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# Degradation of a soil (aridosol) and vegetation in the semi-arid grasslands of southern Africa

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**Abstract.** Degradation of the semi-arid grasslands of southern Africa involves changes in the composition of vegetation and in the characteristics of the soil. We have assigned the state of degradation to three classes, and we correlate them to changes in the physical and chemical characteristics of the surface and the subsurface soil. Decreased basal coverage by species of high ecological status, and changes in the spatial distribution of the species resulted in higher soil density, water run off loss, changes in the surface roughness, and degradation of vesicular structures. Chemical changes included a considerable decrease in the potassium, calcium, and organic carbon content of the surface soil, and an increase in the calcium and magnesium content of the subsurface soils. We discuss possible explanations of the physical characteristics and the changes in the nutritional state of the surface and subsurface soils.

**Keywords:** Degradation; Domains of attraction; Rain simulation; Semi-arid grasslands; Soil characteristics; Vegetational condition.

## Introduction

Degradation of the semi-arid grasslands in southern Africa is a multifaceted problem involving the erosion and degradation of soil, and a changing composition and basal cover of pasture species. Overstocking with grazers is a major cause of the conversion of basal cover from palatable and ecologically stable types of vegetation to an unpalatable, unstable, pioneer type of vegetation (Bosch, 1989). This has a negative influence on the acceptable stocking rate and on the physical and chemical characteristics of the soil (Kellner and Bosch, 1992; Mott et al.). Much is known about the relationship between increased soil erosion and run-off losses, decreased infiltration rates, and decreased vegetation cover and density (Snyman et al., 1985; Snyman and Van Rensburg, 1986; Rostagno, 1989). Bare patches form in degraded areas and lead to changes in the physical condition of the soil, especially on the surface, such as the formation of soil seal scalds, and uneven microtopographical surfaces and pore density. These physical characteristics, as well as the chemistry of surface and subsurface soil in different states of degradation, have a direct influence on seedling establishment, root penetration, water-use efficiency, and nutrient levels (Mott et al., 1979). To assess the state of degradation and of changing vegetation dynamics, changes in the physical and chemical characteristics of the soil should be considered. There is a serious lack of information on the influence of soil factors on rangeland degradation. We studied the relationship between changes in selected factors in surface and subsurface soils representative of three states of degradation.

## Materials and Methods

### Selection of sites

A homogeneous management unit was selected on an aridosol type of soil, in the climax grassland near Senekal in Orange Free State. The vegetation consisted of *Cymbopogon-Themeda* pure grassveld type (no. 48, Acocks, 1988). Three 30-meter-square patches were selected, each representing a different degree of degradation (Bosch and Janse van Rensburg, 1987; Janse van Rensburg and Bosch, 1990). The domain II patch was moderately degraded and was characterized by subclimax grasses with a low ecological status (increaser II-type species). The *Eragrostis* species, Wolf, was the most important in this domain (Bosch and Janse van Rensburg, 1987). The severely degraded patches were characterized mainly by bare ground. The sparse vegetation found in the domain III state is characterized by grass species such as *Aristida congesta* Roem. and Schult. and *Cynodon dactylon* (L.) Pers., and a number of dwarf shrub species, such as *Felicia muricata*, which are normally associated with heavily degraded patches in climax grassland (Kellner and Bosch, 1992). In these patches, we subjectively selected microplots representing the three states.

### Cover vegetation data

Species composition and basal cover were determined using a descending-point quadrat technique. The point-quadrat technique uses a portable 1-meter-square metal frame supporting a fixed grid system of 625 descending points (25 rows of evenly spaced points, 40 mm apart). The frame is 300 mm high and fits over permanently set pegs to ensure that surveys can be repeated at exact positions. We identified the plant at the tip of each of the descending points, and recorded the number of hits as the basal cover of each grass species.

