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Effects of Land uses on Soils Quality in Rwandan Central Plateau Agro-Ecological Zone

Yannick Karimba[1,a,*], Canisius Patrick Mugunga[1,b]

[1]*Department of forestry and nature conservation, School of Forestry, Biodiversity and Conservation, College of agriculture, animal sciences and veterinary medicine, University of Rwanda, Huye campus. P.O. Box 117, Huye, Rwanda*
[*]*Corresponding author*

A R T I C L E I N F O

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Conversion of land use from forest to agricultural uses modifies soil quality through physiochemical soil properties changes. This study was conducted in Rwanda's central plateau agro-ecological zone to evaluate the effect of forest and agricultural land uses on soil quality. The study was conducted in 2020. Soil samples were collected at the top, middle and bottom positions of each of the two land uses. We analyzed soil bulk density, soil moisture content, soil pH, soil organic matter (SOM), total nitrogen (TN), available phosphorus (Av P), and CEC for each position of the land uses. Data were analyzed using ANOVA in GENSTAT version 13. The results revealed that soil properties were significantly affected by land use change. Analysis of variances (LSD<0.05) results showed, however, that treatments were not significantly different within the same land use. The results showed that treatments from top position of forest lands had the highest mean values for soil organic matter and total N parameters with the respective mean values of 6.58 %, and 0.37 %. Treatments from middle position of forest lands had the highest mean values for soil moisture content and Av P parameters respectively with 23.60 % and 29.56 ppm. But, soil bulk density was high on top position of agricultural land with a mean value of 1.49 g/cm^3. Land users are advised to apply crop and soil management techniques which maintain soil quality and productivity on agricultural lands.

[a] ykarimba@gmail.com https://orcid.org/0000-0001-5801-9722 | [b] mugungacp@gmail.com https://orcid.org/0000-0002-9416-6508

Introduction

The land uses determine the fate of the soil quality (Tsadila et al., 2012). Soil quality can be defined as "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 (Karlen et al., 1997). Intensive agriculture, deforestation and overgrazing significantly affect soil quality in different parts of world (Gupta, 2019; Tsadila et al., 2012).It is estimated that more than two billion hectares approximately 52 percent of worldwide agricultural lands is moderately or severely degraded which affect the livelihood of 1.5 billion people (FAO, 2018). Land use conversion into agricultural production generates adverse effects on soil quality (Yansui et al., 2004)

Land use conversion and poor agricultural practices are root causes of soil quality degradation in Rwanda. These result into soil erosion problems and soil fertility decline which affect land use potential (Bizimana, 2018). Deforestation and grazing land conversion to agriculture exposes soil to erosion which removes top soils along with nutrients and organic matter leaving behind unproductive soils. This is exacerbated by other factors such as heavy rainfall, inherent fragile soils, cropping on marginal steep slopes, continuous land tillage, and lack of sufficient soil and water conservation measures (GoR, 2018; Karamage et al., 2016). It was reported that on average 48t/ha/year and 39.2 t/ha/year of soils were lost through soil erosion in 2000 and 2015, respectively, translating into approximatively 110 and 89 millions of tons lost per year for the entire country (Nambajimana, et al., 2020). According to Byizigiro et al. (2020) soil loss was estimated to be at 38.4t/ha/year. Soil erosion reduces soil depth and increases fertility losses which affect soil quality and crop productivity. Soil particles, soil organic matter and nutrients are lost as results of erosion which cost around

US$ 34 million or at least 2 percent of the country GDP (REMA, 2009).

Soil quality degradation is also caused by nutrient and organic matter removal through continuous cultivation of arable lands (Andriesse & Giller, 2017). Continuous cultivation of lands with high nutrient demanding crops accompanied by agricultural practices which do not replenish the same amount of depleted nutrients is further degrading soil quality and impact crop productivity (Okalebo, 2009). Organic inputs such as crop residue and manure applied to improve soil quality were reported to be of low quality and insufficient in tropical region (Palm et al; 2001). A survey by NISR (2018) in a certain study showed that nearly half of all cultivated plots received organic fertilizers and a quarter of all plots were applied with mineral fertilizer for each agricultural season in year 2018. As consequence, soils were reported to have high acidity, low organic matter, and poor soil nutrient contents mostly in Congo-Nile watershed divide and central plateau agro-ecological zones of Rwanda (Muhinda et al.,2009). These soils have high soil acidity, nutrient deficiencies such as N, P, Ca, Mg and high Al toxicity (Nzeyimana et al., 2013; Mukuralinda et al., 2010). Soil quality degradation affects agricultural sector which is still a pillar of Rwandan economy. The sector contributes up to 29 percent of GDP, occupies 70 percent of the labor force (NISR, 2019) and generates more than 45 percent of the country's export revenues (NISR, 2015).

