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THE SOILS OF THE KALAHARI GEMSBOK NATIONAL PARK

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Abstract — Field observations made during a reconnaissance soil survey of the Kalahari Gemsbok National Park showed that a variety of soils occur within the broad group of so-called Kalahari sands. For discussion purposes, the soils were classified into five main groups of which the red and yellow sands took precedence over the other soils because of their geographical distribution and pedological significance. The soils are discussed with special reference to their classification, site and parent material, their morphological, chemical and mineralogical properties and drainage characteristics. Attention was also given to the relationship between the soils and landforms, and a brief note on the inherent fertility status of the soils has been included.

Introduction

In order to assess the potentialities of a region, whether for agricultural purposes, nature conservation development or any other development projects, it is necessary to evaluate the individual components of the natural ecosystem or environment. These major components are climate, vegetation, geology, physiographic features and soils. In the terrestrial ecosystem soils are in three ways the vital link between the living (biotic) and non-living (abiotic) part of this system.

Firstly, soils are the means of support for all terrestrial organisms: plants are anchored to the soil in order to obtain energy and matter needed to drive their photosynthetic and respiration processes; animals and man walk upon it and are supported by it. Secondly, through the colloidal (clay-humus) complex, soils provide the soil solutions from which plants obtain all their necessary water and mineral nutrients. Thirdly, soils provide the habitat for micro-organisms that are essential in the decomposition processes permitting the continual recycling of biochemicals.

In recent years the Kalahari Gemsbok National Park (KGNP), which is situated in the southwestern part of the southern Kalahari Desert (Fig. 1), received increased research attention. This was very obvious during the symposium on the Kalahari ecosystem, at which the need for more data on the soils was also apparent.

During a recent, rapid reconnaissance soil survey of the KGNP more information was gathered on the soils of the park. This data and information from available literature and other sources was used to describe the different major soil types in this paper. Special reference is given to their classification, occurrence in the landscape, properties and parent material. Lastly, a brief review is given on the general fertility status of the soils.

PHYSICAL ENVIRONMENTAL FEATURES

Climate

The climate of the KGNP may be described as arid to semi-arid. The mean annual rainfall varies from about 223 mm in the southwestern part (Twee Rivieren — Weather Bureau 1984) increasing gradually to the north in the order of 250 mm. The rainfall is unreliable and irregular and the rainy season extends usually from November to April. Fifty per cent of the precipitation occurs during January to March. It is estimated from data by Kriel (1967) that the mean class A pan evaporation is in excess of 3 300 mm per annum. It is thus obvious that a very large deficit of water is characteristic of the annual water budget of the KGNP.

Large temperature fluctuations both on a daily and seasonal basis are also characteristic of the park. The mean maximum and minimum air temperatures are 35,7 °C and 19,5 °C for January and 22,2 °C and 1,2 °C for July respectively (Weather Bureau 1984). The most common winds occur during September to November which are northwesterly with accompanying dust (sand) storms. During winter southwesterly winds can bring cold weather for short periods. Frost is common during the winter.

Vegetation

Field observations during this investigation suggest a strong relation between soil type and vegetation. It is intended to report in a separate paper on the plant-ecological significance of the soils of the KGNP.

In general the vegetation is described by Acocks (1975) as the western form of the Kalahari thornveld and is an extremely open shrub or tree savanna. For additional detail on the vegetation of the KGNP see Bothma & De Graaff (1973). In brief it can be said that the red sands occurring as high to low dunes support mainly a grass and shrub veld with occasional trees, of which *Boscia albitrunca* (witgat), *Acacia mellifera* subsp. *detinens* (swarthaak) and *A. erioloba* (kameeldoring) are the most important. In the northern part of the park a tree savanna is present of which *A. erioloba* is the outstanding tree. The Auob and Nossob river valleys and their immediate vicinity are also characterised by *A. erioloba,* but in the southern part *A.*

haematoxylon (vaalkameel) becomes dominant and Karoo flora increases on the shallow soils. Where the red sands occur as high longitudinal dunes, the shrubs decreased considerably and grasses such as *Stipagrostis amabilis* are dominant and *A. haematoxylon* appears in a shrub-like form. The pans and yellowish sands, which are closely associated with lime, support mainly a shrub veld of *Rhigozum trichotomum* (driedoring) and some grasses.

Geology and parent materials

The aggradational landsurface of the KGNP is composed mainly of reddish and to a lesser extent of yellowish sands. These so-called Kalahari sands are of aeolian origin and form the parent materials of the red Hutton and yellow Clovelly soils. They vary in thickness from a few centimetres to several metres and cover the solid geological formations. Some of these geological materials are exposed in close proximity to the rivers and consist mainly of limestone materials, sandstone, etc. The limestone materials, variously known as surface limestone, lime pan, calcrete, caliche and kankar, vary in colour from white to yellowish white to greyish. The uppermost layer, whether exposed or covered by sand, is usually very hard and impervious. This layer is sometimes fissured, breaking into blocks and known by geologists as boulder limestone. The thickness of the boulder limestone varies from a few centimetres to approximately 80 cm. This can be observed in many places along the Auob and Nossob Rivers where the limestone is exposed. Underlying the boulder limestone is a softer porous limestone consisting of a matrix of powder lime with hard and soft lime nodules of varying thickness and probably gradually passing into the underlying disintegrated rock.

