Classification of Soils Supporting Mangroves in the Sultan Qaboos Qurm Nature Reserve (Oman) تقسيم التربة البانية للمنجروف في قرم السلطان قابوس (محمية طبيعية) القرم – مسقط – عمان

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Classification of Soils Supporting Mangroves in the Sultan Qaboos Qurm Nature Reserve (Oman)

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ABSTRACT. Eight soil profiles in the Qurm Nature Reserve (Muscat, Oman) were described and classified according to Soil Taxonomy. A reconnaissance soil map of the Reserve was prepared which includes the following soil types; Typic Torrifluvents in relatively drier areas; Typic Aquisalids on an upper marine terrace; Aquic Torrifluvents on medium terraces; Typic Fluvaquents on the lower terrace and Typic Psammaquents on a coastal sand bar. Mangrove tree (*Avicennia marina*) growth appeared better on the Typic Fluvaquents than on other soils. Mangrove growth performance in relation to soil type is briefly discussed.

Introduction

The Sultan Qaboos Nature Reserve at Qurm is an area of mangrove swamp in Oman which protects a diverse wetland habitat in an otherwise, mostly, arid country. The vegetation of the Reserve is dominated by *Avicennia marina* (Salm, 1991), a hardy mangrove tree known for its tolerance to many environmental stresses, in particular to low temperatures and high salinity (Clough, 1993). Al-Muharrami (1994) found heights of mature *A. marina* trees, to vary between 1.5 and 6.5 meters, probably as a result of a combination of stress factors. Reviewing the ecophysiology of mangroves, Clough *et al.* (1982) and Clough (1984) identified climate, salinity and soil nutrient availability as key factors in regulating mangrove growth and productivity. Ogino (1993) has emphasized that a mangrove ecosystem is an interaction between soils, seawater and plants and as such, soil-related factors may be important in determining mangrove growth in the Qurm Nature Reserve. Unfortunately, no information is available on the classification of soils supporting mangrove growth in the Sultanate of Oman.

Avicennia species appear to thrive in many different soil types, often rooting into deep, water-saturated, anaerobic layers. Mongia *et al.* (1993) reported *A. marina* mangrove growing in acid sulphate, low pH soils in the Indian Andaman and Nicobar islands, classified according to Soil Taxonomy as halic sulfaquepts. Clough (1993) has reported mangroves from Australia to be growing in soils with a wide range of textures, from coarse sand through to fine alluvial silts, heavy clays and peats, but most were usually nutrient poor (pH 6-7.5) with salinity near to that of tidal water. Akhani and Ghorbanli (1993) found *A. marina* in coastal areas of Iran growing on saline alluvial soils, *i.e.* solonchak and solonetz, and salt-marsh soils. In the United Arab Emirates, Embabi (1993) classified the geomorphological locations in which he found mangroves as tidal flats, tidal deltas, tidal channels, sabkhas and sand bars, spits and hooks. He noted that sand and silt contents of soils in these areas differed markedly and, in particular, reported the absence of mangroves on soils that had developed a surface salt crust.

Results from a pioneering study comparing soil chemical composition in the Qurm Nature Reserve with other mangrove sites in the Sultanate (Al-Muharrami, 1994) suggest that Reserve soils are alkaline and relatively low in organic matter, total-nitrogen, available phosphorous and sulphate. However, these results were obtained from samples of surface soil (0-25 cm deep) and are not indicative of soil type or classification.

The aim of the present study was to describe soil profiles of the Qurm Nature Reserve in relation to a visual assessment of mangrove performance in order to first, classify soils in accordance with the requirements of Soil Taxonomy secondly, prepare a reconnaissance soil map of the reserve and lastly, describe those soil characteristics most in common with good growth performance.

Materials and Methods

A recent aerial photograph was used to identify the main landforms in the Reserve and locate sampling sites in the field. A soil pit was dug at each of eight sites, to just below the depth of standing water, during January 1995. Soil profiles (termed 'pedons' when a volume of soil is examined) and horizons were described, using USDA (1975) guidelines, and a representative soil sample of approximately 1 kg taken from each. Samples were dried in forced-air ovens at 50°C for 24 hours, crushed, passed through a 2 mm sieve and stored, before chemical analysis, in rigid sealed polyethylene boxes at room temperature.

Soil pH was measured in 1:2.5 soil to water suspensions and salinity determined using an electrical conductivity (EC) meter (Camlab CG857 model) in filtered 1:1 soil to water extracts. Soil organic-carbon concentrations were determined by a modified Walkley-Black method and total-nitrogen concentrations determined by Kjeldahl acid digestion followed by steam distillation (using a Kjeltec System 1026 semi-automated apparatus). Calcium carbonate concentrations in soil were determined using a calcimeter to measure carbon dioxide evolution after acid addition. Organic-carbon, total-nitrogen and calcium carbonate concentrations in soils are expressed as percentages by weight.

Saturated paste extracts were prepared from each soil sample. Calcium plus magnesium concentrations in extracts were determined by titration with EDTA, and potassium and sodium concentrations measured separately using a photometer (Corning 410 model). Chloride concentrations were determined by titration with silver nitrate using potassium chromate as an indicator. Sulphate concentrations were determined by precipitation with calcium carbonate. Ion concentrations are expressed as milliequivalents per liter of extract, (meq/L). All chemical analyses were performed on triplicate subsamples following procedures given in Page *et al.* (1982).

A mean sodium-adsorption ratio (S.A.R.) was calculated for saturated soil paste extracts, using ionic concentrations expressed in meq/L, for each horizon as follows :

$$SAR = Na^{+} / [(Ca^{++} + Mg^{++}) / 2]^{1/2}$$

High values of SAR of 15 or over can cause damage to plants specifically sensitive to sodium ions (Richards, 1954).

At each site, heights of mature mangrove trees were measured using a hand-held clinometer (Suunto PM-5/360 PC, model) and the range between maximum and minimum values reported. In addition, relative densities of mangrove trees and their leaf colour were visually estimated.

Study Site Description

Geology

The Reserve overlies a Sub-Recent Quaternary terrace surrounded by outcrops to the east and west of Bioclastic yellow marl, marly limestone and limestone of the 'Jafnayn' Formation. Upstream, to the South, lie grey-white and beige, bedded dolomites of the 'Akhdar' Formation (Ministry of Petroleum and Minerals Geology Map, 1992).

