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Physicochemical Properties of Soil from Five Villages in Botswana with Respect to Soil Degradation

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ABSTRACT

A field study was conducted at five villages of Botswana namely, Tsabong, Tshane, Mathathane, Motlhabaneng and Tsetsejwe during the periods of June to August 1999 and June to August 2000. The objective of the study was to assess and compare the soil physicochemical properties of soils at the five villages and to study the effect of cultivation on some soil physical properties. Parameters measured in the field included soil pH, organic carbon (OC), phosphorus (P), cation exchange capacity (CEC), exchangeable cations (Ca, Mg, K and Na), bulk density (BD), soil penetration resistance and infiltration rate. Soil pH, OC, CEC, Mg, Ca and BD were found to be significantly different in the five villages. The non-cultivated soil was found to have significantly lower bulk density, higher infiltration rate and higher penetration resistance compared to the cultivated soil. Soil from the Kgalagadi area was found to be significantly lower in nutrients in comparison with the soil from the Bobirwa area. The cultivated soil was found to have higher, bulk density, lower infiltration rate and lower penetration resistance.

Keywords: bulk density, cultivation, infiltration rate, penetration resistance, physicochemical properties, soil degradation

INTRODUCTION

About two thirds of Africa depend on agriculture for their livelihoods (Henao and Baanante, 1999). As the region's population continues to grow rapidly, outpacing the growth rate in other regions of the world, its agricultural land is becoming increasingly degraded. This is because farmers are intensifying land use to meet food without proper management practices and external inputs. The resulting depletion of nutrients from soils has caused a decline in agricultural production due to the ecosystem being stressed beyond its tolerance limit. This results in soil degradation. Overgrazing and firewood collection are some of the human activities that contribute towards soil degradation. Both of these practices eliminate plants that add organic matter thus encouraging soil erosion. Organic matter acts as a binding agent for soil particles. Livestock also compact the soil with the pounding action of their hooves, an action that reduces water percolation, leading to soil erosion by wind and water. Recent intensification of pastoral land use in the semiarid core of the Kalahari (Kgalagadi in local language) comprising much of Botswana, eastern Namibia and northern South Africa based on the drilling of deep boreholes, has led to concerns of widespread land degradation (Dougill and Thomas, 2004). This degradation of formerly productive land is also known as desertification. Desertification is a natural or human induced process of irreversible change in the soil and vegetation of dryland zones, aridification and reduction in biological productivity (FAO, 1995). Desertification processes render the land difficult to manage for sustainable use. The over utilisation of the basic natural resources such as soil, leads to the reduction in their production potential.

The Kgalagadi region of Botswana represented by Tsabong and Tshane in this study, is located in the south western part of the country. The area is drier than most parts of the country with mean annual rainfall of less than 250 mm (Bhalotra, 1987). This area is highly degraded due to overgrazing and reduction of woody vegetation cover (Dougill and Thomas, 2004; Ringrose and Matheson, 1995). The Bobirwa sub district represented by the villages of Motlhabaneng, Mathathane and Tsetsejwe in this study, located in the eastern part, is one of the degraded areas of the country. The land use in these villages is mixed farming comprising of communal grazing and arable farming. Research has established that in the Kgalagadi area, permanent livestock production may bring about changes in the chemistry of the soil, its erodibility as well as on vegetation cover (Perkins and Thomas, 1993). According to Ringrose and Matheson (1995), this degradation is related to density and distribution of livestock and less on human population density. Serious problems of soil erosion have been identified in the eastern Botswana, and some areas have even been quantified (Fraser and Mabusela, 2001). Very few studies however, have been carried out to assess the chemical and physical properties of soil in degraded areas so as to quantify changes in fertility levels. The objective of this study was therefore, to assess and compare the soil physicochemical properties of five villages from Bobirwa and Kgalagadi regions of Botswana and to study the effect of cultivation on some soil physical properties of the area.