Calcareous materials in pans and other depressions which are seldom submerged are composed of granular material and soft powdery lime and in most areas are very pervious to water.

For additional geological details see Brynard (1958), Smit (1964) and Louw (1964).

Terrain morphology and drainage

Broadly speaking the land surface morphology of the KGNP is dominated by two types of terrain — a sand plain with low relief and a convex-concave curvature (Fig. 1). The latter is associated with a few dune systems consisting of longitudinal and zig-zag dunes of varying height. The most conspicuous dunes are in the southeast where high (15-20 m), well-developed longitudinal dunes with a northwesterly to southeasterly direction occur. The dunes that run parallel to each other consist of red sands of the Hutton form. The crests are sparsely covered with vegetation and the long troughs sometimes show a lighter red colour due to the shallowness of underlying lime. In the dune valleys pans and depressions, mainly in the form of deflation basins, occur.

In the central part of the park and more particularly the area between the two rivers except for the most southern part between the rivers, low (1–2 m) and medium (5–8 m) longitudinal and zig-zag dunes are dominant (Fig. 1). The low and weakly developed dunes are more concentrated in the northern part, where the sands are not so intensely red.

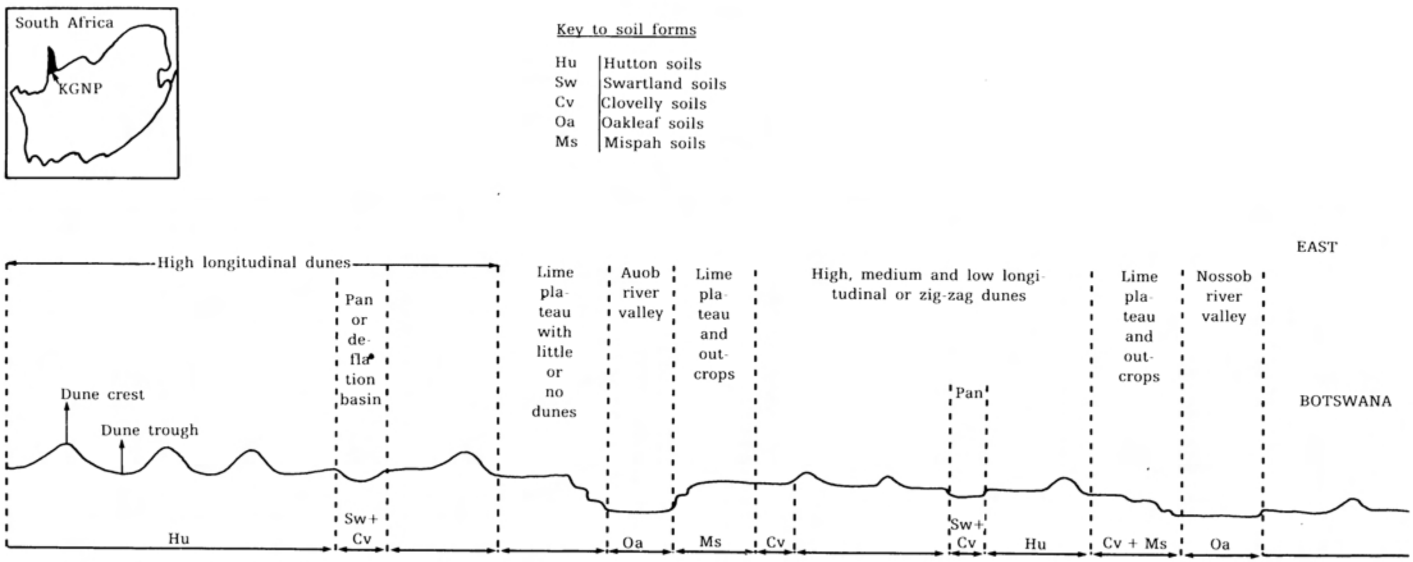

Fig.1. Locality and schematic cross section from west to east of the Kalahari Gemsbok National Park showing the relationship between landform and soils.

A few isolated dune areas occur in the south-central part of the park which is markedly different from all the other dune areas. They consist of a concentration of red sands with a very irregular dune-like occurrence. These dunes are also elevated (5–10 m) and stand up very conspicuously from the surrounding landscape. From field observations it is logical to conclude that they are also of aeolian origin but why they occur irregularly in isolated areas and what caused their elevation is not known.

