Land use and soil organic matter in South Africa 1: A review on spatial variability and the influence of rangeland stock production

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Degradation of soil as a consequence of land use poses a threat to sustainable agriculture in South Africa, resulting in the need for a soil protection strategy and policy. Development of such a strategy and policy require cognisance of the extent and impact of soil degradation processes. One of the identified processes is the decline of soil organic matter, which also plays a central role in soil health or quality. The spatial variability of organic matter and the impact of grazing and burning under rangeland stock production are addressed in this first part of the review. Data from uncoordinated studies showed that South African soils have low organic matter levels. About 58% of soils contain less than 0.5% organic carbon and only 4% contain more than 2% organic carbon. Furthermore, there are large differences in organic matter content within and between soil forms, depending on climatic conditions, vegetative cover, topographical position and soil texture. A countrywide baseline study to quantify organic matter contents within and between soil forms is suggested for future reference. Degradation of rangeland because of overgrazing has resulted in significant losses of soil organic matter, mainly as a result of lower biomass production. The use of fire in rangeland management decreases soil organic matter because litter is destroyed by burning. Maintaining or increasing organic matter levels in degraded rangeland soils by preventing overgrazing and restricting burning could contribute to the restoration of degraded rangelands. This restoration is of the utmost importance because stock farming uses the majority of land in South Africa.

Introduction

The degradation of South Africa's soil resource base poses a serious threat to sustainable agriculture. Soil is essentially a non-renewable resource and protection of this precious resource is of the utmost importance. The country is therefore in need of a soil protection strategy and policy. In the development of such a strategy and policy, cognisance should be taken of the extent and impact of soil degradation processes. The decline of soil organic matter that coincides with some land uses was one of the processes identified for review.

In the broadest context, organic matter can be referred to as the total complement of organic substances present in the soil, including living organisms of various sizes, organic residues in various stages of decomposition and dark-coloured humus consisting of non-humic and humic substances. Humus is relatively stable and has a major effect on various soil properties and processes that play a role in the functioning of soils.[1]

Organic matter, especially the humus fraction, influences the properties of mineral soils disproportionately to the quantity of organic matter present. Organic matter is a major source of nutrients and microbial energy, holds water and nutrients in available form, usually promotes soil aggregation and root development, and improves water infiltration and water-use efficiency.[2]

The organic matter content of soils is therefore a key attribute to both soil health and soil quality. The latter was defined by Doran and Parkin[3] as 'the capacity of soil to function, within ecosystem and land use boundaries, to sustain biological productivity, maintain environmental quality, and promote plant, animal and human health'. Doran and Safley[4] defined soil health as:

> 'the continued capacity of soil to function as a vital living system, within ecosystem and land use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal and human health'.

Hence it is not surprising that these two concepts are often used synonymously without a clear distinction between them.[5] In an attempt to distinguish between the two concepts, Van Antwerpen[6] regarded soil health as the condition of soil at the time of sampling and soil quality as the condition of a soil reflecting management over an extended period of time. However, both soil quality and soil health are important in assessing the condition of soils for sustainable use.

The organic matter content of soils varies widely because the organic matter content of a soil increases over time until an equilibrium is reached. The magnitude of this equilibrium depends on interactions between the factors of soil formation. Variations in the factors responsible for soil formation experienced on a landscape scale and the interdependence of these factors, contribute to the large variability in the contents of soil organic matter, even within localised areas. The relative importance of these factors on soil organic matter follows the order: climate > biota > topography = parent material > time.[1]

Soil organic matter also is important because the soil is both a source and sink for atmospheric CO_2. It is a source because there is more than three times more carbon in the soil than in the atmosphere.[7] Soil can be a sink for carbon when the carbon content of the soil is increased through conservation practices. A clear understanding of the impact of management practices on the contents of soil organic matter is therefore crucial in any attempt to control atmospheric carbon concentrations.

The organic matter equilibrium in soils is disturbed by human activities such as crop and stock farming. Agricultural activities of this nature may either increase or decrease soil organic matter content in the long term, but in the majority of cases it has led to a decrease. The ultimate organic matter content in agricultural soils is governed by land use and the resulting land cover.[8]

Part 1 of this review addresses the spatial variability of organic matter and the impact of grazing and burning under veld stock production in South African soils. The second part of this review[9] addresses the extent of soil organic matter depletion as a result of arable crop production. Some results on the restoration of soil organic matter are also presented. Either organic carbon or total nitrogen is used as an index of soil organic matter.