MATERIALS AND METHODS

Description of the study area

The study was conducted at the villages of Mathathane, Motlhabaneng, Tsetsejwe Tsabong and Tshane (Figure 1) in Botswana from June to August 1999 and repeated in June to August 2000. Mathathane, Motlhabaneng and Tsetsejwe are in the eastern part, in the hardveld, while the villages of Tsabong and Tshane lie in the western part of the country, in the sandveld

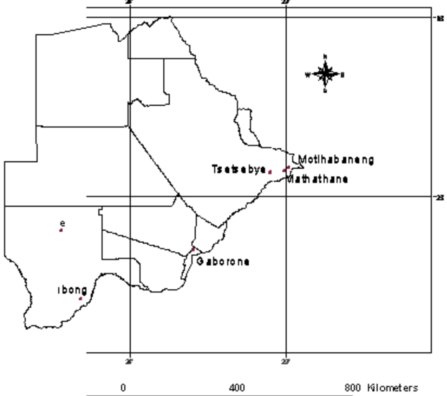

Fig. 1 Map of Botswana showing location of the study sites

(De Wit and Kgatlwane, 1990). Soils of the hardveld are mostly weathered in situ, whereas those of the sandveld are of an aeolian nature. The two areas were selected based on their rainfall amounts and the reported overgrazing.

Soil sampling and analysis

At each of the selected villages, an uncultivated site was selected adjacent to an arable field. Infiltration rates were determined using the double ring infiltrometer on both the cultivated and the non-cultivated soil. Open-ended stainless steel cylinders of 25 to 35 cm in diameter and 30 cm in height were driven into the soil by a heavy hammer to a depth of 15 cm. Another cylinder larger in diameter was driven into the soil to the same depth around the inner one. The intake of water in the inner cylinder was measured for a progressive increase in time intervals while keeping the space in between the inner and the outer cylinder filled with water. The bulk density of the soil was determined by obtaining an undisturbed soil sample of 100 cm^3. The soil was dried at 110 °C for 48 hours. The oven dry soil mass was divided by the field volume of the sample to obtain bulk density. Penetration resistance was determined by driving a penetrometer into the soil and noting its reading. Five measurements were made at each site for infiltration, bulk density and penetration resistance. Infiltration and penetration resistance measurements were not carried out in the Kgalagadi region due to the fact that the soils are sandy, with the sand fraction being about 98-99% in most cases.

Thirty-five samples per hectare from the top 20 cm of soil per hectare were collected from both the field and the non-cultivated soil adjacent to the field. Samples were kept in labelled plastic bags for laboratory analysis. After drying, samples were passed through a 2 mm sieve and stored in plastic bottles. Soil samples were analysed for CEC, using the ammonium acetate method at pH 7. Exchangeable Ca and Mg from the extract were determined by atomic absorption spectrophotometer (Varian model AA 10). Exchangeable Na and K were determined by flame photometry (Corning 410). Phosphorus was determined using the molybdate blue method. Soil pH was determined in a 1:2.5 soil - 0.01 M $CaCl_2$ suspension using a glass electrode, while organic carbon (OC) by the oxidation method with chromic acid. All the methods are outlined in Page *et al.* (1982).

Table 1. Comparison of soil properties of non-cultivated soil at the five different villages

Location	pH	OC (g/kg)	P (ppm)	CEC	Ca	Mg cmol/kg	Na	K	BD (g/cm³)
Mathathane	6.8 [a]	0.6 [b]	4.8 [ab]	20.2 [b]	15.9 [b]	2.6 [bc]	0.02 [ab]	0.6 [ab]	1.68 [a]
Motlhabaneng	7.3 [a]	1.4 [a]	7.7 [a]	35.3 [a]	20.3 [a]	11.4 [a]	0.003 [a]	1.1 [a]	1.44 [c]
Tsetsejwe	5.7 [b]	0.3 [c]	2.0 [b]	11.9 [b]	7.6 [bc]	3.4 [b]	0.00 [b]	0.5 [ab]	1.54 [b]
Tsabong	5.5 [b]	0.1 [c]	0.8 [b]	5.4 [c]	4.5 [c]	0.3 [c]	0.0 [b]	0.6 [a]	1.61 [ab]
Tshane	5.7 [b]	0.2 [c]	1.7 [b]	5.7 [c]	4.0 [c]	0.9 [c]	0.0 [b]	0.2 [b]	1.58 [b]
LSD	0.9*	0.2****	4.2 ns	3.0****	11.2***	3.4****	0.03ns	0.8ns	0.08**

Note: Means along the column with the same letter superscript are not significantly different; *, **, ***, ****, ns = $p < 0.05$, 0.01, 0.001, 0.0001 and $p > 0.05$ respectively

Data Analysis

Data was subjected to analysis of variance (ANOVA) using the General Linear Model procedure of the SAS (2001) package. Means were separated using the least significant difference (LSD) method.

RESULTS

The pH values of Mathathane and Motlhabaneng soils did not differ from each other. There were also no significant differences between soil pH values of Tsetsejwe, Tsabong and Tshane (Table 1). Tsabong, Tshane and Tsetsejwe soils were significantly more acidic than those of Mathathane and Motlhabeng.

