

# Knowledge review on land use and soil organic matter in South Africa

Chris du Preez<sup>A</sup>, Pearson Mnkeni<sup>B</sup> and Cornie van Huyssteen<sup>A</sup>

<sup>A</sup>Department of Soil, Crop and Climate Sciences, University of the Free State, P.O. Box 339, Bloemfontein 9300, South Africa

<sup>B</sup>Department of Agronomy, University of Fort Hare, Private Bag X1314, Alice 5700, South Africa

## Abstract

There is limited data on the soil organic carbon status of South African soils. The limited data is further fragmented and uncoordinated. This study aims to provide a review of the research done in this regard. Approximately 58% of South African soils contain <0.5% organic C, 38% contain 0.5-2% organic C, and 4% contain >2% organic C. There are large differences in organic matter content within and between soil types, depending on climate, vegetation, topography, and soil texture. Over grazing and the use of fire in rangeland management resulted in significant losses of soil organic matter. Dryland cropping resulted in significant losses of soil organic matter, but this was not always the case under irrigation. The restoration of soil organic matter takes place very slow with the introduction of conservational practices like zero, minimum, and mulch tillage or the reversion of cropland to perennial pasture. Changes in soil organic matter content was restricted to the upper 300 mm and in many instances to the upper 50 mm of soil. The extent of these changes is dependant *inter alia* on land use, soil type, and environmental conditions.

## Key Words

Carbon, nitrogen, burning, management, grazing.

## Introduction

Organic matter influences the properties of mineral soils disproportionately to the quantities present. It is a major source of nutrients and microbial energy, holds water and nutrients in an available form, usually promotes soil aggregation and root development, and improves water infiltration and water-use efficiency (Allison 1973). The organic matter content of soils, however, varies widely. This is because the organic matter content of a soil increased during its development until a maximum equilibrium is reached.

Variations in soil forming factors experienced on a landscape scale and the interdependence of these factors contribute to the large variability for soil organic matter contents. The relative importance of the soil forming factors on soil organic matter are viewed as climate > biota > topography  $\approx$  parent material > time (Stevenson and Cole 1999). The equilibrium of organic matter 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. In the majority of cases, however, it is the latter. The equilibrium organic matter content in agricultural soils is governed by the kind of land use and resulting land cover (Arrouays *et al.* 2001). This knowledge review deals with the spatial variability of organic matter in South African soils, the extent of soil organic matter depletion on account of different land uses, and will elucidate some results on the restoration of soil organic matter.

## Results and discussion

The land type survey (Land Type Survey Staff 2003) described and analysed the morphological and chemical data of 2380 soil profiles throughout South Africa. Barnard (2000) used these data to produce a generalized organic C map for virgin topsoils in South Africa. The organic C content ranged from less than 0.5% to more than 4%. Only 4% of the soils contained more than 2% organic C, while 58% of the soils contained less than 0.5% organic C. The remainder of the soils contained 0.5 to 2% organic C (Scotney and Dijkhuis 1990). South Africa is therefore characterized by soils with very low organic matter levels. The distribution of organic C in the topsoils was largely related to the long-term average annual rainfall (Barnard 2000), presumably because rainfall plays such a dominant role in determining the biomass production of the native vegetation in the country.

For master horizons (MacVicar *et al.* 1977; Soil Classification Working Group 1991) the organic O horizons had the highest organic C (25.88%), but only four of these horizons were described. The A horizons had the next highest organic C (1.22%), decreasing to 0.54% in the B, 0.40% in the C, and 0.34% in the R horizons. Organic C in the E (albic) horizons (0.48%) was lower than in the B (0.54%) or G horizons (1.10%), but higher than in the C (0.40%) or R (0.34%) horizons. The distribution of organic C in the master horizons can be related to the various soil forming processes active in these horizons.

Organic C under savannah ranged from 0.18 to 4.86%, with a median of 1.28%, while under grassland it varied from 0.09 to 12.53%, with a median of 2.51% (Barnard 2000). The amount, distribution, origin, and stability of soil organic matter in *Acacia* and *Burkea* savannas were investigated by McKean (1993). Soil organic matter contained between 50 and 95% of the organic C in the two semi-arid savannas. In both savannas, soil organic matter decreased with depth. However, the horizontal gradient of soil organic matter from the sub canopy to open habitat differed between the two savannas. In the case of the *Acacia* savannah it decreased whilst in the *Burkea* savannah it remained constant. Trees and grass contributed to soil organic matter in the two savannas in approximate proportion to their primary production with grasses contributing 76% and trees 24%. A 51% turnover in clay-associated organic C over a period of 26 years was observed suggesting that in sandy savannah soils, clay-associated organic C has a much faster turnover time than the hundreds of years quoted for temperate ecosystems. In both savannas soil organic matter and microbial biomass were well related.

