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Properties and Classification of Soils of Kajimaram Oasis of Northeast Nigeria

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ABSTRACT

Soils of Kajimaram oasis, northeast Nigeria 10° 30' and 12° 00'E, and 13° 00' and 13° 30'N were studied to understand their genesis, properties, classification and management. The soil morphological, physical and chemical properties were examined. These soils occupy the lower slope portion of the landscape where radial flow of ground-water converges and discharges. The soils have high organic carbon content throughout the profiles and mollic epipedons. The soil texture consists of largely peat, clayey-loam, clay and occassionally, silty-clay over fine sandy-loam. The most striking feature of the particle size distribution is the high silt content. Generally, the exchangeable bases of the soils are relatively high and the pH of aged samples is extremely low. According to the US soil taxonomy, the soils in Kajimaram oasis are classified as Fine loamy, Isothermic, Terric Sulfisaprists; Fine loamy, Isothermic, Sulfic Hydraquents; Clayey, Isothermic, Haplic Sulfaquents; and Clayey, Isothermic, Typic Calciaquolls.

Key Words: Oasis; Kajimaram; Terric sulficsaprists; Sulfic hydraquents; Haplic sulfisaprists

INTRODUCTION

Agriculture is the main economic activity in the Manga Grasslands of semi-arid northeast Nigeria (Fig. 1). However, in the last 3 - 4 decades, declining rainfall in the region (Hess *et al*., 1995) has altered the agricultural practices in the Grasslands. The deterioration in the rainfall over the region as a whole and the Grasslands in particular has focused crop production on few limited areas with 'adequate' water supply and fertile soils (Alhassan *et al*., 2003). These are the lands and soils of the *Fadamas* to the south of the Manga Grasslands, and those of the oases (ground-water discharge zones of the Grasslands). The oases soils constitutes about 10% of the land area and the vast majority of the adjoining up-land consists of very fine sandy soils with high production variability that makes agricultural practices risky and un-certain (Alhassan, 1996). However, exploitation of this hydromorphic soils in the oases offer the Manga grasslands dwellers ray of hope for profitable and sustainable agriculture. When properly managed, these soils are capable of offsetting inter annual variation in crop production of the up-land soils.

Hydrology of the oases is fundamental to the understanding of the oases soils as well as the agricultural activities in the area. Local farmers in the area stated that before the on set of the present dry climate, ground-water levels in the Grasslands were much higher than today. However, no documentation exists about the extent of deterioration in the climatic regime of the region that has lowered the water table, but flooded conditions were experienced in the recent past and the land was then of less agricultural importance.

Aerial photographs of the Grasslands (Bawden *et al*., 1972) taken in November 1969 showed that the oases were flooded with water and colonised by reed swamp vegetation, while the presently cultivated lands fringing the oases were not cultivated before. Anecdotal evidence from local farmers in the area suggests that until the early 1970s, all oases in the Grasslands contained year-round standing water, while crop production was restricted only to the higher ground surrounding the oases, which are now densely populated with sand dunes. Studies in the area (Carter, 1994; Carter *et al*., 1994; Alhassan, 1996; Alhassan *et al*., 2003) have confirmed that there is still a shallow water table, which fluctuates within 0 to 0.5 m of the soil surface. Despite of the general aridity of the Grasslands, intensive year-round small-holder farming is being carried out on the land fringing the oases (Carter, 1995; Alhassan, 1996; Carter & Alhassan, 1998). In spite of the importance of the oasis soils to the agricultural economy of the Grasslands, little or no published information exists in the literature on the nature and properties of these soils. This lack of information could lead to un-certainties regarding the kind of management and cropping decisions most appropriate for the farmers using the land. A better understanding of the properties of these soils will provide a basis for more efficient and sustainable agricultural practices around the oases of the Manga Grasslands. The present study aims at classifying the soils and drawing conclusions on their management.

MATERIALS AND METHODS

The study area. The study area is part of the extensive sand plains of the Manga Grasslands in semi-arid northeast Nigeria (Fig. 1). Kajimaram oasis is one of the many large number of oases scattered within the Manga Grasslands. It has a semi-arid climate characterized by a single rainy season that starts on average in late June/ early July and lasts till end of August/ early September, and rarely extending up to October. Annual rainfall in the Grasslands is about 300 mm (Carter, 1994; Alhassan, 1996).

