Rwanda Journal of Agricultural Sciences, Vol 3, No. 2

Variations of soil properties along slope positions in Nyabihu, Rubavu, Ngororero and Rutsiro Districts of Western Rwanda: A baseline soil study for regenerative agriculture

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Abstract

This study aimed at characterizing soil properties and their variations along slope positions in Western Rwanda. It served as a baseline on regenerative agriculture practices introduced by Netherlands Development Organization (SNV) in the Districts of Nyabihu, Ngororero, Rubavu and Rutsiro. Soil samples were collected in a zig-zag pattern at 20 cm depth in triplicates at the top, middle and bottom of slope. Soil texture and chemical properties (pH, Soil Organic Carbon (SOC), total nitrogen, available phosphorus, exchangeable K^+, Ca^{2+} and Mg^{2+}) were analyzed. Results demonstrated that soils of Western Rwanda are mostly fairly acidic (pH5.3 - 6.0) except those in the bottom slopes of Ngororero and Rutsiro which are very acidic (pH4.7 and pH5.2 respectively). The SOC is high in Nyabihu (12.5 – 13.7%), moderate in Rubavu (4.1 – 5.2%) and Rutsiro (4.9 – 5.6%) and low in Ngororero (2.3 – 2.6%) with non-significant differences between effects of slope positions. Total N (0.02 – 0.11%), available P (4.33 – 22.47 ppm) and exchangeable K^+ (0.07 – 0.59 cmol $_{(+)}$ kg^{-1}) levels are weak while exchangeable Ca^{2+} (5.00 – 12.33 cmol $_{(+)}$ kg^{-1}) and Mg^{2+} (7.50 – 21.11 cmol $_{(+)}$ kg^{-1}) are moderate to high. There are non-significant effects of slope positions observed. The soil texture is Sandy Loam and Sandy Clay Loam (52.67 – 70.67% sand, 10.67–29.33% silt and 6.00 – 23.33% clay) which implies a good soil drainage leading to good soil health. The slope positions do not significantly influence soil properties in the study area. Many of the properties are weak and require improvement through regenerative agriculture practices.

Key words: Acidic soils, slope position, soil properties

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Introduction

The Netherlands Development Organization (SNV) has introduced practices of regenerative agriculture in Western Province of Rwanda through one of its projects known as REgenerative Agricultural practices for improved Livelihoods and MarketS (REALMS). Regenerative agriculture is a farming strategy that uses natural processes to increase biological activity, enhance soil health, improve nutrient cycling, restore landscape function, and produce food and fibre, while preserving or increasing farm profitability (Khangura *et al.,* 2023). It improves soil health primarily through practices that increase its organic matter content (Regeneration International, 2017). The practices not only improve the diversity and health of soil biota, but also the internal and surface biodiversity of the soil, increasing its capacity to retain nutrients, water and sequester soil structure is improved to lessen soil loss caused by destructive human production activity (Khangura *et al.,* 2023). The methods used for regenerative agriculture contribute to the regeneration/reconstruction of soils and their fertility. The main principles of regenerative agriculture include (1) promote biodiversity with cover crops and crop rotation, (2) eliminate or decrease tillage, (3) reduce the use of artificial fertilizers and (4) use regenerative grazing management for livestock (Khangura *et al.,* 2023, Vijay, 2021). Advocates and practitioners of regenerative agriculture argue that these methods will prevent soil erosion and depletion, actively build soil, provide appropriate crop nutrients with minimum external inputs, produce healthy, high-yielding crops with few weeds and pests, limit greenhouse gas emissions, promote resilience to extreme weather, increase farmers' financial returns, and improve human health (Khangura *et al.,* 2023; Vijay, 2021). According to Khangura *et al.* (2023), the regenerative agriculture (RA) principles, practices and purported benefits to improve soil health may be summarized as in Table 1.