Du Toit and Du Preez (1993) obtained good relationships between the organic matter contents of virgin orthic topsoils and their fine silt-plus-clay contents (organic C:  $R^2 = 0.83$ ; total N:  $R^2 = 0.83$ ), the aridity indices of the localities where they were sampled (organic C:  $R^2 = 0.81$ ; N:  $R^2 = 0.79$ ) and the products of aridity indices of the localities and the fine silt-plus-clay contents of the soils (organic C:  $R^2 = 0.88$ ; total N:  $R^2 = 0.90$ ).

A baseline study by Le Roux *et al.* (2005) on the soil organic matter and vegetation was done in the Weatherley catchment near Maclear before this Moist Upland Grassland was converted to commercial forest. 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 C and total N were, respectively 111.1 and 8.6 Mg/ha for the excessively drained soils, 85.1 and 6.6 Mg/ha for the moderately well drained soils, 97.0 and 7.2 Mg/ha for the very poorly drained soils, and 88.3 and 7.2 Mg/ha for the freely drained soils. The average oven dry, above-ground biomass yield for the grassland cover was 3400 kg/ha/yr. Carbon sequestration efficiency by the grassland in the catchment was estimated to be 2.1 kg C/ha/yr/mm rain. Using some assumptions, it was possible to estimate that the equivalent value for *Pinus patula* would be approximately 2.8 kg C/ha/yr/mm rain.

Soil C stocks to a depth of 500 mm in untransformed, indigenous veld ranged from 21 Mg/ha in the Karoo to 168 Mg/ha in thicket, while N stocks ranged from 3.4 Mg/ha in the Karoo to 12.8 Mg/ha in grassland (Mills and Fey 2004a). The mean soil C of 5.6% to 100 mm depth in thicket was approximately five times greater than expected for this semi-arid region. Removal of vegetation due to grazing or burning reduced soil C and N at all sites. Soil C under intact thicket was greater than at sites degraded by goats, viz. 71 versus 40 Mg/ha in the upper 100 mm layer. Restoration of the thicket could therefore potentially sequester about 40 Mg C/ha. Soil C under plant cover was greater than exposed soil in the Renosterveld (28 versus 15 Mg/ha) and in the Karoo (7 versus 5 Mg/ha). In the 0-100 mm layer of burnt than unburnt plots the average organic C and total N were respectively 12 and 13% lower, viz. 1.68 versus 1.90% organic C and 0.13 versus 0.15% total N (Mills and Fey 2004b). The differences between the burnt and unburnt plots were accentuated in the 0-10 mm layer, which were respectively 0.8 versus 2.7% for organic C and 0.07 versus 0.23% for total N. They concluded that the top 10 mm of soil, which they named the pedoderm, was therefore likely to have a disproportionate effect on ecosystem functioning.

Cultivation caused average total N losses of 55% in the 0-150 mm layer, 17% in the 150-500 mm layer, and 6% in the 500-1000 mm layer. Reversion to pasture appeared to restore nitrogen fertility in the topsoil where leguminous trees were present, but not in their absence because the average total N was only 13% less in reverted compared to uncultivated soils (Prinsloo *et al.* 1990).

The C and N concentrations of the plinthic soils declined rapidly with increasing time of cultivation to approach equilibrium after about 30 years, when the concentrations of C and N were reduced, by 65 and 55% respectively, when compared to grassland soils. These losses occurred from all particle size fractions, but the organic matter associated with clay was more resistant than that in the sand fractions. The organic matter attached to silt continued to be lost as cropping continued, probably due to wind erosion (Lobe *et al.* 2001).

