ISSN: 3064-9846
Research Article
Journal of Agricultural, Earth and Environmental Sciences

Effects of Land Use Types on Soil Physio-Chemical Properties in Northern Rwanda

Umuhire Pacifique

Senior Communications Account Manager, Co-creation HUB (CcHUB) Limited (RC 918335), Kigali, Kigali City, Rwanda

***Corresponding author:** Umuhire Pacifique, Senior Communications Account Manager, Co-creation HUB (CcHUB) Limited (RC 918335), Kigali, Kigali City, Rwanda.

Submitted: 22 December 2025 **Accepted:** 27 December 2025 **Published:** 03 January 2026

https://doi.org/10.63620/MKJAEES.2026.

Citation: *Umuhire, P. (2025). Effects of Land Use Types on Soil Physio-Chemical Properties in Northern Rwanda. J of Agri Earth & Environmental Sciences, 5(1), 01-05.*

Abstract

This study was conducted to evaluate the effects of land use types on soil physio-chemical properties in Northern Rwanda. Three different land use types were assessed: non-cultivated land (forestland), fallowed land and cultivated land of irish potatoes in a vegetative stage with no fertilizers applied in the season where the research was done. Composite soil samples were collected and analysed in the University of Rwanda's soil laboratory. which randomized systematic grid sampling design Eleven soil physio-chemical properties were measured: pH, soil organic matter (SOM), organic carbon (OC), total nitrogen (TN), carbon-nitrogen (C/N) ratio, available phosphorus (AP), calcium (Ca2+), magnesium (Mg2+), soil bulk density (BD), soil texture, and porosity. The findings demonstrated that non-cultivated land (forest) has high values in SOM (5.59%), Ca2+ (390ppm), Mg2+ (110ppm), TN (0.56%), porosity (64.59%), and pH (6.86) compared to the cultivated land with SOM of 3.12%, TN of 0.29%), calcium (313.33 ppm), Mg2+ (76.67 ppm) and pH (6.59). A trend of decrease was observed in SOM, Ca2+, Mg2+, TN, porosity, and pH when land use changed from non-cultivated (forest) to cultivated land while the soil BD shown an opposite trend for cultivated land which had a BD of 1.05g cm-3 to 0.94g cm-3. However, for both land use shifts, the amount of AP did not vary considerably. Therefore, the loss of forestland and other non-cultivated land results in soil fertility depletion and a greater deterioration of soil properties. This study had shown that a compromise between forested land and arable land can be found and be applicable to the lands and help in replenishing the nutrients required in agriculture, the recommendation of this compromise could be agroforestry and land fallowing.

Keywords: Cultivated Land, Fallowed Land, Forestland, Soil Properties.

Introduction

The characteristics of the Earth's surface have changed because of changes in land use, which have also affected the soil's physicochemical qualities. A growing understanding of how crucially vital soil is to the earth's biosphere functioning not only in the production of food and fiber but also in the preservation of local, regional, and global environmental quality has sparked recent interest in measuring the quality of soil resources. Generalizing the impact of land use changes on the soil quality status is not a direct approach but rather a complex one requiring resources (Yerima, 2018). Nonetheless the land use changes are caused by the driving forces of either human-based activities/anthropogenic (politics, economies, technologies, etc.) or natural forces (weather and climate) can exert the pressure on the landscape hence resulting in the change the soil may undergo [1]. An easy and observable indicator in natural resources status is the interchanging of forested land into arable land. In recent years in international or regional environmental agencies placed a high concern on monitoring the changes in the land use system basing on different factors (such as agriculture, infrastructure, etc.)

influencing the changes that occurs on the land use system (such as deforestation, reforestation, etc.) in order to take into account new scientific and policy inputs (goal #15 of the 2030 Agenda for Sustainable Development). To accomplish the sustainable development goal number 15, it is good to understand the environmental dynamics and process related to the land use system, it is critical to analyze the effects of these changes on soil quality [2].