Table 1. ***Regenerative agriculture (RA) principles, practices and reported benefits to improve soil health***

RA principles	RA practices	RA benefits
Minimise soil disturbance Keep soils covered Keep living roots in soil year round Encourage biodiversity Integrate livestock	No/minimum tillage Stubble retention Diverse crop retentions Multispecies cover crops Intercropping Composting and use biostimulants Rotational grazing Reduce synthetic inputs	Improved soil health through: Increased soil carbon Improved microbial functions and associated nutrient cycling Improved soil moisture Improved resilience to pests and diseases Nutients rich food Reduced greenhouse gas emissions

Source: Khangura *et al.*, 2023

The landscape in Western Province of Rwanda comprises hills and mountains with various shapes and lengths of slopes. Different slope positions lead to different influencing factors such as light, heat, water and air, and soil properties may also show differences (Runhong *et al.*, 2020). Soil physico-chemical properties are important indicators of soil quality. They possess palpable differences and interactions, and close associations with each other, which jointly determine the quality characteristics of the soil (Runhong *et al.*, 2020; García-Ruiz *et al.*, 2009). The Slope positions are among the most important abiotic factors that determine the spatial heterogeneity of soil physico-chemical properties (Runhong *et al.*, 2020). The objective of this study is to characterize the current status of soil properties and their variation along slope positions in Western Rwanda as baseline of soil health prior to studies on effects of regenerative agricultural practices in the Districts of Nyabihu, Ngororero, Rubavu and Rutsiro.

Materials and methods

Description of the study area

The Western Province of Rwanda covers the agro-ecologic zones of Volcanic Summits and High Plains and Congo-Nile Divide. The studied sites were located in the Sectors of Jenda, Ngororero, Nyundo and Mushubati of the Districts Nyabihu, Ngororero, Rubavu and Rutsiro, respectively (Figure 1).

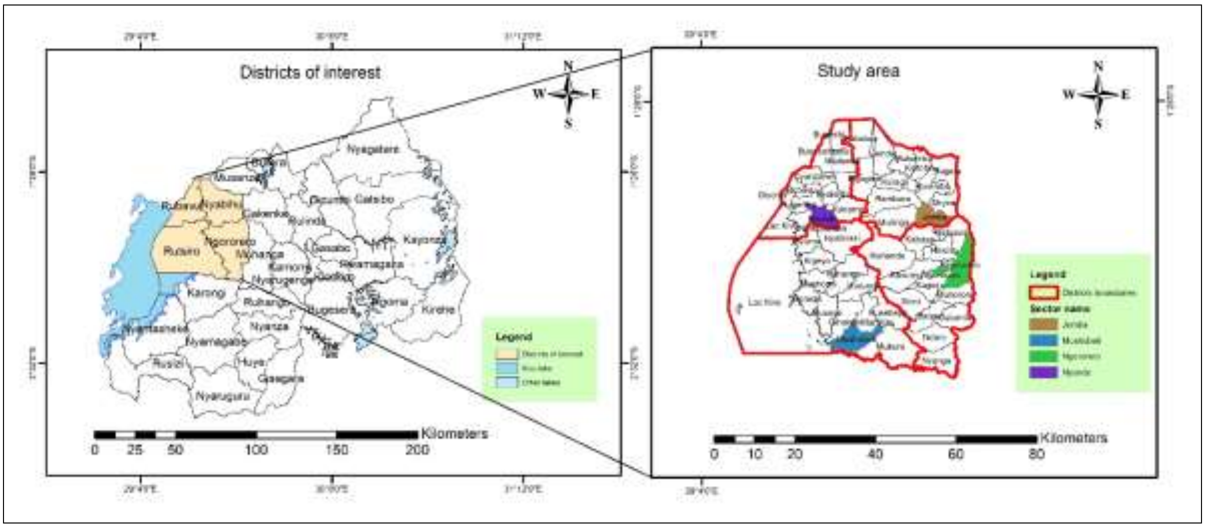

Figure 1. Study sites in Nyabihu, Ngororero, Rubavu and Rutsiro Districts of Western Rwanda

