Land Use Systems and Soil Quality Indicators in a Fersiallitic (5e) Soil at Matopos Research Farm in Zimbabwe

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Abstract This study investigates soil texture and chemical properties on different land use systems in order to determine soil exchange characteristics that influence land quality. In order to assess the effect of land use over time some soil samples were taken to determine the soil quality for agricultural purposes. The experiment was carried out at Matopos Research Institute located at longitude 28°29′ E, latitude of 20°24′ S. A completely randomized block design (CRBD) was used for collecting soil samples for laboratory analyses from four land use systems namely rain-fed fields, irrigation land, fallow and grazing. Data was analyzed using ANOVA. There were significant ($P < 0.05$) differences for the soil properties: soil texture, N, P, K, and Mg in different land use systems. N, P, and K levels were relatively high on land under irrigation compared to other land uses. Exchange properties: Cation Exchange Capacity (CEC), and calcium magnesium ratios had significant ($P < 0.05$) differences among land use systems. From the findings of this investigation, it was therefore concluded that farmers periodically need to fallow their lands to sequester organic matter, stabilize soil aggregates, improves nutrient cycles for sustainable agricultural production. In addition, for best responses for land management it is important to send soils for analysis for correct fertilizer recommendations.

Keywords Soil quality indicator · Land use systems · Land use intensity

Introduction

The sustainability of crop and soil management practices to improve or maintain soil quality depends on the understanding of how soils respond to different site-specific cropping and land-use practices (Tesfahunegn et al. 2020). Site-specific data on soil properties could also support to dealing with spatial variability of soil nutrients

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and physical indicators and their influencing factors. Such information is important to formulate appropriate sustainable cropping systems and land-use type strategies (Negasa et al. 2017; Trivedi et al. 2016). Thus, it necessitates knowing the extent of soil quality degradation in terms of soil physical and chemical properties and nutrient stocks under different management practices such as irrigation and rain-fed cropping and other land-use systems and soil management practices (Tesfahunegn et al. 2020).

Assessing land use-induced changes in soil properties is essential for addressing the issue of agro-ecosystem transformation and sustainable land productivity (Yao et al. 2010).

The soil quality concept that provides a tool to help quantify the physical response of soil to land use changes and soil/crop management practices is the soil physical quality (SPQ) indicators. It primarily refers to soil strength, fluid transmission and storage characteristics in crop's root zone. Land use changes and soil management practices can potentially alter SPQ thereby, influencing basic soil functions such as: moderating and partitioning water, solute movement, and their redistribution and supply to plants; filtering, buffering, immobilizing organic and inorganic materials; promoting and providing resistance to erosion (Karlen et al. 1997).

It is apparent that soil is one of the most important and determinant factors that strongly affects crop production. Soil is the foundation resource for nearly all land uses, and the most important component of sustainable agriculture (Mulugeta and Karl 2010). Therefore, assessment of soil quality indicators with respect to land use types, management practices and slope classes is useful and primary indicator for sustainable agricultural land management. Understanding the effect of these factors on soil properties is useful for devising land management strategies. The information can also be used to forecast the likely effects of any potential changes in land use types and management practices on soil properties. It is apparent that the destruction of vegetative cover can promote soil erosion, which eventually increases the magnitude of soil related constraints to crop production. Generally, a sound understanding of land use and management effects on soil properties provides an opportunity to evaluate sustainability of land use systems (Woldeamlak 2003).

Many smallholder farmers practice subsistence farming that is characterized by continuous cultivation and grazing of very high land use intensities. They fail to produce enough to feed their families because their lands and soils have become aged and infertile. Replacing this with virgin land is almost impossible because the land has become a very scarce resource due to urbanization and increase in populations. It is necessary to investigate the status of soil quality and how it is influenced by the way farmers use the land. So far, very few quantitative studies have been done for example to assess the effects of soil depth on soil. It has already been noted that soil degradation is compounded by shortage of additional arable land for expansion and intensification especially on smallholder farms. Research has revealed that prolonged and intensive cultivation resulted in deteriorating plant nutrients (Admas 2018).