The drainage density of the park is low with only the Auob and Nossob as major river valleys as the other type of terrain (Fig. 1). They very seldom are in flood due to the fact that the drainage is almost through infiltration into the sandy soil and underground zones. Pans and pan-like depressions (deflation basins) of varying sizes occur and are mostly underlain by lime with varying amounts of clay. They also hold water only for very short periods so that the water for human and animal consumption comes from boreholes. The quality of the borehole water also varies considerably. Smit (1964) and Louw (1964) provide more information on the hydrology and water quality of the KGNP.

THE SOILS

The soils were identified and classified during the reconnaissance survey according to the South African binomial soil classification system (MacVicar, De Villiers, Loxton, Verster, Lambrechts, Merryweather, Le Roux, Van Rooyen & Harmse, 1977). A variety of soils (15 soil series of 7 soil forms) have developed mainly from the sandy parent materials and alluvium and are shown in Table 1. These soils were morphologically described by investigating several auger observations selectively sited throughout the park. Field mapping of soil boundaries using a soil auger was done on 1 : 50 000 topocadastral sheets. The intention was to construct a very small scale soil association map (scale approximately 1 : 100 000) of the KGNP. Soil samples of many observations were taken for laboratory analyses. Soil identification and mapping was done with the aid of normal standard techniques and morphological features were described by standard terminology for soil profile descriptions. Morphological features and analytical data of selected soils are presented in Table 2.

Generally speaking, the soils of the KGNP can be subdivided into the following five broad groups: (i) red eutrophic fine and medium sandy soils of the Hutton soil form; (ii) yellow-brown eutrophic and calcareous fine and medium sandy soils of the Clovelly soil form; (iii) deep calcareous reddish brown and grey-brown loam and clay loam soils of the Oakleaf, Dundee and Valsrivier soil forms; (iv) brown calcareous sandy clay loam soils of the Swartland form and (v) shallow brown and yellow-brown calcareous sands and loams of the Mispah form.

In the following paragraphs attention will be focused upon a general description of these broad soil groups with reference to their classification, position in the landscape, properties and distribution.

Table 1

Soil forms, series characteristics and origin

Soil form[1]	Soil series[2]	Soil depth	Clay content of B horizon (%)	Sand grade of B horizon	Other characteristics and origin	Occurrence
Hutton	Roodepoort	2,0 m	2-5	fine	Red (2.5YR 4/6 - 5YR 5/8) eutrophic	Dominant
					structureless sandy soils, non-calcareous,	
	Gaudam	2,0 m	2-5	medium	non-saline. Aeolian sands.	Dominant
Clovelly	Bleskop	1,0 m	2-5	fine	Yellow-brown (5YR 6/8-10YR4/4) eutro-	Dominant
					phic, structureless soils. Non saline.	Dominant
	Oranje	1,0 m	2-5	medium	The former two series are calcareous and	Dominant
	Sunbury	1,0 m	2-5	fine	the latter two non-calcareous. All four of	Sub-dominant
	Sandspruit	1,0 m	2-5	medium	aeolian origin.	Sub-dominant
Oakleaf	Allanridge	2,0 m	10-15	fine	Reddish-brown to grey-brown calcareous	Dominant
	Limpopo	2,0 m	15-25	—	sands to clay loams and sometimes clays	Dominant
	Letaba	2,0 m	15-25	—	and occasionally saline. All Oakleaf soils	Dominant
	Mutale	2,0 m	35-45	—	are of alluvial origin.	Dominant
Dundee	Dundee	2,0 m	12-20	fine and	Stratified alluvium of medium texture,	Sub-dominant
				medium	calcareous.	Sub-dominant
Valsrivier	Lindley	2,0 m	45-55	—	Brown to grey-brown calcareous structured	Sub-dominant
					clays developed from alluvium.	
Swartland	Malakata	0,5 m	20-35	—	Brown calcareous structured clay loams	Sub-dominant
					developed from sedentary sediments.	
Mispah	Loskop	30 cm	2-8	fine and med	Brown and yellow-brown calcareous sands	Sub-dominant
	Kalkbank	30 cm	2-8	fine and med	and loams of mixed origin.	Sub-dominant

[1] A soil form in the SA binomial soil classification system is characterised by a vertical sequence of diagnostic horizons and

[2] Soil series are defined by differences within the form.

