SOIL SURVEY OF UITKOMST RESEARCH STATION

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ABSTRACT

A semi-detailed soil survey of Uitkomst Research Station, near Grootfontein in northern Namibia, was completed by staff of the Namibian Ministry of Agriculture, Water and Rural Development in November 1996. The survey procedure was a compromise between the aerial photograph unit method and the grid method. The final map scale is 1:25 000. Seven main soil types, further divided into 17 soil mapping units, were identified and described.

This article briefly describes the location of the survey area, methods used, geology, (preliminary) agro-ecological zones, land forms and probable landscape evolution, as well as the 17 soil units. The potential and limitations for agriculture of soil units are summarised. Soil units are correlated, where possible, with the FAO Soil Map of the World Legend (1990) and the South African Soil Classification System (1977 & 1990).

INTRODUCTION

A semi-detailed soil survey of Uitkomst Research Station had been executed in November 1996 by Messrs H. Mouton, J. Kutuahupira, A. Calitz and H. Beukes. They were guided by Dr F. Beernaert. This formed part of a Technical Co-operation Project (FAO/TCP/NAM/6611) between the Ministry of Agriculture, Water and Rural Development, and the Food and Agriculture Organisation of the United Nations, under the auspices of the Agro-ecological Zoning (AEZ) Project of the Ministry.

LOCATION OF SURVEY AREA

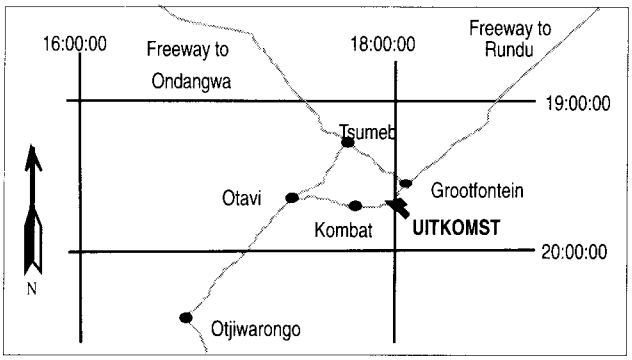

FIGURE 1: LOCATION OF UITKOMST

Uitkomst Research Station is located 20 kilometres south-west of Grootfontein, on the Grootfontein-Otavi road (see Figure 1). The farm has an elongated north-west to south-east length of about 17 kilometres and a maximum width of 7 kilometres. The size of the farm is 6 559,4 hectares. The present boundary includes portions of three original farms: Uitkomst no 41 (2 128.1 ha), Klein Uitkomst no 185 (2 460.7 ha) and Gressenhof no 374 (1 970.6 ha).

METHODS

The first step of the investigation was a desk-study of the vegetation, climate, topography and geology of the survey area. Normal visual and stereoscopic interpretation of aerial photographs (APR Photography 1973, Job No 723/23, Run 10 No 427-429, Run 11 No 285-286) was done to delineate distinctive features. Landforms were identified on 1:50 000 topographic maps (Hoba 1917 DB, Grootfontein 1918 CA, Zwarzfeld 1918 CC, 1978). The Geological Map of Namibia (Geological Survey of Namibia, 1980), to a scale of 1:1 000 000, was also evaluated.

The actual fieldwork served to identify landforms, land units, soils and to characterise each soil type. Surveying was done at a semi-detailed level and the final map was drawn to a scale of 1:25 000.

Fieldwork started with an overview of the geology, landforms and their relationship with the soils and vegetation. Eighty-one soil augerings were done. In steep areas, the pedo-transect method was followed. On the plain, transects were placed mainly along existing roads and tracks. The methodology was, thus, based on a compromise between the grid method and the aerial photograph unit sampling method.

During the augerings, each soil horizon was described according to FAO terminology: colour, texture, consistency, pH, stoniness, presence of carbonate, landform, position in the landscape, surface cover, surface stoniness, signs of erosion, crusting and hardpan formation. Field maps were updated daily.

The final step of the fieldwork consisted of digging soil profiles at typical site locations. At this level, soil horizons were described more accurately. Samples were taken for physical and chemical analysis. Photographs were taken of the profiles. The exact locations of all soil profiles and augerings were mapped.

RESULTS

Geology (Geological Survey, 1980 & 1982)

The Precambrian Lower Mokolian (> 1 800 Ma) unit exists as a narrow band at the foot of the mountain range. The metamorphic complex consists largely of para-gneiss and meta-sedimentary rocks. No outcrops could be observed, as a thick calcrete overlies these rocks.

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The Precambrian, mainly sedimentary Damara Sequence (Namibian 1000 - 750 Ma) underlies most of central and northern Namibia. Carbonates, quartzites, schists, conglomerates and dolomites occur in the Otavi Group. The latter build the east-west oriented mountain range in the north of the farm.

In the Carboniferous to Cretaceous Karoo Sequence, the Etjo Formation is formed of desertic red beds and eolian sandstone. It is buried below the Kalahari Sequence in the area south of Uitkomst. No outcrops were observed, as this unit is buried below a thick calcrete layer.

The Kalahari Group is composed of sand, calcrete and gravel. At Uitkomst the Kalahari Group sediments are also hidden below a thick calcrete layer. Calcretes are secondary formations, precipitated in a pre-existing soil and indurated to a crust of several metres thick.

