Declining soil quality in South Africa: effects of land use on soil organic matter and surface crusting

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Soil conservation in South Africa has historically focused on preventing soil erosion. Effective maintenance of the soil requires, in addition to erosion control, an understanding of how land-use practices affect more subtle indicators of soil quality. This review outlines how land use in South Africa can rapidly result in a marked reduction in soil organic matter (SOM) content and increased tendency of soils to crust. Removal of a cover of vegetation, whether by ploughing, grazing or burning, tends to reduce SOM due to reduced inputs of organic matter and enhanced activity of soil microbes. Loss of SOM, particularly from the top few centimetres of soil (named here the pedoderm), has a disproportionately large effect on soil infiltrability and nutrient supply. The mineralogy of the clay fraction also has great bearing on the response of soil to land-use effects. The unexpected role of quartz in soil dispersion and crusting in South Africa has only recently been revealed. Apart from SOM effects, land use can lead to subtle changes in soil chemistry. Plantation forestry has resulted in an increase in soil nitrate in many areas, possibly due to greater mineralization under forests than grasslands. Annual burning in the Kruger National Park bushveld has been shown to increase clay dispersibility and crusting of the pedoderm, which was ascribed to a reduction in electrical conductivity and SOM as well as to an increase in the exchangeable sodium percentage. Soil quality is a multifaceted concept. One aspect stands out, however, as critical and that is the conservation and replenishment of nitrogen, which is all-important for retaining humus and maintaining soil quality.

Introduction

Although soil quality means different things to different people, it is invariably defined in relation to use[1] and any significant decline in quality therefore implies misuse of soils. The effects of inappropriate land-use practices in South Africa have been in the spotlight of agricultural and political debates for centuries.[2–4] The damage, however, has usually been quantified in terms of soil loss through erosion rather than in terms of more subtle indicators of quality in the soil that has remained intact.

The development of policies and bodies to prevent and mitigate erosion in agricultural landscapes in South Africa began in 1923 with the Drought Investigation Commission report. This was followed by the Soil Erosion Advisory Council in 1930 and the Soil Conservation Act in 1946. The effect of these was effective control of erosion in many parts of the country.[5] The control of erosion is, however, only the first step in managing the soil resource effectively. The second step requires an understanding of the changes in soil chemical and physical properties that may occur under different land-use practices.

Soil quality has been typically equated with soil organic matter (SOM) or its associated indicator elements, carbon and nitrogen. Goldschmidt,[6] for example, reported on the 'nitrogen problem in pasture soils on the Natal Sour Veld'. Du Toit[7] noted that, because of widespread aridity and low humus content, South African soils generally 'have an extremely delicate nature and lack resilience' compared to soils in temperate areas. Penzhorn[8] spoke of the 'thin, vulnerable and unstable soil mantle' in South Africa. Only recently have quantitative studies begun to emerge: Du Toit *et al.*[9] found that 5–90 years of cultivation in the Free State resulted in a loss of 10–73% of C and N relative to natural grassland. Similarly, Nel *et al.*[10] found a 50% decline in C after 50 years of cropping a Hutton soil in Pretoria. The loss can be startlingly rapid. Lobe *et al.*[11] recorded a 50% decline in C after only 3.5 years of cultivation in the Free State.

This review attempts to develop an understanding of how land-use practices in South Africa have led to adverse changes in both chemical and physical properties of soils. In particular, it seeks to explain why a decline in the receptiveness of soil to water infiltration, which in the context of the semi-arid South African landscape is probably the strongest single indicator of soil quality, is not necessarily a simple consequence of the parallel decline in SOM that accompanies many land-use practices. Although the focus is on South African research, this article refers to work done in other parts of the world in order to retain a useful perspective of future research needs and possibilities.

Understanding the causes and mechanisms of soil degradation

Why is SOM depleted when veld is cultivated, heavily stocked or burnt?

Tillage is often highlighted as the main cause of SOM decline. This rests on the hypothesis that the disruption of soil aggregates leads to the exposure of organic matter to microbial attack.[12] Evidence for this mechanism is, however, scarce. Significantly, several authors have shown that increases in soil respiration after tillage cannot account for even a small fraction of the SOM loss under cultivation.[13–17] The factors leading to SOM loss through tillage, intensive grazing or frequent burning are similar in many respects and can probably be attributed, mainly, to erosion and vegetation removal.

The effect of erosion in the absence of cultivation is fairly easily explained because the exponential decrease in SOM concentration with depth[18] means that relatively little topsoil need be lost to reduce substantially the total SOM content. The effects of vegetation removal are more complex. The direct effect is a reduction in inputs of litter and root biomass. Indirectly, however, the effect of temperature,[19] wetting and drying cycles,[19–23] possible inhibitory influences of plant roots on microbial activity and the sometimes excessive removal of N relative to C,[24] may all contribute to a decline in SOM when vegetation is removed. Theron[24] showed that grass leys had a reduced rate of mineralization relative to fallow soils, which he ascribed to the release of antibacterial exudates from grass roots. He noted further that 'an almost complete repression of mineralization is particularly characteristic of permanent grass' and that under annual crops 'the repression, if any, can take place only intermittently'.[24]

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