Table 2

Morphological properties and anlaytical data of selected soils

Profile No.	K41	K41	K27	K31	K46	K46	K89
Soil form	Hutton	Hutton	Hutton	Hutton	Hutton	Hutton	Clovelly
Soil series	Roodepoort	Roodepoort	Gaudam	Gaudam	Gaudam	Gaudam	Allanridge
Diagnostic horizon	Orthic A1	Red apedal B21	Red apedal B21	Red apedal B21	Orthic A1	Red apedal B21	Orthic A1
Depth (cm)	0-20	50-60	50-60	50-60	0-20	50-60	0-20
Colour	5YR 4/6 Yellowish-red	2.5YR 4/6 Red	5YR 4/6 Yellowish-red	2.5YR 4/8 Red	2.5YR 4/6 Red	2.5YR 4/6 Red	10YR 4/3 Brown to dark-brown
Structure	Structureless — single grain	Structureless — massive	Structureless — massive	Structureless — massive	Structureless — single grain	Structureless — massive	Structureless — massive
Consistence	Soft	Soft	Soft	Soft	Soft	Soft	Slightly hard
Material 2 mm	1.2% quartz gravel	0.8% quartz gravel	None	None	None	None	0.5% $CaCo_3$ fragments
Textural class	Coarse sand	Fine sand	Medium sand	Medium sand	Medium sand	Medium sand	
Clay (%)	4.0	5.0	3.0	3.0	1.0	2.0	11.0
Silt (%)	2.0	2.0	1.0	1.0	2.0	0.0	11.0
Sand (%)	94.0	93.0	96.0	96.0	97.0	98.0	78.0
Coarse sand (%)	26.4	15.5	2.8	5.4	1.0	0.2	11.5
Medium sand (%)	24.3	22.6	47.4	44.2	56.5	45.6	30.2
Fine sand (%)	49.3	61.9	49.8	50.4	42.5	53.5	58.3
Exchangeable Na (me/100 g soil)	0.01	0.02	0.00	0.01	0.00	0.00	1.00
Exchangeable K (me/100 g soil)	0.15	0.22	0.11	0.12	0.09	0.09	23.82
Exchangeable Ca (me/100 g soil)	0.71	0.92	0.48	0.30	0.22	0.20	4.10
Exchangeable Mg (me/100 g soil)	0.46	0.67	0.40	0.26	0.15	0.22	
S-value (me/100 g clay)				0.69		0.51	
S-value (me/100 g soil)				23.0		25.5	
CEC (me/100 g soil)				0.81		0.53	
CEC (me/100 g soil)				27.0		26.5	
Base saturation (%)				85.2		96.2	
pH.H_2O	6.9	7.1	5.5	5.5	6.0	5.4	8.1
Electrical conductivity (mS/m)	6	7	2	4	2	2	37
P (mg/kg)	6		2		10	5	

(*Continued overleaf*)

Table 2 (cont.)

Morphological properties and anlaytical data of selected soils

Profile No.	K89	K89	K68	K68	K61	K61	K46
Soil form	Oakleaf	Oakleaf	Oakleaf	Oakleaf	Oakleaf	Oakleaf	Hutton
Soil series	Allanridge	Allanridge	Limpopo	Limpopo	Mutale	Mutale	Gaudam
Diagnostic horizon	Neocutanic B22	Neocutanic B22	Orthic A1	Neocutanic B21	Orthic A1	Neocutanic B21	Red apedal B21
Depth (cm)	20-60	90-100	0-35	65-95	0-30	90-100	50-60
Colour	10YR 5/6 Yellowish-brown	10YR 4/2 Brown	10YR 4/2 Dark greyish-brown	10YR 4/4 Dark yellowish-brown	70YR 4/4 Dark yellowish-brown	10YR 4/3 Brown to dark-brown	2.5YR 4/6 Red
Structure	Weak subangular blocky	Weak subangular blocky	Moderate platy structure	Weak subangular blocky	Structureless – to weak blocky	Weak to moderate blocky	Structureless–massive
Consistence	Hard	Hard	Slightly hard	Very hard	Slightly hard	Very hard	Soft
Material 2 mm	1,0% $CaCO_3$ fragments	1,0% $CaCO_3$ fragments	Rare $CaCO_3$ fragments	Rare $CaCO_3$ fragments	0,3% $CaCO_3$ fragments	0,5% $CaCO_3$ fragments	None
Textural class	Fine sand		Medium sand	Medium sand			Medium sand
Clay (%)	13,0	13,0	8,0	20,0	20,0	36,0	2,0
Silt (%)	11,0	11,0	9,0	4,0	13,0	8,0	0,0
Sand (%)	76,0	76,0	83,0	76,0	67,0	56,0	98,0
Coarse sand (%)	8,4	22,4	11,5	10,9	3,3	6,8	0,2
Medium sand (%)	28,0	20,8	37,3	40,8	19,5	26,8	45,6
Fine sand (%)	63,7	56,8	51,1	46,9	77,2	66,3	53,5
Exchangeable Na (me/100 g soil)	0,00	1,93	4,64	0,87	1,98	1,17	0,00
Exchangeable K (me/100 g soil)	1,06	1,88	0,53	0,44	2,59	1,45	0,09
Exchangeable Ca (me/100 g soil)	0,98	25,50	20,72	22,35	29,28	24,68	0,20
Exchangeable Mg (me/100 g soil)	25,63	5,74	2,12	3,83	6,45	6,16	0,22
S-value (me/100 g clay)	4,13	33,05				33,46	0,51
S-value (me/100 g soil)		351				93,0	25,5
CEC (me/100 g soil)		8,04				7,59	0,53
CEC (me/100 g soil)		8,04				21,1	26,5
Base saturation (%)		>100				81,1	96,2
pH.H_2O	8,4	8,3	9,2	8,6	8,3	8,4	5,4
Electrical conductivity (mS/m)	35	57	51	25	63	41	2
P (mg/kg)	1	1		20			5

(*Continued overleaf*)

Table 2 (cont.)