Agro-ecological zones

According to the preliminary agro-ecological zoning of Namibia (De Pauw, 1996a), Uitkomst is located across four agro-ecological zones (see Figure 2):

- Cpl16-2,
- Kalk-2
- Kalk-3,
- R.

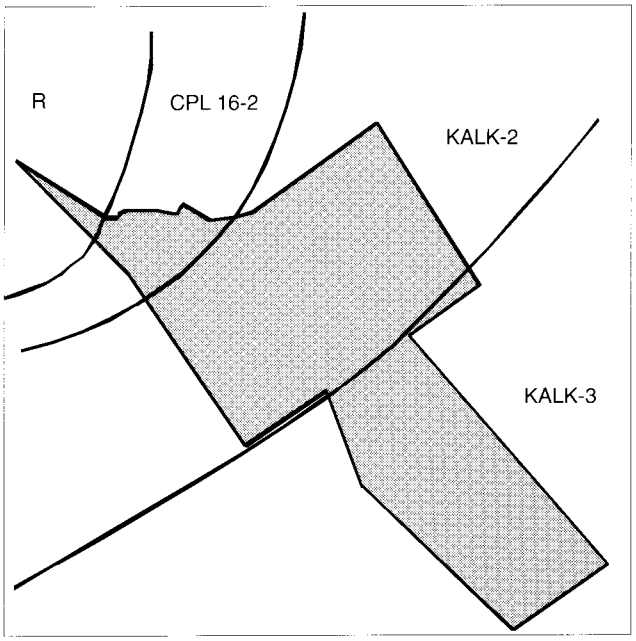

FIGURE 2: AGRO-ECOLOGICAL ZONES OF UITKOMST

- **CPL16-2** Central Plateau, red kalkveld, average growing period 91-120 days

This is the footslope area of the mountain, with a general slope range of 2 to 5 %, a general altitude range of 1000 to 1500 m (roughly 1520 to 1580 m on Uitkomst), an absolute relief interval of 10-30 m and a weakly oriented drainage pattern. The geological substrata consist of Damara metamorphic rocks and calcrete.

The growing period[3] zone is Zone 2, which indicates an average growing period of 91 to 120 days. The dependable growing period is 80 % of the average; that is approximately 86 days. The probability to equal or exceed a growing period of 90 days is 71 %. The percentage of years without a growing period (when precipitation never exceeds half the evapotranspiration) is 4 %. The earliest month for the start of the growing period is October/November. The months with the highest probability for the growing period to start are November to January.

According to the FAO Soil Map of the World, the dominant soils are Luvic Arenosols (ARl) and Cambic Arenosols (ARb), associated with Chromic Cambisols (CMx), Petric Cambisols (CLp), and having inclusions of Gleyic Solonetz (SNg) and Eutric Vertisols (VRe).

This agro-ecological zone is ranked second for agricultural potential, in Namibia. It is suitable for short-maturing crops and livestock grazing. A major limitation is the light soils. The mainly sandy and loamy soils are often shallow and are usually underlain by calcrete. The dependable growing period can be adequate for crop growing, provided deep soils with good moisture retention capacity are used.

- **KALK-2** Kalkveld, average growing period 91 - 120 days, dependable growing period 80 % of average

This is the plain on the northern half of the farm, with a general slope range of 0 to 2 %, a general altitude range of 1100 to 1400 m (1400 m to 1520 m on Uitkomst), an absolute relief interval of less than 10 m and a weakly oriented drainage pattern. The geological substrata consist of Damara dolomite, limestone, phyllite and quartzite. The SOTER landform is LP (plains) and the SOTER lithological units are SO1(sedimentary rock of organic origin; limestone, other carbonate rocks), MA1 (acid metamorphic rock; quartzite) and MB1 (basic metamorphic rock; slate, phyllite).

The growing period zone is also Zone 2, thus it is the same as for CPL16-2.

According to the FAO Soil Map of the World, the dominant soils are Petric Calcisols (CLp), associated with Calcic Vertisols (VRk) and Gleyic Solonetz (SNg), and with inclusions of Haplic Arenosols (ARh).

This agro-ecological zone also has a ranking of two for agricultural potential. Major limitations are shallowness and coarse textures of the soils. Soil depth is restricted by hard calcrete. It is only marginally suitable for short-maturing crops, but highly suitable for livestock grazing. It can be adequate for crop growth on pockets of deeper soils, with a better soil moisture retention capacity.

- **KALK-3** Kalkveld, median growing period 61 - 90 days, dependable growing period 60 % of average

This is the plain on the southern half of the farm, with a general slope range of 0 to 2 %, an altitude range of 1100 to 1400 m (1370 m to 1400 m on Uitkomst), an absolute relief of less than 10 m and a weakly oriented drainage pattern. The geological substrata consist of Damara dolomite, limestone, phyllite and quartzite. The SOTER

3 Growing Period is defined (FAO, 1987) as the period, in days, during a year when precipitation exceeds half the potential evapotranspiration, plus a period required to evapotranspire an assumed 100mm of water from excee precipitation (or less, if not available) stores in the soile profile.

landform is LP (plains) and the SOTER lithological units are SO1(sedimentary rock of organic origin; limestone, other carbonate rocks), MA1 (acid metamorphic rock; quartzite) and MB1 (basic metamorphic rock; slate, phyllite).