### Runoff and soil characteristics

Runoff from the micro-plots was measured during a simulated rainstorm produced by a portable rainfall simulator. The drops were 3.5 mm in diameter, and the simulated rainfall was applied at a rate of 30 mm per hour for a period of two hours. Chemical and physical analyses were done on soil samples taken from the surface (0–50 mm depth) and subsurface (100–150 mm depth). Organic carbon, pH, and the concentration of magnesium, calcium, and potassium were determined according to methods described by Jackson (1958) and van der Merwe et al. (1984). The constant head method (Bowles, 1970) was used to determine the saturated hydraulic conductivity.

Soil clods from 0–100 mm and 100–150 mm depths were taken adjacent to runoff plots prior to the simulated rainfall event. The density of the clods was determined using the method described by Blake (1965), and the visual microrelief of the surface clods was described.

The particle sizes of the surface soil were analysed using the sieve- and hydrometer method described by Bowles (1970). The parameters of sorting, skewness, and kurtosis proposed by Folk (1961) were used to describe the distribution of particle sizes.

## Results

### Vegetation data

The difference in spatial distribution and mosaic pattern of the species in the microplots representing the different domains of attraction could be easily recognized (Figure 1). The domain I state showed an even distribution of decreaser and increaser II species with basal coverage of 12.16% and 5.12%, respectively (Figure 1A and Table 1). Although the species in the domain II microplot, were also evenly distributed (Figure 1B), the basal coverage of the decreaser species was very low (1.10%), while the basal coverage of dwarf shrubs (5.90%) and species with a lower ecological status (increaser II species - 9.12%) was much higher, indicating an unstable, partially degraded state (Figure 1B and Table 1) (Bosch, 1989). The microplot representing the severely degraded domain III had low basal coverage (5.92%) (Figure 1C and Table 1). The increaser III species (pioneer grasses with a low ecological status),

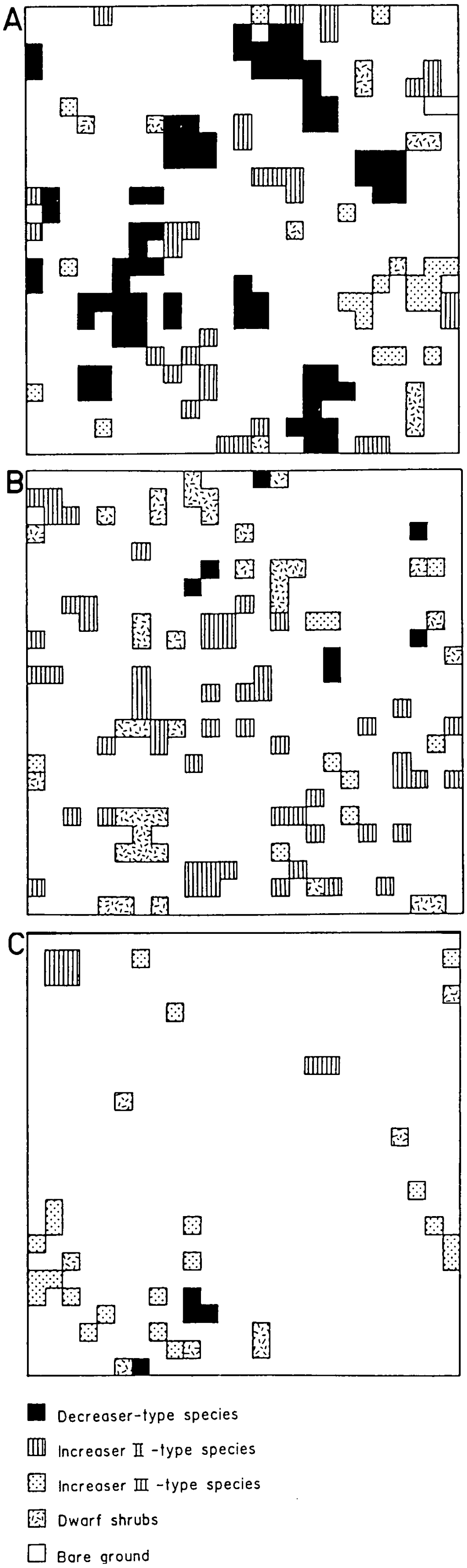


**Figure 1.** The spatial distribution and mosaic pattern of the species of different ecological status in microplots representing three different states of vegetation. **A**) domain I; **B**) domain II; **C**) domain III.

