Soil biological properties beneath canopies of *Acacia erioloba* (syn. *Acacia giraffae*) trees under different land-use practices in a South African semi-arid environment

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Abstract: The study was conducted to quantify the biological properties of soil beneath the canopies of Acacia erioloba trees growing under three dominant local land-use practices in a semi-arid environment of South Africa. The results showed that all biological properties were significantly different (p<0.05) from one land-use practice to another. Fallow land was found to have significantly higher (p<0.05) organic carbon (OC), particulate organic matter fraction (POM), microbial biomass carbon (MBc) and microbial biomass nitrogen (MBn) than grazing and bare land-use practices. The order of rating for all the measured properties was fallow >grazing > bare land. Bare land had the lowest of all the measured properties signifying limited biological activity. Significant higher (p<0.05) values of OC and POM were found in soils that were collected under fallow while MBc and MBn were higher under grazing land-use practice. In both canopy locations, all biological properties were significantly higher (p<0.05) in soils that were collected at 0-10 cm compared to those that were collected at 10-20 cm. High organic matter content under fallow and grazing land was attributed to three possible sources, namely: leaf litter from Acacia erioloba trees, grass and turnover of roots and also dung from grazing animals. The major contributing factor under grazing land was considered to be the large amount of organic materials that are returned to the soil, especially that from animal dung and turnover of grass roots. It was concluded that the quantity and quality of soil organic matter and microbial activity was enhanced by the micro environment beneath the canopy of Acacia erioloba tress. This was attributed to higher decomposition of soil organic matter that takes place on the surface layer of the soil where most of the organic materials are deposited.

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Introduction

Acacia erioloba (synonym: *Acacia giraffae*) is an indigenous leguminous tree of the dry savanna environments of Southern Africa and other tropical areas of West Africa (Carr, 1976). It is an ecologically important tree because of its multipurpose roles in nature as well as the roles it plays in the ecosystem (Palgrave, 1991). Being a leguminous plant, the roots of the *A. erioloba* tree harbor rhizobium bacteria that fix nitrogen into the soil (Palgrave, 1991). A combination of leaf-fall, root nodulation and continuous presence of livestock near the trees in dry environments greatly enhances the microbial activity and cycling of plant nutrients underneath the canopy of *A. erioloba* trees (Murovhi and Materechera, 2006). A canopy of Acacia erioloba tree creates a microclimate beneath the tree that can alter the composition and activity of soil biota. Consequently, the agroforestry roles of *A. erioloba* trees are well established and appreciated in many rural and peri-urban communities of the semi-arid areas of the North West Province in South Africa where the trees are planted or deliberately maintained in the homestead, cropland and grazing land (Materechera, 1999).

Soil biological activity is largely concentrated in the topsoil and it normally decreases greatly with depth, as does, soil organic matter content (Haynes and Graham, 2004). Soil biota is the main driving force behind nutrient and energy transformations in soils (Banerjee et al., 1999). Soil microbial activity affect nitrogen availability to plants by transforming organically held nitrogen into inorganic plant-available forms (Roper and Gupta, 1995). Soil organisms and their activities strongly affect soil properties and processes, and their abundance is largely to be affected by land-use and management practices, thus they serve as important indicators of soil quality (Karlen et al., 1997). Soil quality is defined as the capacity of a specific soil to function, within natural or managed ecosystem boundaries.

Soil organic matter (SOM) refers to all the organic materials found in the soil including litter, light fraction, microbial biomass, water-soluble organics and humus (Stevenson, 1994). SOM is a key attribute of soil quality because of its importance on soil fertility (Gregorich et al., 1994). SOM influences other soil characteristics such as nutrient mineralization potential, cation exchange capacity and aggregate stability. A decrease in soil organic matter is concomitant with a decrease in soil biological activity, which is a cause for concern in agriculture because biologically mediated processes are fundamental to ecological functioning (Gregorich et al., 1994).