The growing period zone is Zone 3, which indicates a median growing period of 61 to 90 days. The dependable growing period is 60 % of the average, that is approximately 52 days. The probability to equal or exceed a growing period of 90 days is 51 %. The percentage of years without a growing period (precipitation never exceeds half the evapotranspiration) is 14 %. The earliest month for the start of the growing period is November. The month with the highest probability for the growing period to start is January.

The dominant FAO soil unit is Petric Calcisols (CLp), associated with Calcic Vertisols (VRk), Gleyic Solonetz (SNg), and with inclusions of Haplic Arenosols (ARh).

This agro-ecological zone has a ranking of three for agricultural potential. It is not recommended for crop production, due to the short dependable growing period and due to the very shallow soils. It is suitable for livestock grazing.

- R Mountains and shallow, stony soils

This agro-ecological zone occurs in the north-western corner of the farm and consists of steep mountains with shallow, stony soils of insignificant agricultural potential.

Land forms and land units

Uitkomst is situated at the boundary of two major land regions of Namibia (see Figure 3), according to the FAO Land Type Map of Namibia (FAO, 1984):

- The Otavi mountain range and its footslopes, in the north-western corner of the farm, belong to the Central Plateau area, and more specifically to the Otjiwarongo High Plain and Mountain Ranges. The mountains are composed of resistant dolomites and quartzites.

Six land units were identified:

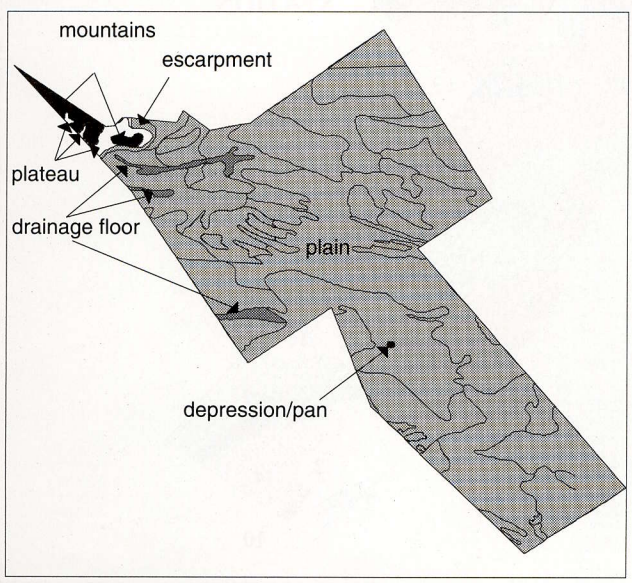

FIGURE 3: LAND UNITS ON UITKOMST.

- The largest part of the farm is located on a slightly sloping plain of the Northern Kalahari Basin, covered by thick calcrete. The Northern Kalahari is characterised by thick sand sheets and fossil linear dunes with an east-west orientation, but these only start some distance east of the farm. The most important drainage system of the area is the Omatako Omuramba, a tributary of the Kavango river.

- The dolomite mountains (1 600 - 1 818 m) have steep, rocky slopes. The dolomite shows very sharp dissolution pinnacles. Irregular slope retreat has formed isolated hills, called inselbergs, such as Quarry Mountain on Uitkomst.

- The plateau (1 570 - 1 600 m) is situated at the foot of the mountains. It is covered by red paleo-soils on calcrete. Older ironstone concretions have locally been cemented into this calcrete matrix. The plateau is the remnant of an old pediment.

- The plateau escarpment (1 520 - 1 570 m) forms the transition between the plateau and the plain. It is approximately 50 metres high.

- The plain is a slightly sloping pediment at the foot of the escarpment. It forms the margin of the Kalahari Basin. The plain is covered by a continuous calcrete layer. In many areas, a conglomeratic calcrete is found, with older, rounded, brownish calcrete gravel cemented into a younger calcrete matrix.
- A single closed depression (pan) is found on the plain, within the farm boundaries.

- The plain has several wide NW-SE oriented drainage floors, without distinct river or stream beds. Drainage towards the Omuramba Omatako occurs through sheet flow on these drainage floors.

Tentative landscape evolution at Uitkomst

The Otavi dolomite mountains, in the north-west of Uitkomst, have steep slopes with abundant rock outcrops. Deep dissolution fissures and razor-sharp pinnacles are common. The dolomite pinnacles were probably formed by dissolution processes in the subsoil (see Figure 4).

Most likely, the Otavi mountains were once covered by a thick mantle of red soils and vegetation, formed during a more humid phase than the present. Remnants of the former red soil cover can still be observed in fissures and pockets. Locally abundant ironstone concretions accumulated in its basal parts. Gradually, climatic conditions became drier and calcrete formed in this soil, cementing the ironstone concretions. As the aridity increased, the red soils were partly removed by wind and water erosion. At those places, one can observe a gentle step where the underlying, ironstone-holding calcrete is exposed at the surface. (This is visible on the present Uitkomst plateau, close to the escarpment.) More recently, shallow Calcisols have formed in and on the exposed calcrete.