Spatial variability

No systematic countrywide study has thus far been carried out to determine the status and spatial distribution of organic matter in South Africa. However, the land type survey[10] that started in 1970 described and analysed a large number of virgin soil profiles throughout South Africa. Morphological and chemical data from these profiles were augmented by various other soil surveys. The land type survey used the binomial soil classification system,[11] whilst most of the later soil surveys used the taxonomical soil classification system.[12] From these surveys, morphological and chemical data of 2380 profiles were captured in a Microsoft Access database by the Agricultural Research Council – Institute for Soil, Climate and Water (South Africa).[13]

Barnard[14] used these data to produce a generalised organic carbon map for virgin topsoils in South Africa (Figure 1). The organic carbon content of topsoils ranged from less than 0.5% to more than 4%. Only 4% of the topsoils contained more than 2% organic carbon, whilst 58% of the topsoils contained less than 0.5% organic carbon. The remainder of the topsoils contained between 0.5% and 2% organic carbon.[15] South Africa is therefore characterised by topsoils with very low organic matter levels. The distribution of organic carbon in the topsoils included in Barnard's study was to a large extent related to the long-term average annual rainfall,[14] presumably because rainfall plays a dominant role in determining the biomass production of native vegetation in the country.

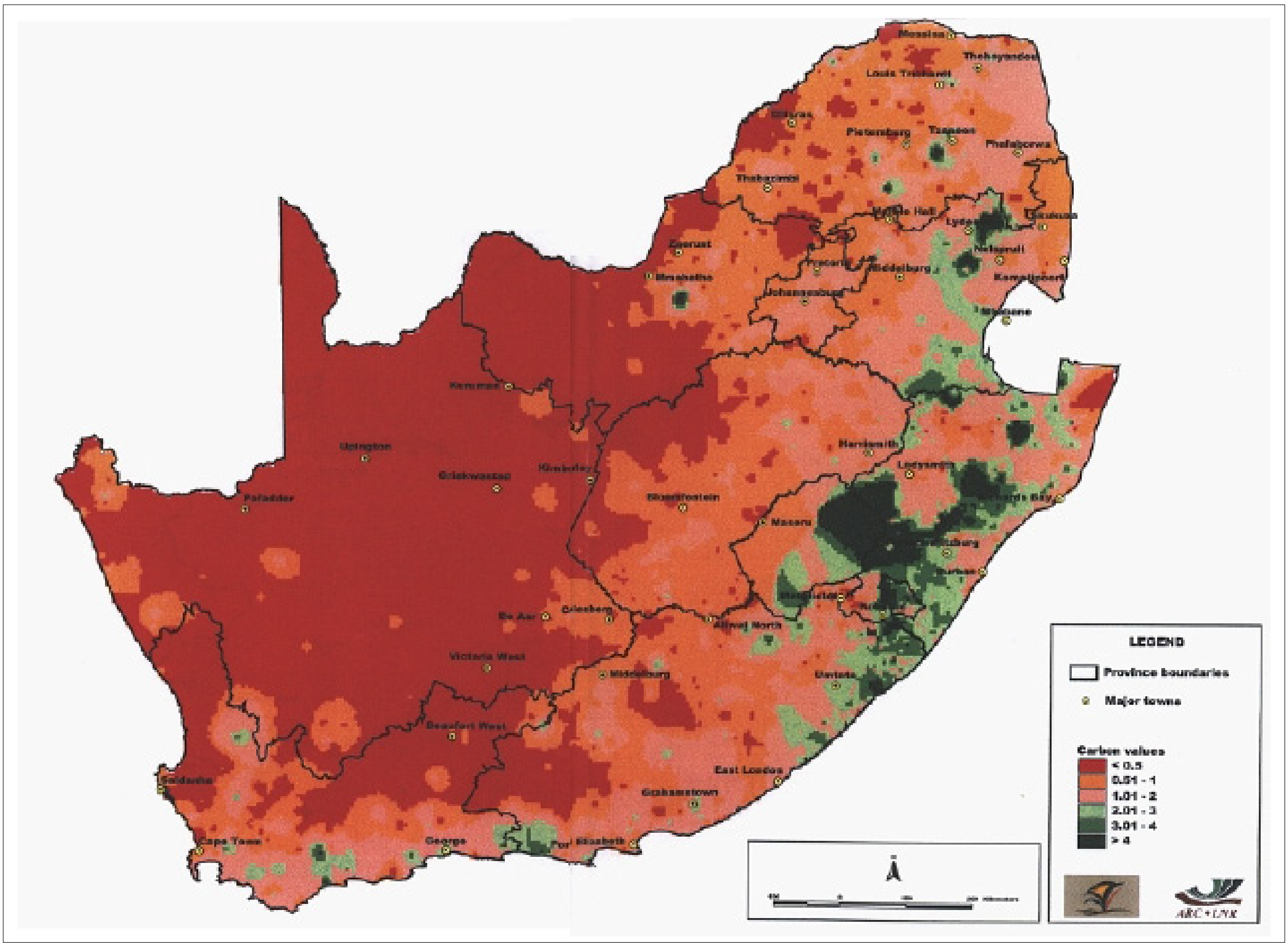
The land type survey data[10] were also grouped per master horizon (Table 1) and per diagnostic horizon (Table 2). Counts between the master and diagnostic horizon classification do not necessarily agree because certain classifications were not done per horizon. No attempt was made by the authors to validate or correct the land type survey data.