The relief in Nyabihu is characterized by 90% rugged mountains with slopes of more than 55% creating a high risk of erosion. Soils comprise of sandy and clay, laterite and volcanic. It is very fertile. The rainfall is 1400 mm per year. It has a climate with an average temperature of 15°C (Nyabihu DDP, 2013). For Rubavu District, the rainfall varies between 1200 mm and 1500 mm per year. The land of Northwest part of the District has a very rich soil, but shallow, volcanic ash and lava decomposed, while land in the south east has deep soils but poor, often acidic, sandy clay and leached by high erosion (Rubavu DDP, 2018). The District of Ngororero has a relief characterized by high mountains with very steep slopes that flow into valleys. The altitude varies between 1,460 m and 2,883 m above sea level. The higher altitudes are found in Gishwati forest along the Congo-Nile Crete. The average annual temperature is 18°C which varies with the altitude, and the rainfall is 1527.7mm per year. High steep slopes combined with land over exploitation due to intense agriculture activities resulted in soil degradation. Soil are mainly Oxisols. For Rutsiro District, the altitude varies between 1,400 m at the edge of Lake Kivu and 2,600 meters beyond the top of Mount Crete Congo-Nile. Rutsiro soil is basaltic, generally permeable and rich in iron. It is an acid soil pH with an average content of clay group karyokinesis. In some places on lake Kivu, there are sometimes derived soils phyllodes, clay, hard, containing quartz crystals and semi-strongly leached quartz. They are very susceptible to erosion and therefore less fertile (Rutsiro DDP, 2013).

Soil sampling and analysis

Soil samples were collected in a zig zag pattern using a soil auger from each selected site at 0– 20 cm depth in triplicates at the top, middle and bottom of slope. The collected soil samples were placed in labelled bags, sealed and transported to the laboratory for analysis. The samples were air-dried for a week and sieved through a 2-mm sieve then soil physical and chemical properties were analyzed. Soil texture was determined using the hydrometer method (Kroetsch and Wang 2006). Percentages of sand (2–0.05 mm), silt (0.05–0.002 mm) and clay (< 0.002 mm) were used to assign the textural class. Soil pH(water) in a 1: 2.5 soil-water solution was determined using the glass electrode method (Pal, 2013; Okalebo *et al*., 2002). Organic carbon was determined using the oxidation method of Walkley and Black (Pal, 2013; Okalebo *et al*., 2002). Total nitrogen was determined using the Kjeldal method (Pal, 2013; Okalebo *et al*., 2002). Available phosphorus was determined using Melhich method which is the specific method for acidic soils (Pal, 2013; Okalebo *et al*., 2002). Exchangeable potassium (K^+), magnesium (Mg^{2+}) and calcium (Ca^{2+}) were determined using atomic absorption spectrophotometry.

Data analysis

Data collected were organized using excel datasheet and subjected to Bartlett Chi-square test of homogeneity. Analysis of variance (ANOVA) was performed using GenStat. Fisher's Protected LSD was performed for means comparison. A

5% probability level was used for tests of statistical significance (Meyers *et al.*, 2009; Gomez and Gomez, 1984).

Results

Soil texture

The texture of soil in the study areas of Nyabihu, Rubavu and Ngororero Districts is Sandy Loam across all slope positions, and Sandy Clay Loam the middle and bottom slopes of Rutsiro Districts (Table 2). This implies good soil drainage. Soil texture refers to the relative proportions of sand (2 - 0.02 mm), silt (0.02 - 0.002 mm) and clay (< 0.002 mm) in a soil. It is a basic soil property that is used to estimate water-holding capacity of a soil, water and nutrient retention or leaching capacity. The distribution of soil particles (sand, silt and clay) and other soil physical properties may be influenced by the slope position and soil depth (Arthur *et al.*, 2022; Fashaho *et al.*, 2020; Gisilanbe *et al.*, 2018).