Mangrove Habitat and Climate

The Qurm Nature Reserve occupies 115 ha of land within the Muscat Capital area which contains approximately 82 ha of mangrove trees. The Reserve is bordered to the north by approximately 1,700 m of open beach and a low sand ridge. The ridge lies in an approximately east-west direction and at each end, permanent tidal channels allow seawater to enter the Reserve. Behind the sand ridge the western channel (called Wadi Aday) bends sharply south-eastwards for approximately 1,000 m approaching, but not joining, the eastern channel and thereafter extends a further 500 m meeting the landscaped grounds of a recently established Nature Park.

Trees of *A. marina* grow in an area approximately 1,100 by 300 m surrounding the western channel and also border the full length of the eastern channel extending, south-eastwards to the edge of the Reserve. To the south-west, however, mangrove growth becomes limited to groups of trees separated by either bare soil or halophytic species.

The mangrove habitat in the Qurm Nature Reserve may be classified as a soft-bottomed (Sheppard *et al.*, 1992) combination of lagoon and estuarine systems. The influence of semidiurnal tides is dominant around inlets channels regularly saturating soil with sea water. The range in mean tide heights at Qurm are predicted to be 2.06 meters (Admirality Tide Tables, 1991) with a maximum difference between Maximum Highwater Springs and Maximum Lowwater Springs (Por, 1984) of 4.5 meters. The Reserve is also fed by Wadi Aday with water originating from inland sources giving the area a clearly estuarine landscape, most apparent furthest from the beachline. Additional water also enters the Reserve following the establishment of a recreation lake upstream from the Reserve in 1993.

Climate data for the Reserve are not available directly, but may be estimated indirectly from published meteorological data taken at Seeb International Airport situated, similarly on the coast, about 30 km away. The climate at the Airport is characterized by high mean annual temperatures (28.7°C) with mean maximum and minimum monthly air temperatures of 40.5 and 17.3°C, respectively. Rainfall is low averaging 93 mm per year with a calculated annual evapotranspiration (ET_0) of 2288 mm (FAO, 1991).

Results and Discussion

Landforms in the Reserve

The major portion of the Reserve consists of a series of three lowlying alluvial terraces surrounding the meandering Wadi Aday. The lowest lying (or lower) terrace is approximately 250 meters wide and over 1,000 meters in length. The medium terrace varies in width from less than 100 to 220 m to the south of Wadi Aday and is less than 100 m in width to the north. The upper terrace extends principally towards the south and south-east where it abruptly terminates when it meets the dry, gravelly plain beyond tidal influence. Between the eastern-most channel and the border of the Reserve, sharply rising cliffs have prevented the formation of an upper terrace. Unlike the lower and medium terraces which are well populated with mangrove trees the only portion of the upper terrace on which trees grow is south-east of Wadi Aday, bordering onto the newly established Nature Park.

The mouth of Wadi Aday is partially blocked by a sand bar which causes the Wadi to turn through nearly 180 degrees before turning again and emptying into the sea. Almost immediately behind the beach runs a long low sand ridge until the eastern-most channel is reached. Separating the two channels lies a raised abandoned deltaic plain on which mangroves do not survive.

Pedon Descriptions

The location of the pedons described are shown in Fig. 1.

Soil Colour and Mottling

Colour is normally regarded to be a permanent soil property and can be a reason-

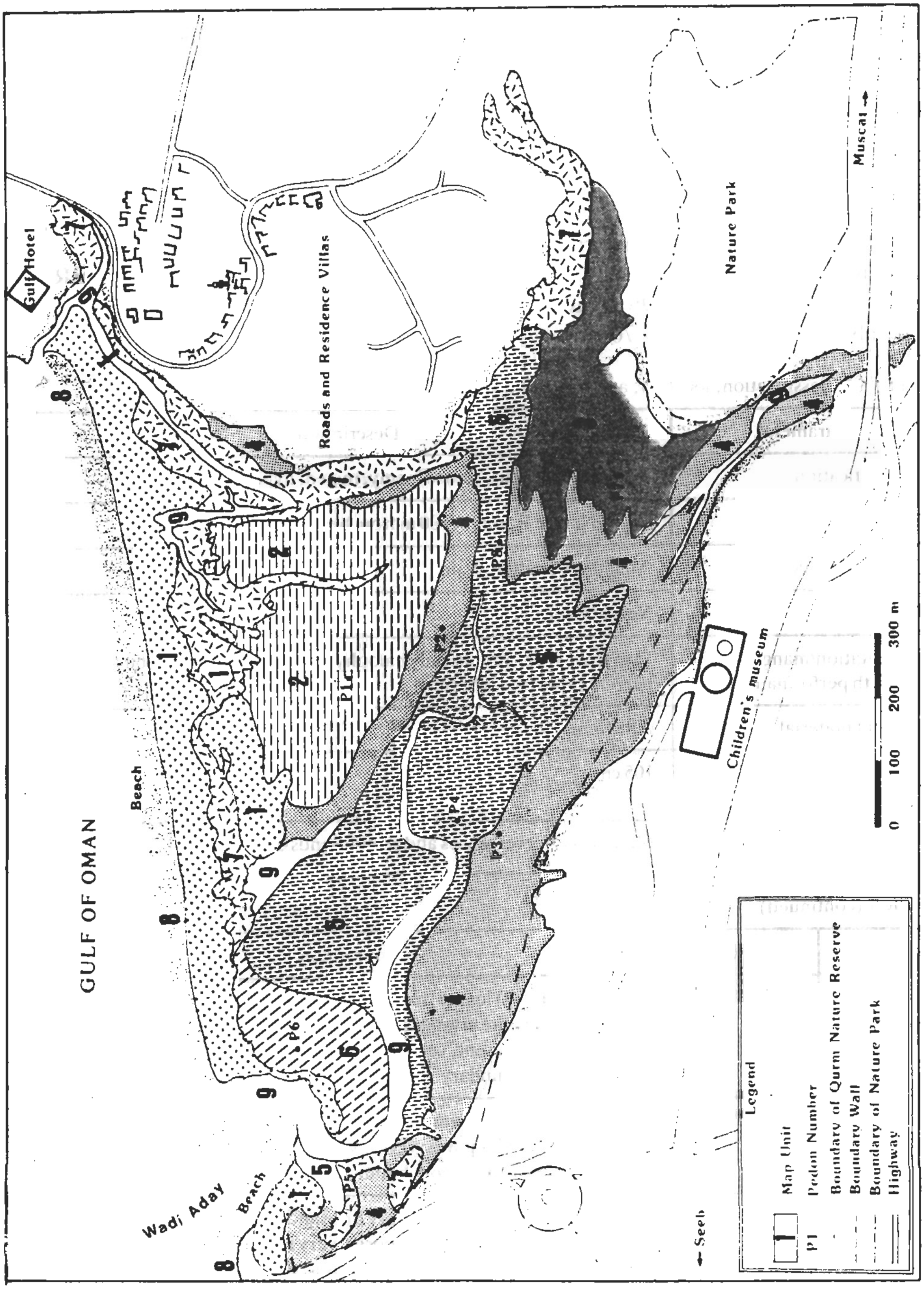

FIG. 1. Reconnaissance soil map of Qurm Nature Reserve.