As expected, organic O horizons had the highest organic carbon – an average of 25.88% – but only four of these horizons were analysed. Of the mineral horizons, the A horizons had the highest organic carbon at 1.21%, decreasing to 0.54% in the B and 0.40% in the C horizons. Organic carbon in the E horizons (0.48%) was lower than in the B (0.54%) or G horizons (1.10%), but higher than in the C horizons (0.40%). The distribution of organic carbon in the master horizons can be related to the various soil forming processes active in these horizons.

In the diagnostic topsoil horizons, organic carbon decreased in order of magnitude from organic O (18.14%) to humic A (3.59%), melanic A (2.20%), orthic A (1.09%) and vertic A (1.09%). Patterns in organic carbon distribution were less clear in the diagnostic B horizons, probably because of a lower organic carbon content compared to the A horizons. In general, organic carbon contents were lower in the B horizons (0.29% in dorbank and 0.16% in hardpan carbonate), which is typical of drier regions. The subsoil horizons typical of wetter regions (gleycutanic = 0.38%, E = 0.49%, soft plinthic = 0.33% and hard plinthic = 0.26%), also had lower organic carbon contents than the B horizons average (0.54%), whilst structured B horizons (pedocutanic = 0.60%, prismacutanic = 0.50% and red structured = 0.87%) had higher organic carbon contents than the average.

In the Mpumalanga province, the organic carbon content of 252 topsoils under grassland was higher than that of 290 topsoils under savannah. Organic carbon under savannah ranged from 0.18% to 4.86% (with a median of 1.28%), whilst under grassland it varied from 0.09% to 12.53% (with a median of 2.51%).[14]

The amount, distribution, origin and stability of soil organic matter in *Acacia* and *Burkea* savannahs were investigated by McKean[16]. Soil organic matter contained between 50% and 95% of the organic carbon in the soil and biomass of the two semi-arid savannahs. In both savannahs, soil organic matter decreased with depth. However, the horizontal gradient



Source: Barnard[14]

FIGURE 1: Generalised organic carbon map for virgin topsoils in South Africa.

of soil organic matter from the subcanopy to open habitat differed between the two savannahs. In the case of the *Acacia* savannah it decreased, whilst it remained constant in the *Burkea* savannah. Trees and grass contributed to soil organic matter in the two savannahs in approximate proportion to their primary production, with grasses contributing 76% and trees 24%. The turnover in organic carbon associated with clay amounted to 51% over a period of 26 years. This suggests that the organic carbon associated with clay in sandy savannah soils has a much faster turnover time than the hundreds of years quoted for temperate ecosystems. In both savannahs, soil organic matter and microbial biomass were strongly correlated.[16]

Some insight into the distribution of soil organic matter in granite landscapes can be obtained from three study areas: north-east of Nelspruit,[17] Pretoriuskop[18] and Pretoria–Johannesburg.[19] In the north-east of Nelspruit, the native vegetation is typical Bushveld. The organic carbon contents of the orthic A horizons in a downslope direction were: 1.97% for the Mispah profile (mid-slope); 0.38%, 0.45% and 0.40% for the Hutton, Oakleaf and Hutton profiles, respectively (upper footslope); 0.44%, 0.42% and 0.33% for the Avalon, Longlands and Avalon profiles, respectively (mid-footslope);

TABLE 1: Organic carbon contents of master horizons.