Natural vegetation in the Grasslands comprises sparse trees and the ground can be bare particularly during the long dry season. The most dominant tree species are *Balanites*, *Adansonia digitata* and *Acacia*; and annual grasses mainly *Cenchrus biflorus* in the dune field. The oases are bordered by dense cover of palms including doum (*Hyphaene thebaica*) and dates (*Phoenix dactylefera*). The palms give way rapidly to reed swamp vegetation towards the bare saline interior of the oasis bed. The land surface elevation varies from about 330 - 350 m above mean sea level (mas l) in the dune field with oases lying 15 – 20 m lower than the up-lands (Mortimore, 1989; Carter, 1994). The valley floor consists mainly of organic rich lacustrine and aeolian sediments, and diatomite remains probably accumulated during the fresh-water swamp conditions presumably the late Pleistocene. These sediments are thought to be un-derlained by the predominantly argillaceous Chad formation (Carter, 1994).

Field study. Four sites were selected based on previous studies in the area (Alhassan, 1996). At each site a soil profile pit was sunk and described using standard procedures as outlined in Soil Survey Field Handbook (Hodgson, 1976). Bulk soil samples as well as un-disturbed core samples were collected from each of the major horizons. The bulk soil samples were air dried for physico-chemical analyses, while un-disturbed core samples 70 mm x 53 mm were used for bulk density determination (Blake & Hartage, 1986). Soil descriptions were for the moist state only.

Laboratory study. The air-dried soil samples were ground and passed through a 2 mm sieve to remove materials larger than 2 mm. The particle size fractions were determined by the pipette method (Bascomb, 1974). Bulk density was determined by oven drying the un-disturded core samples to constant weight at $80^{o}C$ (Munro, 1982). Soil pH of aged sample was measured in a 1:2.5 soil-water suspension after an hour of intermittent shaking and overnight stand (Bascomb, 1974). Electrical conductivity (EC) was determined from saturation paste extract. Organic carbon content was determined by wet-oxidation method of Walkley and Black as described by Nelson and Sommers (1982).

Exchangeable bases (Ca, Mg, Na & K) were extracted with 1 N neutral ammonium acetate solution. The concentrations of Ca and Mg in the extracts were measured by atomic absorption spectrophotometer, while those of Na and K by flame photometry. Cation exchange capacity (CEC) was determined by extracting the soil with buffered molar solution of barium chloride ($BaCl_2$, pH, 8.2). Base saturation was estimated from the sum of exchangeable bases divided by the CEC. Gasometric method (Page *et al*., 1982) using pressure calcimeter was adopted for the determination of $CaCO_3$ equivalent, while gas chromatography was used for SO_4. All analyses unless stated otherwise were carried out in the soil laboratory of the Soil Survey and Land Research Centre and Silsoe College.

RESULTS AND DISCUSSIONS

Morphological and physical characteristics. The morphological characteristics of the four pedons identified are presented in (Table I). The dominant soil color is dark grey and black probably due to water logging, high organic carbon content and reduced sulphide (Table II). Black color in soils has been attributed to coloration due to organic matter (Harden, 1982). No mottles were observed except in a few of the soil horizons (pedon III). This observation suggests that under aquic moisture regime as experienced in the oasis, process akin to the formation of a mollic epipedon (Soil Survey Staff, 1994) could be taking place in pedons II, III, IV, and the dark color that characterized them is thought to be related to the process (Al-Barrak, 1986). These soils developed in fine textured materials mainly consists of aeolian and lacustrine sediments deposited during the pluvial period of the past overlying the Plio-Pleistocene Chad Formation clays in common with most areas in northeast Nigeria. Radio carbon dating of the sediments collected from the oasis (Holmes *et al*., 1997; Salzmann & Walker, 1998; Holmes *et al*., 1999) suggested that the lower horizons of the sediment were deposited probably some 5500 years ago. These soils

Fig. 1. Location of the study area, showing the approximate boundary of the Manga Grasslands

