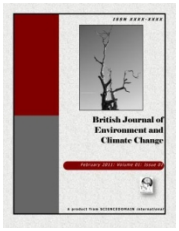

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Soil Microbial Biomass Carbon, Nitrogen and Sulphur as Affected By Different Land Uses in Seronga, Okavango Delta, Botswana

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Aim: The Okavango Delta at Seronga is fragmented into different land uses ranging from grasslands to woodland (Ximenia and mopane), often punctuated with cropped and fallow fields. The influence of land uses on surface (A_1 horizon) soil physico-characteristics, nitrogen, sulphur, carbon, microbial population and biomass were studied to understand soil variability in order to devise conservation strategies for the area.
Methodology: Total soil nitrogen (N) was analysed using a Leco N analyser, total carbon and sulphur by CS800 Carbon–Sulphur analyser. NH_4^+-N, NO_3^- and NO_2^- were extracted with KCl and determined using the indophenol blue method and by Griess-Ilosvay colorimetric method respectively. Microbial populations were determined by plate count method. Biomass carbon and flush of nitrogen were determined by fumigation and re-inoculation technique.
Results: All the soils had a high sand content (> 85%). Total soil N was generally very low, 0.017% in grasslands closest to the channel, 0.013% in cropped fields, 0.007% in fallow and lowest in woodlands (0.002%). Grasslands showed higher NH_4^+-N indicating low nitrification potential. Even if mopane woodlands had low total N, they had higher NH_4^+-N (0.067 ppm) and low NO_2^- compared to other land uses, this could be attributed to their inherent nitrification inhibition ability. No NO_3^--N was detected in these soils, probably due to the low nitrification ability and high leaching capacity of sandy soils.

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Microbial biomass C and population were highest in the grasslands and cultivated soils, while the woodlands had lower levels.
Conclusion: Seronga soils have very low N, with the least in the woodlands furthest from floodplains. Grasslands closest to the channel basin had significantly higher total N, C and microbial biomass C but low S as opposed to the woodlands further from the channel. Cultivated areas had increased N and C levels and microbial biomass C compared to the woodland probably due to incorporation of crop residues and animal manure. The paucity of nitrifiers and undetectable NO_3^--N indicate a low nitrification potential and a high leaching ability of the soils. Fallowing of fields resulted in a decline in nutrient status.

Keywords: Mopane soils; Ximenia woodlands; grassland; soil nitrogen; microbial biomass.

1. INTRODUCTION

Seronga is the largest village on the eastern part of the Okavango Delta. The Okavango is a large, landlocked delta in the north western part of the semi-arid Kalahari basin in Botswana. It covers about 22,000 km^2, of which approximately 6000 km^2 is permanent swamp. The remaining 10,000 - 16,000 km^2 flood plain habours a high density and diversity of fauna and flora [1]. This unique system draws its water from the high rainfall highlands of Angola, as the tributaries converge into the Okavango River and then spread as an alluvial fan. The Okavango is a very important system in the country as it is the only permanent source of water in an otherwise semi-arid region. Due to its hydrologically unique nature, the Okavango Delta is bordered by many villages which depend on it for livelihood. These include fishing, crop farming, cattle rearing and recently, tourism. Tourism as a livelihood has not yet been well established in this part of The Okavango Delta. Although the rich grasslands along the channel may provide rich grazing land and a lot of water for the cattle and other domestic animals, these do not render a cash income source for the people; mostly due to distance to the market and the occasional outbreaks of foot and mouth disease of cattle. Therefore, irrespective of the sandy soils, the people rely on crop farming for their livelihood. The main crops are sorghum (*Sorghum bicolor*), maize (*Zea mays*), beans (*Phaseolus* spp), groundnuts (*Arachis hyphogea*) and water melon (*Citrullus lanatus*). These crops are often grown in mixed farming.

Although the vegetation in the Okavango floodplains consists mostly of densely populated grass species communities, which vary depending on water gradient, flood regime and grazing pressure, these grass communities grow on sandy soils (>85% sand) with low cation exchange capacity (<5meq/100g soil) [2]. The combined effect of sandy soils, low cation exchange capacity and seasonal surface flooding is likely to result in leaching of essential elements such as nitrogen, which in turn could lead to poor plant growth [3]. As such, in most cases the people tend to practice shifting cultivation to try and get to the fertile lands. The new fields cleared may either be grasslands close to the water channel bank or the woodland areas consisting of mopane (*Colosphospermum mopane*) or sour plum (*Ximenia americana*) further from the channel. Once crop yields are low, the fields are normally abandoned and left fallow for some years. The abandonment of old fields and clearing of new ones is done without knowledge of the nutrient status of the fields and technical knowhow of the necessity to conserve the ecosystem. Thus an understanding of the nutrient status of these different land use systems would help provide information necessary in planning towards the most sustainable land use.