ably reliable indicator of the aerobic or anaerobic condition of the soil. Soils in the Reserve have matrix hues in aerobic surface horizons of 10YR which change at varying depths to 2.5 Y in strongly anaerobic horizons. The depth at which hues change is related to the landform on which the soil is located. In Pedon 1 (Table 1) situated on the abandoned deltaic plain, no change in soil hue occurred between the surface and the lowest exposed depth, *i.e.* 110 cm. In Pedon 2 (Table 2) and Pedon 3 (Table 3), both situated on the medium terrace, the change in hue occurred at 50 and 56 cm, respectively, in contrast to Pedon 4 (Table 4), situated in the lower terrace, where the hue changed in a zone at a depth of between 10 and 32 cm. Soils in the minor stream channels in the lower terrace, Pedon 5 (Table 5), had uniform hues of 2.5 Y. In soils found on the sand ridge, Pedon 6 (Table 6) the hue changed from 10YR to 2.5Y at a depth of 30 cm. On the upper terrace soils of Pedon 7 (Table 7) the hue similarly changed at a depth of 70 cm.

TABLE 1. Classification, location, and description of Pedon 1.

Parameter	Description
Classification	Typic Torrifluvent, coarse loamy, mixed, hyperthermic
Location	Qurm Nature Reserve, 300 m from beach line
Physiographic position	Abandoned deltaic plain
Topography	Nearly level
Vegetation/mangrove growth performance	Mangrove trees absent, only halophytic shrubs present. About 70 percent of surface is barren.
Parent material	Alluvium
Depth to free water in profile	105 cm
Remark	Many salt effervescences and pseudosands on surface.

Table 1 (continued).

Horizon	Depth (cm)	Description
A_z	0-5	Brown (10YR 5/3) loamy fine sand; massive, very friable to friable (moist); many white crystals of salt; many very fine and fine vesicular pores; no roots present; very few fine burrows; slightly effervescent; abrupt smooth boundary.
C_1	5-27	Brown (10YR 5/3.5) loamy fine sand; massive, very friable (moists); few very fine tubular pores; very few very fine and fine roots; slightly effervescent; abrupt smooth boundary.
C_2	27-44	Yellowish brown (10YR 5/4) very fine sandy loam; massive, very friable (moist); few, very fine tubular pores; very few, very fine and fine roots; slightly effervescent; clear smooth boundary.

Table 1 (continued).

Horizon	Depth (cm)	Description
C_3	44-69	Dark yellowish brown (10YR 4.5/4) very fine sandy loam; massive, friable (moist); common very fine tubular pores; few, fine and very fine roots; slightly effervescent; gradual smooth boundary.
C_4	69-102	Brown (10YR 5/3) silt loam; few, fine, distinct spots, dark yellowish brown (10YR 4/6) mottles; massive, friable (moist); very few, fine and very fine roots; slightly effervescent; clear smooth boundary.
C_5	> 102	Pale brown (10YR 6/3) fine sandy loam; massive, loose (moist); very few, fine and very fine roots; slightly effervescent.

Note: soil has a surface, 1.5-2 cm thick, hard, salt crust, EC (1:1) value of 615 dS/m.

TABLE 2. Classification, location, and description of Pedon 2.

Parameter	Description
Classification	Aquic Torrifluvent, fine, loamy, mixed, hyperthermic
Location	Qurm Nature Reserve, 500 m from beach line, right bank of Wadi Aday
Physiographic position	Medium marine terrace
Topography	Nearly level
Vegetation/mangrove growth performance	Mangrove trees cover about 40 percent of surface. Tree heights range between 1.5 and 2.5 m and show non-luxuriant leaf growth.
Parent material	Alluvium
Depth to free water in profile	58 cm
Remark	Soil surface rilled and uneven.

Table 2 (continued).

Horizon	Depth (cm)	Description
A	0-6	Brown (10YR 5/3) silt loam; many coarse distinct band, grayish brown (2.5Y 5/3) mottles and common medium prominent spot, olive brown (2.5Y 4/6) mottles; weak platy (laminar) structure, friable (moist); common coarse tubular pores; common roots of all sizes; very few fine burrows; slight effervescent; clear smooth boundary.
C_1	6-40	Brown (10YR 5/3) sandy loam; common medium prominent spot, olive brown (2.5Y 4/4) mottles; massive, friable (moist); common coarse tubular pores; common roots of all sizes; slightly effervescent; clear smooth boundary.

TABLE. 2 (continued).

Horizon	Depth (cm)	Description
C_2	40 - 56	Brown (10YR 5/3) sandy loam; many coarse prominent spot, gray (2.5Y 5/0) mottles; massive, friable (moist); common medium tubular pores; common roots of all sizes; slightly effervescent; clear smooth boundary.
C_3	> 56	Dark gray (2.5Y 4/0) sandy loam; massive, slightly plastic; common medium tubular pores; common roots of all sizes; slightly effervescent.

TABLE 3. Classification, location, and description of Pedon 3.

Parameter	Description
Classification	Typic Aquisalid, coarse loamy, mixed, hyperthermic
Location	Qurm Nature Reserve, 500 m from beach line, left bank of Wadi Aday
Physiographic position	Medium marine terrace
Topography	Nearly level
Vegetation/mangrove growth performance	Mangrove trees cover about 40 percent of surface. Tree heights range between 2.5 and 3.2 m and show non-luxuriant leaf growth.
Parent material	Alluvium
Depth to free water in profile	30 cm
Remark	Soil surface moist and 10-15% rilled with some pseudosand.

Table 3 (continued).

Horizon	Depth (cm)	Description
A	0 - 20	Yellowish brown (10YR 5/3.5) sandy loam; massive, very friable (moist); common roots of all sizes; slightly effervescent; clear smooth boundary.
C_1	20 - 56	Brown (10YR 5/3) sandy loam; common coarse prominent spot, dark yellowish brown (10YR 3/4) mottles with few medium prominent spot, dusky red (2.5YR 3/2) mottles; massive, non-sticky; common roots of all sizes; slightly effervescent; clear smooth boundary.
C_2	> 56	Gray (2.5Y 4.5/0) sandy loam; many coarse prominent spot and band, dark yellowish brown (10YR 4/4) mottles; massive, slightly sticky; common roots of all sizes; slightly effervescent.