During a first pedimentation phase, escarpment retreat formed a footplain, (present-day Uitkomst Plateau) at the foot of the mountains. The retreat of the escarpment was not uniform and some isolated outliers (inselbergs), such

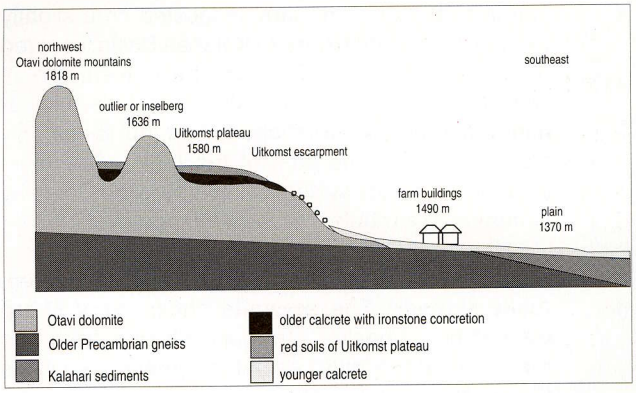

FIGURE 4: SCHEMATIC TRANSECT OF UITKOMST

as Quarry Mountain (1,636 m), remained as witnesses on the plain.

A second pedimentation phase started, probably after slight tectonic uplift of the area. The escarpment retreat gradually reduced the size of above-mentioned older plain, of which Uitkomst Plateau (1580 m) is a last remnant. A new plain developed (at 1370 to 1520 m above sea level) equally over all geological strata. This is the present Uitkomst Plain that covers most of the farm. The retreating escarpment (second phase) nowadays has reached the southern slopes of Quarry Mountain.

A second calcrete layer developed over the entire plain, under semi-arid conditions. Brownish rounded gravel of an older, reworked calcrete (perhaps originally from Uitkomst Plateau) was cemented in the new calcrete matrix.

Since the plain was covered by calcrete, landscape evolution became dominated by two processes:

- in situ weathering of calcrete and formation of grey calcareous soils (C2 - haplic and petric Calcisols);
- transport and reworking of sediments in a north-western to south-eastern direction, over the 1 to 2 % sloping plain. Some weathering products originate from the retreating escarpment. The dominant process is not river transport, but sheet wash, within locally weakly expressed colluvial drainage lines, without confined stream beds. The typical soils formed by this process, are brown non-calcareous soils, abruptly overlying calcrete (B2 - chromic and eutric Cambisols).

In nature both processes are overlapping. More recent erosion has removed much of the soil cover on the plain and left gravelly soils or Leptosols behind.

Soils

The soil survey identified seven main soil types:

- Reddish brown soils (R)
- Brown soils (B)
- Calcareous grey soils (C)
- Sodic (Solonetz) soils (S)
- Dark soils (D)
- Gravelly soils (G)
- Shallow soils (L)

These were further subdivided into 17 different soil mapping units (see Figure 5), according to their texture, soil phase, geomorphological phase, depth and type of underlying material.