Soil microbial biomass (MB) is defined as the small (0-4 %) living component of soil organic matter excluding macro-fauna and plant roots (Dalal, 1998). Although soil microbial biomass constitutes a small proportion of soil organic matter, the composition and activity of soil microbial communities largely determine biogeochemical cycles, turnover processes of organic matter, and fertility of soils (Jenkinson and Ladd, 1981). Microbial biomass is fundamental to organic matter cycling and carbon sequestration by the soil since it is both an agent for decomposition of plant residues and sink for carbon, nitrogen, phosphorus, sulphur and other nutrients (Dalal, 1998). Microbial biomass has been reported to be useful in determining the changes that occur in soil due to any agricultural management or practice (Roper and Gupta, 1995). Similarly, POM is closely linked to soil productivity and it has the capacity to furnish plants with nutrients such as nitrogen (Dalal and Mayer, 1986). This fraction is considered more sensitive than total soil organic matter to change due to management practices (Biederbekc et al., 1994). The objective of this study was to quantify the influence of *Acacia erioloba* trees on the biological properties of soil and to establish the role of land-use practices on soil quality.

Materials And Methods

Study location and climate

The study was conducted in areas surrounding the city of Mafikeng in the North-West province of South Africa. Mafikeng lies at approximately latitude 25°48' S and longitude 25°38' E. The municipal area slopes from 1410m asl in the east and 1210m asl in the west (Schulze, 1984). The area has a typical dry and semi-arid savanna climate (Maraka, 1987). The vegetation consists of a mixture of grasses and scattered trees and shrubs (Maraka, 1987). The area receives summer rainfall with an annual mean of 550mm. The rainfall is unreliable and is highly variable (CV= 31%) in both temporal and spatial distribution (Maraka, 1987). About 68 percent of the annual precipitation falls between November and January in relatively few heavy downpours with a pronounced dry season from April to September (Maraka, 1987). The mean maximum temperatures (15-years average) vary from 26.9°C in June to 37.0°C in January while the mean minimum varies from 7.0°C to 11.4°C. There are very little variations between seasons. The annual average evaporation is 2200 mm (City Council of Mafikeng).

Soils and land-use practices

The predominant soil is a red sandy loam classified by the South African classification system as belonging to the Hutton series (Soil classification working group, 1991). The soils are inherently low in phosphorus (0-15 $mgkg^{-1}$) because of their mineralogy. Nitrogen is also relatively low (0.08-1.5%) and the cultivated soils are usually very low in organic matter (Kowal & Kassam, 1978). Most of the land in the study area has traditionally been used for the cultivation of crops such as maize, millet, sorghum and sunflower. Some pieces of land are used for livestock grazing (mostly cattle, goats and sheep) off the natural vegetation while some is left fallow (to regain soil fertility after a period of cultivation). Three common land use practices were targeted for this study, grazing, fallow and bare land (control). The areas where each land-use system occurred had been under the same management for the past seven years and covered an area of at least 3.5 km^2. The land-use practices were located within close proximity (< 7.0 km) of the North-West University research farm and from each other.

Soil sampling procedure

In March 2009, five mature Acacia erioloba trees were randomly selected within each land-use practice. Soil samples were collected from below each tree canopy within a land-use system between March and May 2009 using a bucket auger to a depth of 0-20 cm. A tree - soil - transect method was utilized for collecting soil samples and involved drawing four lines at right angles to each tree across the tree trunk and area covered by the tree canopy. Transects were extended beyond the tree canopy by a distance equal to the canopy radius. Soil sub-samples were collected randomly from each of the four quadrants of each canopy location of a tree within each land-use. The sub-samples were bulked to obtain about 3.0 kg soil that was used as a replicate for the tree. The bulk soil was air dried and sieved through a 2.0 mm sieve and stored in plastic bottles for analysis.

Soil analyses

Soil organic carbon (OC) was determined by the wet oxidation method (Walkley & Black, 1934). One gram of soil was digested in 20 ml concentrated sulphuric acid (H_2SO_4) and 10 ml aqueous potassium dichromate ($K_2 Cr_2 O_7$) and was titrated against 0.5 N Ferrous ammonium sulphate. The used $K_2 Cr_2 O_7$, the difference between added and residual $K_2 Cr_2 O_7$, was used as a measure of organic carbon content of the soil. Each sample was replicated three times. Microbial biomass was determined by the chloroform fumigation technique (Jenkinson & Powlson, 1976). Two 10-gram sub-samples were weighed, one of which was extracted (unfumigated) in 0.5 M K_2SO_4. The other was placed in a vacuum desiccator over alcohol-free chloroform and stored in a dark cabin for 5 days at room temperature (fumigated). After 5 days, the soil was transferred into watertight bottles and extracted with 0.5 M K_2SO_4. The extracted solution was filtered on a No. 42 whatman filter paper and the clear filtrate was used to measure microbial biomass N and C. Each sample was replicated three times.