Nitrogen (N) is an essential macro element required for plant growth and soil microorganisms. Microorganisms are also involved in many N transformations that take place in soil. These include nitrogen fixation, nitrification, mineralisation of organic residues and denitrification [4]. Plants need N in large quantities and low concentrations of it in soil leads to poor plant growth [5]. Nitrogen occurs in many forms in soil. These include ammonium-N (NH_4^+), nitrate-N (NO_3^-), nitrite-N (NO_2^-), and in organic forms where it is often part of nucleic acids, proteins, amino acids and other amino forms [3]. Thus, the role of nitrogen transforming microorganisms in Seronga soils is of great significance as they determine mineralization of vegetation to release other N forms [5]. Microbial transformations such as nitrification determine the availability of nitrogen to the plants. In some Seronga soils under mopane vegetation, due to its allelopath nature [6] plant diversity and density is extremely low, therefore very few other plants grow. An understanding of the microbial mineralisation and nitrification levels could shed light on the future cropping lands. Although denitrification may be insignificant in sandy soils due to its high aeration, this could be important in the grasslands bordering the channel. Thus, the main objective of this study was to determine soil carbon, sulphur and nitrogen forms, transformations and microbial population and biomass that occur in surface soils (A_1) in the different land use systems of Seronga.

2. MATERIALS AND METHODS

Soil samples from the four main land uses of Seronga i.e., cropped, fallow, grassland, woodland consisting of mopane and Ximenia were analysed for different soil parameters i.e., pH, texture, moisture, S, C, N and its transformations and microbial diversity and biomass.

2.1 Site and Soil Sampling

Seronga, in Botswana (S -18.816°, E 22.415°) on the north east bank of the Okavango Delta was selected as the study site due to the strong landscape contrast between the flood plains and the higher bush veld with the villages and fields stretching along the embankment. The village was chosen because it exhibits all the four land uses typical of the Okavango Delta. Surrounded by cropped fields of mostly sorghum, millet, maize, groundnuts, beans and water melons. The village is also bordered by dense woodlands consisting of mopane (*Colosphospermum mopane*), silver terminalia (*Terminalia sericea*) and sour plum (*Ximenia americana*). These woodlands harbour a lot of wild animals ranging from elephants to small animals, such as jackals and phuduhudu (*Raphicerus campestris*). Adjacent to cultivated fields are the abandoned fields that have been left fallow and are often covered with herbs such as stink weed and wild basil. Close to the channel are the grasslands. The *Cynodon dactylon* grasslands are located higher than other grasses on the banks of the channel and are used mostly for grazing.

Representative land use areas were selected and three sites with a minimum of 5 m apart in each land use were also chosen for sampling. For sampling, three sub soil samples were collected from each site using a depth marked auger to 10 cm depth and combined in one bag to make one replicate of approximately 300 g. The three replicates of at least 5m apart from the same site were labelled immediately and put in one larger bag. Three replicates were sampled from each land use. Soils from a total of 30 sampling sites were collected at 0-10 cm depth from the different land use systems i.e., cropped fields, woodland mopane, woodland Ximenia, fallow and *Cynodon dactylon* grassland. Of the different land uses, the closest to the channel are the grassland, followed by the woodland Ximenia and eventually

the mopane woodland. The cultivated and fallow fields are scattered among the Ximenia and mopane woodlands. The collected samples were packed into plastic bags then cooler boxes and transported to the laboratory immediately. Once in the laboratory the portions of the samples for microbial analyses were separated from the rest and stored in the refrigerator at 4ºC until use. The soil samples for nutrient analyses were air-dried, sieved through a 2 mm sieve and stored at room temperature until analyses.