Note: soil in C_2 horizon has slightly heavier textures than in overlying horizons.

TABLE 4. Classification, location, and description of Pedon 4.

Parameter	Description
Classification	Typic Fluvaquents, coarse loamy, mixed, hyperthermic
Location	Qurm Nature Reserve, 300 m from beach line, interior of Reserve
Physiographic position	Lower marine terrace
Topography	Nearly level
Vegetation/mangrove growth performance	Mangrove trees cover about 80 percent of surface. Tree heights range between 4.2 and 6.2 m and show luxuriant growth with dark green leaves. Moss growing on upper tree branches.
Parent material	Alluvium
Depth to free water in profile	28 cm
Remark	Soil surface moist and even. Large number of snails and shells.

Table 4 (continued).

Horizon	Depth (cm)	Description
A	0 - 10	Brown (10YR 5/3) sandy loam; common coarse faint spot, yellowish brown (10YR 5/4) mottles, massive, slightly sticky; many roots of all sizes; slightly effervescent; clear smooth boundary.
C_1	10 - 22	Dark gray (2.5YR 4/0) sandy loam; few medium prominent spot, brown (10YR 4/3) mottles; massive, slightly sticky; many roots of all sizes; slightly effervescent; clear smooth boundary.
C_2	> 22	Dark gray (2.5Y 4/0) sandy loam; massive, slightly sticky; many roots of all sizes; slightly effervescent.

Note: soil in C_2 horizon has slightly heavier texture than in overlying horizons.

TABLE 5. Classification, location, and description of Pedon 5.

Parameter	Description
Classification	Typic Aquisalids, fine loamy, mixed, hyperthermic
Location	Qurm Nature Reserve, 200 m from beach line, left bank of Wadi Aday
Physiographic position	Natural drainage channel in lower marine terrace
Topography	Nearly level
Vegetation/mangrove growth performance	Mangrove trees absent in channel but tree heights range between 2.2 and 3.4 m growing on edges. Growth is luxuriant with dark green leaves.
Parent material	Alluvium

Table 5 (continued). Classification, location, and description of Pedon 5.

Parameter	Description
Depth to free water in profile	15 cm
Remarks	Soil surface moist and even. Large number of snails and shells.

Table 5. (continued).

Horizon	Depth (cm)	Description
A	> 15	Dark gray (2.5Y 3.5/0) loam (containing very fine sand); massive, slightly sticky; abundant roots of all sizes; slightly effervescent.

TABLE 6. Classification, location, and description of Pedon 6.

Parameter	Description
Classification	Typic Psammaquents, carbonatic, hyperthermic
Location	Qurm Nature Reserve, 50 m from beach line
Physiographic position	Sand bar on lower marine terrace
Topography	Nearly level
Vegetation/mangrove growth performance	Mangrove trees cover about 40 percent of surface. Tree heights range between 1.7 and 2.1 m and show non-luxuriant growth with light green leaves.
Parent material	Alluvium
Depth to free water in profile	33 cm
Remarks	Soil surface uneven. Few snails and shells.

Table 6. (continued).

Horizon	Depth (cm)	Description
A	0 - 20	Brown (10YR 5/3) sandy; massive, loose and very friable (moist); common roots of all sizes; violently effervescent; gradual smooth boundary.
C_1	20 - 30	Brown (10YR 5/3) loamy sand; common coarse faint spot, yellowish brown (10YR 5/4) mottles; massive, non sticky; common roots of all sizes (more thicker roots than above); violently effervescent; clear smooth boundary.
C_2	> 30	Gray (2.5Y 4.5/0) loamy sand; massive, non sticky; common roots of all sizes; violently effervescent.

TABLE 7. Classification, location, and description of Pedon 7.

Parameter	Description
Classification	Typic Aquisalids, coarse loamy, mixed, hyperthermic
Location	Qurm Nature Reserve, 700 m from beach line
Physiographic position	Upper marine terrace
Topography	Nearly level
Vegetation/mangrove growth performance	Mangrove trees covering about 40% surface grow on small surface humps (0.5-1 m high) either individually or in small groups. Tree heights range between 2.8 and 3.6 m and show healthy growth with green leaves. Halophytic species cover about 50 percent of surface.
Parent material	Alluvium
Depth to free water in profile	92 cm
Remarks	Surface is uneven and gullied

Table 7 (continued).

Horizon	Depth (cm)	Description
A_2	0 - 10	Dark brown (10YR 3.5/3) silty loam; weak coarse platy, very friable (moist); very few white crystals of salt; common roots of all sizes; slightly effervescent; clear wavy boundary.
C_1	10 -24	Brown (10YR 4/3) loamy very fine sand; massive, very friable (moist); common roots of all sizes; slightly effervescent; abrupt smooth boundary.
C_2	24 - 70	Grayish brown (2.5Y 5/2) very fine sandy loam; many fine medium and coarse prominent streak, with some tube mottles, following root lines, and spot, brown (7.5YR 4/4) mottles; massive, friable (moist); common roots of all sizes, some rotten; slightly effervescent; clear smooth boundary.
C_3	70 - 92	Dark grayish brown (2.5Y 4.5/2) very fine sandy loam; few fine and medium distinct spot, dark yellowish brown mottles; massive, friable (moist); many roots of all sizes, some rotten; slightly effervescent; abrupt smooth boundary.
C_4	> 92	Gray (2.5Y 4.5/0) loamy coarse sand; loose non-sticky; many roots of all sizes, some rotten, slightly effervescent.

Note: Surface soil (0-10 cm) has an EC (1:1) value of 104.7 dS/m.

Mottling in soils was observed in soil horizons directly above the anaerobic layer. Three distinct colours of mottling were found, red, brown and blue, normally shaped as large spots. Brown mottles were usually more common than others. They were found at shallower depths than blue mottles. Red mottles were found either as large spots or narrow distinct streaks suggesting that the latter are associated with the rooting pattern of mangroves.