Contrary to agricultural land use, forest land use with permanent cover improves soil quality through deep and extended rooting systems that hold soil particles together preventing them from detachment and soil erosion initiation. Soil erosion severely affects deforested areas which loads waterbodies with siltation sediments (Zhao et al., 2009). Forest canopy intercepts rain drops and weakens its impacts on soils and slows down soil erosion. With forests cover soil erosion under forest lands was reported to be low. This is mirrored in Rwandan forest cover which accounted for 21% of the total land but contributes only 0.2% of total soil erosion (Karamage et al., 2016). As results, soil water storage increases through increased infiltration rate and improved soil aggregate stability (Sharma and Sharma, 2004). Forests root exudates and litter falls which accumulate on soils improve soil organic matter and nutrients which further ameliorate forest soil quality.

Land uses are affected differently. It varies between regions, countries and even at zone level. Rwanda Central plateau agricultural zone is the region dominated by agriculture land use with small patches of forestlands. The big part of this agricultural zone was brought under cultivation since many years ago. Although many studies were carried out in the area on nutrient contents of agricultural lands, scanty information exist on how land use affects soil quality. The objective of the study was to analyze the long-term effect of land use on soil quality in central plateau agricultural zone of Rwanda.

Materials and Methods

Site Description

The study was conducted in Ruhande Arboretum and nearby agricultural farms both located in Huye District, in the Southern Province of Rwanda. The District is located in the central plateau agro-ecological zone with average altitude of 1700 m above sea level. It enjoys sub-tropical climate with average rainfall of 1160 mm and average temperature of 20ºC (Huye Ditrict, 2018; Kalinganire & Hall, 1993). The District has only about 10 percent of forests as the remaining percent was converted into agricultural lands. Note that 85 percent of the population practice farming activities (Huye District, 2013). The study area has two cropping seasons. The first season starts in September and ends in January and the second from February to June. Ruhande Arboretum is a forest plantation of 200 hectares with 529 plots. It was established by colonial rulers in 1934 (Mugunga, 2009).

Methods

Sampling procedure started in agricultural season B (February- June) of 2020 by removing all dead plants at each sampling point. The experimental research was randomized complete block design with two land use types which were (1) forestland and (2) cultivated land. For each land use, soil samples were collected at three levels (top, middle and at the base of the hill) and replicated three times. In total, 18 samples were collected. Sampling depth range was 0-20 cm. soil samples from the corner and center of each plot were mixed to generate composite sample and was done following transect sample. The plot size was 4×5 m. undisturbed soil samples were also collected on the same plots and depths. Hand soil auger and steel core cylinder were used to collect disturbed and undisturbed soils respectively. All collected samples were brought to the soil and plant analysis laboratory of University of Rwanda located at Huye campus for analysis.

Laboratory Analysis

After data collection, we brought samples to the laboratory for analysis. Gravimetric method was used to analyze both soil moisture content and bulk density. For disturbed soil samples: soil texture was analyzed using Densimetric method of Bouyoucous; sensitive glass electrode method was used for Soil $pH_{(water)}$; soil organic matter content (SOM), available phosphorus (Av P) and total nitrogen (TN) were measured by UV-Visible Colorimetric method. Kjeldhal distillation method was used to analyze cation exchange capacity (CEC). All analysis followed the protocol developed by Okalebo et al.(2002).

Data Analysis

Data ware analyzed using analysis of variance (ANOVA) which tested the difference in soil parameters analyzed. To determine the significant difference between treatments, we used comparison between two treatments mean and least significant difference (LSD) at 5 %. We considered the results to be statistically significant once the difference between two treatment means was greater than least significant difference (LSD). Data analyses were processed by GENSTAT version 13.