**Table 1.** Basal coverage by ecological status group, and percentage bare ground found in the domain I, II, and III microplots.

| | Basal coverage (%) | | |
|---|---|---|---|
| | Domain I | Domain II | Domain III |
| Decreaser-species[a] | 12.16 | 1.10 | 0.64 |
| Increaser II species[b] | 5.12 | 9.12 | 0.96 |
| Increaser III species[c] | 3.2 | 1.40 | 3.36 |
| Dwarf shrubs | 1.92 | 5.90 | 0.96 |
| Bare ground | 77.6 | 82.4 | 94.08 |

[a] Decreaser species: Dominate in healthy veld and decline when veld deteriorates.

[b] Increaser II species: Not abundant in healthy veld, but increase when veld is over-utilized in the short term.

[c] Increaser III species: Not abundant in healthy veld, but increase when veld is over-utilized in the long term or is selectively grazed.

which indicate severe degradation, had the highest basal coverage (3.36%) (Table 1). Bare patches in this microplot exposed the soil surface (Figure 1C).

### Runoff and soil characteristics

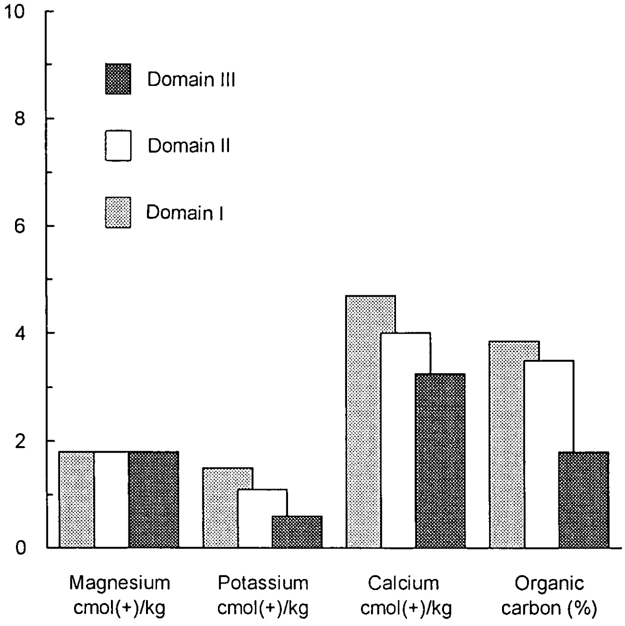
In the domain I microplots, no water runoff occurred during the simulated rainstorm. The runoff in domain II and II microplots was 41% and 45.5% of the applied water, respectively.

Domain I microplots were characterized by a rough surface and surface soil with a high saturated hydraulic conductivity (130 mm d$^{-1}$) and low density (1120 kg m$^{-3}$).

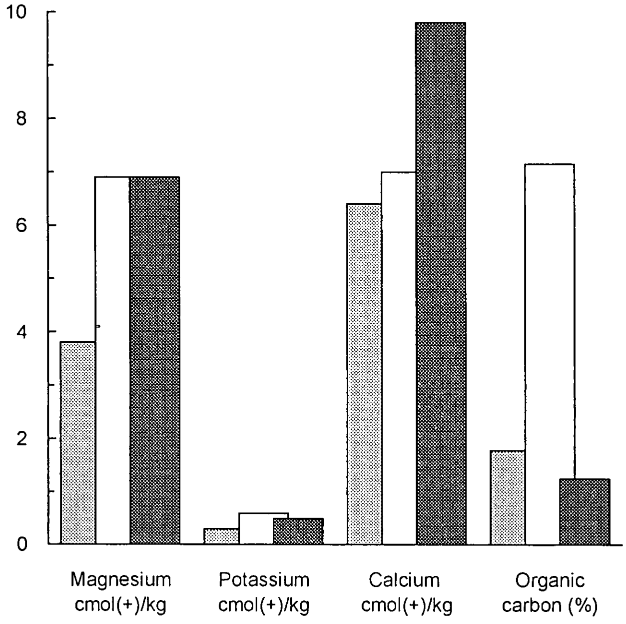
The domain II plots had an even surface with no depressions. The saturated hydraulic conductivity of the surface soil was as low as 16 mm d$^{-1}$. The density of surface soil from domain III was 1356 kg m$^{-3}$. Vesicular structures were observed in the top three millimeters in this domain.