Soil Texture

Textures of soils in the Reserve varied considerably, from coarse sand to silt loam. Pedon 1, on the abandoned deltaic plain contained a hard, approximately 2 cm thick, surface salt crust. Surface texture (0-5 cm) was loamy fine sand, and sequentially in subsurface horizons, very fine sandy loam, silt loam and very fine sandy loam at the depth of standing water. Horizon boundaries were smooth and often abrupt suggesting that the soil had accumulated over time by the deposition of different textured alluvial material. Soils from the medium and lower terraces downstream, (Pedons 2 and 3, and 4, respectively) showed considerably less variation in texture with depth, being mostly sandy loams or heavy sandy loams. However, further upstream the lower terrace soil, Pedon 8 (Table 8), contained a very gravelly coarse sandy horizon at 32 cm depth contrasting with an only slightly gravelly sandy clay loam at 70 cm. On the upper terrace (Pedon 7) soil textures also changed markedly with depth, varying from silt loam on the surface to very fine sand, very fine sandy loam and coarse sand at 92 cm.

TABLE 8. Classification, location, and description of Pedon 8.

Parameter	Description
Classification	Typic Fluvaquents, coarse loamy, mixed, hyperthermic
Location	Qurm Nature Reserve, 800 m from beach line
Physiographic position	Lower marine terrace
Topography	Nearly level
Vegetation/mangrove growth performance	Mangrove trees covering about 80% of surface grow on surface humps 20-30 cm high. Tree heights range between 3.5 and 4.9 m and show luxuriant growth with green leaves
Parent material	Alluvium
Depth to free water in profile	75 cm
Remark	Surface uneven and rilled

Table 8 (continued).

Horizon	Depth (cm)	Description
A	0 - 24	Brown (10Y 4.5/3) sandy loam; massive, friable (moist); common roots of all sizes; slightly effervescent; abrupt smooth boundary.
C_1	24 - 32	Brown (10YR 5/3) coarse sand; massive, loose (moist); 15% fine gravel; common roots of all sizes; slightly effervescent; abrupt smooth boundary

Table 8 (continued).

Horizon	Depth (cm)	Description
C_2	32 - 70	Gray (2.5Y 4.5/0) sandy loam; many coarse distinct spot, dark yellowish brown (10YR 4/4) mottles; massive, firm (moist); common medium and coarse roots; slightly effervescent; clear smooth boundary
C_3	> 70	Gray (2.5Y 5/0) sandy clay loam; massive, friable (moist); common roots of all sizes; slightly effervescent.

Note: soil below 70 cm has a measured Eh value of – 279 mV.

It appears that the tidal flow of water, which constantly moves and mixes soil has produced profiles with relatively uniform textures downstream, but has had less effect further upstream. Consequently, in these locations alluvial gravel and silt carried by water from the wadi have remained in place after deposition.

Soil Chemical Analysis

Results of chemical analysis of the soil horizons from the pedons sampled are given in Table 9.

TABLE 9. Soil chemical analysis.

Profile	Location	Depth	Texture	pH	EC(1:1) (dS/m)	Ca + Mg (mmol/L)	Na (mmol/L)	K (mmol/L)	SAR	Cl (mmol/L)	SO_4 (mmol/L)	% $CaCO_3$	% Organic carbon	% Total nitrogen	C : N Ratio
Pedon 1	Abandoned	salt crust		6.6	61.5	1140	4130	97.4	173.1	5187	41.7	11	1.497	0.013	115
	deltaic	0 - 5	loamy fine sand	6.7	136.7	860	3913	87.2	188.7	4812	62.5	14	0.522	0.012	43.5
	plain	5 - 27	Loamy fine sand	7.6	20.1	78	417.4	9.2	66.9	475	19.8	25	0.095	0.015	6.35
		27 - 44	very fine sandy loam	7.7	22	78	365.2	6.2	58.5	450	24.5	26	0.128	0.015	8.57
		44 - 69	very fine sandy loam	7.5	29.1	90	434.8	7.2	64.8	575	26	25	0.113	0.024	4.71
		69 - 102	silt loam	7.6	13	46	228.3	4.1	47.6	275	20	25	0.103	0.024	4.91
		> 102	fine sandy loam	7.5	11.5	46	217.4	3.1	45.3	262	21.6	21	0.094	0.019	4.93
Pedon 2	Medium	0 - 6	silt loam	7.8	34.9	128	521.7	9.2	65.2	625	49	28	0.451	0.046	9.81
	terrace	6 - 40	sandy loam	7.4	27.1	108	304.3	8.2	41.4	537	41.7	26	0.257	0.039	6.59
		40 - 56	sandy loam	7.3	29.5	148	547.8	12.3	63.7	675	49	23	0.426	0.043	9.91
		> 56	sandy loam	7.3	27.8	184	521.7	13.3	54.4	700	90.3	21	0.316	0.029	10.88
Pedon 3	Medium	0 - 20	sandy loam	7.7	19.8	126	478.3	10.3	60.3	550	46.5	26	0.189	0.037	5.11
	terrace	20 - 50	sandy loam	7.4	26.1	159	573.9	13.3	64.4	675	69.4	26	0.176	0.021	8.82
		> 50	sandy loam	6.8	46.5	300	913.1	20.5	75.5	1125	175	38	0.862	0.046	18.73
Pedon 4	Lower	0 - 10	sandy loam	7.5	24.8	124	500.1	12.3	63.5	600	52.1	26	0.424	0.053	8.01
	terrace	10 - 22	sandy loam	7.4	24.5	138	469.6	11.3	56.5	550	62.5	44	0.538	0.045	11.95
		> 22	sandy loam	7.3	29.5	168	469.6	12.3	51.2	575	93.8	44	0.819	0.039	21.1
Pedon 5	Channel	0 - 15	loam	7.5	32.2	146	417.4	13.3	48.9	525	93.8	35	1.067	0.071	15
Pedon 6	Sand ridge	0 - 20	sandy	7.9	16.3	78	226.1	10.3	36.2	350	26	40	0.171	0.039	4.36
		20 - 30	*loamy sand*	7.9	17.3	80	295.7	7.2	46.8	337	30.9	44	0.177	0.034	5.21
		> 30	loamy sand	7.4	12.3	74	243.5	7.2	40.1	312	31.3	44	0.091	0.051	1.8
Pedon 7	Upper	0 - 10	silt loam	7.8	104.7	440	2391	32.8	161.2	2350	260	28	0.681	0.066	10.3
	terraee	10 - 24	loamy very fine sand	7.8	31.1	140	695.7	15.4	83.1	775	38.9	26	0.277	0.068	4.07
		24 - 70	very fine sandy loam	7.6	41.8	148	782.6	14.4	91.1	850	46.5	35	0.104	0.089	1.17

Table 9 (continued).

