The Nature and Genesis of Certain Aridisols in Kenya

John Makin, Johan Schilstra and Arthur A. Theisen
National Agricultural Laboratory, Kenya

Summary

In the semi-arid Kenya lowlands, strongly contrasting soil units associated with specific positions in the landscape have developed on various ancient alluvial deposits. The soil pattern may be explained by the differential truncation of a previously solodized plateau. These contrasting soil sequences give rise to associated vegetation catenas.

Adaptations are applied to the "7th Approximation" soil classification, involving the introduction of one new Great Group and several sub-groups.

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Introduction

Irrigation investigations in the Tana River Basin provided an opportunity for a comparative study of soils and vegetation in relation to recurrent landscape patterns and associated sediments.

The Lower Tana lies around 1°30' South, extending from sea level to 200 metres. Mean annual temperature is 83° F. Rainfall ranges from 365 m. m. in the South to less than 275 m. m. in the North. About every fifth year a rainfall 'low' of some 175 m. m. occurs. Annual evapotranspiration is estimated at 2575 m. m. Dry seasons tend to be prolonged and rainfall erratic. On all soils there is presumably severe competition between plants for soil moisture: hence the general incidence of xeromorphy.

Tertiary fluviatile and embayment sediments were subsequently eroded in the Pleistocene (Pulfrey, 1960; Rix, 1964) to form an undulating surface of elevated sandy plateaux or ridges, alternating with finer textured shallow valleys. Intervening gullies or basins have more recently been partially filled with clays. Deep drilling failed to locate a water table beneath the old erosion surface.

Note

The Soils are grouped in accordance with the "7th Approximation" of 1960 as modified in 1964. The authors are aware that some further alterations have been (1966; 1967) and still are (1968) being made to this classification system, but consider that there is little virtue in regrouping the Tana soils at this transitional stage. The points made in this paper retain their validity despite continuing minor changes in the nomenclature.

Analytical Methods

pH, gypsum and conductivity assessment of representative soil profiles followed methods of the U. S. Dept. of Agriculture (1954). $CaCO_3$ was determined according to Piper (1943). C. E. C. and individual cations were estimated by the methods of Mehlich et al (1962). Mechanical analysis was performed by hydrometer. Clay samples ($< 2\mu$), prepared according to Theisen and Harward (1962), were analysed by a direct recording X-ray Diffractometer.

Results

A. Higher Lying Alluvium

1. Typic Normipsamment

These form sandy ridges or Plateaux, elevated some 3 to 7 metres above the surrounding country. A considerable depth of pale brown, coarse loamy sand may overlie a very hard natric horizon of finer material. The upper 75 cms. are, however, nonsaline-nonalkali and it is on this basis that these soils are grouped with the

Entisols. It is likely that the normipsamments overlie natric horizons at depth since they are flanked by lower-lying natrargids (the subsoil of the normipsamment example in Table 1 is sub-natric). They are therefore a special form of normipsamment and shall be regarded as non-eroded remnants of a deeply solodized Pleistocene surface.

The permeable normipsamments provide optimum conditions for root development and also for rainfall infiltration, water percolating rapidly through the solum to be largely retained above the deep natric horizon. This situation appears to favour relatively tall, deep-rooting bush of many species. The thicket is dominated by Acacia senegal, Balanites orbicularis, Boscia coriacea, Combretum aculeatum, Commiphora spp., Grewia spp., Lannea alata, amongst others. It is notable that most of these bushes acquire a flush of new leaves after only light showers whilst bush on other soils remains leafless. Certain species are more typical of a higher rainfall regime and do not occur on other soils in the Lower Tana area, e. g. Cordia ovalis and Delonix elata. In clearings within the thicket, there is a contrasting association of shallow-rooting herbs more commonly found in semi-desert, e. g. Eragrostis arenaria, Indigofera spinosa and Schmidtia bulbosa.

