respectively. The ponded soil supported a crop of rice. Lal and Taylor [23] recorded the soil temperature at 1400 hours at the 10cm depth for two constant water table levels and for no water table lysimeters. Soils having a water table at 15cm were 2–6°C cooler than those without a water table. The average soil temperatures were in the order of 20.2, 23 and 24.9 C for the 15 cm, 30cm and no water table treatments respectively. The temperature changes in the soil are influenced by the heat capacity and conductivity. Wet soils generally have much higher heat capacities than dry soils. Thus, the top layers of wet soils tend to have lower temperatures and warm up more slowly than those of dry soils.

Organic soils such as peats generally have much lower thermal conductivities and much higher heat capacities than mineral soils. Thus they expectedly have slower temperature changes and lower temperatures compared to mineral wetlands.

9. LAND USE AND MANAGEMENT

Wetland soils are greatly underutilized in many tropical countries. Estimates show that in Sierra Leone swamps represent about 30–40 percent of the agricultural soils [18] and in southern Nigeria, hydromorphic soils occupy about 10–15 percent of the total land area [20].

Lack of adequate soils and water management technology has contributed immensely to their underutilization. Besides, there is the problem of accessibility and adequate infrastucture which specifically hinder reclamation of say, swamps. However, rapid increase in population will force greater attention on wetland soil improvement and utilization particularly in the tropical regions since their productive potential is relatively high.

Organic soils and wetlands in general where properly managed could become major agricultural areas for rice growing. Besides traditional agriculture in these areas has shown that certain tree and fruit crops of the tropics can be successfully grown on partially drained wetlands. Oil palms, rubber and pineapple are a few of such crops. Marginal wetlands may be suitable in places for cropping of maize, yam, cocoyam and plantain. In some areas of high rainfall, forestry may offer major attraction . In other areas especially the West African subregion, palm wine production is assuming important dimension.

Peat lands may be harnessed for soil amendments and for application as mulch, poultry litter absorbent and stable bedding [36]. In some West African mangroves, peats may be more than 1m thick. Such peats can be cut and used as fuel.

Some major constraints to the use of wetlands for increased food production are directly imposed by the soil physical conditions. These may be broadly listed as waterlogging and the associated problems of gaseous exchange, slow temperature changes, swelling, cracking and crusting. Organic soils have additionally problems of low bearing capacity, poor anchorage for plants, rapid oxidation and subsequent subsidence with the lowering of water table and soil drying. They also shrink and harden irreversibly [27]. On the other hand, organic soils and many wetland soils of medium and fine texture have high water holding capacity and surface bulk density in the favourable range for root growth and development. In general wetlands are found in low–lying areas and are, therefore, expectedly less subject to soil erosion and drought than adjoining lands at higher elevation.

10. SUMMARY AND CONCLUSIONS

The wetland soils are flooded for at least several weeks during the year. The presence of impervious layer within the soil or a high water table contributes immensely to the development of waterlogged soil conditions.

Wetland soils show wide variability in mechanical composition in accordance with their genesis and location. The bulk densities vary from about 1.0 to 1.9 Mg^{-3} for mineral soils with moderate organic matter content and from about 0.02 to 0.2 $Mg\,m^{-3}$ for organic soils. Total porosities are generally high with dominance of micropores in the organic and clayey wetland soils. Also, in these wetland types there is the tendency to have high degree of swelling and shrinking leading to the development of cracks with any recession of water from the surface.

Oxygen diffusion is greatly lowered if not elimianted by waterlogging. The development of anaerobiosis condition is, therefore, a constant problem in wetland soils. Additionally the carbon dioxide concentration may increase to hardly tolerable levels. Both factors will combine to offer restrictive effects on root growth and development.

Water retentivity is particularly high in some peats and in some fine textured wetland soils in keeping with their high microporosity. Water infiltration and percolation are highly variable phenomena in these soils. The heat capacities are generally high with resultant reduced temperatures.

The selection of adapted crops, carefully planned drainage systems, dry season irrigation for marginal wetlands, control of soil temperature, crusting and cracking by say application of crop residue, peat or plastic mulch, proper timing of tillage operations and the use of appropriate tillage machinery – these are some of the management strategies for the integration of substantial portions of the tropical wetland soils into the agricultural system.

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Table 1

Texture of 37 hydromorphic soils of forest region of West Africa *

Properties	Range	Distribution (%)	
		surface	subsurface
clay	0-15	46	19
content	15-25	19	35
(%)	25-35	14	16
	35-45	8	16
	45-55	5	3
	55-65	8	11
silt	0-10	16	24
content	11-20	22	24
(%)	21-30	16	14
	31-40	24	19
	41-50	12	14
	51-80	10	5

* IITA (1981).