According to Rwanda Water Resources Board ((Rwanda water portal, 2022)), the average amount of topsoil lost across the country is 25 tons ha-1 per year (or 27 million tons of topsoil lost yearly, and an estimated 16 million tons of soil displaced each year carrying about 1,282,560 tons of carbon and 128,256 tons of nitrogen loss). Considering the market value of topsoil in Rwanda, a proxy for soil productive capability, which ranges between US$34/ton (RwF 30,000) and US$57/ton (RwF 50,000); the annual loss is therefore estimated to be RwF 810 billion on average, which is roughly one and a half fold of what landscape restoration of the entire country would cost (RwF 513 billion) (Rwanda water portal, 2022). According to Karamage (2016), a large portion of the Rwandan population relies on subsistence agricultural methods and has less than 1 ha/household, so this puts a tremendous strain on natural resources due to an increased rapidly growing population density. According to his observation this result in land use changes, deforestation occurring to accommodate the needs of the population in finding food through agriculture.

According to [3], Africa's high population density, combined with ongoing demand for agricultural land, will increase deforestation pressure. In reality, land degradation is a major issue because it causes hunger and destitution and is at the base of many disputes. Progress toward achieving SDG # 15 of the 2030 agenda for Sustainable Development necessitates a grasp of the causes of soil deterioration. According to reports, an extensive surface area of African forests has been destroyed, with small-scale agriculture having a substantial impact [3-4]. The need for sustainable land use ecosystems prompts the creation of efficient site-specific actions to control erosion and restore soil quality, thereby improving the conditions and productivity of Rwanda's landscapes in the northern highlands' region. In the previous studies done in Rwanda concerning the land use types, Karamage (2016) and [4] dealt their impact on deforestation, soil erosion, water pollution, etc. were carried out in Rwanda throughout different period and different areas and their research concluded that the land use types influenced the properties of the soil influenced by the activities carried out. Furthermore, existing research in the region is insufficient to define the amount of soil property variation related with land use change categories. Also, for the establishment of sound land use planning and soil conservation strategies, it is crucial to examine soil physico-chemical characteristics in connection to shifting land use. Laboratory analysis is one method for examining how land use types affect the physiochemical characteristics of soil. Therefore, the goal of this study was to evaluate how types in land use have affected soil physico-chemical characteristics.

Materials and Methods

Description of The Study Area

This study was carried out in Gisesero cell, Busogo sector, Musanze district of the northern province of Rwanda. In 2022 the soil in this area, It has agricultural potential due to its volcanic soil type with a sandy loam texture, which is loose, highly aerated, and rich in organic matter. The Busogo Sector has a mean altitude of 2300 m with the highest point being at 2800 m. The climate has a mean temperature of 16.7°C and much rainfall comprising between 1400 mm and 1800 mm per year. The four seasons in the Busogo Sector are as follows: Long Rainy Season (March to May), Long Dry Season (June to September), Short Rainy Season (October to November) and Short Dry Season (December to February): though the climate can exhibit some variability, and the timing and intensity of seasons may vary slightly from year to year (Uwiringiyimana, 2019; Uwitonze, 2016). In this area much of the activities carried out is agriculture mainly growing irish potatoes and beans though vegetables such as cabbages, most observable areas not covered by farming areas is covered by forests, trees planted here are mainly eucalyptus and it is where most samples were taken, in cultivated land where the samples were taken irish potatoes in their vegetative stage were the crops in the field and and no fertlizers were applied when planting the crops.