Table 2. *Soil texture (sand, silt and clay contents %) in the top, middle and bottom slopes in Nyabihu, Ngororero, Rubavu and Rutsiro Districts*

Districts	Slope position	Sand (%)	Silt (%)	Clay (%)	Texture class*
Nyabihu	Top	67	26	7	SL
	Middle	67	27	7	SL
	Bottom	66	28	6	SL
Ngororero	Top	60	24	16	SL
	Middle	59	26	15	SL
	Bottom	58	29	13	SL
Rubavu	Top	65	24	11	SL
	Middle	71	19	11	SL
	Bottom	68	22	10	SL
Rutsiro	Top	57	27	15	SL
	Middle	53	24	23	SCL
	Bottom	57	24	23	SCL

*Texture class: SL = Sandy Loam, SCL = Sandy Clay Loam (Texture triangle source: Gupta, 2004)

Soil reaction (pH)

Results revealed that soils in Nyabihu and Rubavu Districts are fairly acidic, according to the standards of interpretation by Landon (1991), at the top, middle and bottom slopes with pH ranging between 5.3 and 5.8 in Nyabihu and 5.8 - 6.0 in Rubavu (Figure 2). These might be due to moderate calcium and high magnesium contents in the soils of the study area (Figure 6). For Ngororero, soils are fairly acidic at the top (pH5.4) and very acidic at the middle and bottom slopes (pH4.7 - 4.8), while those in Rutsiro are fairly acidic at the top and middle and bottom slopes with pH ranging between 5.2 and 5.5 (Figure 2).

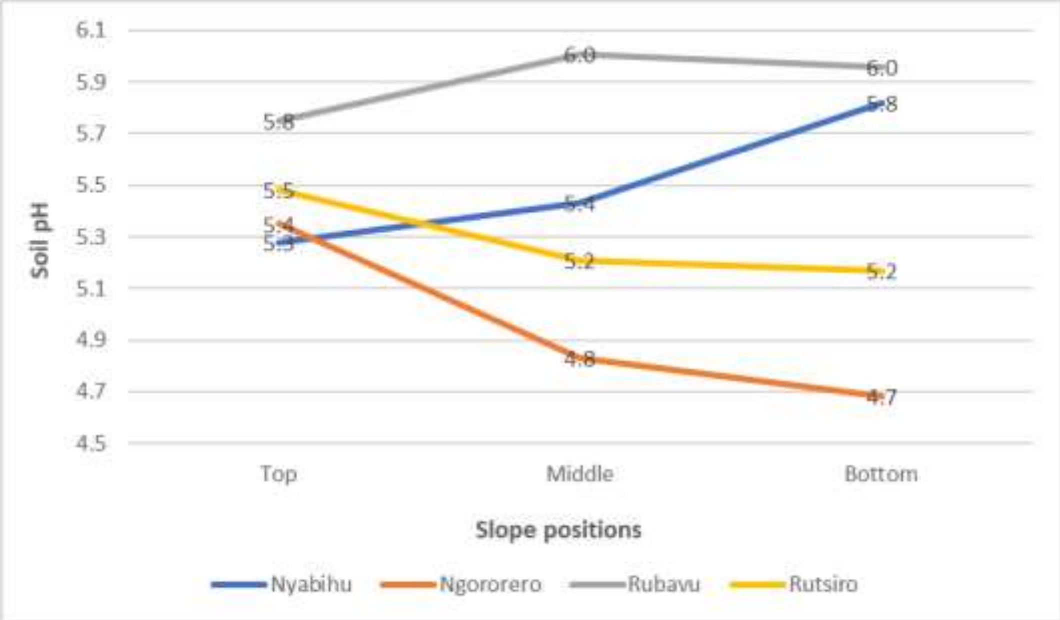

Figure 2. Soil pH along the top, middle and bottom slopes of Nyabihu, Ngororero, Rubavu and Rutsiro Districts of Western Province of Rwanda

Organic Carbon

Soil organic carbon (SOC) levels are high in Nyabihu District (12.47-13.70%), low in Ngororero (2.30 – 2.60%) and moderate in Rubavu (4.90 – 5.60%) and Rutsiro (4.13 – 5.20%) (Table 3). There were significant differences (P<0.05) between SOC contents across slope positions in Rubavu where higher levels of SOC were found in bottom. This might due to the deposition of organic matter in the bottom caused by erosion. There was no influence of slope positions on SOC found in other Districts.