2.2 Soil Physical-Chemical Characteristics

Soil moisture was determined gravimetrically and calculated from weight loss after oven drying the samples at 105ºC overnight and then expressed on dry weight basis [7]. The hydrometer method of *Bouyoucos* was used to determine the sand, silt and clay content and then determining the soil textural class by using the soil textural triangle [7]. Soil pH of the samples from the different land uses was determined in water for active acidity and in 0.01M $CaCl_2$ for potential acidity. Replicate 10 g soil samples of each were mixed with 20 ml of the solution (water or $CaCl_2$). The mixture was stirred and then left to stand for 30 minutes while stirring occasionally and the pH of each soil sample was then read on a Corning scale pH meter electrode (model 215) and recorded.

2.3 Soil Carbon, Sulphur and Nitrogen and Its Components

The total soil carbon and sulphur contents of the different samples were determined using a CS 800 Carbon & Sulphur Analyser (Ultra CS800-Sci Lab UK). The CS 800 is a computer controlled carbon and sulphur analyser designed for rapid simultaneous determination of carbon and sulphur in soil and other samples. The equipment combusts the sample at 1350ºC and uses Mintek reference materials containing 0.56% S and 4.0% C as standards. Total N was determined using an automatic N analyser (EA 1100, Thermo Quest). The system was calibrated using EDTA as a standard.

The NH_4^+in the soil was first extracted with 2M KCl and then the filtered extract was analysed for NH_4^+using the indophenol blue method described by Keeney and Nelson [8]. The intensity of the blue colour that developed from sample extracts and standards was measured calorimetrically using a spectrophotometer at 636 nm wavelength. The readings from the standards were used to prepare a calibration curve which was used for the determination of sample concentrations. A solution of 2 M KCl processed in the same way as the soil extract samples was used as the blank.

Nitrite (NO_2^-) nitrogen was determined using the modified Griess-Ilosvay method [8]. The method involves extraction of nitrite with 2 M KCl, and then addition of a diatozing reagent (sulphanilamide) in HCl to convert the NO_2^- into a diazonium salt which is later treated with a coupling reagent N-ethylenediamine to convert it to an azo compound. The red colour of the azo compound was then measured on the spectrophotometer at 540nm. The NO_2^- content in the samples was determined with reference to a standard curve that had been prepared in a similar manner but using samples containing 1-5µg NO_2^--N. The NO_3^- in the KCl extract was determined by first reducing it to NO_2^- by passing it through a copperized Cd column and the resulting NO_2^- quantified using the Griess-Ilosvay method as above [8].

2.4 Soil Microbial Diversity and Biomass

Fungal, bacterial and actinomycetes populations were determined by plate count technique on different solid agar media. Soil serial dilutions of up to 10^5 from the different land uses were made in sterile tap water and then plated on respective sterile solid agar media. For total bacteria plating was done on Trypticase soy broth (BIOMEREUX Y42830) amended with 15 g/lagar (High Media M290), fungi on potato dextrose agar and incubated at 25ºC for 72 h. The actinomycetes populations were enumerated by spread plating the dilutions on starch casein agar [9] and then incubating at 25ºC for 14 days, to obtain ashy-like colonies typical of actinomycetes. In all cases, after incubation colony counting was done using a colony counter and recorded for each land use. The most probable number (MPN) of biophagic protozoan was determined using the baited plate technique as outlined by Gupta and Germida [10]. Soil dilutions (10^{-2} to 10^{-5}) were plated on to the 24 multi-well MPN plates containing 0.8% NaCl solid agar (15%) and over laid with 0.5 ml of concentrated cell suspension of *Enterobacter aerogenes*as prey and incubated at 25ºC and observed microscopically from 8 to 14 days.

Soil nitrification plays a significant role in converting soil NH_4^+ nitrogen to a plant available form (NO_3^-). Thus nitrification potential of these soils was estimated by determining the most probable number (MPN) of microorganisms capable of converting NH_4^+ to NO_3^- [12]. Serial dilutions (10^{-1} to 10^{-5}) of soil were inoculated into sterile 4X6 MPN plates containing inorganic NH_4^+ medium as a sole source of nitrogen for the nitrifying population capable of converting NH_4^+ to NO_3^-. While the NO_2^-oxidisers were determined by inoculating the soil dilutions into sterile inorganic medium containing NO_2^- as a sole source of nitrogen. The samples were incubated for 4 weeks at 25ºC. After the incubation period the NH_4^+ medium samples were tested for the presence of NO_2^- using the GriessIlosvay reagent [11] while the NO_2^- samples were tested for the presence of NO_3^- using the zinc-copper manganese dioxide powder (Zn-Cu-MnO_2). The assumptions made were that if *Nitrosomonas* were present in the soil dilutions inoculated into the NH_4^+ medium, it oxidizes to NO_2^- and gives a change of colour when tested with the GriessIlosvay reagent. Meanwhile in the NO_2^- tubes if it has been oxidized to NO_3^- the presence of NO_3^- was detected by the Zn-Cu-MnO_2 [11]. The NH_4^+ and NO_2^- oxidising bacteria population were interpreted with reference to the MPN table of Cochran [12] for use with ten-fold dilutions and five tubes per dilution.