Soil Sampling and Laboratory Analyses

Soil samples were collected in forestry, grassland/fallowed land, and arable land with sparingly planted trees. Traditional hand hoes are pivotal in Rwanda's agricultural history, serving a crucial role in precise soil cultivation for optimal seedbed conditions. These manual tools exemplify the enduring effectiveness of low-tech methods, especially in resource-limited regions, where cultural traditions influence farming practices. The reliance on such traditional implements highlights the resilience of Rwandan farmers as they adeptly balance age-old techniques with the evolving demands of their agricultural mountainous landscape. After harvesting, farmers gather agricultural wastes for various household purposes like improving soil, feeding animals, and using them as fuel for cooking and heating. This not only cuts down on fuel and animal feed expenses but also helps in minimizing agricultural waste. Collecting and using these wastes play a vital role in sustainable farming, as they boost soil fertility and nutrient cycling. This blend of traditional knowledge and eco-friendly practices showcases how farmers adapt and thrive in today's agriculture, making the most of what they have while being mindful of the environment. Local farmers have access to commercial fertilizers and compost and manure. During the sampling period the systematic grid sampling design was employed to ensures that samples were collected in a structured and representative manner. We collected soil samples to measure soil organic matter (SOM) and soil organic carbon (SOC), available phosphorus, total nitrogen (TN), carbon-nitrogen ratio (C/N ratio), magnesium (Mg2+), calcium (Ca2+), soil pH, soil texture, soil bulk density, and total porosity because the main goal of our study was to assess how changes in land use affected the physico-chemical properties of the soil.

Soil samples, one composite sample contained 7 randomly selected subsamples within the designated area, were taken at a consistent depth of 0-20 cm for each land use (cultivated, farrowed and forested area), avoiding dead plants, furrow, old manure, wet spots, areas near the trees, and compost pits. Each sampling location provided an average composite sample weight of 1.5 kg, which was then put into plastic or paper bags and transported, air-dried, homogenized, crushed, and put through a 2 mm screen sieve. Nine composite samples in total from the site were gathered for chemical laboratory testing. Moreover, undisturbed soil samples were taken individually from each soil depth using a core sampler for in situ physical property measurement. Soil samples were analyzed at the University of Rwanda's Busogo campus's Soil Science Laboratory using the usual processes and methods. The soil texture was determined following the hydrometer method. Soil bulk density was determined after the soil was oven dried at 105 °C for 24 h. SOC and SOM were determined according to loss on ignition method. The pH value of the soil samples was measured using potentiometric pH measurement. TN was determined using colorimetric method, available phosphorus was determined by Mehlich III method, calcium and magnesium was determined using complexometric with EDTA method, total porosity was derived from the bulk density while carbon-nitrogen ratio was obtained by calculating the ratio of the result obtained from TN and SOC.

Data Analysis

The data were analyzed and stored in a Microsoft Excel. Later, the analysis of variance (ANOVA) was performed on the data using the online tool OPSTAT at the 5% level of probability (p 0.05) based on the F-test of the analysis of variance to check the differences between the three selected land uses.

Results and Discussion

Land-use types and Soil Chemical Properties

Table 1 presents the effects of different land-use types on selected soil chemical properties. The analyzed properties include pH, total nitrogen (TN), organic matter (OM), organic carbon (OC), carbon-to-nitrogen ratio (C/N), available phosphorus (AP), calcium (Ca2+), and magnesium (Mg2+). The table provides numerical values for each property under three different land-use conditions: Cultivated land, non-cultivated land, and Fallowed land. Additionally, the table includes statistical significance indicators (p-values) denoted by asterisks (*), indicating the level of significance for differences observed between land-use types. The p-values below the table suggest statistically significant variations in some soil properties across the different land-use categories.

Table 1: Effects of Land-use on Selected soil Chemical Properties of PH, TN, OM,OC, C/N, AP, Ca^2+ and Mg^2+

Type of land	pH	TN (%)	OM (%)	OC (%)	C/N ratio	AP (ppm)	Ca^2+ (ppm)	Mg^2+ (ppm)
Cultivated land	6.59	0.29	5.39	3.12	10.8	31.46	313.33	76.67
Non cultivated land	6.86	0.56	9.63	5.59	9.91	23.97	390	110
Fallowed land	6.64	0.33	6.45	3.74	11.34	22.47	350	93.33
p<0.05	0.02	0.00*	0.00073	0.00073	0.41361	0.35011	0.0148	0.0046