Total Nitrogen

Results showed that the nitrogen levels ranged between 0.05 to 0.11% in Nyabihu, 0.03 - 0.11 in Ngororero and 0.02 – 0.04 in Rubavu and Rutsiro (Table 3). They fall in the weak class, according to the standards of interpretation by Landon (1991), hence deficient. There were non-significant differences found along slope positions. The C/N ratio is high which implies low mineralization of organic matter. This is due to low microorganisms' activity; hence, low rate at which soil organic matter is broken down by soil micro-organisms (Fashaho *et al.*, 2019).

Table 3. *The SOC, Total N, Available P and Exchangeable $K^{+}cmol_{(+)}kg^{-1}$ along the top, middle and bottom slopes in Nyabihu, Ngororero, Rubavu and Rutsiro Districts of Western Province of Rwanda*

Districts	Slope positions	SOC (%)	Total N (%)	Available P (ppm)	Exch. K^{+} ($cmol_{(+)}kg^{-1}$)
Nyabihu	Top	13.70	0.05	8.48	0.11
	Middle	12.47	0.11	9.48	0.09
	Bottom	13.17	0.09	6.49	0.07
Ngororero	Top	2.60	0.04	10.50	0.54
	Middle	2.50	0.03	11.00	0.47
	Bottom	2.30	0.11	21.40	0.59
Rubavu	Top	4.90[b]	0.03	5.49	0.11
	Middle	4.90[b]	0.02	4.49	0.10
	Bottom	5.60[a]	0.04	4.33	0.17
Rutsiro	Top	5.20	0.03	18.75	0.15
	Middle	5.00	0.02	22.96	0.20
	Bottom	4.13	0.04	22.47	0.22

Phosphorus

The levels of available phosphorus ranged between 6.49 and 9.48 ppm in Nyabihu District, 10.50 – 21.40 ppm in Ngororero and 4.33 - 5.49 ppm in Rubavu (Table 3). They are classified as weak according to the rating by Landon (1991). In Rutsiro District, the available phosphorus contents are moderate (18.75 – 22.96 ppm) (Table 3). There is non-significant influence of slope positions on the available phosphorus.

Exchangeable Potassium

The exchangeable potassium contents rated between 0.07 and 0.11 $cmol_{(+)}kg^{-1}$ in Nyabihu District, 0.47 - 5.59 $cmol_{(+)}kg^{-1}$ in Ngororero, 0.10 – 0.17 $cmol_{(+)}kg^{-1}$ in Rubavu and 0.15 - 0.22 $cmol_{(+)}kg^{-1}$ in Rutsiro (Table 3). They fall in weak class according to the rating by Landon (1991). The influence of slope positions was not significant on exchangeable potassium. The results also indicated that exchangeable potassium was readily lost through leaching due to high rainfall received in the area.

Exchangeable Calcium and Magnesium

The exchangeable calcium ranged from 6.67 to 10.17 $cmol_{(+)}kg^{-1}$ in Nyabihu District, 5.00 – 11.67 $cmol_{(+)}kg^{-1}$ in Ngororero, 12.00 – 12.33 $cmol_{(+)}kg^{-1}$ in Rubavu and 6.50 – 6.83 $cmol_{(+)}kg^{-1}$ in Rutsiro (Figure 3). The exchangeable magnesium ranged from 7.50 to 15.00 $cmol_{(+)}kg^{-1}$in Nyabihu District, 8.89 – 15.28 $cmol_{(+)}kg^{-1}$ in Ngororero, 17.11 – 21.11 $cmol_{(+)}kg^{-1}$ in Rubavu and 14.72 – 20.00 $cmol_{(+)}kg^{-1}$ in Rutsiro (Figure 3). The levels of exachngeable calcium and magnesium in the soils of the studied areas are rated from moderate to high classes according to the rating by Landon (1991). There was non-significant influence of slope positions on the soil contents in exchangeable calcium and magnesium.