Biomass C was determined using the fumigation re-inoculation technique outlined by Jenkinson and Powlson [13] and calculated as the difference between fumigated and un-fumigated sample using a K value of 0.45 [13]. Biomass N which represents the largest portion of organic N in soils in this case was calculated as a flush of N after fumigation and re-inoculation and then determining the amount of biomass C and extrapolating to Flush of N. The flush of N was calculated from the formula: Flush of N=Biomass C/9 [14].

2.5 Statistical Analysis

Analysis of variance was performed using the SPSS 11 package. *Post hoc* analyses were performed using the Tukey Test. In the analysis, group separation was based on land use (grassland, woodland Ximenia, woodland mopane, cultivated and fallow), and the parameter studied.

3. RESULTS

3.1 Soil Physical-Chemical Characteristics in the Different Land Uses

Soil textural analysis of the different land uses showed that all the soils contained more than 85% sand and were thus classified as sandy in the soil textural triangle (Table 1) [7]. The soil pH ranged from 7.0 in the Cynodon grassland near the channel basin to 5.28 in the mopane woodland. Generally there was a decrease in soil pH as distance from the channel basin increased, with the mopane woodland soils being the most acidic. The cultivated fields generally had higher pH than the fallow fields.

Table 1. Physical land chemical properties of soil from the different land uses¥

Land use	% Soil moisture	Textural class	Soil pH	
			Active acidity	Potential acidity
Grassland	3.89±0.02b	Sandy	7.oo	6.23
Woodland Ximenia	5.77±0.01b	Sandy	5.74	5.3
Woodland mopane	2.88±0.02ab	Sandy	5.61	5.28
Cultivated	50±0.01a	Sandy	7.oo	6.22
Fallow	5.25±0.01b	Sandy	6.36	6.15

¥Values given are mean ± SD (*).
Means followed by the same letter are not significantly different at 5% level.
Moisture content on oven dry weight basis.

Soil moisture analyses indicated that these soils are generally dry as they contained moisture contents ranging from 1.50 to 5.77 % on dry weight basis (Table 1). Not surprising though because sandy soils generally exhibit low moisture holding capacity. Although the soil moisture contents were low in all the land uses, the fallow fields had significantly higher moisture content than the ploughed fields confirming the Canadian farming systems where some fields are left fallow to conserve soil moisture in some years [16].

3.2 Soil Nitrogen Components and their Microbial Transformation.

Table 2 shows the total carbon, sulphur and nitrogen content of the different land uses in the Okavango Delta soils at Seronga.

Table 2. Soil carbon, sulphur and nitrogen levels in the A_1 horizon of the different land uses¥

Land use	% C	%S	% Total N	ppm NH_4^+	ppm NO_2
Grassland	1.007±0.3c	0.002±0.1a	0.017±0.70c	0.816±0.12c	0.070±0.2c
Woodland *Ximenia*	0.617±0.1b	0.007±0.2c	0.002±1.87a	0.394±0.11a	0.025±0.1b
Woodland mopane	0.529±0.1a	0.004±0.3b	0.002±1.79a	0.671±0.12b	0.010±0.1a
Cultivated	0.719±0.2b	0.006±0.2c	0.013±0.04c	0.430±0.11a	0.037±0.2b
Fallow	0.581±0.1ab	0.004±0.1b	0.007±0.04b	0.647±0.13b	0.011±0.1a

¥Values given are means ± SD x 10^{-2}; NO_3^- content was below the 10^{-4} ppm detection level. Means followed by the same letter are not significantly different at (P=.05)