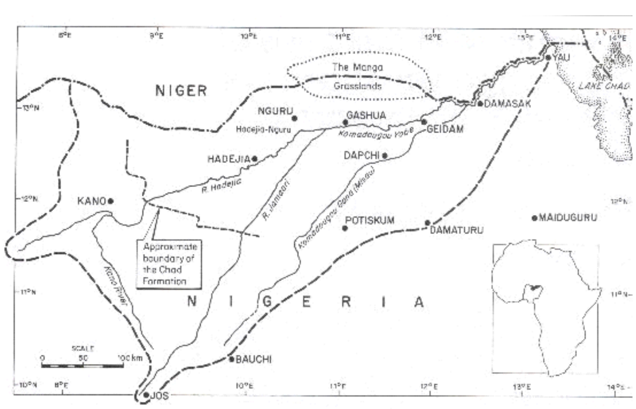

Table I. Some selected morphological properties of soils in Kajimaram oasis

Horizon Designation[1]	Depth (cm)	Munsell colour moist Matrix	Mottles	Structure
		Pedon I Terric sulfisaprists		
Op	0-16	2.5Y 3/1		1msbk
Oa1	16-31	10YR 3/1		1csbk
Oa2	31-51	10YR 3/1		1csbk
Oa3	51-66	10YR 3/1		1csbk
Bh1	66-99	N2.5/0		massive
Bh2	99-106	5Y 5/1		massive
Cg	106-145	2.5Y 4/1		1fpl
		Pedon II Sulfic Hydraquents		
Ap	0-10	2.5Y 3/1		2csbk
Bg1	10-30	2.5Y 3/1		2csbk
Bg2	30-55	5Y 5/1	10YR 3/6	1sbk
Cg	55-99	2.5Y 3/3		massive
2Cg	99-128	2.5Y 3/1		massive
3Cg	128-156	5Y 4/1		massive
		Pedon III Haplic Sulfaquents		
Ap	0-16	2.5Y 3/1	7.5YR 4/4	2mgr
Bg1	16-26	2.5Y 3/1	2.5Y 3/3	2msbk
Bg2	26-55	2.5Y 3/1	2.5YR 2.5/3	2fpr
Bg3	55-80	5Y 5/1	5G 4/1	1csbk
BCg	80-101	5Y 4/2		massive
Cg	101-134	5Y 3/1		1csbk
		Pedon IV Typic Calciaquolls		
Akp	0-16	2.5Y 3/1		3fmsbk
Bkg	16-41	5Y 2.5/1		2msbk
Bg	41-86	5G 4/1, 5GY 4/1		1fpr, 1msbk
Cg	86-116	5G 4/1, 5GY 4/1		1fpr, 1msbk
2Cg	116-145	N3/0, 3BG/1		1fpr

Grades: 1= weak, 2= moderate, 3= strong; Size: c= coarse, f= fine, m= medium; and Shape: gr= granular, pl= platy, pr= prismatic and sbk= sub angular blocky

[1]horizon designation according to Soil Survey Field Handbook (Hodgson, 1976)

occupy the ground-water discharge zone of the Grasslands and constitute the most intensely cultivated soils in the Grasslands.

The dominant structural units in all the four pedons are weak to moderate sub angular blocky or massive. The weak to moderate structure in these soils could be attributed to the high silt content (Table II). Fanning and Fanning (1989) observed that high silt content in soils do not allow the soils to experience excessive shrink-swell actions during drying and wetting cycles. This observation might be responsible for the lack of well-developed permanent cracks in the soils studied even where the soils are predominantly clayey in texture (pedon IV). The particle size distribution shows dominance of clay loam textures in pedons I, II and III; and clay textures in pedon IV (Table II). The high silt and clay fractions, high organic carbon content in these soils could foster high water holding capacity. This observation together with shallow but fluctuating water table (Carter *et al*., 1994; Alhassan, 1996) makes the oases soils suitable for intensive year round cropping (Carter, 1995; Alhassan, 1996; Alhassan *et al*., 2003). The sources of these fine sediments however, might be attributed to deposition either by aeolian or fluvial processes or both. Drees *et al.* (1993) observed that about 40% of the particle size composition of aeolian dust in the study area is silt, suggesting substantial addition of silt-sized particles to the soils of the region. Also, the greenish colour of the sediments, their regularity and continuity and the gradual increase in thickness towards the interior of the oasis suggests sedimentation in a body of water. The up-ward fining of the sediments is also an indication of deposition under a low energy environment.

The soil bulk density was generally low because of the high organic carbon contents (Table III).

Chemical properties. Some selected chemical properties of the four pedons studied are presented in Table III. The most striking characteristics of the four pedons are their high organic carbon contents and water-soluble sulphate contents, extremely acid-slightly alkaline reactions of aged soil samples. The organic carbon content ranges from 3.6% in the surface horizon of pedon IV to 17.9% in pedon I; and < 1% in the Bg horizon in pedon IV (Table III). The high plant productivity in the oasis, annual die back of grasses and other plant species and slow break down of plant remains under the seasonally water logged conditions of the oasis probably accounts for the build up of organic carbon in this environment.