Motlhabaneng soil contained significantly higher organic carbon content than soils from the other four villages. There were no significant differences in organic carbon content of soils from Tsetsejwe, Tsabong and Tshane (Table 1).

The soils from Motlhabaneng and Mathathane did not differ significantly in their P contents but were significantly higher than those of Tsetsejwe, Tsabong and Tshane. The P contents of Mathathane, Tsetsejwe, Tsabong and Tshane soils did not differ significantly. Motlhabaneng soil had significantly higher CEC than the other sites (Table 1). There were no significant differences in the CEC of Tsabong and Tshane, as well as those of Mathathane and Tsetsejwe (Table 1). The same trends were observed for exchangeable Ca contents. Motlhabaneng soil contained significantly higher amounts of exchangeable Mg than Mathathane, Tsetsejwe, Tsabong and Tshane. Tsetsejwe soil contained a significantly higher amount of exchangeable Mg than soil from Tsabong and Tshane (Table 1).
Motlhabaneng soil had significantly higher exchangeable Na content compared to Tsetsejwe, Tsabong and Tshane. Despite the significantly higher Na content of Motlhabaneng soil, overall, there were no significant differences among all the villages in terms of exchangeable Na (Table 1). The exchangeable K content of Motlhabaneng soil was significantly higher than that of Tshane soil. These K contents were, however, not significantly different (Table 1).
Mathathane soil had the highest bulk density and it was significantly different from soils of the other villages. There were significant differences among bulk densities of soil from Tsetsejwe, Tsabong and Tshane (Table 1).
Cultivation had a significant effect on the soil bulk density. The non-cultivated soil had a significantly lower bulk density and higher infiltration rate than the cultivated one. It also had a higher penetration resistance compared to the cultivated one (Table 2).

DISCUSSION

The villages of Mathathane and Motlhabaneng are both in the eastern part of Botswana, on the hardveld. Soils of the hardveld have been mostly weathered in situ whereas those of the sandveld, as the name suggests are of an aeolian nature (De Wit *et al.*, 1990). Soil pH was found to be higher for Mathathane and Motlhabaneng because the leaching of the basic cations is not as fast as on sandy soils, due to a restricted drainage caused by soil texture. In these soils, an illuvial Bt horizon/layer was found. A Bt horizon is a layer of clay that has been translocated by water through leaching from the topsoil. Soil water move relatively slowly through this layer. Although Tsetsejwe is also in the eastern part of the country, its soil pH was more comparable to that of Tsabong and Tshane soils, which lie on the sandveld. The nature of soil from Tsetsejwe is sandy,

Table 2. Effect of cultivation on soil physical properties

Status	Bulk density (g/cm^3)	Infiltration rate (mm/hour)	Soil Penetration Resistance (MPa)
Cultivated	1.61^a	127.0^a	0.77^a
Non-cultivated	1.53^b	110.0^b	3.83^b
LSD	0.054 ***	26.5*	0.50*

Note: Means along the column with the same letter superscript are not significantly different; *, *** = $p < 0.05$ and $p < 0.001$ respectively

not because of an aeolian nature, but because they were weathered from granite (Rhebergen and Mafoko, 1984).

Mathathane and Motlhabaneng soils had significantly higher OC values than the others probably due to the differences in rainfall amount between the eastern and the western parts of the country, which leads to variation in vegetation. The eastern part of Botswana receives a mean annual rainfall of 450 mm while the west receives less than 250mm (Bhalotra, 1987). Higher rainfall produces a larger amount of vegetation, which results in high plant litter production, leading to higher soil organic matter. The potential to increase soil organic matter also depends on the type of soil (Brady and Weil, 1999). Medium and heavy (loams and clays) textured soils will have higher organic matter due to their ability to support vegetation compared to light textured soils (sands). Organic matter content values are inherently low in these soils because of the high decomposition rates imposed by the climatic conditions. Soil organic matter is important because it improves both the physical and the chemical properties of soil. It decreases soil erosion by stabilising soil particles. It also enhances aeration, increases water holding capacity and restores and supplies nutrients such as nitrogen, phosphorus and sulphur for the growth of plants and soil micro-organisms. Soils, which are low in organic matter, are generally low in fertility.