-----TABLE 1-----

2. Typic Camborthid

These nonsaline-nonalkali red sandy clays (Table 1) occur on isolated flat plateaux where they may overlie, at varying depths, water-worn gravels intimately associated with caliche. The more or less decalcified horizons are dominated by illite with subsidiary kaolinite. Compared with other aridisols, these soils demonstrate higher quartz to felspar ratios, especially in the sand fraction: this may be indicative of a more advanced stage of weathering. Whereas the normipsamments represent remnants of a more recent erosion surface, it is considered that the camborthids derive from remains of the original (pre-embayment) Submiocene peneplane (c.f. Willis, 1933; Pulfrey, 1960).

There is analytical evidence for very local and incipient solodization on the Camborthid plateaux (see Table 3), though resultant clay mobilisation has little effect on profile morphology and does not merit the designation 'natric'.

The low and intermittent cover of bush is in contrast with the dense thickets on sandy ridges. This open bush includes _Acacia reficiens_, _Commiphora spp._, _Cordia sp. nov._, and _Grewia tenax_. The herbs _Aristida spp._, _Blepharis linariifolia_, _Chloris virgata_, _Eragrostis ciliianensis_ and _Sericocomopsis pallida_ are dominant. There are a few bush components in common with the normipsamment thicket that are not found as part of other associations, e.g. _Ehretia sp. nov._, _Grewia villosa_, _Sesamothamnus rivae_ and _Wrightia demartiniana_.

B. SEDIMENTS OF INTERMEDIATE TOPOGRAPHIC POSITION

1. Typic Natrargid

On plateau edges and sandy ridge bases (Fig. 1), typic natrargids occur with varying depths of loose sandy loam. Beneath this topsoil there is an extremely hard, nonsaline, natric or subnatric, impervious sandy clay loam 'cap' (hard pan), which in turn overlies a somewhat calcareous and invariably saline-alkali reddish sandy clay (Table 2). Weak columnar or prismatic structural development is normally evident immediately below the 'cap' but, deeper in the profile, increasing quantities of electrolyte render the soil more friable. The clay mineral composition of the natrargids resembles that of the camborthids.

Vegetation cover decreases as argillic horizon formation becomes more pronounced and as the loose sandy topsoil becomes shallower. Some bushes (e.g. Boscia coriacea and Commiphora rostrata) and some herbs typically associated with normipsamments (e.g. Dactyloctenium aegyptium) are established on higher-lying natrargids with sandy loam topsoils exceeding 25 cms. Where the surface horizon is less than 25 cms., thick, solitary specimens of the "salt bush", Salsola dendroides, dominate the landscape; associated with a sparse and stunted growth of species well adapted to growing through hard natric horizons with roots ramifying in saline-alkaline subsoil, e.g. Asparagus africanus, Blepharis sp. nov. and Sporobolus marginatus. The soil surface is typically covered by a dark crust held together by lichen.

With distance from the sand ridges, sediments tend to be finer textured and the non-natric upper layers become shallower.

----TABLE 2----

2. Mazic Natrargid

Scattered within tracts of typic natrargids are bare mazic natrargids associated with locally severe erosion and invaded only by a diminutive species of *Portulaca* which roots in the shallow covering of nonsaline-nonalkali loose sand. Erosion generally removes both the sand cover and the 'cap', to expose the alkali or saline-alkali sandy clay subsoil of the typic natrargid, depending on the depth of truncation (Table 2). Where remnants of the 'cap' are present, there is a local covering of *Salsola* and *Blepharis*. Mineralogy, analytical data and topographic position indicate a common origin for the mazic and typic natrargids.

Natrargids are subject to grazing pressure by the nomadic Orma who, when camping near water holes (all located on or close to sand ridges), choose the neighbouring natrargids as camp sites since these are clear of thicket.

---- FIGURE 1 ----

3. Saline and Alkaline Orthid (Halorthid)

These brown calcareous sandy clays of near-level sites are distinguished by blocky saline-alkali sub-surface horizons (Table 4). These soils have not developed an argillic horizon: hence their classification as Orthids, though their subsoil E. S. P. averages 24. An increase in the depth of the nonsaline-nonalkali surface horizon from dry North to moister South, associated with an overall decrease in the subsoil salt content is attributed to leaching. The clay fraction is composed of almost equal proportions of illite and montmorillonite with low levels of kaolinite.

