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Influence of agricultural land use and management practices on selected soil properties of a semi-arid savanna environment in South Africa

Simeon A. Materechera

Food Security & Safety Research Niche Area, Faculty of Agriculture, Science & Technology, North West University, Mafikeng Campus, P/B X 2046, Mmabatho 2735, South Africa

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ABSTRACT

The contribution of agricultural land use and management practices to soil degradation was compared on land with: more than 20-years of natural grazing (NG), cultivation of horticultural (HC) and field (FC) crops, and undisturbed savanna (US) in South Africa. Tillage with tractors in the FC and HC plots resulted in greater soil compaction compared with NG and US systems. The soil under FC and HC had a greater percentage of micro-aggregates (<0.25 mm; 56.2% and 60.4%, respectively) than NG (16.1%) or US (22.7%). The aggregates in FC were the least water stable followed by that of HC, NG and US. Soil water content was significantly higher ($p < 0.05$) in soil from HC (3.46%) than NG (2.13%), US (1.67%) or FC (0.87%). Soil compaction was greater in the profile of the FC, NG and HC than US. Grazing and cultivation significantly reduced soil organic matter and microbial biomass carbon. Both organic and microbial biomass carbon were significantly positively correlated with many soil properties. Overall, the study showed that both animal grazing and cultivation of crops significantly reduced soil physical and biological properties compared with undisturbed land. The results provide evidence that land management practices are an important component of sustainability in this dry savanna ecosystem.

1. Introduction

The growing human population in the world has placed enormous pressures on land resources thereby increasing the need to assess impacts of land use change on soil quality. It is well known that any activity associated with change in land use and agricultural management practices can affect soil properties (Haghighi et al., 2010; Islam and Weil, 2000; Zucca et al., 2010). The causes of these changes in soil properties are related to many factors (Zhang et al., 2007), however, the dynamics of soil organic matter and its different pool fractions have received a lot of attention due to their significance in soil quality (Guimarães et al., 2013; Papini et al., 2011). This is because soil organic matter fractions are more sensitive to changes in management practices associated with agricultural land use such as tillage, manure application, irrigation, fertilizer, pesticide, crop rotation and grazing (Kioko, 2012). Furthermore, soil organic matter has been suggested as an important element linked to soil quality because it plays an important role in maintaining the productivity of many soils since it provides energy and substrates, and promotes the biological diversity that helps to maintain soil quality and ecosystem functionality (Gajda et al., 2001; Guimarães et al., 2013; Stevenson and Cole, 1999). Consequently, soil properties that are correlated with organic matter fractions such as microbial biomass C and N, microbial activity, enzyme activity, C and N mineralization and aggregate size distribution are all considered to be important for assessing the effects of land use on soil quality (Gregorich et al., 2006). Agricultural land use practices have been associated with reducing enzyme activities that are important in carbon cycling, low microbial biomass carbon compared with other land uses such as pasture and forestry (Abe et al., 2009; Ayanaba et al., 1976; Sotomayor-Ramirez et al., 2009). In many ecosystems, especially in the tropics and semi-arid regions, soil organic matter rapidly declines once the soil is disturbed for agriculture (Wendling et al., 2010).

Savannas make up 35% of the land area in South Africa and form the basis of two major industries: cattle ranching and wildlife-related tourism (Scholes and Walker, 1993). Trees and grasses make the principal elements of the ecology of the

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E-mail address: 20560915@nwu.ac.za.

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savanna. Although a variety of soils are found under savanna vegetation, the dry savanna areas of the North-West province have predominantly sandy soils, which are poorly aggregated due to low organic matter and low-activity clays (Mills and Fey, 2004). The delicate savanna environment has in many areas been subjected to intense agricultural production due to increasing demand for food (Scholes and Archer, 1997). It is well known that any activity associated with change in land use and agricultural management practices can affect soil properties (Geissen et al., 2009; Haghighi et al., 2010). The causes of these changes in soil properties are related to many factors (Abbasi et al., 2007), but the dynamics of soil organic matter and its different pool fractions have received a lot of attention due to their significance in soil quality (Celik, 2005; Li et al., 2007; Papini et al., 2011). Furthermore, changes in soil organic matter of a soil affects important chemical and physical properties which influences its productive capacity (Mills and Fey, 2004; Stevenson and Cole, 1999).

The possible contribution of agricultural management practices to soil degradation under the dry savanna environment has raised concerns regarding their sustainability. The objective of the study was to assess changes in soil quality properties associated with the influence of over 20-years of different agricultural land use and management practices at a farm located in a dry savanna ecosystem of the North-West province in South Africa. The hypothesis of the study was that land use and management was the primary anthropogenic factor degrading soil quality in this savanna environment.