A statistical analysis showed that the pH varies greatly depending on the kind of land use, with an average low value of pH recorded in cultivated/arable land. Low pH values in farmland may be caused by excessive tillage frequency, high rates of inorganic fertilizer application or a low amount of organic matter because of erosion. However, significant differences in the mean pH values between soils under cultivation and those under natural vegetation across various locations suggest that the pH of the soil lowers when natural plant cover (forests) is converted to farming. (KIZILKAYA, 2010) research in Turkey showed a significant increase of pH from 6.03 in natural forest to 7.71 in cultivated land.The implementation of sustainable agricultural land management techniques, including organic manure, mulching, rotation, and restricted tillage, has been identified as a contributing factor to the observed increase in pH. This highlights the importance of adopting sustainable practices in mitigating soil acidity and promoting healthier soil conditions in agricultural landscapes. The study reveals significant variations in soil pH across different land-use types, with cultivated land showing lower average values. This highlights the complexity and variability of soil responses to agricultural practices, possibly influenced by regional differences or diverse management techniques. Further research and site-specific investigations are needed to understand the dynamics of soil pH and tailor sustainable agricultural practices to specific regions' unique characteristics.

This study found that soil organic carbon (OC) content varied with land use types, with noncultivated/forest land having the highest mean soil organic carbon content (5.59%) and cultivated/arable land/arable use systems having the lowest mean percentage (3.12%). The source of organic matter (OM) in this study site primarily stems from various organic amendments, encompassing tree leaves, stems, barks, flowers, logs, and fruits that falls and latter decay and decomposed. The introduction of these organic materials to the soil contributes to an increase in organic matter content. Additionally, microorganisms, animals, and the roots of trees present in the study area play vital roles in the enrichment of organic matter either when they die and decomposes or they the decomposer themselves beside aerating the soil for further decomposition. Organic matter is regarded as a highly beneficial amendment for soils due to its positive effects on water retention capacity and overall improvement of physical properties. Notably, the study underscores the significance of organic matter as a potent indicator for assessing the potential productivity of the soil. It's noteworthy that cultivated soils tend to exhibit lower organic matter content compared to native ecosystems. This observation is attributed to the cultivation process, which enhances soil aeration, consequently promoting the decomposition of soil organic matter (SOM). The dynamic interplay between cultivation practices and the resulting organic matter content highlights the intricate relationship between land management, soil health, and the preservation of organic resources in the study site.. Most of the soil organic matter produced in cultivated lands is removed with harvest [5]. The higher SOC content in forest/non-cultivated land use types could be due to the lower organic carbon turnover rate as a result of minimum soil disturbance in the agroforestry system. Additionally, the continuous addition of SOM from litter fall probably becomes the main source of SOC in the forest land use types [6].

The results of TN obtained in this study showed that there was a significance difference between the selected land uses, with the lowest value being 0.28% in the cultivated land. Non-cultivated land showed to have high nitrogen content in all 3 types of land uses, while cultivated had the lowest value. The low organic total N content may be due to frequent harvesting, the high value of C/N ratio and mineralization of SOM, and tillage practices reducing soil nitrogen content by exposing the soil to more air. Forested land and fallowed land had a high content compared to their counterparts cultivated land, which has a direct relationship with organic matter content. The similarities between animal grazing and litter dropping under those two land use systems in the region suggest that the high amounts of nitrogen in soils may be due to the litter rich in nitrogen and other major nutrients. Additionally, grazing can promote nutrient cycling and SOM mineralization rates. However, the TN contents are low in farms due to the poor nitrogen retention ability of the soils under cultivated land uses and the loss of organic matter due to human activities. [7].

The findings also indicated that there were no significant differences between land use categories and the C/N ratio. The C/N ratio is one way to represent the quality of biological materials. The fallow and cultivated land in this area had a medium quality (C/N =10–14), but the uncultivated land and woodland displayed a fair quality (C/N<10) (Yerima, 2018). A critical indication of soil quality is the C/N ratio of the soil. The capacity of soil to mineralize nitrogen is often gauged by the soil C/N ratio. By restricting the capacity of soil microbial activities, high C/N ratios in soils might slow the pace of OM and organic nitrogen decomposition. Conversely, low C/N ratios in soils could hasten the microbial decomposition of organic matter and nitrogen. Although not statistically significant, the amount of available phosphorus in the soil varied significantly depending on the kind of land use. Yet, the findings show that the cultivated area had high levels of soil-available phosphorus. Another conclusion that can be drawn from this is that leftover harvest waste may have increased the P concentrations beneath cultivable land. On some farmlands in this region, the application of chemical P-fertilizers and organic manure (poultry manure and cow dung) may have increased the P concentrations [2].