Master horizon	Organic carbon (%)				
	Minimum	Maximum	Average	Median	Count
O	18.03	32.60	25.88	24.70	4
A	0.01	12.50	1.21	0.80	2469
G	0.10	24.80	1.10	0.49	51
B	0.01	7.70	0.54	0.40	2871
E	0.05	2.20	0.48	0.38	277
C	0.01	33.00	0.40	0.20	462

Source: Agricultural Research Council – Institute for Soil, Climate and Water (South Africa)[13]

0.10% and 0.56% for the Longlands and Cartref profiles, respectively (lower footslope); and 0.36% for the Estcourt profile (valley bottom). Bushveld is also the typical native vegetation in the Pretoriuskop area where the organic carbon contents of the orthic A horizons downslope were found to be 1.27%, 0.71% and 0.75% for the three Hutton profiles (crest) and 0.79%, 0.95%, 1.31% and 0.95% for the two Clovelly, Longlands and Kroonstad profiles, respectively (mid-slope). In the Pretoria–Johannesburg area the native vegetation is grassland. The organic carbon contents of the orthic A horizons downslope were 0.97%, 1.13% and 0.68% for the three Hutton profiles (crest); 0.57%, 0.73% and 0.50% for the Clovelly, Avalon and Longlands profiles, respectively (mid-slope); 0.50%, 0.41% and 0.64% for the three Longlands

TABLE 2: Organic carbon contents of diagnostic horizons in ARC–ISCW database.

Diagnostic horizon	Organic carbon (%)				
	Minimum	Maximum	Average	Median	Count
Organic O	1.60	32.60	18.14	18.30	7
Humic A	1.30	11.08	3.59	2.93	67
Melanic A	0.50	5.79	2.20	1.90	113
Vertic A	0.10	2.80	1.09	1.00	70
Orthic A	0.01	9.60	1.09	0.71	2175
Podzol B	0.05	7.60	1.65	1.00	13
Overburden	1.20	1.24	1.22	1.20	2
Red structured B	0.16	2.87	0.87	0.71	100
G horizon	0.05	3.40	0.68	0.43	43
Yellow-brown apedal B	0.02	5.50	0.66	0.47	478
Soft carbonate B	0.63	0.69	0.66	0.66	2
Lithocutanic B	0.06	3.40	0.61	0.50	183
Pedocutanic B	0.05	3.05	0.60	0.51	370
Prismacutanic B	0.02	3.10	0.50	0.40	189
Red apedal B	0.01	7.70	0.50	0.38	872
E horizon	0.05	2.21	0.49	0.39	296
Unspecified material	0.07	1.00	0.46	0.30	5
Saprolite	0.06	1.99	0.44	0.30	22
Neocutanic B	0.02	2.87	0.44	0.31	241
Gleycutanic (G)	0.04	4.06	0.38	0.23	95
Soft plinthic B	0.06	2.10	0.33	0.30	204
Unconsolidated material	0.04	6.11	0.32	0.20	60
Stratified alluvium	0.10	1.40	0.31	0.10	25
Dorbank	0.03	0.50	0.29	0.40	5
Hard plinthic B	0.10	0.54	0.26	0.20	9
Unconsolidated material with signs of wetness	0.16	0.16	0.16	0.18	12
Regic sand	0.04	0.90	0.16	0.10	43
Hardpan carbonate	0.10	0.21	0.16	0.16	2

Source: Agricultural Research Council – Institute for Soil, Climate and Water (South Africa)[13]

profiles (footslope); and 0.61% and 0.34% for the Cartref and Dundee profiles, respectively (valley bottom). In all three areas, the organic carbon contents in the orthic A horizons downslope decreased, regardless of the soil form.