Under irrigation, the sub-surface horizon is rapidly desalinized and, on drying, forms a true natric horizon.

Associated open bush-grassland is in marked contrast to the vegetation on the texturally similar but nonsaline-nonalkali camborthids. The grassland is dominated by *Chloris roxburghiana*, *Dactyloctenium scindicum*, *Neuracanthus scaber* and *Sporobolus helvolus*. The light bush includes *Acacia spp.*, *Blepharispermum fruticosum*, *Cadaba ruspolii* and *Cordia sp. nov.*

--- TABLE 3 ---

--- TABLE 4 ---

4. Salorthid

Salic horizons are uniquely encountered on the eroding slopes dividing the Tana flood basin from the old erosion surface, where lateral seepage gives rise to salt deposition (Table 3). The brown alkali clay is dominated by montmorillonite. The sparse vegetation resembles that on the typic natrargids. Where saline ground waters accumulate near the base of the slope there is often a line of *Salvadora persica*.

C. LOW-LYING VERTISOLS

Broad drainage channels are partially infilled with montmorillonitic material which has developed into brown grumusterts and greyish grumaquerts. In view of the prismatic subsurface natric horizon, these vertisols have been designated "natric" and are thereby distinguished as two new subgroups----Natric Grumustert (Table 4) and Natric Grumaquert. These have saline-alkali clay subsoils with slickensides. The depth of the nonsaline-nonalkali upper layer is slightly greater in the grumaquerts than in the grumusterts, indicating more intense leaching in the lowest-lying areas. Associated grassland is dominated by a single species, *Sporobolus helvolus*. The occasional bushes are of species associated with flood plains--- e.g. *Acacia mellifera*, *A. zanzibarica*, *Cordia gharaf*, *Dobera loranthifolia* and *Salvadora persica*.

Vertic natrargids occur in transitional situations between the higher-lying natrargids and the vertisols (Fig. 1); their essential properties are likewise intermediate.

--- TABLE 5 ---

Discussion

The course of soil genesis has been profoundly influenced by geological history. The predominance of quartz relative to felspar in sand and silt fractions of soils derived from this erosion surface indicates a degree of weathering prior to redeposition. Intense initial concentrations of salt derived from a marine environment prevailing during sedimentation may have been reinforced by lateral accumulation from drainage and by continuous weathering in situ.

During pluvials, however, the surface salt would have easily been leached (wherever soil permeability permitted), yet the likely presence of saline ground water (present in even relatively high rainfall areas of contemporary tropical Kenya) would have permitted a degree of resalinization whenever semi-arid conditions were resumed (Makin and Nyandat, 1964). The low E. S. P. of the contemporary nonsaline upper soil layers is attributed to profile development by leaching, and it would seem that, during earlier pluvials, there was extensive deep solodization within the saline-alkali sediments giving rise to the normipsamments and typic natrargids with deep sand cover: this process may have occurred during a gradual lowering of the water table. The lower-lying natrargids remain saline-alkali below the illuvial horizon.

Sheet erosion, enhanced by a sparse vegetation cover, would subsequently have caused differential truncation, whilst local gullying gave rise to broad drainage channels which were later aggraded. The resulting landscape comprised a succession of sinuous sand ridges, more or less parallel, separated by broad, relatively level valleys composed of finer textured infill threaded by gullies. In certain areas, extensive sand plateaux have remained intact.

Erosion following a main phase of solodization would have effected the truncation of an extensively occurring solod, leaving remnant ridges (normipsamments). Along the sides of these ridges, limited erosion of the sandy topsoil would have caused the natric horizon to appear not far below the surface (typic natrargid). Subsequent local erosion of the loose sandy layer revealed the natric horizon (mazic natrargid). Where erosion was most severe, the sandy top and natric subsurface were removed to expose intensely saline-alkali subsoils which have subsequently been only slightly leached. Indeed, these saline-alkali orthids (halorthids) are calcareous throughout, in contrast with the less truncated natrargids and normipsamments, which have no free calcium carbonate, at least in the upper horizons.