Profile	Location	Depth	Texture	pH	EC(1:1) (dS/m)	Ca + Mg (mmol/L)	Na (mmol/L)	K (mmol/L)	SAR	Cl (mmol/L)	SO_4 (mmol/L)	% $CaCO_3$	% Organic carbon	% Total nitrogen	C:N Ratio
		70-92	very fine sandy loam	7.7	18.9	92	443.5	8.2	65.4	525	25	35	0.139	0.028	4.95
		>92	loamy coarse sand	7.8	18.2	94	413.1	8.2	60.2	500	28.8	36	0.143	0.039	3.65
Pedon 8	Upper	0-24	sandy loam	7.8	21.9	106	469.6	10.3	64.5	525	31.3	28	0.112	0.035	3.37
	terrace	32-70	sandy loam	7.6	28.4	130	521.7	10.3	64.7	600	52.1	28	0.169	0.028	6.05
	(upstream)	>70	sandy clay loam	7.4	27.1	138	591.3	10.3	71.2	650	58.3	35	0.101	0.047	2.13

Salinity

In the most recent changes to definitions in keys to Soil Taxonomy (USDA 1994), a salic horizon now requires the following; a thickness of at least 15 cm; an electrical conductivity (EC) greater than 30 dS/m in a 1:1 soil:water extract for at least 90 consecutive days per year; and a product of EC in dS/m and thickness in cm equal to 900 or more. The definition is given in full here, because of its importance in correctly classifying the soils of the Reserve. The central concept of a salic horizon is one in which salts have accumulated in substantial amounts mainly through capillary rise of salt saturated water from subsurface horizons in response to high rates of evaporation of water from a soil surface, followed by subsequent salt precipitation.

Such a mechanism probably accounts for the presence of surface salt in soils of the upper terrace and the abandoned deltaic plain. EC (1:1)) values in the upper terrace soil exceeded 30 dS/m to a depth of 70 cm, compared with a depth of only 5 cm in soil from the plain. The latter depth is insufficient to satisfy the requirements for a salic horizon.

The only other locations in the Reserve where salic horizons were found were in anaerobic subsurface horizons in some soils of the middle terrace and minor channels of the lower terrace. It appears that although subsurface horizons are reasonably saline (mean EC (1:1) value of all subsurface samples is 27.1 dS/m), salt accumulation does not generally occur in the medium and lower terraces. This finding is similar to that of Dagar *et al.* (1993) in which soils of Bay Islands in India were also found not to accumulate salt probably as a result of the constant flow of tidal water carrying salt into and out of mangrove swamps.

Sodium-adsorption ratios in saturated soil paste extracts were high, ranging between 36.2 and 188.7, indicating strongly sodic soil conditions. Sodium ion concentrations in extracts were high, exceeding 226.1 meq/L in all samples and especially high in surface horizons of Pedon 7. Chloride ion concentrations in extracts were also high, exceeding 262.5 meq/l in all samples and more than 1,000 meq/l in Pedons 3 and 7.

Soil Total-Nitrogen and Organic Carbon Concentrations and C:N Ratios

Total-nitrogen and organic-carbon concentrations in all soils analyzed are rated *very low (mean* 0.034 and 0.299 percent respectively), according to values given in the Booker Tropical Soil Manual (London, 1991). C:N ratios in soils were also generally low (mean, of all samples, is 8.4), compared with a value of 10:1 for aerobic soils. Mean C:N ratios were relatively higher in soils of the lower and medium terraces than the upper terrace (8.8, 11.6 and 4.8, respectively). Variations in C:N ratios in estuary sediments as a function of distance from the sea have been previously reported (Matson and Brinson, 1990).

The low soil C:N ratio values found in the Reserve indicate that mineralization of soil organic nitrogen, if added through litter fall, for example, should occur rapidly releasing inorganic nitrogen. However, nitrogen and carbon do not appear to accumulate in soils of the reserve suggesting that either, organic inputs are very low or, nitrogen and carbon are lost through, perhaps, denitrification and methanogenesis. Wong *et al.* (1995) also reported that, in mangrove swamps polluted in China for one year with wastewater, soils did not appear to accumulate carbon and nitrogen. Kemp *et al.* (1990) have suggested that denitrification is controlled by nitrification processes in Chesapeake Bay sediments. Whether similar mechanisms occur in the Qurm Nature Reserve has not been investigated. Methanogenesis, on the other hand, has been detected in anaerobic soils of the Reserve (Cookson, 1996) but its rate is low, unless stimulated by the addition of organic materials, such as cellulose, methanol and L-methionine.

It is important for the management of the Reserve to understand more fully the biological activity of the soils in order to assess the amount of nutrient cycling occurring and possibly amend nutrient inputs to overcome any nutrient deficiencies in mangrove trees.

Soil Classification and Mapping

The soils of the Reserve were mapped in relation to their classification and location on differing landforms. Mapping units were established to either reflect similarities between soils on the same landform or group soils into associations when differing soils could not be separated at the scale the survey was conducted. For example Map Unit 4, shown in Fig. 1 and listed in Table 10, consists of both Typic Aquisalids and Aquic Torrifluvents situated on the middle terrace. In contrast, Map Unit 1 consists of only Typic Torripsamments situated on the sand ridge. The soil map presented should be considered as a reconnaissance since the density of profiles examined to area map was less than 1 pedon to 12 ha. Nevertheless some interesting relationships between soil classifications and landform were found.

The soils of the lower terrace in the central part of the Reserve were classified as Typic Fluvaquents (Pedon 4). These soils were sandy loam in texture, mottled to a depth of 22 cm and appeared anaerobic below 28 cm. EC (1:1) values were reasonably high in all horizons, (mean 26.1 dS/m) but were always less than 30 dS/m the value required to define a salic horizon. Chloride ion concentrations in soil saturated pastes were nearly uniform throughout the profile (mean 575 meq/L) with SAR values reducing gradually from 63.5 in surface to 51.2 in lowest horizons.

Soils of the medium terraces were classified as either Aquic Torrifluvents (Pedon 2) or Typic Aquisalids (Pedon 3). The two soils differed in the amount of mottling found, particularly in the surface horizon. The Aquic Torrifluvents were mottled throughout the profile whereas mottling commenced in the Typic Aquisalids only at below 20 cm. Other differences between the two soils were the higher EC (1:1) values, 46.5 compared with 26 dS/m, and chloride ion concentrations, 1,125 compared with 700 meq/L, found in the lowest horizons (*i.e.* deeper than 56 cm) in the Aquisalids and the Torrifluvents, respectively.