Soil reaction varied from neutral to slightly alkaline in the surface of pedons I and IV to acidic in pedons II and III (Table III). However, the sub soil pH became increasingly acidic with depth especially pedon I where extremely low pH (1.6) was observed within the seasonally saturated zone of the soil (0.5 - 1.0 m soil depth). The low sub soil pH coupled with high water soluble sulphate contents may be attributed to oxidation of reduced sulphur minerals often present in the form of pyrite (Lin & Melville, 1994), which under saturated conditions remain reduced and un-acidified (Ahmad & Wilson, 1992). The presence of the pyrite was recognized in the field by smell of hydrogen sulphide emanating from sub sample treated with hydrochloric acid, and greenish grey colours with black specks. However, exceptions to this generally low trend sub soil pH occurred in pedon IV, which contain calcitic materials in sufficient quantities to neutralise the acidity that could result from oxidation of the pyrite or other reduced sulphate compounds. The saline-acid sulphate nature of these soils has serious management implications for sustainable agricultural practices in the oasis in particular and the Manga Grasslands as a whole. Their management for sustainable agriculture would require sound water management together with the use of acid or salt tolerant crop varieties.

The water management practices should include limited drainage to allow limited oxidation of reduced sulphate, while toxic elements produced can be leached by either rain-water or irrigation. As promising as this is, the lack of sufficient water from either rainfall or irrigation sources coupled with shallow water table in the oasis, this management option are not feasible in the oasis.

Another management practice that could be adopted in the oasis is that of minimum tillage as a means of land preparation. The farmers in the oasis are currently practicing this. The practice does not however, in any way disturb the pyrite in the sub soil and the peat layer serves as mulch. The surface peat layers play key role in the cultivation of these saline-sulphidic soils. The peat layers serve not only as source of nutrients, but also regulate the loss of water due to evaporation during the long dry season and they maintain reduced conditions in the underneath, preventing the oxidation of the pyrite. However, the recent climatic trend in the region (declining rainfall) shows that soil acidification is expected to have a potentially damaging impact on the environment. Under a dry climatic regime, reduction in rainfall amounts as well as in recharge value will reduce the available ground-water resources in the region (Carter & Alhassan, 1998). Continuous reduction in the amount of rainfall in the region could worsen the water resource situation. The reduction in ground-water resources could lead to lowering of the water table level in the oases. The consequences of this reduction in the water table level in the oases are drying up of the upper parts of the soil profile, which under normal circumstances would be of less importance. The organic and potential acid sulphate nature of this soil suggests that drying up of the soil could lead to the subsidence of the organic surface, oxidation and real soil loss. Loss of the organic layer on the surface would expose the underlying pyrite layer, whose oxidation will give rise to acid sulphate soil condition. Once the soil is acidified, the fertility of the threatening the oasis.

The catio medium with Cmol kg[-1] exce (Table III). The could be explai of the soils and of harmattan d yearly addition characteristics (Moberg & Es dominate the e makes them sui of these cations from 1.3 - 9.5 C Ca especially in explained by t during minerali matter (van Wa dusts containin (Moberg *et al.*,

Table II. Some selected physical properties of soils in Kajimaram oasis

Horizon Designation	Depth (cm)	Particle size distribution (%) Sand	Silt	Clay	Texture[1]	Bulk Density (kg/m^3)
		Pedon I Terric Sulfisaprists				
Op	0-16	20.0	51.8	28.2	peat	0.4
Oa1	16-31	26.3	55.0	18.7	peat	0.3
Oa2	31-51	29.0	41.5	29.5	peat	0.3
Oa3	51-66	33.4	44.1	22.5	peat	0.3
Bh1	66-99	22.7	53.1	24.2	cl	0.6
Bh2	99-106	28.9	36.0	35.1	cl	0.6
Cg	106-145	85.2	10.2	4.6	fls	0.7
		Pedon II Sulfic Hydraquents				
Ap	0-10	26.2	57.1	16.7	zc	0.5
Bg1	10-30	26.3	50.0	23.7	cl	0.6
Bg2	30-55	42.0	26.6	31.4	cl	0.7
Cg	55-99	77.9	12.2	9.9	fls	0.8
2Cg	99-128	60.7	15.4	23.9	fscl	0.8
3Cg	128-156	87.5	6.0	6.5	fls	0.8
		Pedon III Haplic Sulfaquents				
Ap	0-16	25.4	55.0	19.6	cl	0.5
Bg1	16-26	21.0	42.9	36.1	cl	0.5
Bg2	26-55	20.0	40.8	39.2	cl	0.7
Bg3	55-80	34.0	28.6	37.4	cl	0.8
BCg	80-101	70.9	10.9	18.2	Fscl	0.8
Cg	101-134	80.8	7.2	12.0	Fls	0.8
		Pedon IV Typic Calciaquolls				
Akp	0-16	11.4	44.4	44.2	c	1.0
Bkg	16-41	12.6	43.1	44.3	c	0.8
Bg1	41-86	19.7	36.7	43.6	c	0.7
Cg	86-116	21.4	33.2	45.4	c	0.7
2Cg	116-145	67.6	11.6	20.8	fscl	0.6