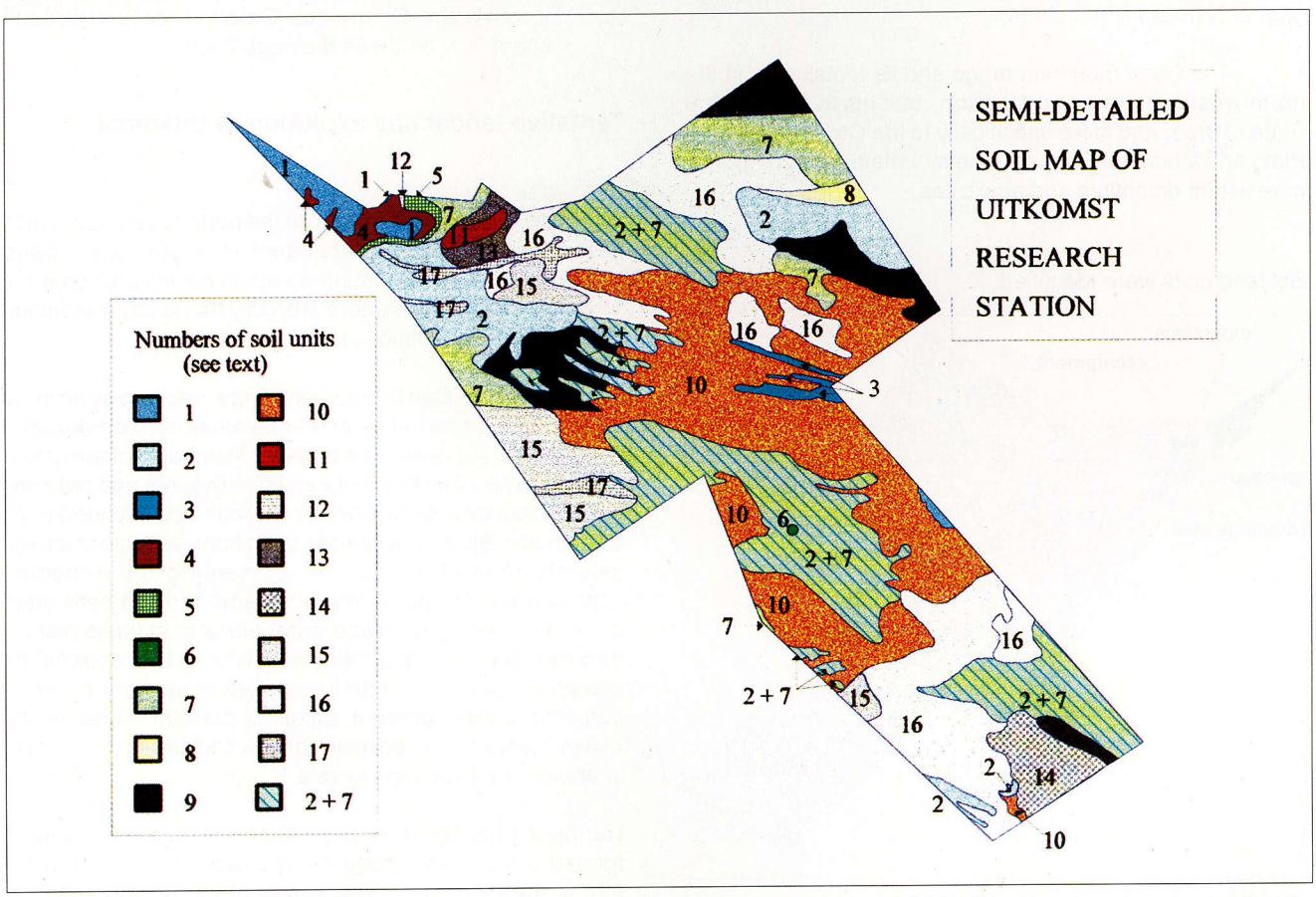

FIGURE 5: SOIL MAP OF UITKOMST

TABLE 1: SUMMARY OF SOIL MAPPING UNITS.

Soil Symbol		Soil Description
Shallow Non-Calcareous Soils		
1	m - L2,r •RD	stony, shallow (<30 cm), medium-textured, brown soils (FAO Leptosols); on steep mountains, overlying hard dolomite rock
2	x - L2,s(k) •K	shallow (<30 cm), medium-textured, dark soils (FAO Leptosols), overlying hard calcrete, with surface and sub-surface stones, with moderate surface crusting and sheet erosion; on plain
3	x - LB2,e •K	shallow (<30 cm), medium-textured, brown, non-calcareous soils, abruptly overlying hard calcrete; A-horizon and part of B-horizon have been eroded; on plain
Reddish Brown Non-Calcareous Soils		
4	p - R2,r p - R2,S,r	deep (> 1.5 m, up to 4 m), medium-textured, reddish brown soils, with (1% boulders (30 cm - 2 m) on surface and in soil, strong surface crusting and sheet erosion in some areas; on plateau
Gravelly Calcareous Soils		
5	e - G2,k,r	medium-textured, dark, calcareous topsoil, abruptly overlying calcrete gravel (70 - 80%) mixed with fine earth of the topsoil; on escarpment
6	d - G2,k, /K	medium-textured, dark, calcareous topsoil, overlying calcrete gravel mixed with fine earth of the topsoil, overlying continuous, hard calcrete; in depression on plain
7	x - G2,k,s /K	medium-textured, hard, dark, calcareous soils, abruptly overlying abundant calcrete gravel (70 - 90 %) mixed with fine earth of the topsoil, overlying hard calcrete, with moderate surface crusting and sheet erosion; on plain
Sodic Soils		
8	x - S2•3,k,s	deep, Solonetz soils with medium-textured topsoil, extremely hard, alkaline, silty clay to clayey subsoil, pH of subsoil > 9.0, with moderate surface crusting and sheet erosion; on plain
Dark, Hard, Non-Calcareous Soils		
9	x - D2,s /K x - D2,s /XK /K	moderately deep (30 - 100 cm), very hard, medium-textured, dark, non-calcareous soils, abruptly overlying hard calcrete OR weathered calcrete on hard calcrete, with moderate surface crusting and sheet erosion; on plain
Brown, Non-Calcareous Soils		
10	x - B2,s-S /K x - B2<3,s /K	moderately deep (30 - 100 cm), brown, non-calcareous soils, with medium-textured topsoil overlying either medium textured subsoil, OR a silty clay subsoil at a depth of 25 - 50 cm, with a temporary water stagnation horizon below the Bw-horizon, abruptly overlying hard calcrete, with moderate to strong surface crusting and sheet erosion; on plain
11	x - B2,s,h-H	deep, medium-textured, brown, non-calcareous soils, with a temporary water stagnation horizon below the Bw-horizon, with moderate surface crusting and sheet erosion, with a hardpan when cultivated; on plain
Calcareous Soils		
12	p - C2,s /K	moderately deep (30 - 100 cm), medium-textured, grey, calcareous soils, developed in weathered calcrete and overlaying hard calcrete, with moderate surface crusting and sheet erosion; on plateau
13	x - C2,s,h-H x - C2<3,s,h-H	deep, calcareous soils, with dark, sometimes very hard medium-textured topsoil, with either medium-textured grey subsoil OR a grey, (silty) clay loam to clay subsoil at a depth of 25 - 50 cm, containing powdery lime and pieces of weathered calcrete, with moderate surface crusting and sheet erosion, with a hardpan when cultivated; on plain
14	x - C2,s-S /K x - C2<3,s /K	moderately deep (30 - 100 cm), calcareous soils, with dark, sometimes very hard medium-textured topsoil, with grey medium-textured subsoil OR clayey subsoil, developed in weathered calcrete, overlying hard calcrete, with moderate to strong surface crusting and sheet erosion; on plain
15	x - C2,s //K	deep (100 - 125 cm), medium-textured, calcareous soils, with dark, sometimes very hard topsoil, with grey subsoil, developed in weathered calcrete and overlying hard calcrete at 100 - 125 cm, with moderate surface crusting and sheet erosion; on plain
16	x - C2,s	deep (> 125 cm), medium-textured, calcareous soils, with dark, sometimes very hard topsoil, with grey subsoil, developed in weathered calcrete and overlying hard calcrete at > 125 cm, with moderate surface crusting and sheet erosion; on plain
17	f - C2,s (/K)	deep (100 - 150 cm), medium-textured, calcareous soils, with dark topsoil and grey subsoil, overlying hard calcrete, with moderate surface crusting and sheet erosion; on drainage floors without confined stream beds