The soils of the sand ridge, classified as Typic Psammaquents, were characterized by sand or loamy sand textures, with high concentrations (more than 40.0 percent) of calcium carbonate. Mottling was apparent at 20 cm depth and anaerobic conditions below 30 cm. These were the least saline soils of those examined in the Reserve, having a mean EC (1:1) value of 15.3 dS/m. Chloride ion concentration from saturated soil pastes was also relatively low, mean 333.3 meq/L, compared with a mean of 575 meq/L in soils of the lower terrace.

Typic Aquisalids were found in shallow, tributary channels which drain surface water through the low terrace, from the medium terrace, towards the main tidal inlets. These soils were entirely water saturated with uniform anaerobic matrix hues.

TABLE 10. Key to landform, soils and mangrove growth in the Nature Reserve at Qurm.

Map unit	Landform	Dominant soil subgroups	Particle size class	Mangrove growth[a] and height range
1	Sand ridge	Typic Torripsamments	Sandy	None
2	Abandoned deltaic plain	Typic Torrifluvents	Coarse loamy	None
3	Upper terrace	Typic Aquisalids	Coarse loamy	Healthy, sparse growth, 2.8 - 3.6 m
4	Middle terrace	Typic Aquisalids-Aquic Torrifluvents	Fine loamy	Poor, sparse growth, 2.1 - 3.2 m
5	Lower terrace	Typic Fluvaquents	Fine loamy	Healthy, dense growth, 3.5 - 6.2 m
6	Sand bar	Typic Psammaquents	Sandy	Fair, sparse growth, 1.7 - 2.1 m

Table 10 (continued).

Map unit	Landform	Dominant soil subgroups	Particle size class	Mangrove growth[a] and height range
7	Channels	Typic Fluvaquents - Typic Aquisalids	Coarse loamy	Healthy, dense growth, 1.8 - 3.2 m
8	Beach			
9	Streams			

[a]Healthy or fair categories indicate mangrove trees with distinctly greener or yellower leaves, respectively. Tree densities in the Qurm Nature Reserve have been reported to vary between 15.2 and 139.8 stems per 0.1 ha, with a mean of 42.2 (Al-Muharrmi, 1994).

The Typic Torrifluvents of the abandoned deltaic plain had excessively saline surface crusts (EC(1:1) of 615 dS/m, approximately 2 cm thick. Soil, to a depth of 5 cm below the crust, was also highly saline (EC(1:1) of 136.7 dS/m). Below 5 cm, however, soil salinity declined rapidly and was too low to meet both the EC and depth requirements for a salic horizon. Chloride ion concentrations in saturated paste extracts of the 0-5 cm layer were very high, 4,812 meq/L, but concentrations also declined with depth to less than 300 meq/L.

Relation between Soil Type and Visual Mangrove Tree Growth Performance

Mangrove tree growth was estimated visually on the basis of leaf colour, stand density and tree height and, as shown in Table 10, varies between different soil types. Tallest trees (varying between 3.5 and 6.2 m in height) and showing luxuriant leaf growth were found on the Typic Fluvaquents on the lower terrace. Mangrove trees on the Aquic Torrifluvents (1.5 to 2.5 m high) and Typic Aquisalids (2.1 to 3.2 m high) of the medium terrace were generally shorter than trees on the lower terrace.

Above-ground mangrove growth was absent in the entirely water-saturated Typic Aquisalids found in shallow tributary channels in the lower terraces. These soils contained abundant amounts of fine roots but it appears that actively flowing water in the channel has prevented mangrove establishment. Mangroves and aerial roots were, however, observed growing on the edges of the channels.

Mangroves were also established on the light-textured Typic Psammaquents of the sand bar but tree heights were shorter (1.7 to 2.1 m high) and had distinctly yellower leaves than trees on the lower terrace.

Relatively tall (3.5 to 4.9 m) mangrove trees grew individually or in small groups (approximately 1 km from the beach) on Typic Fluvaquents (*e.g.* Pedon 8). These trees may be more influenced than others by water flowing from inland sources through Wadi Aday towards the sea.

The absence of mangrove trees growing on the Typic Torrifluvents of the abandoned deltaic plain is probably related to the presence of excessively saline, surface crusts of these soils.

One purpose for classifying the soils of the Qurm Nature Reserve was to ellucidate soil-related factors which are suitable for mangrove growth, in order to identify other coastal areas, having similar soil conditions, as possible mangrove regeneration sites. Two such soil properties are texture and degree of mottling. Mangroves in the Reserve survive on soils with textures ranging from sand to silt loam but growth appears better on the heavier sandy loam soils. In addition, growth appears better in soils which are water-saturated below about 30 cm, but which also contain distinct red mottles between 10 and 20 cm below the soil surface. If substantial red mottling occurs deeper than 20 cm or alternatively the soil is completely water-saturated, then growth appears to be reduced as, for example, on the medium terraces and in drainage channels of the Reserve, respectively. For best growth performance mangrove trees appear to require a wet soil overlain by a more aerobic and drier soil layer of at least 20 cm depth with a sandy loam texture. To more clearly distinguish between aerobic and anaerobic soil conditions in the Reserve requires a detailed study of soil redox potentials.

Conclusions

The Nature Reserve at Qurm consists of a terraced alluvial area, regularly inundated with a tidal seawater, which is partially blocked to the sea by a beach and sand ridge. Behind the sand ridge and between two tidal, inlet channels, there is, in addition, a raised abandoned deltaic plain. Soil types vary in the Reserve in accordance with their position on the terraces; Typic Fluvaquents on the lower; Aquic Torrifluvents and Typic Aquisalids on the medium; and Typic Aquisalids on the upper. Typic Psammaquents are found on the sand ridge and Typic Toffifluvents on the abandoned deltaic plain. The Reserve is strongly influenced by a fluctuating saline groundwater table which appears to prevent excessive salt accumulation in soil horizons except in permanently water-saturated anaerobic subsurface horizons in some soils of the medium terrace and in surface horizons in soils of the upper terrace.

A. marina tolerates soil salinities of EC (1:1) values of up to 29.5 dS/m in the lower terrace, but growth is reduced on the medium terrace where EC(1:1) values exceed 46 dS/m. Luxuriant mangrove growth is found where chloride ion concentrations in saturated soil paste extracts are lower than 600 meq/L and growth suffers at higher sodium concentrations, especially when in excess of 1,000 meq/L. *A. marina* survives in the Reserve on a wide range of soil textures from sands and loamy sands to silt loams. Growth performance is best, however, on sandy loam textured soils, where water saturation occurs at a depth of below 25-30 cm.

References

Admirality Tide Tables (1991) The Hydrographer of the Navy, Hydrographic Office, Ministry of Defence (Navy), U.K.