The distinction between orthids with a saline horizon close to the surface and the heavier vertisols which only show evidence of salt in the deeper subsoil is explicable on the basis of this theory since the saline orthids are a consequence of the exposure of intensely saline sediments, whilst the vertisols are derived from more recent alluvium now periodically leached by seasonal ponding.

The varying depths of the typic natrargid sand cover, the occurrence of hardpan remnants within the mazic natrargids and the presence (in Camborthids) of caliche at fluctuating depths help substantiate a view of soil and landscape development resulting from truncation caused by sheet erosion.

Such a conception would appear more plausible than an alternative theory of a once-and-for-all erosion cycle succeeded by continuing solodization largely unaffected by subsequent erosion. This latter concept would view the present depth of solodization as reflecting the permeability of the parent sediments and hence the intensity of the process. This deep solodization would have occurred within coarser textured ridges and plateaux as a consequence of relatively intense leaching. Along lower slopes, finer sediments exposed by erosion would be subject to less intense leaching due to their slower permeability, so that natric horizons developed near the soil surface. On the majority of level sites, where soil textures were yet heavier, rainfall infiltration less effective and permeability slower still, solodization would be virtually inhibited.

The evidence suggests, however, that the apparently contrasting degrees of solodization are merely a product of the differential erosion of a pre-existing solodized plateau.

The non-saline camborthids are anomalous. Though clay composition resembles that of the natrargids there is no evidence for solodization, yet leaching certainly plays a role in camborthid genesis. Their more advanced stage of weathering considered together with the geological evidence would suggest that, whereas normipsamments and other aridisols represent remnants of the altered post-embayment erosion surface, the camborthids may have an earlier origin as part of the Tertiary peneplane that somehow remained uncontaminated by marine sedimentation and subsequent ground water salinization. Since the sandy ridges only developed following marine inundation, their position in the landscape relative to the camborthids may not necessarily be relevant when considering the level of the marine advance. Since, however, the camborthids are not in fact the highest-lying feature in the entire landscape, it is difficult to understand how they have escaped later salinization and subsequent solodization. Furthermore, the underlying caliche probably developed as a precipitation product derived from an alkaline ground water. Camborthid genesis thus remains a subject for conjecture.

Significant quantities of montmorillonite are found only on sites receiving drainage (Saline- alkali orthids, Salorthids, Vertisols). This mineral is more clearly defined in the salorthids (subject to the reception of lateral drainage) than in the vertisols where standing water accumulates. It should, however, be stressed that in no single horizon of any of these soils was really characteristic montmorillonite found (Figure 2).

The labile nature of the C-axis spacing was the most unusual feature of this material. Upon Mg saturation a C-axis spacing was observed which is too large by several Å units for montmorillonite. Moreover, upon solvation and upon K saturation, the expansion and the collapse exceeded that of true montmorillonite.

---- Figure 2 ----

Exchangeable magnesium occupies a significant part of the adsorption complex of most of the soil units. It was found that rather poor physical conditions (e.g. slow permeability, high level of dispersion, etc.) were associated with exchangeable magnesium percentage (E.M. P.) values between 12 and 30; and very poor physical conditions with an E.M. P. in excess of 35. (N.B. In the cases considered, the associated E.S.P. was below 15.)