TABLE 2: SYMBOLS USED TO CHARACTERISE SOIL MAPPING UNITS.

Symbol	Land Unit (simplified description)
m	'Otavi Group' dolomite mountains
p	Uitkomst plateau at the food of the mountains
e	escarpment, bordering the plateau towards the plains
x	slightly sloping footplain of the escarpment; margin unit of the Kalahari Basin
d	closed depression or pan
f	wide drainage floor on the plain, without confined stream bed
Symbol	**Soil Type (simplified description)**
L	shallow soils, overlying calcrete or hard rock at a depth of less than 30 cm (FAO eutric Leptosols)
B	brown (10 YR) to strong brown (7.5 - 5 YR), non-calcareous soils, abruptly overlying platy and sub-rounded calcrete
R	reddish brown soils (5 - 2.5 YR)
D	dark, shallow, non-calcareous soils
S	Solonetz soils (pH of B-horizon > 8.5)
LB	shallow (< 30 cm) brownish soils (eroded B soils)
C	grey calcareous soils in strongly weathered calcrete, overlying hard calcrete
G	gravelly soils (> 50 % of gravel in the soil)
Symbol	**Texture description**
2	medium soils (sandy loam, sandy clay loam, loam, silty loam, silt, silty clay loam, clay loam)
3	clayey soils (sandy clay, clay, silty clay)
Symbol	**Contrasting textural classes in one soil**
2 < 3	a medium layer overlies a clayey layer, at a depth of 25 - 50 cm
2 • 3	a medium layer overlies a clayey layer, at a depth of 10 - 25 cm
Symbol	**Soil phases**
r	rudic or stony phase; difficult for mechanised agriculture, due to surface stoniness
k	calcareous, non-cemented material
e	eroded topsoil; areas affected by strong sheet erosion
h	a slight hardpan below or in the topsoil
H	a strong hardpan below or in the topsoil
s	slight to moderate surface sealing and crusting (sheet erosion and runoff problem)
S	strong surface sealing and crusting (important sheet erosion and runoff problems)
Symbol	**Soil depth limitations**
•	rock at a depth of < 30 cm (leptosols)
/	rock at a depth of 30 - 100 cm
//	rock at a depth of 100 - 150 cm
R	rock outcrop, no soil cover
Symbol	**Type of substratum overlain at a depth of < 125 cm**
XK	weathered rock: calcrete
K	hard rock: calcrete (petrocalcic)
RD	hard rock: dolomite

TABLE 3: CORRELATION OF SOILS FOUND ON UITKOMST WITH THE FAO'S LEGEND OF THE SOIL MAP OF THE WORLD (FAO,1974 & 1977 & 1990) AND THE SOUTH AFRICAN BINOMIAL SOIL CLASSIFICATION SYSTEM (MACVICAR ET AL.,1977; SOIL CLASSIFICATION WORKING GROUP, 1991).

Soil Type	FAO Classification	South African Classification
m - L2,r •RD	eutric Leptosols, rudic phase	Mispah Form, Mispah Series (1977) Mispah Form, Myhill Series (1991)
x - L2,s(k) •K	petrocalcic eutric Leptosols	Mispah Form, Loskop Series (1977) Coega Form, Nabies Series (1991)
x - LB2,e •K	petrocalcic eutric Leptosols	Mispah Form, Kalkbank or Loskop Series (1977) Coega Form, Marydale or Nabies Series (1991)
p - R2,r p - R2,S,r	chromic Luvisols, rudic phase	Hutton Form, Shorrocks Series (1977), Hutton Form, Ventersdorp Series (1991)
e - G2,k,r	haplic Calcisols, rudic phase	Mispah Form, Kalkbank or Loskop Series (1977) Coega Form, Marydale or Nabies Series (1991)
d - G2,k, /K x - G2,k,s /K	petric Calcisols, rudic phase	Mispah Form, Kalkbank or Loskop Series (1977) Coega Form, Marydale or Nabies Series (1991)
x - S2•3,k,s	calcic Solonetz	Estcourt Form, Buffelsdrif Series (1977) Estcourt Form, Zastron Series (1991)