Akhani, H. and **Ghorbanli, M.** (1993) A contribution to the halophytic vegetation and flora of Iran. In: *Towards the Rational Use of High Salinity Tolerant Plants,* (eds. **H. Lieth** and **A. Al Masoom**) Vol. **1:** 35-44. Kluwer Academic Publishers, The Netherlands.

Al-Muharrami, A.B.A. (1994) *An initial assessment of mangrove resources and human activities at Mahout Island, Arabian Sea, Oman.* Unpublished M.Sc. thesis, University of Newcastle-upon-Tyne, U.K.

Clough, B.F. (1984) Growth and salt balance of the Mangroves *Avicennia marina* (Forsk.) Vierh. and *Rhizphora stylosa* Griff. in relation to salinity. *Aust. J. Plant Physiol.* **11:** 419-430.

———— (1993) Constraints on the growth, propagation and utilization of mangroves in arid regions. In: *Towards the Rational Use of High Salinity Tolerant Plants,* (eds. **H. Lieth** and **A. Al Massom**) Vol. **1:** 341-352. Kluwer Academic Publishers, The Netherlands.

————, **Andrews, T.J.** and **Cown, I.R.** (1982) Physiological processes in mangroves. In: *Mangrove Ecosystems in Australia: Structure, Function and Management,* (ed. **B.F. Clough**), 193-310, Australian National University Press, Canberra.

Cookson, P. (1996) Measurement of Potential Rates of Methanogenesis in Mangrove Swamps of the Sultan Qaboos Nature Reserve at Qurm (Oman). *Journal of King Abdulaziz University: Marine Sciences,* **8:** 91-107.

Dagar, J.C., Singh, N.T. and **Mongia, A.A.** (1993) Characteristics of mangrove soils and vegetation of Bay Islands in India. In: *Towards the Rational Use of High Salinity Tolerant Plants,* (eds. **H. Lieth** and **A. Al Massom**) Vol. **1:** 59-80. Kluwer Academic Publishers, The Netherlands.

Embabi, N.S. (1993) Environmental aspects of geographical distribution of mangrove in the United Arab Emirates. In: *Towards the Rational Use of High Salinity Tolerant Plants,* (eds. **H. Lieth** and **A. Al Massom**) Vol. **1:** 45-58. Kluwer Academic Publishers, The Netherlands.

FAO (1991) *Irrigation Planning and Management Tool.* Water Resources, Development and Management Service, Land and Water Development Division, Rome.

Kemp, W.M., Sampou, P., Caffrey, J., Mayer, M., Henriksen, K. and **Boynton, W.R.** (1990) Ammomium recycling versus denitrification in Chesapeake Bay sediments. *Limnol. Oceanogr.,* **35:** 1545-1563.

Landon, J.R. (editor) (1991) *Booker Tropical Soil Manual.* Longman Scientific and Technical, Longman Group, Harlow, England.

Matson, E.A. and **Brinson, M.M.** (1990) Stable carbon isotopes and the C:N ratio in the estuaries of the Pamlico and Neuse Rivers, North Carolina. *Limnol. Oceanogr.,* **35:** 1290-1300.

Ministry of Petroleum and Minerals (1992) *Geological Map of Seeb, Sheet* NF 40-03, Explanatory Notes. Bureau de Recherches Geologiques et Minieres, BP 6009, 45060 Oceans Cedex 2, France.

Mongia, A.D., Singh, N.T. and **Dagar, J.C.** (1993) Soils of the mangrove habitats in the Andaman and Nicobar Islands. In: *Towards the Rational Use of High Salinity Tolerant Plants,* (eds. **H. Lieth** and **A. Al Masoom**) Vol. **1:** 501-509. Kluwer Academic Publishers, The Netherlands.

Page, A.L., Miller, R.H. and **Keeney, D.R.** (1982) *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties.* 2nd ed. American Society of Agronomy, Madison WI.

Por, F.D. (1984) Editor's note on tides and water levels in the mangal. In: *Hydrobiology of the Mangal,* (eds. **F.D. Por** and **I. Dor**) pp. 25-26. Dr. W. Junk Publishers, The Hague.

Richards, L.A. (1954) *Diagnosis and Improvement of Saline and Alkali Soils.* Agricultural Handbook No. 60. U.S. Government Printing Office, Washington, D.C.

Salm, R.V. (1991) *Shoreland and Marine Environments, Sultanate of Oman.* Scientific Result of the IUCN Coastal Zone Management Report. Muscat, Sultanate of Oman.

Sheppard, C., Price, A. and **Roberts, C.** (1992) *Marine Ecology of the Arabian Region, Patterns and Processes in Extreme Tropical Environments.* Academic Press, London.

United States Department of Agriculture (1994) *Keys to Soil Taxonomy,* Sixth Edition, Soil Conservation Service, Washington, D.C.

USDA (1975) *Soil Taxonomy.* Agricultural Handbook No. 436, U.S. Government Printing Office, Washington, D.W.

Wong, Y.S., Lan, C.Y., Chen, G.Z., Li, S.H., Chen, X.R., Liu, Z.P. and **Tam, N.F.Y.** (1995) Effect of wastewater discharge on nutrient contamination of mangrove soils and plants. In: *Asia-Pacific Symposium on Mangrove Ecosystems,* (eds. **Y.S. Wong** and **N.F.Y. Tam**) pp. 243-254. Kluwer Academic Publishers. Belgium.

تقسيم التربة البانية للمانجروف في قرم السلطان قابوس (محمية طبيعية) القرم - مسقط - عمان

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المستخلص . وصفت ثمانية مقاطع من التربة في محمية القرم الطبيعية (قرم السلطان قابوس) حسب قانون تصنيف التربة ، ورسمت خارطة لهذه المنطقة متضمنة لهذه المقاطع وأهم أنواعها كما يلي :

- نوع توريفلوفنتس - في المنطقة الجافة نسبيًا .
- نوع أكواساليدس - على الشرفة البحرية العليا .
- نوع أكوبك توريفلوفنتس - على الشرفة الوسطى .
- نوع فلوفاكوينت - على الشرفة السفلي .
- نوع بساماكوينت - على الحافة الرملية الساحلية .

ويستنتج من هذا البحث أن أشجار المانجروف (أفينيسيا مارينا) تنمو بشكل أفضل على التربة من نوع (فلوفاكوينت) عنها من الأنواع الأخرى .

كما أن علاقة الأداء والنمو بالنسبة للأنواع الأخرى مشروحة باختصار .