Morphological properties and analytical data of selected soils

Profile No.	K58	K58	K74	K74	K55	K55
Soil form	Clovelly	Clovelly	Clovelly	Clovelly	Clovelly	Clovelly
Soil series	Bleskop	Bleskop	Bleskop	Bleskop	Oranje	Oranje
Diagnostic horizon	Orthic A1	Yellow-brown apedal B21	Orthic A1	Yellow-brown apedal B21	Orthic A1	Yellow-brown B21
Depth (cm)	0-30	50-60	0-25	50-60	0-30	50-60
Colour	7.5YR 4/6 Strong brown	7.5YR 5/6 Strong brown	10YR 5/6 Yellowish-brown	10YR 5/6 Yellowish-brown	7.5YR 5/6 Strong brown	7.5YR 4/6 Strong brown
Structure	Structureless — single grain	Structureless — massive	Structureless — single grain	Structureless — massive	Structureless — single grain	Structureless — single grain
Consistence	Soft	Loose	Loose	Loose	Loose	Loose
Material 2 mm	0,2%quartz gravel	0,4% quartz gravel	0,2% quartz gravel	0,4% quartz gravel	0,8% quartz gravel	0,8% quartz gravel
Textural class	Fine sand	Fine sand	Fine sand	Fine sand	Fine sand	Medium sand
Clay (%)	2,0	3,0	3,0	2,0	2,0	4,0
Silt (%)	3,0	2,0	2,0	4,0	2,0	3,0
Sand (%)	93,0	95,0	95,0	94,0	96,0	93,0
Coarse sand (%)	5,3	10,8	1,9	2,9	13,2	16,5
Medium sand (%)	28,9	33,9	33,9	36,3	24,6	24,5
Fine sand (%)	65,8	52,0	64,2	60,8	62,1	57,5
Exchangeable Na (me/100 g soil)	0,00	0,03	0,03	0,02	0,01	0,06
Exchangeable K (me/100 g soil)	0,17	0,16	0,18	0,13	0,17	0,18
Exchangeable Ca (me/100 g soil)	5,30	10,30	5,16	11,79	2,17	15,10
Exchangeable Mg (me/100 g soil)	0,34	0,35	0,20	0,22	0,15	0,32
S-value (me/100 g clay)			5,57	12,14		15,66
S-value (me/100 g soil)			185	607		392
CEC (me/100 g soil)			1,05	1,11		1,16
CEC (me/100 g soil)			53,0	55,5		29,0
Base saturation (%)			>100	>100		>100
pH.H_2O	7,8	8,2	8,0	8,2	8,0	7,9
Electrical conductivity (mS/m)	11	7	7	10	7	13
P (mg/kg)			14	5	11	

(i) *Soils of the Hutton form*

The soils of this form cover the largest area in the park and therefore take principality together with the Clovelly soils over the soils in these discussions.

Soils of the Hutton form are characterised by prominent red colours and very weak horizon differentiation. Profiles consist of a reddish orthic A horizon (Table 1) of varying thickness, overlying a red B horizon, which is structureless.

Differentiation into series is based upon clay content, sand grade and exchangeable base status of the clay fraction. Two soil series, the Roodepoort and Gaudam, were identified. The only difference between the two is the sand grade (Table 1). Profiles of these two series are thus very similar in morphology, parent material, chemical and physical properties. Vertically the texture of the profile is very homogeneous and may continue so for great depths in certain areas. In fact, the depth of the profile varies from a few centimetres to scores of metres as indicated by boreholes. But in general it is estimated that these soils are over 2,0 m deep.

Site and parent material

The Hutton soils generally occupy positions in the sand plains in the form of dunes as discussed under terrain morphology (Fig. 1).

The parent material of these soils is largely aeolian sand. Iron oxide-coated quartz grains form the major constituent of the soils. Minor quantities of heavy minerals (approximately 1%) consist largely of opaque minerals. Aeolian transportation is undoubtedly responsible for the distribution of their sandy parent materials over large areas of the whole Kalahari and, in some cases, long distances. Sand grains in general are well rounded and sorted. Some admixture of these aeolian materials has taken place with locally derived minerals but to a very minor extent.

Morphology

As stated earlier the morphology of these soils is dominated by striking red colours, mainly in the southeastern section of the park, weak horizon differentiation and virtual absence of structure. The orthic (topsoil) horizon of the two soil series has colours varying from reddish to yellowish red, with a fine or medium sand texture and loose consistence, and it is structureless, usually single grained or massive. The transition from A to B horizon is very diffuse, the B being essentially similar to the A horizon. With depth very slight changes in colour, texture and consistence are observable. Colour tends to become a little redder and clay content increases very slightly down the profile. The texture of the B horizon is a fine or medium sand with a loose to very soft consistence.