Du Toit and Du Preez[20] obtained significant relationships ($p < 0.01$) between the organic matter contents of 41 virgin orthic A topsoils and their fine silt–plus–clay contents (organic carbon: $r = 0.91$ and total nitrogen: $r = 0.91$), the aridity indices of the localities where they were sampled (organic carbon: $r = 0.90$ and nitrogen: $r = 0.89$) and the products of aridity indices of the localities and the fine silt–plus–clay contents of the soils (organic carbon: $r = 0.94$ and total nitrogen: $r = 0.95$). These orthic A horizons from the Free State, Limpopo, Mpumalanga and North West provinces are underlain by red apedal, yellow–brown apedal and soft plinthic B horizons. The organic matter content of these virgin orthic A topsoils increased linearly with increasing fine silt–plus–clay contents and exponentially with increasing aridity index values. Organic matter content was found to be lower in the warmer, drier areas than in the wetter, cooler areas. In an area with a given aridity index the organic matter content increased with an increase in fine silt–plus–clay content. Inclusion of orthic A horizons underlain by either red structured or pedocutanic B horizons resulted in poorer relationships.

A baseline study on soil organic matter and vegetation was done in the Weatherley catchment near Maclear before this Moist Upland Grassland was converted to commercial forest.[21] Organic matter was quantified to a depth of 1200 mm in 27 profiles, representative of the soils in this 160 ha catchment. The total amounts of organic carbon and total nitrogen were 111.1 Mg/ha and 8.6 Mg/ha, respectively, for the excessively drained soils (Hutton and Clovelly forms); 85.1 Mg/ha and 6.6 Mg/ha, respectively, for the moderately drained soils (Bloemdal and Pinedene forms); 97.0 Mg/ha and 7.2 Mg/ha, respectively, for the very poorly drained soils (Katspruit, Kroonstad, Westleigh, Longlands and Klapmuts forms); and 88.3 Mg/ha and 7.2 Mg/ha, respectively, for the freely drained soils (Tukulu form).

A prominent feature is an almost similar and linear decrease in organic carbon from the surface to a depth of 650 mm, irrespective of the kind of B horizon present. For the different soil groups mentioned in the previous paragraph, the decrease was from about 0.015 Mg/m^3 to 0.020 Mg/m^3 at the surface to an average of about 0.005 Mg/m^3 at a depth of 650 mm. This decrease was followed by a much slower decrease to a fairly uniform value of about 0.003 Mg/m^3 at a depth of 1150 mm.

With regard to total nitrogen two observations are significant. Firstly, the decrease in total nitrogen with increasing depth was less pronounced than that of organic carbon, resulting in considerably lower carbon to nitrogen ratios towards the bottom of the profiles. Across all the soils, the average decrease in total nitrogen from the surface to a depth of 1150 mm was from 0.0011 Mg/m^3 to

0.0004 Mg/m^3. The equivalent decrease in the carbon to nitrogen ratio was from 15 to 6. Secondly, relative to the excessively to moderately well-drained soils, there was an accumulation of total nitrogen in the deep layers of the poorly to very poorly drained soils.

The average oven-dry biomass yield from the grassland cover was 3400 kg/ha per year. Carbon sequestration efficiency by the grassland in the catchment was estimated to be 2.1 kg/ha/mm rainfall per year. It was possible, after making some assumptions, to estimate that the equivalent value for *Pinus patula* would be approximately 2.8 kg/ha/mm rainfall per year.

In a study on the nutrient status of virgin soils in the Lusikisiki area, Bühmann et al.[22] concluded that cation exchange capacity and base status in the A horizons were much more strongly associated with organic matter than with clay content and/or the nature of the clay fraction. The organic matter content of these soils is high for South African conditions because organic carbon averaged 3.63% in the A horizons. An average of 70% of the cation exchange capacity in the A horizons was associated with organic matter. Consequently, any agricultural activities on these soils that lead to a depletion of organic matter will cause a significant reduction in cation exchange capacity, and therefore the fertility status of the soils.

Rangeland stock production

Grazing

A comprehensive doctoral study on the reciprocal relationships between vegetation structure and soil properties in selected biomes of South Africa was done by Mills[23]. Some of the findings reported in review[24,25] and research articles[26,27,28] are discussed here.