The U. S. Salinity Laboratory uses E. C. greater than 4 m.mhos/cm. as its salinity criterion, whilst for orthids the 7th. Approximation employs a lower limit. Though salic concentrations of salt are rarely found, salinity is widespread and electrolyte is present in sufficient concentration within the saline-alkali orthids to transform profoundly the soil morphology besides influencing floral composition and adversely affecting potential crop growth (e.g. where the alkaline subsurface horizon contains significant amounts of salt, blocky structure develops rather than the prisms characteristic of the classic solonetz). The saline-alkali orthids are distinct, in morphology, mineralogy, origin and topographic position, from the salorthids, the camborthids and the natric vertisols. It is therefore proposed to introduce a new diagnostic sub-surface horizon, the "halic" horizon, to indicate significant levels of electrolyte within the solum. A sub-surface horizon is designated "Halic" if its saturation extract exceeds a conductivity of 4 m. mhos./cm.; provided some part of that horizon lies within one metre of the soil surface; and that it does not satisfy the criteria for a salic horizon. Sub-surface horizons of the Halorthids do not meet the requirements of the natric concept since they lack prismatic or columnar structure. This appears to be a normal feature of alkaline horizons which are also saline; these saline-alkali orthids are therefore classed as a new sub-group of Typic Halorthids.

The sequences of contrasting materials associated with specific positions in the terrain maintain corresponding vegetation catenas (Greenway, 1943). These characteristic vegetation associations,and the herbaceous components in particular, sensitively reflect the distribution of the soil units.

The presence in the typic natrargids of an extremely hard 'cap' within the potential rooting zone limits the composition of the vegetation cover: the number of species present and their growth habit are a function of the consistence of the argillic horizon and the depth of the nonsaline-nonalkali sandy topsoil. The contrasting absence of even the more specialised halophytes on the mazic natrargids may be explained by the presence, close to the soil surface, of relatively high levels of salt and alkali which must prevent establishment at the critical seedling stage.

--- TABLE 6 ---

There is a marked contrast between the relatively tall dense thicket on normipsamments and the dry open vertisol grasslands. Furthermore, there are few species represented on the vertisols. It was originally considered that this was due to differences in available soil moisture. The data in Table 6 indicate, however, that the heavier textured soils have the higher levels of available moisture. For most soils, much of this available moisture is held at tensions in excess of pF 3.

The species composition of the normipsamment thicket considered together with its relative longevity of foliation would nevertheless suggest a better moisture status on the sandy ridges compared with the clay plain. This may be due to a combination of several factors:

1. High rates of infiltration which reduce losses through surface evaporation.

2. Rapid permeability for moisture which is then retained at depth.

3. Facile rooting conditions and absence of structural impediments.

4. Lack of significant levels of electrolyte in the rooting zone.

5. Whilst wide cracks (in vertisols) may permit locally deep penetration of rain water, the large surface area exposed by cracks

allows intensive drying; cracking also causes localized root severance.

The prevalence of grassland in the lowest-lying situations may be promoted by the severe conditions caused by alternate periods of desiccation and water-logging; it is maintained in part by a high incidence of hot grass fires that deter the invasion of fire-sensitive bush species (e.g. Commiphora). Because the halorthids do not suffer this water-logging and moreover are not subject to cracking, they are able to support an open cover of halophytic bushes.

There is a further contrast between the relatively vigorous bush on sandy ridges and the dry stunted nature of plant growth on the equally well drained, nonsaline-nonalkali camborthids. Since the latter have an inherently higher level of available moisture, it is clear that more subtle factors must be operating. A major difference between the normipsamments and the sandy clay camborthids lies in the texture. It is suggested that the infiltration of water into a soil and the permeability of that soil in relation to root ramification may be more important edaphic factors than have hitherto been recognized.