Percentage soil carbon and sulphur differed with land use (Table 2). The carbon content was significantly higher *(P=.05*) in the grassland close to the channel than in other land use systems. The cultivated fields although scattered among the woodlands also exhibited a higher C content than the fallow and the woodland systems. The high carbon content in both the grassland and cultivated land may be attributed to the high root mass in the A_1 horizons. This carbon may be contained in organic matter or root exudates due to the heavy root masses. The cultivated land's high carbon content may also be attributed to the crop residues and manure incorporation, which with time can increase soil organic matter [16]. On the contrary the woodlands due to their deep root systems showed low carbon contents in the A_1 horizon. There was a significant difference *(P=.05*) in the carbon content of cultivated and fallow fields, with lower levels occurring in the fallow. This may be occurring due microbial grazing of organic matter without replacement as in cultivated fields where there is annual amendment of cattle manure and crop residues.

The % total N in Seronga soils ranged from 0.017 to 0.002 % (Table 2). It was relatively low in all the land uses when compared to 0.02-0.05 % in other Delta soils studied elsewhere [17,18]. Lowest mean values of 0.002 % in the woodland soils and highest mean values of 0.017% in the grasslands closest to channel bankwere observed. The slightly higher N content observed in the grassland in this study could be attributed to the N fixing ability of *Cynodon dactylon* [19]. Studies from other areas indicate that this grass harbours diazotrophs such as *Azospirillum* which may fix N in the rhizosphere. When N is fixed by diazotrophs this N is usually in the NH_4^+ form. This is in agreement with this study data that shows that the NH_4^+ N was highest in the grasslands. Cultivated fields also showed slightly higher total N than the woodlands, a parameter which may be attributed to N fixation by legumes. In Seronga, most farmers do not have access to chemical fertilizers. As such, they amend their soils with cattle manure which is often rich in total N toenrich their soils [16]. The farmers also practice mixed cropping of cereals and legumes such as groundnuts (*Arachishyphogea*) and beans (*Phaseolus* spp). The N fixing ability of legumes such as groundnuts has long been understood [20]. Incorporation of crop residues often containing groundnuts, beans and water melon straw is also a common practice in these areas. Thus the combined effect of mixed cropping with legumes and manure amendments may be the factors that lead to higher total N in the cultivated fields as opposed to the uncultivated woodlands. Once the fields are abandoned the fields turn to fallow, there is neither N additions due to cultivation of legumes nor manure amendments, thus the low total N observed in the fallow fields (Table 2). Except for cultivated fields, generally total N decreased as distance from the floodplains increased. Studies by Omari et al. [21] indicate that most of the N in Okavango soils is of flood origin. The woodlands are located further from the floodplains (wetland) and receive less flood water and alluvial deposits of nutrients hence the less total N observed in these soils.

Although total N is important in soils, it is important to know the forms in which the N occurs as some N forms are more plant available than others. Furthermore plants take up N mostly in the form of nitrates. To a certain extent in acidic soils, some plants may take in N in the form of NH_4^+ [22]. Nitrogen forms such as NH_4^+ although not plant available, serve as N reservoirs for plants and microorganism. The grassland had significantly higher (*P=.05*) NH_4^+ content (0.82 ppm), followed by woodland mopane, fallow, cultivated and finally woodland *X*imenia had the lowest content (0.43 ppm).The higher NH_4^+ observed in the grasslands may be attributed to asymbiotic N fixation potential of *Cynodon dactylon* and the low nitrification potential associated with ethylene, a nitrification inhibitor produced by grassland soils under aerobic conditions [23]. The Cynodon grasslands studied are located along the floodplains of the Okavango delta, which are often grazed by cattle. The results agreed with those of

Bonyongo and Mubyana [24] who stated that the Okavango grasslands contain more organic matter due to faecal matter from animals that graze in the grassland. They also state that the area along the floodplains receive more nutrient deposition from the surface floods of the Okavango delta. Therefore NH_4^+ is also most likely to be released from mineralisation of organic material such as roots in grassland, hence the high content of NH_4^+ recorded in the grassland. Because soil moisture plays a major role in microbial mineralisation and transformation of elements [5,11], the low moisture content in cropped fields (1.50 %) (Table 1) could also explain the low NH_4^+-N content because low soil moisture also favours the formation of insoluble nutrient-containing compounds. The Grasslands total N and NH4+-N contents could also be attributed to the low bacteria populations indicating the presence of negative parameters affecting ammonization and nitrification processes. On the contrary, this could explain the high content of nitrite ion (NO_2^-) obtained in Grasslands area.