Stocks of carbon and nitrogen at selected sites in five contrasting biomes exposed to different land uses were examined by Mills and Fey[26]. The biomes included: West Coast Renosterveld (renosterveld), Central Nama Karoo (karoo), Xeric Succulent Thicket (thicket), Moist Upland Grassland (grassland) and Mixed Lowveld Bushveld (bushveld). Stocks of soil carbon to a depth of 500 mm in untransformed, indigenous veld ranged from 21 Mg/ha in karoo to 168 Mg/ha in thicket. Stocks of nitrogen ranged from 3.4 Mg/ha in karoo to 12.8 Mg/ha in grassland. The mean soil carbon of 5.6% in the upper 100 mm soil layer under thicket was approximately five times greater than expected for this semi-arid region. Removal of vegetation as a result of grazing or burning reduced soil carbon and nitrogen at all sites. Soil carbon in the upper 100 mm layer under intact thicket was greater (71 Mg/ha) than at sites degraded by goats (40 Mg/ha). Restoration of thicket could potentially sequester about 40 Mg of carbon per hectare. Soil carbon under plant cover was greater than in exposed soil under renosterveld (28 Mg/ha versus 15 Mg/ha) and in karoo (7 Mg/ha versus 5 Mg/ha). Parent material was also related to soil carbon content. In grassland, soil carbon was greater in dolerite-derived than in sandstone-derived soils (54 Mg/ha versus 27 Mg/ha), and in bushveld it was greater in basalt-derived than in granite-derived soils (28 Mg/ha versus 14 Mg/ha). Annual burning in bushveld reduced soil carbon, particularly at the surface. Soil carbon in the 0 mm – 10 mm layer of unburnt plots was 2–3 times greater than that in burnt plots. Mills and Fey[26] concluded that carbon and nitrogen stocks in untransformed, indigenous veld of the studied biomes were largely a function of climate, parent material and the cover of vegetation. Removal of this vegetation by grazing and burning reduced soil carbon and nitrogen stocks, especially in the upper 100 mm layer. They recommended that it may be worthwhile to include the 0 mm – 50 mm layer, and even the 0 mm – 10 mm layer, in future studies of this nature.

In a subsequent paper, Mills et al.[27] provided some insights on ecosystem carbon storage in four of the five biomes. They examined the storage of carbon in intact indigenous vegetation and under different land uses in thicket (with a mean annual precipitation [MAP] of 250 mm – 400 mm), xeric shrubland (MAP of 350 mm), karoo (MAP of 250 mm) and grassland (MAP of 900 mm – 1200 mm). Mean soil carbon storage to a depth of 500 mm followed the order: 168 Mg/ha in thicket = 164 Mg/ha in grassland > 65 Mg/ha in xeric shrubland on Dwyka sediments > 34 Mg/ha in xeric shrubland on dolerite > 26 Mg/ha in karoo. Root biomass carbon to a depth of 300 mm followed a trend similar to that of soil carbon, with the following means: 25.4 Mg/ha in thicket > 11.4 Mg/ha in grassland > 7.2 Mg/ha in xeric shrubland on Dwyka sediments = 7.1 Mg/ha in xeric shrubland on dolerite. Mean aboveground carbon stocks were: 51.6 Mg/ha in thicket > 12.9 Mg/ha in xeric shrubland on Dwyka sediments > 2.0 Mg/ha in grassland > 1.7 Mg/ha in karoo > 1.5 Mg/ha in xeric shrubland on dolerite. Total carbon storage therefore amounted to: 245 Mg/ha in thicket > 172 Mg/ha in grassland > 81 Mg/ha in xeric shrubland on Dwyka sediments > 42 Mg/ha in xeric shrubland on dolerite > 30 Mg/ha in karoo. The carbon stocks in intact indigenous vegetation were related more to the woodiness of the vegetation and the frequency of fire than to climate. Biomass carbon was greatest in woody thicket whilst soil carbon stocks were greatest in thicket and grassland. Soil carbon dominated ecosystem carbon storage in grassland and was influenced more by parent material than by land use. The xeric shrubland and thicket were more sensitive to effects of land use on carbon storage than grassland. Effects of land use on carbon stocks were therefore site and land use specific, which defied prediction in many instances.