In view of the very sandy nature of both topsoil and subsoil, the Hutton soils are freely permeable to water. Concretions of lime and sesquioxide, stones and mottling are absent. The solum of Hutton soils is underlain, at various depths and with a clear to abrupt transition, mostly by calcrete which is regarded as a geological formation and not as a soil horizon.

Chemical properties

Both series of the Hutton form are very homogeneous with respect to chemical properties. The pH and electrical conductivity values vary little, both vertically and laterally over large areas. Reaction of the topsoil is moderately acid (pH 5–6) tending to increase slightly with depth to slightly acid (pH 6–7) to slightly alkaline (pH 7–8). Electrical conductivity values of all the Hutton soils indicate that they are relatively free from soluble salts, but have nevertheless a high base status. The total exchangeable cation contents of these soils varies according to their clay contents, CEC of the clay being approximately 0,5–1,0 me/100 g. In all the soils Ca^{++} and Mg^{++} are the dominant exchangeable cations. Organic carbon content of the topsoil is less than 0,3% and decreases rapidly with depth. The general fertility status of the Hutton and other soils is discussed in a separate section.

Mineralogical properties

As already stated the sand fractions consist almost exclusively of quartz grains coated with films of reddish iron oxide, the quartz content being of the order of up to 98%. About 50% of the heavy minerals of 1% are iron-bearing minerals. Weatherable minerals are practically non-existent.

Drainage

Because of the sandy nature and position of the Hutton soils in the landscape, practically all rain water is absorbed. Infiltration and internal drainage are very rapid or rapid. In keeping with their coarse texture, these soils have low moisture-retaining capacities. Soils of the Roodepoort and Gaudam series are somewhat droughty when of shallow depth. Soils deeper than 2 m have, however, considerable moisture storage capacities for deep-rooted plants, *e.g. Acacia* spp. From experience and field observations of similar soils in other parts of the Kalahari by the author, it can be said that moisture is retained for a considerable time after good rains, expecially under a good grass cover. Only the topsoil dries out relatively quickly. After good late summer rains the deeper Hutton soils stay moist for several months during the following winter, when vegetative activity is at its minimum.

Under the prevailing climatic conditions it is most probable that rain water rarely if ever penetrates to soil layers or geological substrata in excess of 2–3 m, except in the two main natural drainageways which receive water from catchment areas outside the park.

(ii) *Soils of the Clovelly form*

The soils of this form are similar to the soils of the Hutton form with respect to aeolian origin and texture. They are, however, markedly different in colour, chemical and mineralogical properties and to a certain extent genesis. They are also of a characteristic geographical and positional occurrence.

The profiles have a yellowish to yellow-brown or yellowish red orthic A horizon overlying a yellow or yellow-brown structureless B horizon (Table 1). Horizon differentiation is very weak and these are not highly leached, *i.e.* they are eutrophic.

Soil series differentiation is based upon clay content, sand grade and calcareousness. Table 1 shows the identified four soil series of the Clovelly form.

These four series are closely related with regard to the origin of their parent material, their morphology and chemical and mineralogical properties. Because these soils are closely related and because they occur geographically associated with each other, they are discussed as a group.

Site and parent material

Of the four series the Bleskop and Oranje soil series are dominant and occupy a characteristic position in the immediate vicinity of the Auob and Nossob Rivers. Their occurrence is limited to the banks of the rivers and especially where the direction of the river course permits westerly to northwesterly winds to blow sandy material out of the riverbed.

The landsurface on which these soils occur has a somewhat undulating appearance. These undulations are probably the result of the effect of erosion of the rivers and the materials underlying these Clovelly soils are calcareous. The sands of the Clovelly form also occur in dune-like formations, and in many places present aeolian activity is much in evidence.

The Bleskop and Oranje series also occur on the eastern leeward side of pans and deflation basins away from the rivers. They occur as sand banks or as smallish lunettes of wind-blown sand. This sand was blown out of the pans or deflation basins during dry periods and varies in colour from reddish yellow (7.5YR 7/6) to very pale brown (10YR 7/4). The sands contain calcium carbonate like the Clovelly soils closely associated with the rivers as a result of the admixture of calcareous materials. Some of the sand grains are covered with thin lime films.

The other two soil series, the Sunbury and Sandspruit, occur only as isolated patches within the dune veld and more to the north of the park and are more associated with the less red (5YR) Hutton soils. They are non-calcareous and their properties are very similar to that of the red sands.

Windblown riverine materials and an admixture of other aeolian sands form the main source of parent material. A large part of the aeolian materials has not been transported over very long distances as evidenced by its confinement to the river valleys. In the light of their distribution pattern and weak horizon differentiation it is concluded that these soils are comparatively young. At least part of the parent material is of very recent age, material still being blown out of the riverbeds under favourable conditions.