Table 2

Texture of 27 hydromorphic soils from the savanna zone and the forest/savanna transition zones of Nigeria *

zone	texture	surface soil		subsurface soil	
forest/savanna		range	mean	range	mean
(17 soils)		%		%	
	clay	4-68	15	3-70	21
	silt	9-15	21	5-53	18
	sand	13-89	64	10-84	61
savanna	clay	6-50	22	5-70	28
(10 soils)	silt	8-51	37	6–55	29
	sand	4–82	42	5–89	43

* IITA (1981).

Table 3

Mechanical composition of some hydromorphic soils of southeastern Nigeria

location	soil depth cm	sand	silt	clay	silt + clay
				%	
Ikem	0-30	55.5	28.0	16.5	44.5
	30-60	51.5	28.0	20.5	48.5
	60-90	43.5	18.3	38.2	56.5
Ehamufu	0-30	25.1	44.7	30.2	74.9
	30-60	19.1	40.7	40.2	80.9
	60-90	11.1	40.7	48.2	88.9
Ezilo	0-30	30.8	61.0	8.2	69.2
	30-60	26.8	51.0	22.2	73.2
	60-90	33.8	34.0	32.2	66.2
Opanda	0-10	31.0	29.0	40.0	69.0
	10-20	28.0	27.0	50.0	77.0
	20-30	23.0	25.0	52.0	77.0
	30-40	23.0	23.0	54.0	77.0
	40-50	21.0	23.0	56.0	77.0

Table 4
Mechanical composition of flood plain and tidal marsh soils

location	depth cm	coarse sand	fine sand	silt	clay
			%		
Niger-Anambra flood plain (Nigeria)					
OT-12	0-10	11.2	20.4	12.0	56.4
	50-60	0.3	2.9	82.8	14.0
UA-24	0-10	7.4	17.0	24.0	51.6
	50-60	1.0	3.4	34.0	61.6
UA-29	0-10	3.8	25.4	40.8	30.0
	50-60	3.0	2.2	30.0	64.8
Niger-Ofu River flood plain (Nigeria)					
IB-16	0-12	45.0	31.0	6.0	18.0
	12-34	40.0	30.0	2.0	28.0
	34-55	60.0	36.0	2.0	2.0
	55-100	73.0	27.0	0.0	0.0
	100-125	70.0	30.0	0.0	0.0
IB-18	0-10	3.0	47.0	32.0	18.0
	10-38	2.0	54.0	32.0	22.0
	38-60	1.0	39.0	32.0	28.0
	60-80	0.0	24.0	34.0	42.0
	80-120	7.0	27.0	28.0	48.0
	120-140	20.0	18.0	14.0	48.0
IB-22	0-6	4.0	56.0	24.0	16.0
	6-16	6.0	54.0	20.0	20.0
	16-33	5.0	55.0	16.0	24.0
	33-48	33.0	61.0	4.0	2.0
	48-70	12.0	72.0	10.0	6.0
IB-24	0-4	0.0	50.0	18.0	32.0
	4-15	1.0	27.0	24.0	48.0
	15-34	1.0	53.0	10.0	36.0
	34-64	1.0	53.0	8.0	38.0
	64-84	1.0	65.0	6.0	28.0
	84-110	2.0	74.0	4.0	20.0
Niger-Ofu River flood plain (Nigeria)					
IB-26	0-16	6.0	38.0	32.0	24.0
	16-46	4.0	36.0	24.0	36.0
	46-92	2.0	38.0	28.0	32.0
	92-104	44.0	30.0	10.0	16.0
	104-136	43.0	33.0	2.0	22.0
	136-170	57.0	37.0	2.0	4.0
Apalachee Bay, Florida, USA (tidal marsh) *					
	0-18	7.2	17.1	38.6	37.1
	18-64	10.1	26.6	20.9	42.4
	64-114	17.4	24.1	20.4	38.1
	114-140	31.8	44.0	6.5	17.7
	114-140	48.6	47.4	0.5	3.5
	146	46.6	47.4	0.6	2.4

* Coultas and Gross (1975).