Heavy browsing of xeric succulent thicket by goats resulted in the loss of *Portulacaria afra* and transformed this habitat to an open savannah dominated by annual grasses.[28] This transformation of thicket to savannah, west of Kirkwood, reduced soil carbon by 46% from 5.6% to 3.0% and soil nitrogen by 27% from 0.33% to 0.24% in the 0 mm – 100 mm layer. The tendency of these soils to crust increased with organic matter depletion.

The effect of vegetation canopy on soil organic matter was also evident within thicket and savannah. In thicket, the organic carbon of soil sampled to a depth of 100 mm under canopies of *Portulacaria afra* and in the open averaged 5.6% and 3.7%, respectively.[28] The corresponding total nitrogen values were 0.33% under the canopies and 0.26% in the open. Soil sampled in savannah under canopies of *Pappea capensis* and in the open, respectively contained 4.1% and 3.0% organic carbon and 0.30% and 0.24% total nitrogen. These differences of ~30% in organic carbon and ~20% in total nitrogen illustrate the importance of good vegetative cover in thicket and savannah to ensure high organic matter contents in the upper 100 mm soil layer. The surprising high soil organic matter in thicket suggests that the dense *Portulacaria afra* bush in this semi-arid region strongly regulates its content through microclimate, erosion control, litter quantity, and perhaps chemistry, which, according to Mills and Fey[28], merits further investigation.

A change in the condition of veld from good veld to either poor veld or bare soil was induced and maintained for 5 years on a Bloemdal form soil, near Bloemfontein.[29] After this 5-year period, significant decreases in organic matter content were observed. The largest differences were measured in the upper 25 mm where the poor veld and bare soil respectively contained 14% and 26% less organic carbon than the good veld.[29] These results were in accord with previous research on a similar soil, where conversion of veld in a good to a poor ecological condition resulted in an organic carbon loss of 33% in the upper 50 mm after 15 years;[30] these differences decreased with depth. If the organic matter content was the same for the two veld conditions at the inception of this study, the loss in organic carbon over the first 300 mm soil depth for the veld in poor condition is estimated at 1660 kg/ha over 5 years and 4200 kg/ha over 15 years. Reasons for this loss are, *inter alia,* less phytomass production, which is the major source of soil organic matter, and high soil temperatures, which accelerate decomposition of organic matter.[29,30]

Bond et al.[31] confirmed, by means of a carbon isotope study on the soil organic matter, that Karoo shrublands have spread at the expense of grasslands as a result of livestock farming since European settlement. However, evidence for a much earlier cycle of change evolved from the deeper soil layers. Their study supports the view that grass cover has declined under grazing pressure, but not that grasslands covered most of the central Karoo before European settlement.

In the Kalahari, soil organic carbon was significantly lower where either reduced rainfall or grazing lowered litter inputs to soil. Site-averaged concentrations of soil organic carbon showed no significant differences beneath plant canopies, but woody plant canopies alone showed elevated soil organic carbon at some sites.[32]

Results reported by Hansen-Quartey et al.[33] showed that the cultivation of the aromatic shrub *Artemisia afra* near Alice had no significant effect on organic matter in the upper 100 mm soil. The organic carbon content of soil under this shrub was 1.06% whilst that of the control soil was 0.91%. However, soil aggregates under the aromatic shrub had a higher stability than those of the control soil.

Burning

The long-term effects of annual burning and fire exclusion on soil organic matter were examined by Mills and Fey[34] during experiments conducted for at least 28 years in Mixed Lowveld Bushveld (Kruger National Park), Southern Tall Grassveld (Ukulingu Research Station) and Eastern Thorn Bushveld (University of Fort Hare). In the 0 mm – 100 mm layer, organic carbon and total nitrogen were respectively, on average, 12% and 13% lower in the burnt than unburnt plots: 1.68% in the burnt plots versus 1.90% in the unburnt plots for organic carbon and 0.13% in the burnt plots versus 0.15% in the unburnt plots for total nitrogen. The differences between burnt and unburnt plots were accentuated in the 0 mm – 10 mm layer: 70% for organic carbon (0.8% versus 2.7%) and 69% for total nitrogen (0.07% versus 0.23%). Mills and Fey[34] concluded that the top 10 mm of soil, which they named the pedoderm, was therefore likely to have a disproportionate effect on ecosystem functioning.