In the Harrismith, Kroonstad, and Tweespruit ecotopes some lands, continuously cultivated for more than 20 years were converted to perennial pasture of different ages. The restoration of organic matter, studied on

pasture lands 25 years or less old, showed that on average 25% of organic C and 20% of total N, lost during the 20 years or more of cultivation, had been restored (Birru 2002). Most of this restoration took place in the 0-50 mm layer, a little in the 50-100 mm layer, and very little in the 100-200 mm layer. Results showed a wide variation in the rate of organic matter restoration between sites in each of the ecotopes, due mainly to differences in natural resource factors and management techniques. Positive factors and techniques were: a favourable soil water regime, promoted by an adequate rooting depth of at least 500 mm; a clay content above 12%; gentle slopes; an aridity index above about 0.35; plant available nitrogen levels above 15 mg/kg; and the presence of a legume in the pasture. Burning negatively impacted on C and N restoration.

A study in northern KwaZulu-Natal compared cultivated fields to adjacent virgin soils and found that dryland sugarcane production depleted the average soil organic matter content from 3.87 to 3.31% in the 0-150 mm layer, from 3.33 to 3.19% in the 150-300 mm layer, and from 3.16 to 3.04% in the 300-450 mm layer (Van Antwerpen and Meyer 1996). The average depletion of soil organic matter under irrigated sugar cane was from 2.40 to 1.88% in the 0-150 mm layer, from 2.08 to 1.69% in the 150-300 mm layer, and from 1.46 to 1.39% in the 300-450 mm layer. Depletion of soil organic matter was therefore relatively higher in the irrigated than dryland areas. In both cases the depletion of soil organic matter decreased with depth.

In the Swartland near Malmesbury, Smit (2004) reported that after 11 years cropping systems had little influence on either organic C or total N in the 0-50 mm layer. In the 50-100 mm layer higher C and N were measured in the monoculture wheat plots than in the wheat-lupine-wheat-canola rotation plots. Deeper than 100 mm, especially total N and to a lesser extent organic C were, however, higher in the rotation than monoculture plots. Tillage practices, in contrast to cropping systems, had a large influence on both organic C and total N in the 0-50 mm layer. In this layer and to a lesser extent in the 50-100 mm layer organic C and total N increased as the intensity of tillage decreased from conventional clean tillage to no tillage. However, at 100-200 mm the conventional clean tillage plots had higher organic C and total N content than the conventional mulch tillage, minimum tillage, and no tillage plots. In general both organic C and total N increased in the 0-50 mm layer as the intervals between minimum tillage actions increased from every year to every fourth year.

Annually cultivated and permanent pasture soils had gained soil organic matter in the sandy, lower rainfall eastern Tsitsikamma, when compared to the undisturbed native vegetation (Milne 2002). At the higher rainfall, more clayey western end there was a loss of soil organic matter under both types of pasture in comparison to the undisturbed native vegetation. Soil organic C content was also lower under annual ryegrass than under permanent kikuyu pasture at all the sites reflecting the degrading effect of annual cultivation on soil organic matter.

A study by Du Preez and Wiltshire (1997) to establish organic matter changes as a result of crop production under irrigation focused on 21 farms at Ramah, Riet River, and Vaalharts irrigation schemes, with aridity index values of 0.13, 0.16, and 0.17, respectively. Average annual biomass production of the native veld in the vicinity of the irrigation schemes is usually less than 0.8 Mg/ha, while the biomass production of irrigated wheat on the schemes was more than 17 Mg/ha. Soil organic C increased at eight farms, decreased at nine farms, and was not affected at four farms. Similar changes in total N were recorded at these 21 farms. Neither cultivation nor irrigation history of farms, nor soil properties provided any obvious explanation for these contrasting findings. It is therefore likely that irrigation, with the associated increase in biomass production counteracted the declining effect of cultivation on soil organic matter.

## Conclusions

The results on soil organic C in South Africa, reported here are based on a few uncoordinated studies, by a few researchers. There is therefore no data based on a systematic and geo-referenced sampling programme. The limited available data shows that South African soils are characterized by very low organic matter levels. About 58% of the soils contain less than 0.5% organic C, 38% of the soils contain 0.5 to 2% organic C, and only 4% contain more than 2% organic C. There are large differences in organic matter content within and between soil types, depending on climate, vegetation, topography, and soil texture. Degradation of rangeland on account of over grazing resulted in significant losses of soil organic matter and is mainly attributed to less biomass production. The use of fire in rangeland management similarly decreased soil organic matter because the plant litter is destroyed. Dryland cropping resulted in significant losses of soil organic matter, but this was not always the case under irrigation. The restoration of soil organic matter takes

place very slow with the introduction of conservational practices like zero, minimum, and mulch tillage. Reversion of cropland to perennial pasture also resulted in disappointingly slow soil organic matter restoration. Increases or decreases in soil organic matter content manifested only in the upper 300 mm and in many instances only in the upper 50 mm. The extent of these changes is dependant *inter alia* on land use, soil type, and environmental conditions.