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TABLE I. NORMIPSAMMENT

PHYSIOGNOMY		TYPIC ~~PSAMMUSTENT~~			TYPIC CAMBORTH		
		HIGHER - LYING SANDY RIDGES			PLATEAUX		
Horizon Depth; cms.		0 - 76	76 - 114	> 114	0 - 10	10 - 33	3
Colour; Moist		7.5 YR 6/4 Light Brown	10 YR 7/3 Very Pale Brown	7.5 YR 6/4 Light Brown	2.5 YR 3/6 Dark Red	2.5 YR 3/4 Dark Reddish	2.5
Structure		Single Grain	Single Grain	Sub-Angular Blocky	Fine Crumb	Medium Crumb	Weak
Consistence		Slightly Hard	Slightly Hard	Extremely Hard	Soft	Soft	Sligh
Secondary Inclusions		-	-	-	-	-	Calic Grave > 1
	% $CaCO_3$	Nil	Nil	Nil	0.4	0.4	
Texture	% Sand	94	93	83	55	44	
	% Silt	4	6	6	7	6	
	% Clay	3	1	11	38	50	
	% Carbon	0.13	-	-	0.29	0.25	
% Moisture	In Air Dry Soil	4.7	4.4	6.8	3.5	5.2	
	At Saturation	15.1	17.4	36.3	25.0	28.0	4
pH (1:5)	In Water	7.4	7.0	7.7	7.6	8.3	
	In KCl	6.1	5.7	5.4	6.3	6.7	
	$EC_{1:5}$	0.03	0.03	0.16	0.06	0.04	
	EC_e	0.4	0.2	1.9	0.5	0.4	
	C.E.C.	2.6	2.0	7.4	13.6	19.2	2
Exchangeable Bases : m.e. %	Ca	1.4	0.8	2.2	5.8	8.4	1
	Mg	0.1	0.4	1.6	3.8	5.4	
	K	0.2	0.1	0.7	3.2	3.5	
	Na	0.1	0.2	0.8	0.1	0.3	
	E.S.P.	3.8	10.0	10.8	0.7	1.6	

TABLE 2

	TYPIC NATRARGID				MAZIC NATRARG			
Physiognomy	Intermediate Slight Slopes				Eroded Typic Natrargids			
Horizon Depth : Cms.	0-15	15-41	41 -76	> 76	0-5	5-30	30-61	61-
Colour ; Moist	10 YR 6/4 Light Yellowish Brown	7.5 YR 5/4 Brown	5 YR 5/4 Reddish Brown	7.5 YR5/6 Strong Brown	5 YR 3/4 Dark Reddish Brown	2.5 YR 3/6 Dark Red	2.5 YR 3/4 Dark Reddish Brown	5
Structure	Single Grain	Massive	Sub-Angular Blocky	Sub-Angular Blocky	Sub-Angular Blocky	Weak Prismatic	Sub-Angular Blocky	Sub Bl
Consistence	Slightly Hard	Extremely Hard	Hard	Slightly Hard	Slightly Hard	Hard	Hard	Sli H
Secondary Inclusions	Coarse Sandy 2 m.m. Surface Crust	-	Abundant salt Crystals	$CaCO_3$ Concretions and Abundant Salt crystals	-	Very hard Porous Grey 'Cap'	Lime Spots and Abundant Salt Crystals	1. Con 2. Con 3.
%$CaCO_3$	Nil	Nil	0.4	12.2	0.2	0.2	0.4	
Texture % Sand	76	70	52	46	82	52	38	
Texture % Silt	8	6	8	14	6	6	6	
Texture % Clay	16	24	40	40	12	42	56	
%Carbon	0.17	0.20	-	-	0.13	0.27	-	
% Moisture In Air Dry Soil	0.7	3.3	6.5	6.9	0.4	5.5	7.9	
% Moisture At Saturation	12.6	23.2	37.0	55.5	12.8	37.7	51.3	
pH (1:5) In water	7.9	8.1	8.3	7.7	8.1	8.8	8.8	
pH (1:5) In KCl	5.3	5.5	5.3	5.8	5.9	7.6	7.6	
EC_5	0.04	0.16	2.2	5.0	0.14	1.8	2.9	
EC_e	0.3	1.5	21.0	19.0	2.4	17.2	27.6	
C.E.C.	4.7	12.2	23.3	27.6	5.0	16.5	22.5	
Exchangeable Bases: m.e.% Ca	1.7	4.4	10.0	13.0	3.0	4.1	5.6	
Exchangeable Bases: m.e.% Mg	0.1	3.4	5.8	7.7	0.3	2.7	3.4	
Exchangeable Bases: m.e.% K	0.8	0.8	0.5	0.4	0.4	1.7	1.8	
Exchangeable Bases: m.e.% Na	0.1	1.4	3.6	6.4	0.5	7.7	10.7	
E.S.P.	2.1	11.4	19.9	27.5	10.0	46.7	47.5	