Microbial biomass carbon (MBC) was determined on fresh soil samples using the complete 'wet' oxidation method by acidified potassium dichromate (Anderson & Ingram, 1993). Microbial biomass nitrogen (MBN) was determined using the micro-Kjeldhal technique outlined by Okalebo et al. (1993). The liberated nitrogen was determined titrimetrically after distillation. MBC and MBN were calculated from the difference between carbon and nitrogen extracted by 0.5 M K_2SO_4 from alcohol-free fumigated and unfumigated soil samples.

Physical fraction of soil to collect the POM fraction was conducted using a modification of the method described by Okalebo et al., (1993). A 20 g sample of soil was first dispersed in 30 ml of 0.5 % calgon solution (sodium hexametaphosphate) by mechanical shaking for 5 minutes. The dispersed soil sample was wet sieved through a set of sieves 2.0 mm and 53 µm in diameter by running a moderate stream of tap water through the soil. The fraction greater than 2.0 mm was discarded while that retained on the 53 µm sieve was kept. The wet sieving procedure was repeated until the entire POM was removed. Each sample was replicated three times. The POM fraction was considered as the particles floating in the suspension that was poured off and dried in an oven at 50 °C for three days.

Statistical analysis

All data was exposed to analysis of variance (ANOVA) using a Statistical Analysis System (SAS) programme (SAS Institute Inc., 1985). Duncan's Multiple Range Test and student's t-test were used to compare the means where significance was indicated (Sokal & Rohlf, 1969).

Results

A summary of the analysis of variance (ANOVA) for the properties (OC, POM, MBC and MBN) is presented in Table 1. Generally, the results show that all the main factors had a significant influence on soil biological properties. The results also show that there were significant interactive effects of the main factors on the properties of the soils. Land-use practice had a significant effect on all biological properties of the soil (Table 2). The results show that all biological properties were significantly different ($p<0.05$) from one land-use practice to the other. Fallow was found to have significantly higher ($p<0.05$) OC, POM, MBC and MBN than grazing and bare land-use practices. The order of the rating for all the measured properties was fallow >grazing > bare land. Bare land has the lowest of all the measured properties.

Table 1: Mean square of analyses of variance for biological properties of soil from beneath canopies of *A. erioloba* trees

Source	OC	POM	MBC	MBN	%
Land-use practice (L)	2	12.22**	32.60**	4.40**	2.19**
Canopy location (S)	1	0.004	0.05**	3.63**	0.11**
Depth (D)	1	40.07**	37.16**	54.61**	4.97**
LxS	2	0.001	0.02	0.83**	0.29**
SxD	1	0.03**	0.12**	1.08**	0.00
LxD	2	4.56**	3.97**	1.73**	0.03**
LxSxD	2	0.03**	0.31**	0.20	0.00
Error	96	0.00**	0.01**	0.26**	0.003**

**= P < 0.01

Table 2 : Effect of land-use practice on biological properties of soil from beneath canopies of *A. erioloba* trees

Land-use practice	OC	POM (%)	MBC	MBN
Fallow	1.6±0.5a	2.7±0.8a	3.2±0.9a	0.5±0.2a
Grazing	2.2±0.7b	3.1±0.4b	5.6±1.2b	0.8±0.3b
Bare	0.6±0.2c	0.8±0.2c	2.9±0.7c	0.4±0.2c

Values are means ± standard deviation; n=36
Within a column means bearing the same letter are not significantly different at P < 0.05 by the Duncan's Multiple Range Test