x - D2,s /K x - D2,s /XK /K	petrocalcic and eutric Regosols	Mispah Form, Loskop Series (1977) Coega Form, Nabies Series (1991)
x - B2,s-S /K x - B2<3,s /K x - B2,s,h-H	eutric and chromic Cambisols	Oakleaf Form, Leeufontein Series (red) and Jozini Series (brown) (1977) Oakleaf Form, Caledon Series (red) and Ritchie Series (brown) (1991)
p - C2,s /K x - C2,s-S /K x - C2<3,s /K x - C2,s //K	petric Calcisols	Mispah Form, Kalkbank Series (1977) (tentative) Prieska Form, Hougham Series (1991)
x - C2,s,h-H x - C2<3,s,h-H x - C2,s	haplic Calcisols	Mispah Form, Kalkbank Series (1977) (tentative) Etosha Form, Platdoorns Series or Addo Form, Glenconnor Series (1991)
f - C2,s (/K)	petric or haplic Calcisols	Mispah Form, Kalkbank Series (1977) (tentative) Etosha Form, Platdoorns Series or Addo Form, Glenconnor Series (1991)

TABLE 4: SUMMARY OF THE AGRICULTURAL POTENTIAL AND LIMITATIONS OF SOIL MAPPING UNITS.

SOIL SYMBOL	AREA	FAVOURABLE CHARACTERISTICS FOR CROP PRODUCTION AND PASTURE	MAIN LIMITATIONS FOR CROP PRODUCTION AND PASTURE
Land Favourable For Crop Production And Pasture			
p - R2,r p - R2,S,r	1.0% 65.1 ha	deep soils; deep rooting; favourable water storage capacity; soil water storage benefits from runoff from mountains	when cleared for pasture: strong sheet erosion and surface crusting, low organic matter content (no or thin A horizon); low topsoil fertility; some dolomite boulders in soil and on surface
x - B2,s-S /K x - B2<3,s /K	0.5 % 32.5 ha	easily workable soils; favourable consistency; good rooting; favourable water storage due to temporary water stagnation on hard calcrete	low organic matter content; low topsoil fertility; surface crusting and sheet erosion; hard calcrete limits soil depth to 0.5 - 1 m; hardpan formation when cultivated
x - B2,s,h-H	25.0 % 1642.8 ha	very deep, easily workable soils; favourable consistency; good rooting	low organic matter content; low topsoil fertility; surface crusting; sheet erosion; strong hardpan formation; compaction when cultivated
x - C2,s x - C2,s,h-H x - C2<3,s,h-H	6.6 % 434.0 ha	very deep; favourable water storage capacity	low topsoil fertility; surface crusting; sheet erosion; hardpan formation when cultivated; too calcareous in depth; rooting reduction in depth due to soil hardness; alkaline at > 1.2 m
f - C2,s (/K)	1.8 % 117.1 ha	very deep; favourable water storage capacity	low topsoil fertility; surface crusting; sheet erosion; hardpan formation when cultivated; too calcareous in depth; rooting reduction in depth due to soil hardness; alkaline at > 1.2 m
x - C2,s //K	2.3 % 153.4 ha	deep; favourable water storage capacity	low topsoil fertility; surface crusting; sheet erosion; hardpan formation when cultivated; too calcareous in depth; rooting reduction in depth due to soil hardness and compaction
x - C2,s-S /K x - C2<3,s /K	17.7 % 1159.1 ha		low topsoil fertility; surface crusting; sheet erosion; hardpan formation when cultivated; too calcareous in depth; rooting reduction in depth due to soil hardness; hard calcrete limits soil depth to 0.5 - 1m
p - C2,s /K	0.2 % 13.1 ha		low topsoil fertility; surface crusting; sheet erosion; hardpan formation when cultivated; too calcareous in depth; rooting reduction in depth due to soil hardness; hard calcrete limits soil depth to 0.5 - 1m
TOTAL	55.1 % 3617.1 ha		

Land Not Recommended For Crop Production			
m - L2,r •RD	1.2 % 78.1 ha		too steep slopes; rock outcrops; shallow soils; low organic matter content; low topsoil fertility
x - L2,s(k) •K	5.5 % 362.5 ha		very shallow soils; low water storage; low organic matter content; low soil fertility; surface crusting; sheet erosion; surface stoniness
x - LB2,e •K	1.0 % 64.4 ha		very shallow soils on hard calcrete; limited rooting depth; no A horizon; low soil fertility
e - G2,k,r	0.4 % 26.1 ha	some soil water storage in fine earth between gravel	steep slopes; very gravelly
d - G2,k, /K x - G2,k,s /K	2.0 % 130.0 ha	some soil water storage in fine earth between gravel	very gravelly; low water storage capacity; low organic matter content; low soil fertility; surface crusting; sheet erosion
G2 + L2	28.2 % 1847.6 ha	some soil water storage in fine earth between gravel	same as for separate units discussed above
x - S2•3,k,s	0.5 % 32.4 ha		very alkaline (pH > 9.0) & extremely hard B horizon; rooting limitation at 50-80 cm; surface crusting; sheet erosion
x - D2,s /K x - D2,s /XK /K	6.1 % 400.6 ha		shallow; very hard subsoil prevents good rooting; low organic matter content; low fertility
TOTAL	44.9 % 2941.7 ha		

DISCUSSION

Almost the whole plain of Uitkomst Research Station is characterised by 5% inclusions of slightly raised areas, with a diameter of about 10 m, where outcrops of abundant calcrete gravel are found. These occur over all soil mapping units. The calcrete fragments reach diameters of 50 cm and hard calcrete can often be observed at the surface. These raised areas are often surrounded by deep soils. When mechanised cultivation is considered, these shallow, stony areas will have to be excluded, to prevent damage to machinery.