Morphology

Horizon development is generally very weak. The A horizon is structureless and loose and overlies a yellow-brown structureless B horizon. The latter consists of a soft or friable sand of fine or medium grade. Profiles are freely permeable down to the substratum. Small soft and hard lime fragments are frequent in the sand fraction of the Bleskop and Oranje series and distributed throughout the profile. The Sunbury and Sandspruit series contain no free lime. The solum of all four series is free from mottling and varies in depth between 0,45 m and 2 m but in general it can be said that they are deeper than 1,0 m. The substrata are mostly calcrete.

Chemical properties

Soil reaction is slightly alkaline (pH 7–8) to moderately alkaline (pH 8–9) in the case of the Bleskop and Oranje series. The other two series exhibit a soil reaction similar to that of the Hutton soils and this also applies to the other chemical properties of these two series. Electrical conductivity values indicate that they are relatively free from soluble salts, but are also nevertheless base-saturated. The S-value of the yellow-brown B horizon is between 1 and 15 me/100 g. Divalent cations are dominant and organic carbon content of the A horizon is very low, about 0,2%.

Mineralogical properties

The sand fraction comprises mainly quartz and also 1–3% heavy minerals. Preliminary studies on the heavy mineral residues indicated some weatherable mineral reserves in this fraction and a fairly large number of lime fragments are contained in the coarse and gravel fractions.

The principal minerals in the clay fraction are illite and mixed layer minerals with lesser amounts of quartz and felspar. Iron oxide content is less than 1%.

Drainage

The internal drainage down the profile is excessively rapid (more so than in the case of the red Hutton soils) and water-holding capacity and run-off are low. The overall moisture regime of deep soils is somewhat droughty compared to that of the Hutton soils. That of the shallow soils ($< \pm$ 50 cm) is distinctly droughty.

(iii) *Soils of the Oakleaf, Dundee and Valsrivier forms*

Apart from the red and yellow-brown aeolian soils discussed in the previous paragraphs the soils of alluvial origin form the third most important group of soils in the park. These soils are confined to the beds of the Auob and Nossob Rivers. The series identified within these forms are shown in Table 1. The Allanridge, Limpopo and Letaba are the dominant soil series.

The soils of the three forms occur either as narrow continuous strips in the river beds or on broader floodplains and very low level terraces of mainly the Nossob River.

Because alluvial soils usually have such variable texture, both vertically and laterally, it is not possible to describe the position of the different series in the floodplains of the rivers. A broad distinction is evident between the soils of the two rivers, in that the Allanridge soil series occurs more abundantly in the Auob than in the Nossob River.

Site and parent material

As said, these soils occur in the floodplains of the two rivers. It is interesting to note that along the Nossob River, especially in the central and northern parts, these soils also occur in the old meandering floodplains of this river. These floodplains are the result of the change of the river course, probably as a result of climatic changes. It is also possible that in these cut-off floodplains paleosols may occur, but this necessitates further investigation.

Alluvium is the parent material of these soils and in many places in the floodplains micro-relief features can be observed due to water erosion in the river.

Morphology

Morphologically the topsoil of the soil series of the Oakleaf form varies from sandy loam or a sandy clay loam with a structureless to weak blocky structure. The subsoil is sometimes a firm, darker-coloured sandy clay loam to even a sandy clay or clay in some instances with a weak to moderate blocky structure. As can be deduced from Table 1 the majority of the soils of this group have a loamy texture. In general the colour of these soils varies from reddish brown and brown to grey-brown. Lime concretions and nodules are commonly present in the subsoil.

In some places stratification appears and these soils belong to the Dundee soil form. Alternating sandy and silty layers of varying thickness appear and the colour ranges from brown to grey-brown. Members of the Valsrivier form are rare but are characterised by a moderate to strong blocky structure in the subsoil and a clayey texture.

Chemical properties

A marked feature of all these soils is their alkaline nature. The soil reaction is always over 7 and increases to moderately alkaline (pH 7–8) or even strong alkaline (pH 8–9). Soluble salt contents vary considerably. High concentrations of soluble salts are present in places and the soils are high in exchangeable sodium contents.

Exchangeable potassium contents are relatively high and Ca^{++} and Mg^{++} are the principal exchangeable cations in the soils not affected by high salinity. Topsoils generally have less then 0,5% organic carbon, and low C : N ratios will be encountered throughout the entire profile.

Mineralogical properties

The clay and silt fractions are the dominant mineralogical components of these soils. Having been developed mainly from rocks (mainly Karoo sediments) in the catchment area of the two rivers, it may be deduced that the clay and silt minerals are to some extent of lithological origin. This is very evident in the Nossob River where silt-size mica is abundant in recent deposits and probably originates in the upper catchment area of the Nossob in Namibia. The shales and mudstones of the Karoo formation consist of 2 : 1 clay minerals. The remainder of the clay fraction probably consisted of illitic and mixed layer minerals.