Table 3 shows the effect of canopy location on biological properties of the soil. A significant difference ($p<0.05$) was not found in all parameters that were measured. Soil biological properties were found not to be significantly different ($p<0.05$) in soils collected beneath and beyond Acacia erioloba canopies. The effect of soil depth on the biological properties of the soil is presented in Table 4. A significant difference ($p<0.05$) was observed between soils that were collected at a depth of 0-10 cm and those that were collected at 10-20 cm. The results show that soils that were collected at a depth of 0-10 cm had significantly higher ($p<0.05$) values of biological properties than those collected at 10-20 cm. Table 5 shows the effect of canopy location within each land-use practice on biological properties of soil. The results show that there were no significant differences ($p<0.05$) in all properties that were measured in soils from beneath and beyond tree canopies. Significant higher ($p<0.05$) values of OC and POM were found in soils that were collected under fallow while MBC and MBN were higher under grazing land-use practice.

Table 3 : Effect of *A. erioloba* tree canopy location on biological properties of soil

Canopy Location	OC	POM (%)	MBC	MBN
Beneath canopy	1.6±0.3	1.9±0.2	3.8±0.5	0.7±0.2
Beyond canopy	0.9±0.1	1.1±0.1	2.4±0.2	0.4±0.1
t –test	*	*	*	*

Values are means ± standard deviation; n=54
* = P< 0.05

Table 4: Effect of depth of sampling on biological properties of soil collected from beneath canopies of *A. erioloba* trees

Depth (cm)	OC	POM (%)	MBC	MBN
0-10	1.8±0.77	2.4±1.1	5.3±1.4	0.9±0.2
10-20	0.6±0.22	1.2±0.5	3.9±1.2	0.5±0.2
t - test	* *	* *	* *	* *

Values are means ± standard deviation; n=54
* = P< 0.05

Table 5: Biological properties of soils as influenced by canopy location of *A. erioloba* under different land-use practices

Land-use practice	Canopy location	OC	POM (%)	MBC	MBN
Fallow	Beneath	1.7±0.9c	2.7±0.8c	5.3±0.8b	1.4±0.2b
	Beyond	0.8±0.9d	1.5±0.9d	3.1±1.0c	0.8±0.5c
Grazing	Beneath	2.2±0.4b	2.6±0.3b	5.9±1.0c	1.2±0.3c
	Beyond	0.9±0.6c	1.0±0.8c	3.2±1.2d	0.7±0.4b
Bare	Beneath	0.7±0.2a	1.2±0.2a	2.7±0.6a	0.8±0.2a
	Beyond	0.3±0.1b	0.7±0.3b	0.9±0.7b	0.3±0.2b

Values are means ± standard deviation; n=18
Within a column means within a land-use type bearing the same letter are not significantly different at P < 0.05 by the Duncan's Multiple Range Test

Table 6 shows the influence of depth of sampling on biological properties in each land-use practice. Organic carbon (OC), particulate organic matter (POM), microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) were found to be significantly higher (p<0.05) in topsoil (0-10 cm) under all land-use practices compared to those from subsoil (10-20 cm). The influence of soil sampling depth on the biological properties of the soil is presented in Table 7. In both locations, all biological properties were significantly higher (p<0.05) in soils that were collected at 0-10 cm compared to those that were collected at 10-20 cm.

Table 6 : Influence of sampling depth on biological properties of soil from *A. erioloba* trees under different land-use practices

Land-use practice	Depth (cm)	OC	POM ………………………….. (%) ………	MBC	MBN
Fallow	0-10	2.6±0.2f	3.5±0.1f	5.9±0.4d	1.0±0.1c
	10-20	0.8±0.1d	1.8±0.1d	4.5±0.7c	0.6±0.1b
Grazing	0-10	1.9±0.1e	2.8±0.2e	6.5±0.5e	1.1±0.2d
	10-20	0.4±0.1b	1.3±0.1c	4.6±0.8c	0.6±0.1b
Bare	0-10	0.8±0.1c	1.0±0.1b	3.4±0.3b	0.6±0.1b
	10-20	0.4±0.03a	0.6±0.1a	2.4±0.5a	0.2±0.1c

Values are means ± standard deviation; n=18..Within a land-use type, means bearing the same letter are not significantly different at P < 0.05 by the Duncan's Multiple Range Test

Table 7: Effect of depth of sampling on soil biological properties as influenced by location of canopy under *A. erioloba* trees