Texture: c= clay; cl = clay loam; zc = silty clay; fls = fine loamy sand; fscl = fine sandy clay loam

[1] horizon designation according to Soil Survey Field Handbook (Hodgson, 1976)

Table III. Some selected chemical properties of soils in Kajimaram oasis

Horizon Designation	Depth (cm)	PH	EC$_e$ dSm^{-1}	OC (%)	CEC Cmol/kg	Exchangeable cations cmol kg^{-1} Ca^{2+}	Mg^{2+}	Na$^+$	K$^+$	SO$_4^{2-}$ Mg/l	CaCO$_3$ (%)	BS (%)
					Pedon I Terric sulfisaprists							
Op	0-16	6.9	34	17.9	46.1	29.6	5.5	1.5	2.6	1300	nil	87.0
Oa1	16-31	4.3	3.4	17.0	45.8	20.2	4.8	1.4	1.3	1169	nil	100+
Oa2	31-51	3.4	3.5	13.8	43.6	19.4	3.3	1.5	0.7	2300	nil	47.8
Oa2	51-66	1.6	31.0	14.6	16.5	18.1	7.4	0.6	0.5	94000	nil	100+
Bh	66-99	2.1	14.6	7.5	41.5	19.4	6.3	1.3	0.9	16800	nil	67.0
Bh2	99-106	2.6	5.8	2.5	12.2	6.8	2.8	0.9	0.3	3900	nil	88.4
Cg	106-145	2.3	16.6	3.1	5.5	4.4	1.5	1.1	0..4	2950	nil	100+
					Pedon II Sulfic Hydraquents							
Ap	0-10	3.5	4.3	5.0	17.1	9.9	2.5	1.2	0.7	189	nil	83.9
Bg	10-30	4.6	0.6	5.0	19.7	8.2	4.2	1.2	0.4	201	nil	40.4
Bg2	30-55	4.7	0.7	3.3	17.9	4.9	4.1	0.9	0.2	1171	nil	56.7
Cg	55-99	3.6	3.4	5.7	10.6	2.2	1.9	0.6	0.2	283	nil	46.2
2Cg	99-128	2.7	96	4.4	26.9	4.0	3.5	1.2	0.2	4042	nil	33.9
3Cg	128-156	3.2	4..0	3.0	5.5	1.5	1.3	0.6	0.2	1172	nil	63.0
					Pedon III Haplic Sulfaquents							
Ap	0-16	4.2	6.0	6.6	27.9	24.6	8.9	3.6	2.1	532	nil	100+
Bg	16-26	4.3	2.3	4.9	34.1	9.3	6.5	0.7	0.2	1792	nil	48.7
Bg2	26-55	4.9	5.1	4.4	37.5	11.9	7.3	1.9	0.3	2231	nil	37.3
Bg3	55-80	3.5	2.8	2.6	15.9	7.0	2.4	1.3	0.4	2797	nil	67.7
Bcg	80-101	3.2	3.2	5.2	13.0	4.4	1.5	0.8	0.2	2521	nil	53.3
Cg	101-134	3.4	2.7	3.5	10.9	4.0	1.3	0.8	0.2	373	nil	57.4
					Pedon IV Typic calciaquolls							
Akp	0-16	7.6	5.1	3.6	22.6	52.3	9.5	2.0	2.7	2047	26.6	100+
Bkg	16-41	7.6	2.3	4.1	36.5	35.8	3.8	2.7	0.8	906	21.0	100+
Bg2	41-86	6.7	2.5	0.8	36.9	23.1	4.9	2.4	0.6	1408	0.4	84.1
Cg	86-116	6.5	2.7	1.6	28.8	28.2	6.3	3.5	0.9	2378	0.6	100+
2Cg	116-145	5.5	2.8	2.5	16.5	8.9	3.0	1.0	0.3	2765	trace	79.4