## References

- Allison FE (1973) Soil organic matter and its role in crop production. (Elsevier: Amsterdam)
- Arrouays D, Deslais W, Badaeu V (2001) The carbon content of top soils and its geographical distribution in France. *Soil Use and Management* **17**, 7-11.
- Barnard RO (2000) Carbon sequestration in South African soils. ARC-ISCW Report No GW/A/2000/48. (ARC-Institute for Soil, Climate and Water: Pretoria)
- Birru TC (2002) Organic matter restoration by conversion of cultivated land to perennial pasture on three agro-ecosystems in the Free State. M.Sc. dissertation. (University of the Free State: Bloemfontein)
- Du Preez CC, Wiltshire GH (1997) Changes in the organic matter and nutrient contents of some South African irrigated soils. *South African Journal of Plant and Soil* **14**, 49-53.
- Du Toit ME, Du Preez CC (1993) Relationship between organic matter content of certain virgin orthic topsoils, soil properties and climatic data in South Africa. *South African Journal of Plant and Soil* **10**, 168-173.
- Land Type Survey Staff (2003) Land types of South Africa. (ARC-Institute for Soil, Climate and Water: Pretoria).
- Le Roux PAL, Hensley M, Du Preez CC, Kotzé E, Van Huyssteen CW, Collins NB, Zere TB (2005) The Weatherley catchment: Soil organic matter and vegetation baseline study. WRC Report No. KV170/50. (Water Research Commission: Pretoria)
- Lobe I, Amelung W, Du Preez CC (2001) Losses of soil carbon and nitrogen with prolonged arable cropping from sandy soils of the South African Highveld. *European Journal of Soil Science* **52**, 93-101.
- MacVicar CN, De Villiers JM, Loxton RF, Verster E, Lambrechts JJN, Merryweather FR, Le Roux J, Van Rooyen TH, Harmse HJ Von M (1977) Soil classification - A binomial system for South Africa. (Department of Agriculture Technical Services: Pretoria).
- McKean SG (1993) Soil organic matter patterns, processes and effects in two contrasting savannas. M.Sc. dissertation. (University of Witwatersrand: Johannesburg).
- Mills AJ, Fey MV (2004a) Soil carbon and nitrogen in five contrasting biomes of South Africa exposed to different land uses. *South African Journal of Plant and Soil* **21**, 94-102.
- Mills AJ, Fey MV (2004b) Frequent fires intensify soil crusting: physico-chemical feed back in the pedoderm of long-term burn experiments in South Africa. *Geoderma* **121**, 45-64.
- Milne RK (2002) An investigation of factors contributing to soil degradation under diary farming in the Tsitsikamma. M.Sc. Agric. dissertation. (University of KwaZulu-Natal: Pietermaritzburg).
- Prinsloo MA, Wiltshire GH, Du Preez CC (1990) Loss of nitrogen fertility and its restoration in some Orange Free State soils. *South African Journal of Plant and Soil* **7**, 55-61.
- Scotney DM, Dijkhuis FJ (1990) Changes in the fertility status of South African soils. *South African Journal of Science* **86**, 395-402.
- Smit ML (2004) The effect of cropping systems and tillage practices on some fertility indicators of a Swartland soil near Malmesbury. M.Sc. Agric. Dissertation. (University of the Free State: Bloemfontein).
- Soil Classification Working Group (1991) Soil classification - A taxonomic system for South Africa. Memoirs on the Agricultural Resources of South Africa No 15. (Department of Agricultural Development: Pretoria).
- Stevenson FJ, Cole MA (1999) Cycles of soil: carbon, nitrogen, phosphorus, sulphur and micronutrients. 2<sup>nd</sup> edn. (John Wiley and Sons: New York).
- Van Antwerpen R, Meyer JH (1996) Soil degradation under sugarcane cultivation in Northern KwaZulu-Natal. *Proceedings of the South African Sugar Technology Association* **70**, 29-33.