Canopy Location	Depth (cm)	OC	POM ……………… …. (%) ……	MBC	MBN
Beneath	0-10	1.7±0.8b	2.4±1.1c	5.4±1.5c	0.9±0.2d
	10-20	0.6±0.2a	1.3±0.5b	4.1±1.3b	0.5±0.2b
Beyond	0-10	1.8±0.8c	2.4±1.1c	5.2±1.3c	0.9±0.2b
	10-20	0.5±0.2a	1.2±0.6a	3.6±1.2a	0.4±0.2a

Values are means ± standard deviation; n=27
Within a canopy location, means bearing the same letter are not significantly different at P < 0.05 by the Duncan's Multiple Range test

Discussion and Conclusions

Soil biological properties are very sensitive to changes in land-use practices (Dalal, 1998; Gregorich et al, 1994; Miller et al., 1999). Organic carbon (OC), particulate organic matter (POM), and microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN)) were found to be significantly higher in land under fallow and grazing compared to bare land. This is likely due to the higher amounts of organic material returned to the soil under fallow and grazing than that in bare land. High organic matter content under fallow and grazing can be traced to three possible sources, namely: leaf litter from Acacia erioloba trees, grass and turnover of roots and also dung from grazing animals. Animal dung tends to enhance microbial activities and therefore influence the process of organic matter decomposition that releases plant nutrients that are essential for plant growth. Microorganisms attack organic matter in search of food. They use carbon as a source of energy. During this process, some of the carbon is lost as CO_2, which is then used by plants again.

It was observed that grass and other plants were common in both fallow and grazing land. High organic carbon content under these two land-use practices was likely due to enhanced biomass addition. It was estimated that about 4.0 t ha^{-1} of grass biomass could be produced annually and 1.2 t ha^{-1} under grazing. Apart from additions from grass biomass, *Acacia erioloba* could also add some biomass to the soil through leaf fall. The amount of leaf litter biomass from one Acacia erioloba tree (42 years) was estimated to be 39 kg per annum. These organic materials contain some carbon and nutrients. The C:N ratio of Acacia erioloba leaves was estimated to 13:1. This suggests that the biomass from *Acacia erioloba* trees could easily be decomposed and the nutrients in them released over a short period.

Microbial biomass carbon was significantly higher in land under fallow and grazing than in bare land. The major contributing factor under grazing land is likely to be the large amount of organic materials that are returned to the soil, especially that from animal dung and turnover of grass roots (Campbell et al., 1992). Land-use practices that promote large organic matter inputs tend to have higher soil microbial biomass contents and activities because they provide soluble carbohydrates that are used as sources of energy for the organisms (Dlamini, 2002). Furthermore, the shade provided by *Acacia erioloba* canopy reduced evaporation losses and maintained higher soil moisture content in the surface soil. These conditions created a microenvironment that favours microbial activity (Gliessman, 1989). Organic matter under fallow came mainly from senescing plant tops and roots, exudation of organic compounds from grass roots and the turnover of large microbial biomass found in the rhizosphere of roots (Haynes & Williams, 1993). The common practice of burning grass in the veld reduces the soil organic matter content as well as the microbial activity (Rasmussen et al., 1980). As a consequence, there is a decline in microbial biomass carbon and nitrogen due to smaller return of organic matter (Collins et al., 1992). It was observed that the concentration of almost all biological properties tended to decrease with depth. This was shown by significantly higher values of all biological properties in the topsoil layers (0-10 cm) of the soil compared to sub-soil layers (10-20 cm). The variation was due to that fact that the concentration of organic matter is highest in the surface layer and was lower in the sub-soil.

It was concluded that the quantity and quality of soil organic matter was influenced by land-use practice. This was indicated by significantly higher values of soil biological properties in land under grazing and fallow compared to bare land. Generally, the values of soil biological properties was significantly higher in land under grazing and fallow compared to bare land around homesteads. These findings confirm the hypothesis that there were high biological activities and fertility in grazing and fallow lands compared to bare land. The high organic matter on the topsoil layers beneath the tree canopies in all land-use practices contributed to improving the properties of all biological properties of the soil. It was attributed to the fact that much of the decomposition of soil organic matter takes place on the surface layer of the soil where most of the organic materials are added.

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