Drainage

The flat topography of the floodplains results in poor surface drainage conditions. Ponding of water on silty and clayey surface layers is a common feature during the rainy season. Although high salinity is found in these soils, areas are found that are low in soluble salts but are affected by high Na^+ saturation. Such soils are easily dispersed upon wetting with pure water becoming impermeable. During the survey, it was noticed in some instances below the confluence of the Auob and Nossob Rivers, that standing water did not penetrate deeper then 4–6 cm after three or four days.

(iv) *Soils of the Swartland form*

As the Malakata series of the Swartland form were identified as the most important soil of the pans, they will not be discussed in this paper in great detail. This soil consists of a thin light brown A horizon underlain by a grey-brown to yellow-brown moderately developed structured B horizon. The profile invariably is underlain by calcareous materials. The consistence is hard to extremely hard. Depth of the solum varies between 30 and 100 cm.

Crystals of either sodium salts or gypsum are often encountered in the lower parts of the profile. These soils are very calcareous and are also very alkaline in nature with pH values above 7,0. Subsoils are generally moderately to strongly alkaline with extreme values of up to 10,2.

The clay and silt fractions are the dominant mineralogical components of these soils.

In association with the Malakata series the Bleskop and Oranje series of the Clovelly form are found on the eastern leeward side of the pans and deflation basins in the form of smallish lunettes of aeolian sand. Many theories on the evolution of pans have been advanced and this topic is widely discussed in literature. Van Rooyen & Burger (1973) discussed the formation of pans and relevant aspects in the arid and semi-arid parts of South Africa in more detail.

(v) *Soils of the Mispah form*

Two series were identified in this form, and a characteristic feature of these soils is their relatively shallow depth, thin (usually less than 0,45 m) brown or yellow-brown A horizon, very low in organic matter, overlying calcrete. They also occur in the immediate vicinity of the river floodplains where calcrete materials are sometimes exposed (Fig. 1).

The difference between the two series identified is that the Loskop series is non-calcareous in the A horizon and the Kalkbank is calcareous in the A. The texture of their A horizons varies from a sand to sandy loam and the sand grade is either fine or medium. These soils do not occupy large areas in the KGNP.

Plant nutrient status of the soils of the KGNP

The plant nutrient status of any soil, whether cultivated or utilised in its natural state as pasture, needs consideration. In a park like the KGNP where vegetation is very important not only in terms of yield during certain times of the year, the quality is of equal importance. A deficiency in one or more plant nutrients, or a state of imbalance among nutrients, has a much greater and more immediate influence on plant growth.

The soils of arid to semi-arid regions are, as a rule, well supplied with most of the essential plant nutrients. Such soils suffer little loss of solubilised nutrient compounds through leaching. In contrast to this, the sandy soils of the Hutton and Clovelly forms in the KGNP are inherently infertile. Hutton soils are extremely deficient in available phosphate. All the series of both forms have clay contents of less than 6% and are correspondingly poor in exchangeable cations. Potassium is low to medium and also magnesium. Calcium is low in the Hutton soils and in the Sunbury and Sandspruit series of the Clovelly form, but high in the Bleskop and Oranje series. It can thus be said that these soils are in general free from soluble salts and especially exchangeable Na^+ and sodium salts as far as the major plant nutrients are concerned. This also applies to the Mispah soils.

Total nitrogen, which is mainly contained in the organic matter fraction, is generally low in all the soils of the KGNP.

In contrast to the general infertility status of the Hutton, Clovelly and Mispah soils, the fine textured soils are inherently more fertile. Soils of the Oakleaf, Valsrivier, Swartland and even Dundee forms are rich in exchangeable cations. Available phosphate content is, however, relatively low but higher than in the sandy soils. Calcium carbonate is often present in concentrations so that the pH values are well above neutral, which can cause the non-availability of one or more nutrients, notably minor plant elements such as zinc, copper, manganese and iron. As said previously some soils of alluvial origin contain high concentrations of saline salts. Crystallisation of soluble salts on the surface is commonly found in these soils and also in Swartland soils in the pans. In this dry climate, desiccation of the salt-encrusted surface soil leads to the formation of a fluffy surface layer. This type of salt crust is characteristic of areas where low air humidity prevails with consequent desiccation and pulverisation of the salt crust upon and in the uppermost soil layer. Thus a porous fluffy salty surface layer is formed.

In conclusion, the low phosphate status of the Hutton soils had great economic implications with regard to cattle production in the previous century and the first decades of the 20th century. Cattle suffered heavily from bovine parabotulism, a contagious disease contracted from eating bones as a result of phosphate hunger. Sir Arnold Theiler solved this mystery disease by feeding the cattle phosphate licks.

In the soil ecosystem that is present in the KGNP, it may be that the more fertile soils of the rivers and pans, and especially the relatively higher phosphate status of these soils, play a role in preventing phosphate hunger among game. It remains a mystery how the large *Acacia erioloba* trees are able to absorb sufficient phosphate from the extremely P-deficient Hutton soils in the Kalahari. The higher phosphate and water levels in the alluvial soils of the Auob and Nossob Rivers may account for the large *A. erioloba* trees in these riverbeds.

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