Results

Results for soil bulk density and soil moisture content are presented in Table 1.

Table 1. Mean value of some soil properties in relation to land use (20 cm of depth) and position

Land use type	Position	Parameters						
		Soil Density	Moisture content	pH H_2O	SOM	Total N	Av. P	CEC.
		g/cm^3	%		%	%	ppm	Cmol$_{(+)}$/kg
Forest	Top	1.29c	22.53a a	5.5a	6.58b	0.37a	28.56a	16.96a
	Middle	1.32bc	23.60a a	5.5a	6.54b	0.32a	29.56a	16.26a
	Bottom	1.36abc	23.31a a	5.4a	6.16ab	0.35a	29.22aa	17.94a
Agriculture	Top	1.49a	18.45b b	5,0b	5.00ab	0.19b	21.22b	10.86b
	Middle	1.47ab	17.38b b	5,0b	4.63a	0.23b	20.56b	11.56b
	Bottom	1.43abc	17.67b b	4.9 b	4.60a	0.19b	20.22b	9.88b
F-P (5 %)		0.06	<.001	0.020	0.04	<.001	0.001	0.006
LSD		1.29	2.36	0.46	1.54	0.06	4.37	4.08
CV %		5.5	6.1	4.8	14.7		9.3	15.6

Discussion of Results

Soil Bulk Density (BD) and Soil Moisture Content (MC)

Results for soil bulk density and soil moisture content are presented in Table 1. The results showed significant difference between treatments for both soil bulk density (BD) and soil moisture content (MC). The lowest BD value (1.29g/cm^3) was observed on the top position of forest land and the highest value (1.49g/cm^3) was found on the top of agricultural land. For MC, the highest value (23.60 %) was found in the middle of forest land and the lowest value (17.38 %) was recorded in the middle of agricultural land. The small result of BD in forest land could be ascribed to its high organic matter content as compared to agricultural land. The results concur with that of Gol (2009) and Hajabbasi et al. (1997) who reported low BD in forest lands compared to agricultural lands. It was reported by Weil & Brady (2017) that intensive tillage reduces soil organic matter and breaks soil structure which increases soil bulk density

The higher values of moisture content in forest areas could be assigned to its high organic deposition compared to agricultural land. The results are in line with that of Manpoong and Tripathi (2019) who reported high moisture content in forest lands and attributed it to high organic matter content and plant communities which maintain moisture content in natural forests compared to other types of land uses. Fesha et al. (2002) reported high soil water retention in non-cultivated treatments as compared to conventional treatments.

Soil pH (H_2O) and Soil Organic Matter (SOM)

Analysis of variance showed the significant difference ($P<0.05$) among treatments for pH. The highest pH value was observed on top and middle positions of forest land with 5.5. Small pH value was obtained on bottom position of agricultural land. No significant difference in mean values of pH observed within the same land use. The small pH value in agricultural lands could be a result of nutrients loss through crop harvests and soil erosion which carry them and not being replenished. The results concur with those reported by Emiru & Gebrekid (2013) who attributed low pH in agricultural lands compared to forest land to leaching of cation bases from surface layers, accelerating soil erosion which eventually drains them into streams and their removal through crop harvests. Fetene & Amera (2018) ascribed low pH values on grazing lands and agricultural lands to soil disturbance which cause soil erosion and deplete basic cations. He also attributed it to base cation losses through leaching and use of diammonium phosphate ($(NH_4)_2HPO_4$) which release H^+ ions that replace them in soil solution.

For SOM, the highest value (6.58 %) was obtained on the top position of forest land while the bottom position of agricultural land use had the lowest value (4.60 %). Forest land use had higher SOM than agricultural land uses. This could be attributed to the permanent forest cover which improves SOM through accumulation of plant litter and roots exudation on upper layers of soils and their low rate of decomposition. Contrary to forest land, agricultural land uses experience continuous nutrient removal trough harvests and leaching, rapid decomposition of SOM and its removal through soil erosion. These results concur to those of Moges et al. (2013) and Selassie et al. (2015) who reported that farming lands had significantly lowered SOM contents compared to protected forests. Low SOM content was attributed to low quantity of SOM returned in the farms, its high oxidation that takes place as well as its loss through soil erosion. According to Wasige (2014) land cover type was the main cause of low SOC content in agricultural land compared to forest land. Liu at al. (2006) and Hajabbasi et al. (1997) reported that continuous cultivation exposes SOM to decomposition which decreases its content in soils.