Even if the mopane woodlands had low total N, these woodlands contained higher NH_4^+ when compared to the other land uses apart from grasslands (Table 1). In this study, this was not just attributed to the high wildlife grazing manure deposition, but also the low nitrification potential associated with the mopane woodlands [25]. These soils also showed minute levels of nitrite (NO_2^-). Nitrite, is the intermediate product in the conversion of NH_4^+ to NO_3^- and is toxic to plants; fortunately it is rapidly converted to NO_3^-) or leached in sandy soils. Thus the minute levels of the NO_2^- observed in this study. Nitrate N in these soils were all below the detection level. Although this was partly explained by the low nitrification levels of grassland and mopane soils, it could also be due to the very high sand content of these soils (Table 1). Thus, any NO_3^- that may arise from nitrification is either taken up by plants right away or lost by leaching as sand soils are highly susceptible to leaching [26].

3.3 Soil Microbial Diversity and Biomass

Bacterial populations in the different land uses did not differ significantly except in the grassland which showed lower bacterial counts compared to the other four land uses (Table 3). However, the grassland had significantly higher *(P=.05*) fungal populations than the other land uses. Fungi play a major role in decomposition of organic residues, thus are bound to be higher in grassland than in the woodland surface soils. Mopane woodlands are known to exhibit allelopath behaviour to other plants especially grasses. This is due to its roots' ability to secrete phenolic compounds which inhibit the growth of other plants [6]. Thus, there is usually very low population of grasses or other plants growing under the mopane canopy [26]. In Serongamopane woodlands, very few grass species grow in the tree canopy, as such the low fungal population observed due to lack of the substrates. Actinomycetes populations were highest in the mopane woodland. Mopane leaves are known to contain tannins and other compounds highly resistant to most microbial degradation. Although resistant to other microorganisms, actinomycetes are capable of degrading highly resistant compounds and can carry out the process at high soil temperatures (>40ºC). Seronga region has very high temperatures (>40ºC) during the dry hot season, as such actinomycetes are most likely the only microorganisms that can survive and degrade resistant compounds at those soil temperatures.

Table 3. Mean microbial populations in the different land uses of Seronga soils

Land use	Bacteria	Fungi	Actinomycetes
		(CFU/g soil)	
Grassland	3.4 x 10^6	1.6 x10^6	6.4x10^5
Woodland Ximenia	1.1x10^7	3.1x10^4	3.3x10^5
Woodland mopane	5.5x10^7	1.4x10^4	9.4x10^5
Cultivated	5.2x10^7	1.2x10^5	1.5x10^4
Fallow	5.3x10^7	1.2x10^5	9.1x10^5

Biophagic protozoa populations in all the land uses were very low. With none observed in all the other land uses except, 70 and 90 MPN/g soil in the cultivated and fallow fields respectively. This is in accordance with the low bacteria populations of these soils. Protozoans have a low grazing population limit of 10^6. Below that they form cysts. Similar studies from mopane soils in the Okavango have also shown insignificant biophagic protozoan populations [25].

Table 4 shows the most probable number (MPN) of nitrifiers in the different land use soils. Most probable number of (NH_4^+) nitrifiers in the different land uses of Seronga showed the lowest levels in the grassland. The paucity of the nitrifiers confirms the low nitrification ability of the grassland. This land use systems also showed significantly higher *(P=.05*) NH_4^+ than the other land use types (Table 2). The NO_2^-nitrifiers on the contrary did not differ with land use except for the woodland Ximenia, a parameter that may be associated with low availability of the substrate in all the land use systems probably due to leaching of nitrites before the bacteria could use them.

Table 4. Most probable number of nitrifiers and microbial biomass C and flush of N in Seronga soil under different land use

Land use	MPN nitrifiers±SD/g soil	
	NH4+	NO2-
Grassland	78±24a	14±5a
Woodland *Ximenia*	170±36b	260±29b
Woodland mopane	330±38c	22±6a
Cultivated	790±54d	22±7a
Fallow	170±29b	28±11a

Fig. 1 also shows the microbial biomass carbon contents of the soils under different land uses. The highest microbial biomass was observed in the grassland (120.76 mgC/kg soil) followed by the cultivated and then soils under fallow. The high microbial biomass observed in the grasslands also corresponds well with the high total carbon observed there (Table 2). This may indicate high substrate for the microorganisms and as such the high microbial biomass observed. On the contrary, mopane soils only had 11.73 mgC/kg soil. The low microbial biomass carbon observed in the mopane soils actually corresponds with the low total carbon (Table 2) and fungal counts (Table 3) observed in those soils. Due to their size, soil fungi contribute more to microbial biomass than bacteria. Mopane soils also have very little other vegetation in terms of grass species growing on them. As such, the A_1 horizon has lower root density compared to the other land uses. Grasslands due to the fibrous root system prevailing in the A_1 horizon habour a lot of microorganisms on their roots thus the higher biomass C observed in grassland and the fallow fields.