Another general characteristic of many soils is the occurrence of a very hard, prismatic and cracked A (Ah2 or AC) horizon, overlain by a loose surface layer of 1-3 cm. The soil structure can be improved by applying organic matter, though it may not be practically and economically feasible.

The *reddish brown soils* (R2) are high in bases, but poor in organic matter and phosphorus. They are best suited for livestock production.

The *calcareous soils* (C2) have a very hard, massive and compact Ah2 horizon. This layer becomes an even more compacted hardpan or plough-pan, when cultivated. Erosion of the topsoil exposes the hardpan at the surface, where it forms large ploughing clods (50-60 cm diameter). The grey subsoil is extremely hard when dry and forms a barrier to most coarse and medium roots. Fine and very fine roots are able to penetrate and take advantage of the favourable water storage capacity of the deep haplic Calcisols. The petric Calcisols overlie a hard petrocalcic horizon at less than 1 m and have a more limited depth. Development of these soils will require enough water for irrigation, frequent application of nitrogen and phosphate fertilisers, and probably a need for regular application of micro-nutrients (iron, zinc) through foliar feeds. With these inputs, production of cotton and maize are possible. Without these costly inputs, the Calcisols should rather be left under natural vegetation for livestock production.

The *dark, non-calcareous soils* (D2) have the same problem of very hard subsoil, low fertility and low organic matter content. Poor root formation will severely restrict crop development and production, and they are best left under natural vegetation for livestock production.

The *brown, non-calcareous soils* (B2) are more productive, as can be seen by the dense grass cover of favourable species, such as *Antephora pubescens*. This is caused by temporary water stagnation on the hard, impermeable calcrete. These soils have optimal pH for most plants, but sheet erosion has removed most of the nutrients in the topsoil. The brown soils are not as hard as the other soils of the farm, and have favourable structure for rooting.

The *sodic soils* (S2.3) should best be left under natural vegetation. Any efforts to reclaim the soil, will involve very expensive management: establishment of a drainage system, application of ameliorants such as gypsum or sulphur, and leaching of the replaced sodium with large volumes of high quality irrigation water. The natural vegetation could be augmented with salt-tolerant and sodium-tolerant pasture species, such as *Atriplex* species.

The *shallow soils* (leptosols L2) and *gravelly soils* (G2) should be left under natural vegetation. The leptosols have too low water holding capacity for agronomic applications, and the gravel soils are too difficult to cultivate.

In general, the calcareous soils (C2) and brown soils (B2) have the highest potential for crop production. Both types are prone to formation of hardpans or plough-pans, which limits water infiltration. This can be controlled by ripping. The reddish brown soils (R2) on the plateau can also be considered for types of crop production where the presence of some boulders in the soil and on the surface is not an obstacle, such as planting of fruit trees. Regular fertilisation will be a prerequisite for good yields.

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REFERENCES

BEERNAERT, F., 1996. Consultancy in Land Use Planning / Agro-Ecological Zones. Mission Report. Volume I. FAO/TCP/NAM/6611. Windhoek.

DE PAUW, E., 1996a. Agro-ecological Zones Map of Namibia. Scale 1:1,000,000; FAO/TCP/NAM/6611.

DE PAUW, E., 1996b. Growing Period Map of Namibia. Scale 1:2,000,000; FAO/TCP/NAM/6611.

FAO, 1978. Report on the Agro-Ecological Zones Project. Volume 1. Methodology and Results for Africa. Rome.

FAO, 1984. Land Type Map of Namibia. Scale 1:1 000 000. 2 Sheets. Project AG:DP/NAM/78/004. Rome.

FAO, 1993. Global and National Soils and Terrain Digital Databases (SOTER). Procedures Manual. World Soil Resources Reports no 74. Rome.

FAO-UNESCO, 1974. Soil map of the world, Volume I, Legend. Paris.

FAO-UNESCO, 1977. Soil map of the world, 1:5 000 000. Volume VI, Africa. Paris.

FAO-UNESCO, 1990. Soil map of the world, Revised Legend. Rome.

GEOLOGICAL SURVEY OF NAMIBIA, 1980. Geological Map of Namibia. Scale 1:1 000 000. Windhoek.

GEOLOGICAL SURVEY OF NAMIBIA, 1982. The Geology of South West Africa/Namibia. Windhoek.

MACVICAR, C.N., LOXTON, R.F., LAMBRECHTS, J.J.N., LE ROUX, J., DE VILLIERS, J.M., VERSTER, E., MERRYWEATHER, F.R., VAN ROOYEN,T.H., HARMSE, H.J. VON M. ET AL., 1977. Grondklassifikasie, 'n binomiese sisteem vir Suid-Afrika. Navorsingsinstituut vir Grond en Besproeiing, Departement van Landbou-Tegniese Dienste. Pretoria.

SOIL CLASSIFICATION WORKING GROUP, 1991. Soil classification: A Taxonomic System for South Africa. Memoirs on the Agricultural Natural Resources of South Africa No. 15. Soil and Irrigation Research Institute. Pretoria.