TABLE 3

		TYPIC CAMBORTHID : AFFECTED BY SALT + ALKALI			TYPIC SALORTHID			
Physiognomy		Plateaux Receiving Drainage.			Steep Inclines Receiving Se			
Horizon Depth: Cms.		0 - 10	10 - 30	30 - 107	0 - 8	8 - 48	48 - 102	
Colour; Moist		2.5 YR 3/8 Dark Red	2.5 YR 5/4 Reddish Brown	2.5 YR 5/6 Red	7.5 YR 4/4 Dark Brown	7.5 YR 4/2 Brown	7.5 YR 4/2 Brown	10 Greyi
Structure		Fine Crumb	Sub-Angular Blocky	Weak Prismatic	Medium Crumb	Sub-Angular Blocky	Weak Blocky	Weak
Consistence		Soft	Soft	Slightly Hard	Soft	Friable	Friable	
Secondary Inclusions		-	-	Caliche and Gravels > 127 cms.	Lime Spots	Lime Spots and salt Crystals	Abundant Salt Crystals	Coar Spot Salt
	% $CaCO_3$	0.4	0.3	0.4	1.0	2.8	2.1	
Texture	% Sand	69	59	36	40	25	16	
	% Silt	4	6	16	10	11	12	
	% Clay	27	35	48	50	64	72	
	% Carbon	0.51	-	-	0.45	-	-	
% Moisture	In Air Dry Soil	2.5	3.7	7.4	7.3	11.2	13.8	1
	At Saturation	20.5	23.3	48.1	33.0	72	77	
pH (1:5)	In Water	7.5	6.9	7.8	9.2	8.5	8.3	
	In KCl	5.4	5.4	6.6	7.3	7.5	7.5	
	EC_5 ~~x 10³~~	0.06	0.06	1.4	1.2	9.3	11.6	
	EC_e	0.6	0.4	11.5	9.0	44.0	45.0	2
	C.E.C.	11.6	16.0	28.3	26.5	41.0	48.1	5
Exchangeable Bases: m.e. %	Ca	4.2	4.5	10.1	13.3	12.6	15.3	1
	Mg	3.0	3.9	9.1	0.7	8.0	10.9	1
	K	1.4	2.0	4.7	2.8	0.9	0.7	
	Na	0.2	0.2	3.5	8.9	18.6	20.0	2
	E.S.P.	1.7	1.3	12.4	33.6	45.4	41.6	4

TABLE 4

	"HALORTHID"				NATRIC GRUMUSTERT		
Physiognomy	INTERMEDIATE LEVEL AREAS				BASIN DEPRESSIONS		
Horizon Depth : Cms.	0 - 28	28 - 56	56 - 117	> 117	0 - 13	13 - 56	> 56
Colour ; Dry	5 YR 4/6 Yellowish Red	2.5 YR 3/6 Dark Red	5 YR 4/6 Yellowish Red	5 YR 4/6 Yellowish Red	7.5 YR 4/4 Dark Brown	7.5 YR 4/4 Dark Brown	7.5 YR 5/4 Brown
Structure	Crumb	Blocky	Blocky	Sub-Angular Blocky	Medium Crumb	Prismatic	Medium Blocky
Consistence	Soft	Hard	Hard	Hard	Soft	Very Hard	Hard
Secondary Inclusions	Few $CaCO_3$ Concretions	Few $CaCO_3$ Concretions and Lime Spots	Abundant Lime Spots	1. $CaCO_3$ Concretions 2. Lime Spots 3. Salt Crystals	$CaCO_3$ Concretions	Abundant $CaCO_3$ Concretions	Abundant $CaCO_3$ Concretions and Salt Crystals
% $CaCO_3$	4.9	8.0	13.7	9.6	1.0	2.7	2.0
Texture % Sand	46	29	27	19	35	27	17
Texture % Silt	7	12	13	16	8	10	12
Texture % Clay	47	59	60	65	57	63	71
% Carbon	0.45	-	-	-	0.63	0.47	-
% Moisture In Air Dry Soil	7.5	8.0	9.4	12.1	8.5	9.8	12.2
% Moisture At Saturation	56.0	45.3	50.8	36.0	46.7	95.5	103.0
pH (1:5) In Water	8.5	9.0	8.5	8.5	8.5	9.0	9.0
pH (1:5) In KCl.	6.0	6.1	6.4	6.2	6.2	6.2	6.3
EC_5	0.15	0.70	3.0	4.2	0.15	0.46	4.0
EC_e	1.1	5.1	22.0	25.2	0.8	1.1	12.6
C.E.C.	34.3	38.4	43.5	48.0	30.6	38.1	48.0
Exchangeable Bases : m.e. % Ca	24.0	18.2	15.5	16.4	14.3	12.7	13.2
Mg	6.8	12.3	15.7	16.7	10.2	13.1	13.2
K	1.8	0.9	1.1	1.3	3.1	1.3	1.6
Na	1.1	5.3	10.6	13.0	0.8	9.2	19.4
E.S.P.	3.2	13.8	24.4	27.1	2.6	24.1	40.4