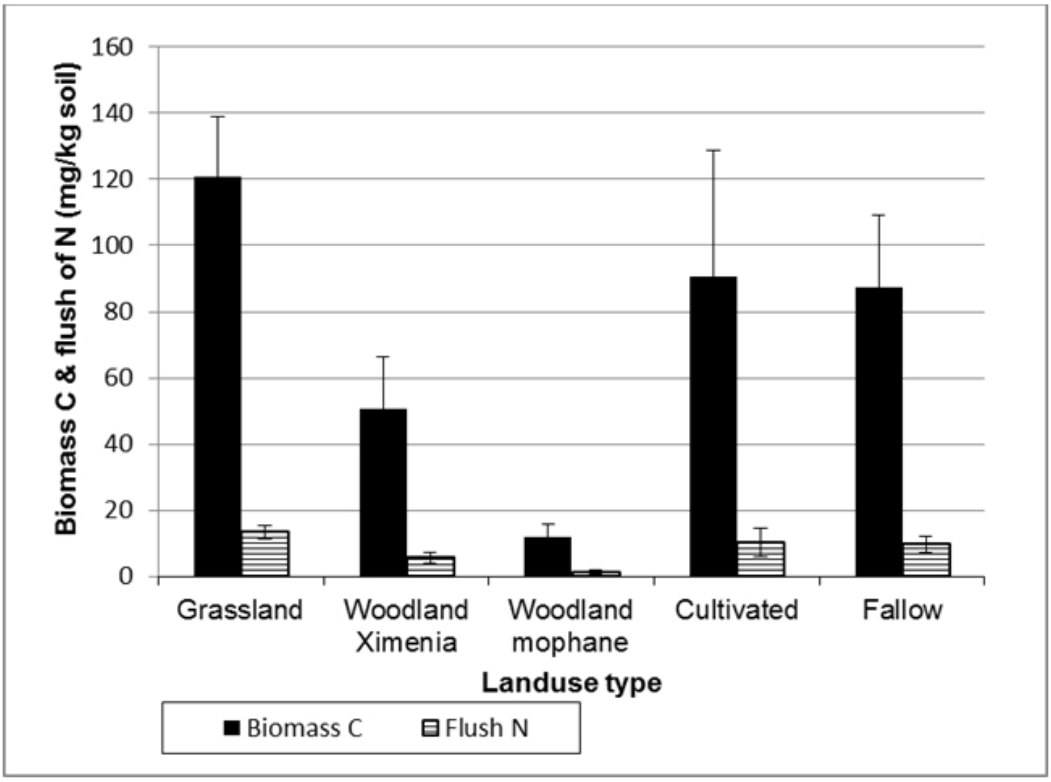

Fig. 1. Influence of land use microbial biomass C and flush of N.
Error bars represent standard deviations.

Crop residues and animal manure amendments in cultivated fields may increase microbial population due to their role in decomposition and mineralisation [26]. The increased microbial population may thus also contribute to increased microbial biomass C and flush of nitrogen observed in cultivated fields as opposed to the two woodland systems.

4. CONCLUSION

Soil microbial population, biomass and soil nitrogen, carbon and sulphur status in the surface soils of the Okavango channel basin of Seronga differed with land use. Overall total N was very low. However, total N and Cwas significantly higher in the grasslands close to the channel and was lowest in the mopane woodlands furthest from the channel. Both cultivated fields and grasslands had significantly higher *(P=.05)* N, C, and microbial biomass carbon than the other land use soils studied. Cultivation of woodlands followed by soil amendments with cattle manure and crop residues seems to increase total N and microbial biomass C. However these decrease when the fields are left fallow. Overall this study indicates that the fallow system practiced lowers the N and C content of the previously cultivated soils, as such is an unjustified practice.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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