The contents of exchangeable Ca2+ and Mg2+ were significantly affected by land use. The Ca2+content in cultivated land varied from 290 ppm to 400 ppm, while Mg2 varied from 70ppm to 110ppm. This variation in the values among land use types might be associated with an increase in acidity levels in the soils of cultivated and grazing lands, which could have favored solubilization and removal of cations by leaching water. Deforestation, leaching, limited recycling of dung and crop residues in the soil, very low use of chemical fertilizers, continuous cropping with no or short fallow periods and soil erosion have contributed to the depletion of basic cations on the cultivated as compared to the adjacent forest land.

Land Use Types and Soil Physical Properties

Table 2: Impact of Land-use on Physical Soil Properties

Type of land use	Bulk density	Soil texture Sand	Silt	Clay	Porosity
	g/cm³	%	%	%	
Cultivated/arable land	1.05	64.91	16.17	18.92	60.30
Non-cultivated/forest land	0.94	64.51	15.17	20.31	64.59
p-value	0.12	0.97	0.91	0.95	0.12

The results showed that particle size distribution varied with land use systems, but the mean percentage of sand content showed no significant difference. Generally, sand content increased when converting forest to arable land, likely due to preferential removal of clay and silt and residual accumulation of sand in soil surface. Clay content and silt content varied not significantly between different land use types, with the increase in clay content from cultivated land to forest land likely due to disturbance during tillage practice, while the lower clay fraction in cultivated land was likely caused by plowing and selective removal of clay particles. Soil erosion can modify soil properties by reducing soil depth, changing soil texture, and by loss of nutrients and organic matter [8].

The results of this research showed that soil bulk density did not significantly vary between land use types. Natural forest had the lowest bulk density (0.94 g cm-3), while cultivated and arable lands had higher bulk densities. This decrease is likely due to the accumulation of higher organic matter from added organic amendments, better soil aggregate, better least limiting water range and increased root growth. For arable/cultivated land, the cause of the higher bulk density is due to frequent tillage and animals/humans trampling on the land during wet season. Soil bulk density is a measure of soil compaction and health, and a lower soil bulk density means soil is less compacted and are able to retain more water. Since the soil bulk densities found in all the land uses were lower and within this range, it can be concluded that the soil productivity in the area is good [10].

Soil bulk density is inversely proportional to the soil porosity, the highest porosity was found in forestland with 64.59%, while the lowest was found in cultivated land with 60.30%. Porosity was high in forestland use due to the high organic matter content and earthworms that play an important role in the decomposition of organic material [11]. The decrease in bulk density with organic amendments is directly related to the increased porosity, which is related to the improved soil aggregation. Good soil compaction leads to aggregate stability, increasing pore size and volume [12].

Conclusion

This study found that the change and transformation of forestland to arable land is degrading the natural ecosystem, soil structure, soil fertility and soil productivity [13]. Degradation of natural forest and subsequent cultivation of soils had negative effects on measured soil physico and chemical properties [14-17]. To improve the soil conditions and advance sustainable land use and agricultural productivity, this study recommends the use of water-saving methods, fallowing, crop rotation, agroforestry, mulching, cover crops, and vegetative restoration [18]. Regenerative agriculture techniques are intended to improve and restore soil health, lessen the impact of environmental deterioration, and encourage productive and sustainable land usage.

Acknowledgment

This work would not have been possible without the assistance and support of people and institutions. The authors express their appreciation to the different farmers of Gisesero cell for their collaboration during data collection, the University of Rwanda, College of Agriculture Animal Sciences and Veterinary Medicine for providing the research infrastructures.