The main objective of this study therefore, was to investigate the impact of four different land use patterns namely rain fed cultivation, irrigation, grazing and fallow on soil physical and chemical characteristics in order to identify critical soil quality indicators for management. Specific objectives were:

i. To examine the effects of land use systems on soil quality based on soil pH, cation exchange capacity (CEC); exchangeable sodium percentage (ESP): exchangeable potassium percentage (EKP) and Calcium to Magnesium (Ca: Mg) ratios in the soil at Matopos.
ii. To suggest suitable land management practices that would improve soil quality in small holder farming.

Materials and Methods

Study Area

The experiment was carried out at Matopos Research Institute (28°29′ E and 20°24′ S) in Zimbabwe approximately 1340 m altitude in agro-ecological region IV (Vincent and Thomas 1961). Rainfall is both limited and variable (250–1400 mm per year, median 570 mm) and occurs between October and April. October is the hottest month (mean maximum 29.4 °C). The soil type is called Fersiallitic soil (5E) that is medium Sandy Clay Loam (mSaCL) or Clay Loam (CL) textured with dark reddish brown or brown colour (10YR 4/3 Munsell soil colour notation) of good permeability and drainage, derived from or mafic (basic) rocks known in Zimbabwean soil literature as epidiorite. The area has a mosaic vegetation type made up of Tree Bush Savanna (TBS) of varying densities, with the most dominated tree species being *Acacia karoo, Acacia gerrardi, Acacia rehmanniana, Acacia nigrescens and Maytenus senegalensis* in combination with a continuous and discontinuous cover of commoner grass species that include *Heteropogon contortus, Cymbopogon plurinodis, Themeda triandra* and *Hyparrhenia filipendula* (Zhou 2004).

Experimental Description

The experiment was arranged in four land use patterns with depths for top soil (A horizon); upper sub soil (B horizon) and lower sub soil (BC horizon) having soil samples taken from them. A completely randomized block design (CRBD) was used for collecting soil samples in each of the four representative land use systems selected namely: rain fed fields, irrigation land, fallow land and grazing area.

Procedure for Soil Preparation

The targeted soil for study was the fersialitic 5E soils at Matopos Research Station. These soils do reflect diverse physical, chemical and biotic properties but the scale is small (Zhou 2004). For many years Matopos and the local small holder farming

community soils under different land use systems have not been sent for laboratory analyses to check for soil quality which is a key in deciding land management and improving soil productivity. This involves an assessment of "the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation" (Doran and Zeiss 2000). Soil samples were collected from different land use patterns (rain fed fields, irrigation plots; fallow land and grazing area) using an auger from three different horizons namely top soil (A horizon); upper sub soil (B horizon) and lower sub soil (BC horizon) and then prepared for laboratory analyses at the Department of Research and Specialist Services (DR and SS) in Harare. Data analysis was done using Analysis of Variance (ANOVA) in Genstat 19th edition.

Results

The results for the four-land use systems are shown in tables and graphs.

Soil Physical Properties

There is no marked variation in soil texture as indicated by the soil textural classes as these generally range between sandy clay loam and clay loam especially in fallow and grazing land use systems. However, there are some discernible differences in textural classes between irrigated and rain fed, and fallow and grazing (Table 1) possibly due to different land use intensities with soil cultivation in irrigation and rain fed and not in the other two land use systems (Table 1).

The highest sand content across all sand types (fine, medium and course) and land use patterns was obtained in irrigation, this may be associated with continuous

Table 1 Soil texture in different land use patterns

Soil texture	Fallow	Grazing	Irrigation	Rain fed	P level
Fine sand (%)	18.7	20.0	25.0	21.3	Not significant
Medium sand (%)	5.67[a]	7.00[a]	21.67[b]	3.00[a]	<0.001
Coarse sand (%)	4.67[a]	9.00[b]	11.33[b]	2.00[a]	0.003
Silt (%)	33.33[b]	25.67[a]	20.67[a]	43.00[c]	<0.001
Clay (%)	37.67[c]	38.33[c]	21.33[a]	30.67[b]	<0.001
Soil textural class	SaCL	CL	m Sa L	Si CL	

Notes f Sand = fine Sand; m Sand = medium Sand; c Sand = coarse Sand; CL = clay loam; Sa CL = sandy clay loam; m Sa L = medium sandy loam; c Sa CL = clay sandy clay loam; Si CL = Silt clay loam

cultivation using inorganic fertilizer for long-time in which such practices aggravate erosion that erode fine soil particles and leaves coarser particles. As for clay content, the highest value (up to 38.33%) was obtained in grazing and fallow fields. Irrigated land had the lowest clay content of 21.33%. There was a significant ($P < 0.05$) difference on the clay content among the different land use patterns (Table 1).