CEC= cation exchange capacity, BS= base saturation, OC= organic carbon

[1]horizon designation according to Soil Survey Field Handbook (Hodgson, 1976)

0.5 m of the surface for most part of the year, there may be little or no difference in the soil temperature during the rainy and dry seasons, hence an isothermic temperature regime.

All horizons in the four pedons have chromas of 2 or less, and grey or greenish grey hues (2.5 Y, 4 GY or BG). In addition, some horizons emanate smell of hydrogen sulphide when treated with hydrochloric acid indicating the presence of pyrite. In consequence, these soils are potential acid sulphate soils. Also, most of the horizons except those of pedon IV have aged pH values less than 4.0 within 0.7 m of the soil surface to qualify for sulfic group of soil taxonomy (Soil Survey Staff, 1994). For almost all horizons, the levels of soluble salts in the saturation paste extracts exceeded $2dSm^{-1}$ (Table II). This would qualify these soils as saline.

In the oasis, the Histosols, have bulk density as large as 0.3 kg m^{-3} to qualify for saprists sub order of the Soil Taxonomy scheme (Soil Survey Staff, 1994). In addition, these soils have sulphidic materials within 0.7 m of the soil surface, and a mineral layer at least 0.3 m thick with its upper boundary within 0.7 m below the soil surface. The pedon I qualifies as *Fine loamy, Isothermic, Terric Sulfisaprists* (Soil Survey Staff, 1994) because they have organic carbon horizon at least 0.6 m thick, organic carbon content greater than 13%, bulk density of about 0.3 kg m^{-3} throughout the organic horizons, remain saturated with water within 0.5 m of the soil surface, and horizons with oxidised pH (1:2.5 in water) values between 1.6 and 3.4 with its upper boundary within 0.5 m of the soil surface.

Pedons II and III show properties that are diagnostic of aquents in the US Soil Taxonomy scheme. They show evidence of umbric epipedon, low chroma values of 2 or less, and organic carbon content of at least 3.2% throughout the horizons, and sub soil base saturation of less than 50%. In addition, they have sulphidic materials within the soil profile to qualify as sulfaquents (Soil Survey Staff, 1994). The pedon II has in addition an estimated n-value greater than 0.7. These soils therefore can be classified as *Fine loamy, Isothermic, Sulfic Hydraquents*, while the pedon III as *Clayey, Isothermic, Haplic Sulfaquents* (Soil Survey Staff, 1994) because they have umbric epipedon; oxidised soil pH values of less than 4.0 within 0.8 m of the soil surface. The Mollisols in Kajimaram oasis have low chroma values of 2 or less, organic carbon content of at least 0.8%, base saturation of at least 80% throughout the profile to meet the mollic epipedon requirements (Soil Survey Staff, 1994). In addition, they contain calcium carbonate equivalent of atleast 21% within 0.5 m of the soils surface, and soft calcium carbonate nodules throughout the profile to meet the calcic endopedon requirements (Soil Survey Staff, 1994). The pedon IV has all of these features and qualifies as *Clayey, Isothermic, Typic Calciaquolls* (Soil Survey Staff, 1994).

CONCLUSIONS

The study showed that soils of Kajimaram oasis are rich in organic carbon, have low bulk density and remain saturated for substantial part of the year. These soils have the potentials to develop in to saline-acid sulphate soils. The organic and salin-acid sulphate nature of these soils indicate that reduction in the water table level and consequent drying of the soil profile could lead to subsidence of the organic surface, oxidation and real soil loss. Loss of the organic layer on the soil surface would expose the underlying saline-sulphidic layer, whose oxidation will give rise to acid sulphate soil condition. Once the soil becomes acidified, soil fertility problems relating to acid soil conditions could become so serious that the most important requirements for sustainability, soil fertility is destroyed. Despite these limitations, these soils remain suitable for intensive year-round cropping under the prevailing climatic regimes. However, continuous reduction in rainfall amounts and the associated changes in the hydrologic and soils conditions suggest that the farming practices in the oasis are opportunistic and short-lived.

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