The values for sorting, skewness or asymmetry, and kurtosis of peakedness of the domain I surface soil were 1.45, 0.04, and 2.97, respectively. The surface soil from domain III can be described as moderately sorted, finely skewed, and platykurtic.

Pronounced differences in the chemical characteristics of the soils were found. From domain I to domain III, a decrease in potassium, calcium, and organic carbon content (Figure 2) was observed in the surface soils, while in the subsurface soils, an increase in calcium and magnesium content was observed (Figure 2). Slight differences in potassium and organic carbon content were found between the subsurface soils of the three domains. The pH-values of the surface (pH 6) and subsurface (pH 5) of the three domains were constant and are not discussed further.



Surface soil (0–50 mm)



Subsurface soil (100–150 mm)

**Figure 2.** Magnesium, potassium, calcium, and organic carbon content of surface and subsurface soils from different domains.

## Discussion

Differences in basal cover, floristic composition, and spatial distribution of species resulted in less water runoff from domain I plots than from domain III plots. The higher degree of compaction of the surface soil in domain III and differences in surface roughness may have contributed to the greater runoff in the second and third domains. It has been reported that rough surfaces such as those in domain I are characterized by a greater water storage capacity and enhanced infiltration (Eldridge, 1991).

The formation of vesicular structures in the domain III microplots was probably caused by physical forces operating on trapped air in voids, as well as by capillary pressure exerted within the air-filled voids surrounded by water after rains in the structurally unstable soil. The vesicles formed were stabilized by heat expansion of the air during periods of high temperature. Ellis (1990) associates vesicular structures in the semi-arid grasslands of the Karoo with bare patches and desert pavement areas.

The higher concentration of nutrients in the surface soil of the domain I microplots probably resulted from the decomposition of a greater amount of deposited organic matter. The lower concentration of nutrients in the surface layer of the domain III microplot could be attributed to the occurrence of sheet erosion. Such similar decreases in organic carbon content in degraded veld conditions were observed by Du Preez and Snyman (1993). Once organic carbon is lost, recovery is slow. The influence of soil on recovery of degraded veld should be investigated in more detail.

The lower concentration of nutrients in the subsoil of the domain I microplots in comparison with that of Domains II and III, can be attributed to the higher density of vegetation cover. The perennial grasses of this domain have deep root systems—thus there is a higher rate of nutrient uptake from the sub-surface soil.

From these data, it is evident that degradation of certain soil characteristics can be correlated with the degradation in vegetation. The influence of differences in soil particle size distribution on the reversibility of veld in a poor condition remains unknown. Of further concern is that the ratio between cone penetration resistance and bulk density of wind blown sand in the Orange Free State is influenced by the degree of sorting (Henning et al., 1986). Poor sorting (for example soil from the domain I microplots) results in a lower cone penetration resistance than moderate sorting (for example soil from the domain III microplots) at selected bulk densities (Henning et al., 1986). The influence of soil grain size parameters on root penetration and seedling emergence in severely degraded veld need further investigation.

## Literature Cited

Acocks, J. P. H. 1988. Veld types of South Africa. Memoirs of the Botanical Survey of South Africa No. 57, 3rd edn. Pretoria Department of Agriculture and Water Supply.

Blake, G. R. 1965. Bulk density. *In* C. A. Black (ed.), Methods of Soil Analysis, Part 1. Physical and mineralogical properties, including statistics of measurement and sampling. American Society of Agronomy, Wisconson.