Soil Chemical and Exchangeable Properties

ANOVA results for N, P, K and magnesium assessed showed significant ($P < 0.05$) differences for all the four land use systems (Table 2). Soil pH appears to be within slightly acidic range notably under rain fed cultivation and irrigation. The soil pH did not vary between the land uses systems.

The chemical properties of soils in the study areas as shown by Total Exchangeable Bases (TEB) and CEC of the soil vary with position along the catena. High values of TEB and CEC are found in the lower parts of the catenas and in the sub soils where clay content is higher and drainage is poorer than in the top parts of the catenas (Zhou 2004). Generally, CEC was high in all land use systems with highest figure of 21.94 c mol c/kg on grazing land which is similar to fallow land (Tables 2 and 3).

Table 2 Chemical characteristics (N, P, K, Mg ad Na) of soils in different land use systems

Soil nutrient	Fallow	Grazing	Irrigation	Rainfed	P level
N (ppm)	20.00[a]	28.67b[c]	26.67[b]	23.00[a]	<0.017
P (ppm)	20.0[a]	8.7[a]	88.3[b]	14.7[a]	<0.001
K (c mol c/kg)	0.363[b]	0.200[a]	0.257[a]	0.167[a]	<0.047
Mg (c mol c/kg)	8.10[c]	9.62[d]	5.55[a]	7.03[b]	<0.001
Na (c mol c/kg)	0.077	0.093	0.067	0.077	Not significant
Ca (c mol c/kg)	13.36	12.02	10.33	11.68	Not significant

letters [a–d] are for the separations of means, means with same letter are similar while different letters denotes significant difference of the means

Table 3 Changes in soil pH, CEC, ESP and Ca: Mg ratios as indicators of soil quality in different land use systems

Soil characteristic	Fallow	Grazing	Irrigation	Rainfed	P level
pH	6.10	6.53	6.37	6.00	Not significant
CEC (c mol c kg^{-1})	21.91[b]	21.94[b]	16.74[a]	18.95[a]	<0.003
ESP (%)	0.363	0.423	0.397	0.403	Not significant
Ca:Mg (ratio)	1.667[b]	1.253[a]	1.860[b]	1.667[b]	0.002

letters [a, b] are for the separations of means, means with same letter are similar while different letters denotes significant difference of the means

Discussion

Land Use Systems Influence Soil Characteristics

Total nitrogen was significantly different ($P < 0.05$) among the land uses. High nitrogen was noticed on grazing land and this could be associated with the relatively high organic carbon which in turn resulted from plant and root biomass as well as residues being returned in the soil system (Chemada et al. 2017). Total nitrogen was found to be low on fallow land and this could be due to the fact that it has lost most of the nutrients and need to be reclaimed. The principal cause for lower contents of total nitrogen comes from biomass removal during crop harvest and insufficient replenishment through organic and or inorganic fertilizers. Available phosphorous was higher on irrigated land presumably due to continuous application of inorganic fertilizers like Single Super Phosphate. The lower P levels on grazing land might be due to phosphorous fixation (Nedessa et al. 2005). Potassium significantly varied across land use types. The higher K content was noticed in fallow land. The lower K^+ in the rain fed land and grazing land could be probably due to soil degradation and losses by leaching as the rain fed and grazing land were devoid of vegetation cover. Possibly, continuous cultivation practices, excessive precipitation and application of inorganic fertilizer could be responsible for the reduction of pH in the soil in these land use systems (Ahmed 2002).