Motlhabaneng soil had a significantly higher P content than the other soils. All the soils however, were found to contain generally low (less than 10 ppm) P contents for optimum growth of crops. The low P content is an important soil fertility problem of both the tropics and subtropics (Fiantis *et al*., 2002; Fox and Searle, 1978; Uehara and Gillman, 1981). Low P is one of the most limiting factors to crop production in Botswana (Anon, 1984; Pardo *et al*., 2000; Pule-Meulenberg and Batisani, 2003). Phosphorus deficiency in most of the Botswana soils is due to fixation of P non-available forms, but not from inadequate total P content (Molapong, 1986).

Cation exchange capacity (CEC) and exchangeable cations followed the same trend as the other parameters where the villages of Mathathane and Motlhabaneng had significantly higher values. Soil containing higher clay and organic carbon contents are expected to have higher CEC values. Due to their positive charge, cations are adsorbed onto the negatively charged soil surfaces of clay and organic matter. The organic fraction of the soil has –COOH and –OH groups that dissociate and lead to a negative charge resulting in more adsorption of cations. On clay minerals, adsorption occurs as a result of isomorphic substitution (Brady and Weil, 1999).

Mathathane soil had a significantly high bulk density and low organic carbon. This is probably due to trampling by both livestock and wildlife that compacts the soil. Low soil organic carbon contents have been associated with high bulk density (Brady and Weil, 1999). Increased bulk density causes decreased aeration and impedes root penetration. Reduced water permeability that may result from high bulk densities can result in soil erosion that has serious negative effects on the environment (Horn *et al*., 1995). High soil bulk density may strongly indicate that the soil may have a problem of compaction.

The low bulk density of Motlhabaneng soil corresponds to the relatively higher organic matter content. This soil also had the highest P, CEC and exchangeable cations and hence was less degraded as compared to the soil from other areas. No significant differences were found among the soil bulk densities of Tsabong, Tshane and Tsetsejwe. This is consistent with the similarities found in the chemical properties of these soils.

Soils under cultivation had significantly higher bulk density than the adjacent soil. This property is a useful criterion for evaluating the rooting depth, water storage capacity in the root zone and for developing tillage systems (Greenland, 1981). A high bulk density also implies that water infiltrates slowly into the soil. This is detrimental during rainstorms where there is a lot of runoff and erosion. The combination of high bulk density and lower infiltration rate is a clear indication that already some of the topsoil has been removed by erosion. The higher infiltration rates for the cultivated soil in Table 2 compared to the virgin soil are, therefore, misleading in this respect. According to Thompson and Troeh (1978), cultivation loosens the soil temporarily, but the cultivated soil gradually becomes denser than adjacent uncultivated soil of the same type. Evidence of sheet erosion was recorded during the soil survey in all the five villages.

The penetration resistance of the non-cultivated soil was found to be significantly higher than that of the cultivated one. This is contrary to the findings of Islam and Weil (2000). Factors that affect soil penetration resistance include water content, bulk density, soil compressibility, soil strength parameters, and soil structure. (Bradford, 1986). It is possible that the lower penetration resistance of the cultivated soil was temporary due to the loosening of the soil and that in the long run soil compaction will take place. According to McQueen and Shepherd (2002), tillage results in soil particle rearrangement, breakdown of aggregates, and pore discontinuity. Cultivation also enhances decomposition rates of organic matter, leading to higher bulk density. Mullins *et al*. (1992) classified penetration resistance as a measure of resistance to root growth as follows: easily rootable, < 0.75 MPa; significant impedence, 0.75 – 1.5 MPa; poorly rootable, 1.5 – 3.0 MPa and little or no root growth, 3.0 – 6.0 MPa; and impenetrable, >6.0 MPa. The significantly higher penetration resistance for the uncultivated soil could be an effect of livestock and wildlife trampling. All the sites have large populations of livestock and wildlife. Populations of wildlife are large because there are game reserves close by all the study sites. According to Moleele *et al*. (2002), animal grazing and trampling as well as movement of people have been known to cause trampling which results in bare soil patches.

After comparing the physicochemical soil properties of the two areas, it is concluded that the Bobirwa area (Mathathane, Motlhabaneng and Tsetsejwe) had higher and slightly better physical and chemical properties than the Kgalagadi (Tsabong and Tshane). The organic carbon and the P contents were slightly higher in Bobirwa than the Kgalagadi soils. This study also showed that the cultivated soil had higher bulk densities and lower infiltration rates as compared to the non-cultivated one. A higher penetration resistance was recorded for the non-cultivated soil than the cultivated one. Given the measurements for the bulk density and the infiltration rate, this was not expected. According to Islam and Weil (2000), soil degradation can occur as a result of the macro-aggregate disruptions and loss of labile organic matter due to amongst other factors, tillage. This could have happened in the cultivated soil.

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