The effect of fire frequency on the organic matter content of a basaltic soil in the Kruger National Park was investigated by Jones et al.[35] After 34 years the organic carbon and total nitrogen contents in the 0 mm – 150 mm layer were approximately 25% higher in the fire-protected plots than in the burned plots. In the annually, biennially and triennially burned plots there was a gradual decline in organic carbon and total nitrogen with increasing fire frequency. The microbial biomass in the unburnt plots was twice that of the burnt plots, but it tended to increase with increasing fire frequency.

The effects of burning of native grassland on soil organic matter status were investigated by Fynn et al.[36] in a long-term field experiment in which the effects of burning in different seasons and at different frequencies were compared. They reported significant decreases in organic carbon only up to a depth of 20 mm, as a result of annual and biennial winter burning as well as biennial and triennial autumn burning. Burning in spring did not affect organic carbon content significantly, presumably because substantial amounts of litter decomposed and/or were incorporated into the soil by faunal activity prior to burning. The content of total nitrogen decreased substantially to a depth of 60 mm for all burning treatments. As a result of this decrease, the carbon to nitrogen ratio widened. Burning also induced a decrease in light fraction carbon (partially decomposed and readily decomposable plant tissue) and hot water extractable carbon (soluble and readily metabolisable carbon) in the 0 mm – 20 mm layer. Both the light and hot water extractable carbon fractions are regarded as early indicators of changes in soil carbon status. However, an increase in these two parameters and microbial biomass carbon were measured in the 40 mm – 100 mm layer. Fynn et al.[36] attributed this increase to burning that caused a decrease in aboveground litter impacts but an increased turnover of root material below the surface. Potentially mineralisable nitrogen increased with depth in spite of the decrease in organic carbon and total nitrogen.

Fire is an important tool for the management of rangeland in the False Thornveld, which consists of grassland thickly interspersed with dwarf *Acacia karoo*. Hence the effect of long-term burning frequencies on the organic carbon content of a Glenrosa soil near Alice was examined by Materechera et al.[37] After 17 years, the soil organic carbon to a depth of 400 mm was 1.23% for vegetation that was not burned, 0.71% for vegetation that was annually burned, 0.83% for vegetation that was triennially burned and 0.77% for vegetation that was sexennially burned. By contrast, soil organic carbon in the strips of land between the experimental plots was 0.51% and that from adjacent pasture that was not burnt but was continuously grazed was 0.96%. Burning of rangeland in the False Thornveld should therefore be reconsidered as a management option if the importance of organic matter in maintaining soil fertility and productivity is taken into account.

Conclusions

The limited available data on soil organic matter in South Africa is based on a few uncoordinated studies done by a few researchers acting on their own. There is no data available that is based on systematic and georeferenced sampling programmes. The limited data available shows that South African soils are characterised by very low organic matter levels. About 58% of the soils contain less than 0.5% organic carbon, 38% of the soils contain 0.5% – 2% organic carbon and only 4% contain more than 2% organic carbon. There are large differences in organic matter content within and between soil forms, depending on climatic conditions, vegetation cover, topographical position and soil texture. Degradation of rangeland on account of overgrazing results in significant losses of soil organic matter, which is mainly attributed to a lower biomass production. The use of fire in rangeland management decreases soil organic matter because the primary source of organic matter, the plant litter, is destroyed with burning.

A countrywide baseline study to quantify organic matter contents within and between soil forms is essential for future reference. Such a study should make use of a systematic sampling programme covering important agro–ecological regions in the country and using georeferenced sites to permit future monitoring of changes in soil organic matter levels. Clearer relationships between soil properties and functions are needed to establish whether it is possible to determine threshold values for soil organic matter. Management of soil organic matter must be optimised on an ecotope basis because of the great variability of this soil quality indicator as a result of climate, slope and soil. Maintaining, and, if possible, increasing organic matter content in degraded rangeland soils by preventing overgrazing and restricted burning is of the utmost importance because stock farming claims most of the land in South Africa.

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