Percentage of clay is the most variable soil physical characteristic in the granite soil. Of the chemical characteristics measured, soil pH is the least variable characteristic of the granite soils. Cation exchange capacity (CEC) and exchangeable sodium percentage (ESP) in the A and B-horizons are the most variable characteristics (Zhou 2004). For all the four land use systems assessed at Matopos, most of them were medium to coarse textured with low ESP relative to other cations which indicate good soil quality as shown by a low sodicity hazard and presumably low salinity problem and dominance of soluble sodium in the soil. The major issue arising from high sodium levels relative to the other exchangeable cations is on the physical properties of soil. In surface soil layers, this imbalance in the ratio of cations results in poor soil structure (Rengasamy et al. 2011). This is evidenced by surface soil crusts or the setting of soil into large blocks or columns on drying. Additionally, the poor soil structure leads to a decreased permeability to water and thus poor soil drainage.

Land Use Systems and Soil Quality Indicators

A Land use planning system in smallholder farming is the centre of attention in Zimbabwe as this has a direct influence on soil quality. Evaluating soil physical and chemical characteristics in various land use systems in a farm is therefore essential in order to understand soil quality in soils under different land use and management systems especially in rural areas. Studies in soils and agronomic practices

in crop production in Zimbabwe are abundant but investigations to compare the impact of different land use systems followed by small holder farmers on soil quality and management are lacking. Soil quality indicators at Matopos were assessed and described. It was noted that soil pH as a total integrator of chemical properties was rather less variable and low with soils tending to be slightly acidic especially in those land use systems that involve tillage of the land. Due to high level of urea and ammonium phosphates for agriculture in Matopos, the cultivated soils are made acidic in nature thereby reducing soil quality.

Many farmers rely on CEC to assess soil quality in their fields as an important parameter of soil because it gives an indication of the type of clay minerals present in the soil, its capacity to retain nutrients against leaching and assessing their fertility and environmental behavior change (Landon 1991). Generally, the chemical activity of the soil depends on its CEC. However, although the CEC of a soil is strongly affected by the amount and type of clay, and amount of organic matter present in the soil (Lal 2006) the way land and soil are being used affects soil quality. There appears to be a diminutive effect of land use systems on soil quality in terms of CEC an indication of good natural potential of the soils to supply nutrients to growing plants at Matopos. Through a judicious liming and land management practice, levels of calcium could be raised in the soils to boost CEC and increase calcium to magnesium ratio thereby reducing possibilities of poor soil quality through heavy metal toxicities as well as other nutrient deficiency conditions in the soil. Good grass cover and organic matter in fallow, grazing and forest land should be maintained as this will improve soil quality in terms of CEC. Recent research (Admas 2018) indicated that incorporation of black carbon significantly increases soil CEC. It is noted that, for Matopos, continuously cultivated land without incorporation of black carbon will affect soil quality by lowering CEC but good soil management practices on cultivated land could influence the amount, quality and turnover of soil organic matter of the land (Nedessa et al. 2005) thereby improving soil quality.

The lowest mean CEC was observed in the irrigation land with 16.74 c mol c/ kg. This might be due to uptake of basic cations (Mg and Ca) through crop harvest and soil erosion. Calcium to magnesium ratio appears to be quite lower than ideal values of 3:1 or 4:1 for the reddish brown Fersiallitic soils across all land use systems at Matopos. Exchangeable sodium percentage (ESP) was low indicating that soils are not sodic.

Poor soil quality in land use systems due to soil chemical degradation involves depletion of essential nutrients for plant growth, salts and heavy metal accumulation to toxic amounts levels, washing away of basic soil nutrients and loss of soil organic matter. Continuous cropping with no or sub-optimal nutrients addition, disposal of toxic wastes and use of poor-quality irrigation water are some of the major contributors to soil chemical degradation in cropping systems.

Conclusions and Recommendations

It is concluded that land use systems at Matopos influence soil quality indicators. The assessed land use systems especially rain fed fields and irrigation does seem to influence and exchangeable bases and CEC. The research findings also reveal that fallow and grazing land had the highest CEC due to the accumulation of litter on the surface of the soil which recycles nutrients and makes them available in the soil. Therefore, farmers need periodically fallow their lands to sequester organic matter, stabilize soil aggregates, improves nutrient cycles for sustainable agricultural production. It is recommended that use of dolomitic lime (Mg CO_3), gypsum (Ca SO_4) be made to boost the level of calcium and magnesium in the soil thereby increasing capacity of the soil to supply nutrients. This must be coupled with a careful education and training program for local farmers in various techniques that are critical for soil conservation and land management.

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