Total N, Available P and CEC

Analysis of variance showed significant difference among mean values of different treatments for total N, available P and CEC parameters. Total N, available P and CEC were significantly higher on the top, middle and bottom of forest land use while all levels of agricultural land use showed the lowest values. The highest values for total N, available P and CEC were recorded, respectively; on top (0.37 %), middle (29.56 ppm) and on bottom with (17.94 cmol$_{(+)}$/kg). The lowest values were observed for total N, available P and CEC, respectively; on the top (0.19 %), on the bottom (20.22 ppm), and on the bottom (9.88cmol$_{(+)}$/kg). However, mean values were not statistically different within each land use. Low TN and Av. P contents in agricultural lands could be ascribed to low fertilizer use both organic and mineral, nutrient removal through harvests, and nutrient losses through soil erosion and leaching as compared to forest lands. The results are in line with those of Wang et al (2001) and

Moges et al (2013) who reported lower TN content and attributed it to nutrients removal through crops harvests and inadequate application of fertilizers in farmland. Solomon (2002) reported low TN content in grazing and farming lands which is attributed to mineralization of SOM and leaching of nitrate-N. According to Selassie et al (2015) TN content was high in forest land in comparison to agricultural land due to N which is bound in organic carbon. Wang et al. (2001) reported high TN content in uncultivated land use as compared to cultivated land and attributed it to destructive soil management practices which cause soil erosion in cultivated lands.

The results of Av.P were higher in forest land than in agricultural land. According to Fetene and Amera (2018), who reported similar results, Av.P followed the trend of SOM of which it is associated with and was affected by conversion of natural forest into cultivated land. Emiru & Gebrekid (2013) reported high Av. P in forest lands. Conversely, agricultural lands had lower Av. P in forest land. Mukuralinda *at al*.(2010) reported low quantity of available P in agricultural land in southern Rwanda caused by native soils with poor P content, its retention by aluminum and iron oxides and insufficient use of fertilizer. Abera and Wana (2023) reported that agricultural land uses without land management practices also showed lower Av P as compared to that one with land management practices.

The results showed that CEC was higher in all positions of forest lands compared to that of agricultural lands. The trend of CEC variation among land uses nearly followed that of SOM. High CEC content in forest land could be attributed to the limited disturbance on soil structure and accumulation of SOM from tree biomass. Normally, CEC depends on the amount and types of clay and SOM contents which are negatively charged. Tesfahunegn and Gebru (2020) and Mandal et al. (2013) reported that CEC was higher in forest land and was related to its high OM and clay content. Emiru and Gebrekid (2013) attributed low CEC content in agricultural land to low quantity of SOM content.

Conclusion and Recommendations

The findings of this study revealed that agricultural land uses reduce the soil quality than forest land uses. The analysis of variances have shown that there was statistical difference (lsd<0.005) between treatments from forest lands and agricultural lands but there was no statistical differences among treatments within the same land use. Treatments under forest land uses had shown high mean values on soil moisture content, soil pH, and soil organic matter, soil N, Av P, and CEC. Treatments of top position of forests had the highest mean values for soil organic matter and TN with 6.58 % and 3.7 % respectively, while mean values were high on middle positon of forest land uses for soil moisture content and Av P parameters with 23.60 % and 29.56 ppm as their respective mean values.

The highest bulk density was obtained on the top position of agricultural land with 1.49 as mean value. Soil disturbances through some agricultural practices had contributed to speed up soil properties dynamics in unsustainable manner. This study advice to use agricultural practices that minimize soil disturbance and reduce soil erosion by maintaining land cover such as perennial crops, agroforestry, and soil and water conservation measures. Application of organic fertilizers such as crop residues, manure and compost combined with mineral fertilizer can contribute to reduce nutrient deficits, improve soil quality and sustain crop productivity.

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