2. Materials and methods

2.1. Site location and land use history

For over a decade prior to 1985, the whole farm of about 15.3 ha was under natural vegetation and was lying fallow. However, in 1989, the land was leased to the North West University to be used for agricultural training and thus the land was converted into different land uses. In July 2010, plots of about 0.5 ha each representing dominant agricultural land use practices (for over 20 years) including natural grazing (NG), cultivation of horticultural (HC) and field crops (FC), and undisturbed savanna (US) were identified within close proximity of each other at a farm located about 2 km outside the city of Mafikeng (longitude 25o48′ S, latitude 25o38′ E; 1218 m asl) in a dry savanna ecosystem of the North West Province of South Africa.

2.2. Climate and soil type

Mafikeng has a typical semi-arid tropical savanna climate and receives summer rainfall with an annual mean of 571 mm. The rainfall is unreliable and highly variable (CV = 31%) in both temporal and spatial distribution. The mean monthly minimum and maximum temperatures vary from 4.0 °C in July to 17.1 °C in January and 20.4 °C in July to 29.7 °C in February respectively. The surface (0–20 cm) soil at the site is predominantly a dark red sandy loam with 56% sand, 33% silt, 11% clay, and is classified as a Hutton form according to the South African soil classification system (Soil Classification Working Group, 1991). It has characteristics similar to a Chromic Luvisol (FAO-ISS-ISRIC, 1998). The distribution of particle sizes in the soil across the farm was comparable. The clay mineralogy is dominated by well crystallized illite and kaolinite (Loxton and Associates, 1984). The average organic carbon content is 0.69% and pH_{H2O} is 6.3.

2.3. Experimental treatments and design

Four plots each 0.5 ha representing the different land use and management practices including natural grazing (NG), cultivation of horticultural (HC) and field crops (FC), and undisturbed savanna (US) were selected within close proximity to each other and designated as treatments for the study. Tractor traffic and irrigation were associated with crop management while the grazing land was burnt annually. For purposes of statistical analysis, each of the plots was divided into three equal sub-plots which were used as replicates during sampling and analysis.

2.4. Soil sampling procedure

Two sets of soil samples were collected from each of the four treatments in July 2010. The first set was collected using an auger 5.6-cm in diameter from ten randomly located positions in each replicate at depths of 0–20 and 20–40 cm. About 2.5 kg of soil was collected from each depth and the sub-samples were thoroughly mixed to form a composite sample. Fresh sub-samples were used for the measurements of particulate organic matter fraction and microbial biomass. These samples were kept in airtight plastic bags and stored in a refrigerator. The rest of the soil was air dried, passed through a 2.0 mm sieve and used for the determination of pH, particle size distribution, organic carbon and nutrient elements.

The second set of samples was collected using a spade from five randomly selected positions within each replicate. The soil on each spade was gently removed and delicately handled to avoid destroying the aggregates. Sub-samples from each replicate were mixed to make a composite sample on which the analyses of aggregate size distribution, tensile strength and bulk density conducted.

2.5. Measurements of soil properties

2.5.1. Soil penetrometer resistance

Soil penetrometer resistance in the profile was measured using soil penetration resistance at the time of sampling (July 2010) using a cone type proving ring penetrometer model 29-3739 with a cone diameter of 12.8 mm (Davidson, 1965). Penetration resistance was recorded at a depth of 15 cm from the surface. Fifty random penetrations were made in each treatment. Soil samples were collected to the same depth immediately after the penetrations from ten randomly selected positions in the treatment using an auger. The samples were dried in the oven at 105 °C to determine the gravimetric water content of the soil.

2.5.2. Aggregate size distribution

The distribution/abundance of aggregate sizes in each treatment was determined from 50 g sub-samples of air-dried soil by the method of Kemper and Rosenau (1986). The soil was sieved through a nest of sieves of sizes 8.0, 4.0, 2.0, 1.0, 0.5, 0.25 and 0.106 mm by shaking the sieves on an automatic sieve shaker for 5 min. The fractions of aggregates in each size range ($<$0.106, 0.106–0.25, 0.25–0.5, 0.5–1, 1–2, 2–4, 4–8 and $>$8 mm) were weighed and their proportions of the whole mass of aggregates were calculated. A sub-sample of aggregates from the same batch was oven dried to correct the air-dried sample for moisture content. Dry mean weight diameter (DMWD) of the aggregates was calculated according to the method of Kemper and Rosenau (1986). Five replicate determinations were made for each treatment.

2.5.3. Aggregate tensile strength

Tensile strength of aggregates was measured by an indirect tension (crushing) test similar to that described by Dexter (1988).