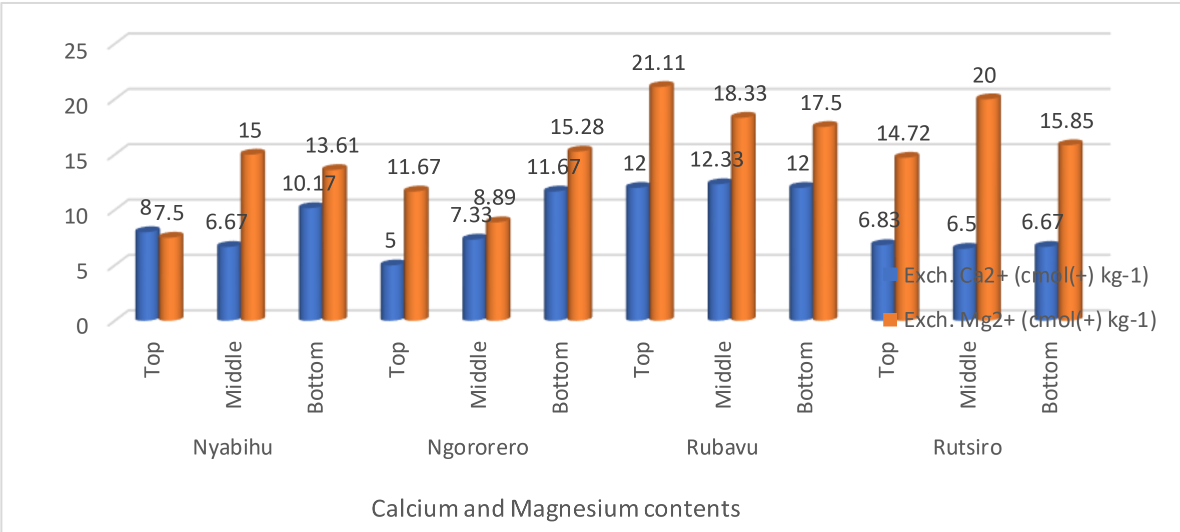

Figure 3. Exchangeable Ca^{2+} and Mg^{2+}cmol(+)kg^{-1} along the top, middle and bottom slope positions in Nyabihu, Ngororero, Rubavu and Rutsiro Districts of Rwanda

Conclusion

Soil properties along slope positions in Western Rwanda, Districts of Nyabihu, Ngororero, Rubavu and Rutsiro are mostly fairly acidic except the bottom of Ngororero and Rutsiro which are very acidic. The SOC is high in Nyabihu, moderate in Rubavu and Rutsiro and low in Ngororero without significant differences between slope positions. Total N, available P and exchangeable K^{+} levels are weak while exchangeable Ca^{2+} and Mg^{2+} are moderate to high without significant differences between effects of slope positions. The soil texture is Sandy Loam which implies good drainage. Many of the properties are weak and the slope positions do not significantly influence them. For sustainable soil fertility management, there is need of regenerative agricultural practices that control soil erosion, fix nitrogen, improve soil organic matter contents and mineralization, and improve biological, chemical and physical health of the soil. The results reported in this paper shall serve as baseline to evaluate this sustainability and improvement of soil health.

Acknowledgement

Authors would like to acknowledge the SNV Rwanda for funding this study, and the University of Rwanda, College of Agriculture, Animal Sciences and Veterinary Medicine for providing research facilities including laboratory for soil analysis.

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