AVERAGE PHYSICO-CHEMICAL CHARACTERISTICS

SUBGROUP	% CLAY	CEC	EC_5	EC_e	ESP	pH-H_2O	% $CaCO_3$	NUMBER OF PROFILES
TYPIC NORMIPSAMMENT PROFILE	14	7	0.1	0.3	2	8.5	0.3	7
TYPIC NATRARGID								
TOPSOIL	14	6	0.1	1.3	5	7.8	0.2	110
ALKALI HORIZON	29	16	0.3	2.6	16	8.1	0.7	
SUBSOIL	39	22	2.8	18.0	26	8.7	1.4	
MAZIC NATRARGID								
TOPSOIL	26	14	0.3	1.8	6	8.2	0.4	87
ALKALI HORIZON	28	16	0.5	3.5	22	8.9	1.1	
SUBSOIL	42	27	4.0	25.0	31	8.4	2.3	
TYPIC CAMBORTHID PROFILE	41	22	0.1	1.1	4	8.1	0.7	16
TYPIC HALORTHID								
TOPSOIL	41	24	0.2	1.3	5	8.4	1.5	116
SUBSOIL	50	31	2.5	15.0	24	8.7	4.0	
NATRIC GRUMUSTERT								
TOPSOIL	52	34	0.2	1.1	5	8.6	1.6	85
ALKALI HORIZON	58	39	0.5	1.4	23	9.3	2.7	
SUBSOIL	63	43	4.1	16.0	33	8.6	2.7	

TABLE 6

SOIL MOISTURE TENSION

SOIL UNIT	LAYER	0.1 atm pF 2	0.3 atm pF 2.5	1 atm pF 3	10 atm pF 4	15.2 atm pF 4.2	AVAILABLE MOISTURE PERCENTAGE	CLAY PERCENTA
TYPIC NATRARGID	TOPSOIL	8.7	7.4	6.0	3.7	3.1	5.6	16
	SUBSOIL	22.2	20.7	17.7	14.2	13.3	8.9	46
MAZIC NATRARGID	TOPSOIL	12.2	10.7	9.4	8.4	7.7	4.5	41
	SUBSOIL	27.9	25.6	24.1	18.0	16.8	11.1	49
CAMBORTHID	TOPSOIL	27.3	24.3	21.3	13.6	12.9	14.4	51
	SUBSOIL	30.4	28.2	25.9	19.4	18.3	12.1	53
HALORTHID	TOPSOIL	29.4	26.7	24.3	16.5	14.7	14.7	47
	SUBSOIL	38.1	35.9	33.4	23.6	21.4	16.7	56
VERTISOLS	TOPSOIL	41.6	36.3	31.0	20.3	19.2	22.4	59
	SUBSOIL	40.7	38.8	35.7	27.8	25.8	14.9	63