References

1. Dale, V. H. (1997). The relationship between land-use change and climate change. Ecological Applications, 7(3), 753–769.
2. Bizuhoraho, T., & Karamage, F. (2018). The effect of land use systems on soil properties: A case study from Rwanda. Sustainable Agriculture Research, 7(2). https://doi.org/10.5539/sar.v7n2p30
3. Food and Agriculture Organization of the United Nations. (2009). State of the world's forests. FAO. https://www.fao.org/3/i0350e/i0350e00.htm
4. Nambajimana, J. de D., & Hakizimana, S. (2020). Land use change impacts on water erosion in Rwanda. Sustainability, 12(1), 50. https://doi.org/10.3390/su12010050
5. Rezaei, M. H. (2012). Effect of land use change on soil properties and clay mineralogy of forest soils developed in the Caspian Sea region in Iran. Journal of Agricultural Science and Technology, 14, 1617–1624.
6. Negasa, T., & Kibret, K. (2017). Influence of different land use types and soil depths on selected soil properties related to soil fertility in Warandhab area, Horo Guduru Wallaga Zone, Oromiya, Ethiopia. International Journal of Environmental Sciences and Natural Resources, 4(2). https://doi.org/10.19080/IJESNR.2017.04.555634
7. Bizuhoraho, T., & Karamage, F. (2018). The effect of land use systems on soil properties: A case study from Rwanda. Sustainable Agriculture Research, 7(2). https://doi.org/10.5539/sar.v7n2p30
8. Six, J., Conant, R. T., Paul, E. A., & Paustian, K. (2002). Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils. Plant and Soil, 241, 155–176.
9. Kakaire, J. G., & Lwasa, S. (2015). Effects of mulching on soil hydro-physical properties in Kibaale sub-catchment, south central Uganda. Applied Ecology and Environmental Sciences, 3(5), 127–135. https://doi.org/10.12691/aees-3-5-1
10. Amera, E. M. (2018). The effects of land use types and soil depth on soil properties of Agedit watershed, northwest Ethiopia. Ethiopian Journal of Science and Technology, 11(1), 39–56. https://doi.org/10.4314/ejst.v11i1.4
11. Getahun, H., & Fikreyesus, I. (2022). Variation in soil properties under different land use types managed by smallholder farmers in central Ethiopia. Sustainable Environment, 8(1). https://doi.org/10.1080/27658511.2022.2093058
12. Yeboah, S. O., & Kyei-Baffour, N. (2022). Variability of soil physicochemical properties under different land use types in the Guinea savanna zone of northern Ghana. Cogent Food & Agriculture, 8(2). https://doi.org/10.1080/23311932.2022.2105906
13. Abbasi, A. K., & Khalil, A. (2010). Comparative effectiveness of urea-N, poultry manure, and their combination in changing soil properties and maize productivity under rainfed conditions in northeast Pakistan. Experimental Agriculture, 46(2), 211–230. https://doi.org/10.1017/S0014479709991050
14. Angelique, M. (2007). Caractérisation physico-chimique des sols de Busogo. Busogo: Institut Supérieur d'Agriculture et d'Élevage (ISAE).
15. Lewis, L. A., & Clark, D. (1988). Soil loss, agriculture, and conservation in Rwanda: Toward sound strategies for soil management. Journal of Soil and Water Conservation, 43(5), 418–421.
16. Fidele, K., & Hakuzimana, S. (2016). Deforestation effects on soil erosion in the Lake Kivu Basin, D.R. Congo–Rwanda. Forests, 7(11), 281. https://doi.org/10.3390/f7110281
17. Miller, C. (2000, April). Carbon–nitrogen ratio: Understanding chemical elements in organic matter. Eco Farming Daily. https://www.ecofarmingdaily.com/buildsoil/soil-inputs/minerals-nutrients/carbon-nitrogen-ratio/
18. Sharif Abad, J. R., & Karimzadeh, H. (2014). Assessment of the effects of land use changes on soil physicochemical properties in Jafarabad, Golestan Province, Iran. Bulletin of Environment, Pharmacology and Life Sciences, 3(3), 296–300.