Bosch, O. J. H. 1989. Degradation of the semi-arid grasslands of southern Africa. J. Arid Environments **16:** 143–147.

Bosch, O. J. H. and F. P. Janse Van Rensburg. 1987. Ecological status of species on grazing gradients on the shallow soils of the western grassland biome in South Africa. J. Grassl. Soc. South Africa **4:** 143–147.

Bowles, J. E. 1970. Engineering properties of soils and their measurements. McGraw-Hill, New York.

Du Preez, C. C. and H. A. Snyman. 1993. Organic matter content of a soil in semi-arid climate with three long-standing veld conditions. J. Grassl. Soc. South Africa **10:** (in press).

Eldridge, D. J. 1991. An evaluation of cover type as a predictor of soil surface roughness in a semi-arid grassland. ranger. Journal **13:** 61–66.

Ellis, F. 1990. Note on soils with vesicular structure and other micromorphological features in Karoo soils. Pro. 16th Annu. Congress of the Soil Science Society of South Africa. University of Pretoria, Pretoria, pp. 326–336.

Folk, R. L. 1961. Petrology of sedimentary rocks. Hemphills, Austin.

Henning, J. A. G., D. J. Nel, and H. J. Von Harmse. 1986. Die invloed van verdigtingspoging, kleien waterinhoud op verdigting van geselekteerde Hoëveldgronde. S. Afr. J. Plant Soil **3:** 119–122.

Jackson, M. L. 1958. Soil Chemical Analysis. Constable and Company, London.

Janse Van Rensburg, F. P. and O. J. H. Bosch. 1990. Influence of habitat differences on the ecological grouping of grass species on a grazing gradient. J. Grassl. Soc. South Africa **7 (11):** 11–15.

Kellner, K. and O. J. H. Bosch. 1992. Influence of patch formation in determining the stocking rate for southern African grassland. J. Arid Environments **22:** 99–105.

Mott, J., B. J. Bridge, and W. Arndt. 1979. Soil seals in tropical tall grass pastures of Northern Australia. Aust. J. Soil Research **30:** 483–494.

Rostagno, C. M. 1989. Infiltration and sediment production as an effect by soil surface conditions in a shrubland of Patagonia, Argentinia. J. Range Management **42(5):** 382–385.

Snyman, H. A. and W. L. J. Van Rensburg. 1986. Effect of slope and plant cover on run-off, soil loss and water efficiency of natural veld. J. Grassl. South Africa **3(4):** 153–158.

Snyman, H. A., W. L. J. Van Rensburg, and D. P. J. Opperman. 1985. Soil and run-off measurements form natural veld with a rainfall simulator. J. Grassl. Soc. South Africa **2(4):** 35–40.

Van Der Merwe, A. J., J. C. Johnston, and L. S. K. Ras. 1984. A $NH_4HCO_3$-$NH_4F$ $(NH_4)$ 2-EDTA method for the determination of extractable P, K, Ca, Mg, Cu, Fe, Mn, and As in soils. Soil and Irrigation Research Institute, (Information Bulletin B2/2), Pretoria.

# 南非半乾旱草原之植被與 Aridosol 土壤之退化作用

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半乾旱草原之退化作用，包括了植被組成與土壤性質的變化。本項研究係於植被環境相異的三個地區進行，其植被退化的程度與表層及次表層土壤的物理及化學性質之變化呈現相關性。基底覆蓋植物種類之減少與其在空間分佈之改變，造成土壤密度與地表流量加大。並且影響到地面的平滑程度，甚至形成孔狀結構等等現象，構成了輕度乃至嚴重的退化程度。在土壤化學性質的改變方面，包括有表層土壤中鉀、鈣、有機態碳含量顯著減少，次表層土壤中鈣、鎂含量增加之現象。本篇報告亦論及土壤物理性質、表層及次表層土壤養分之變化等等有關退化作用過程之種種可能原因。

**關鍵詞**：退化作用；模擬降雨；半乾旱草原；土壤性質；植被狀態。