Table 5

Porosity, pore size distribution and bulk density of two flood plains and hydromorphic soils of Nigeria

location	depth	total porosity	macro porosity	microporosity	bulk density
	cm		%		Mgm^{-3}
Niger-Anambra flood plains					
OT-5	0-10	58.9	4.8	54.1	1.25
	50-60	45.5	2.6	42.9	1.48
OT-12	0-10	47.8	16.5	31.3	1.12
	50-60	55.8	3.5	52.4	1.32
UA-29	0-10	54.6	5.3	49.3	1.29
	50-60	53.3	4.5	48.8	1.51
Niger-Ofu flood plain					
IB-16	0-10	53.2	12.6	40.6	1.28
	50-60	37.0	14.0	23.0	1.59
IB-23	0-10	41.3	5.0	36.3	1.63
	50-60	38.5	7.7	30.8	1.70
IB-24	0-10	44.1	4.7	39.4	1.36
	50-60	38.6	2.4	36.2	1.65
Ikem *	0-30	51.1	15.2	35.9	1.33
	30-60	39.4	8.6	30.8	1.65
	60-90	39.1	6.4	32.7	1.62
Ehamufu *	0-30	40.2	8.3	31.9	1.56
	30-60	43.2	6.4	36.8	1.51
	60-90	43.1	8.1	35.0	1.48

Table 5 (continued)

location	depth	total porosity	macro porosity	microporosity	bulk density
	cm		%		Mgm^{-3}
Ezilo *	0-30	49.0	7.2	41.8	1.37
	30-60	45.0	5.7	39.3	1.62
	60-90	43.7	6.1	37.6	1.61
Opanda *	0-10	56.0	21.9	34.1	
	10-20	51.4	11.5	39.9	
	20-30	51.4	10.9	40.5	
	30-40	49.5	15.0	34.5	
	40-50	47.6	12.3	35.3	

* hydromorphic soils
(Obi and Akamigbo, 1979).

Table 6

Porosity, bulk density and maximum water holding capacity of some organic materials *

type of organic horizon	total porosity %	bulk density Mgm^{-3}	saturation water content %
fibric	> 90	< 0.08	850-> 3000
hemic	85-90	0.08-0.2	450-850
sapric	< 85	> 0.2	< 450

*Boelter (1969)

Table 7

Moisture characteristics of some selected peat types (vol/vol)*

peat type	suction bars					
	0.0	0.06	0.1	0.33	1	15
Moss peat						
live undecomposed	1.012	0.143	0.127	0.081	0.058	0.035
partially decomposed	0.865	0.690	0.636	0.473	0.353	0.205
decomposed	0.833	0.747	0.715	0.589	0.440	0.223
herbaceous peat						
70-80cm	0.869	0.766	0.738	0.501	0.352	0.177
90-100 cm	0.891	0.780	0.740	0.459	0.315	0.142

* Boelter (1964)

Table 8

Moisture characteristics of some selected tropical wetland soils

location	depth cm	Suction bar 0.0	0.06	0.1	0.33	1	15	available water cm/m
Niger-Ofu floodplain (Nigeria)[1]								
IB–14	0-10	-	51.9	46.2	-	28.2	24.5	21.9
	50-60	-	44.6	42.5	-	40.6	36.1	6.4
IB-16	0-10	-	45.5	36.7	-	21.9	14.5	22.2
	50-60	-	30.2	18.5	-	11.1	8.6	9.8
IB-26	0-10	-	50.6	41.5	-	27.8	18.1	23.4
	50-60	-	60.8	54.4	-	46.0	34.4	20.0
"Gerf soil" Sudan[1]		58.4	-	-	54.3	-	16.1	-
"Aquept" Phillipines[2]								
	0-20	-	-	-	48.5	-	29.5	-
	20-37	-	-	-	58.9	-	34.2	-
	37-58	-	-	-	47.0	-	36.3	-

[1] Drover(1966)

[2] Sanchez (1976)

Table 9

Saturated hydraulic conductivity of some wetland soils

Location	Depth cm	K_{sat} cmh^{-1}
Ikem (Nigeria)	0-30	6.1
hydromorphic	30-60	0.4
	60-90	< 0.1
Ezilo (Nigeria) *		
hydromorphic	0-30	2.8
	30-60	<0.1
	60-90	<0.1
Florida (United States)[1]		
tidal marsh	0-12	7.2
	12-17	11.8
	17-22	0.2
	22-38	0.4
	38^+	-
Florida (United States)[1]		
tidal marsh	0-23	1.49
	46-54	13.7
	54-61	19.7
lake states (US)[2]		
organic soil		
moss peat	surface	150.8
moss peat	deeper horizon	5.7
woody peat		15.4
decomposed peat		0.02

* Obi and Akamigbo (1979)

[1] Coultas and Calhoun (1976)

[2] Boelter (1966).