International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

The Effect of Slope Cultivation on Soil Quality at Nabweya Sub County: Bududa District

Hiisa Samuel[1], Hassan Mwanga[2]

[1,2]Department of environmental science Islamic University in Uganda

ABSTRACT
The study investigated the relationship between slope cultivation and nutrient availability. It evaluated the effect of slope cultivation on soil PH, Organic Matter (OM) and base cations. It documented practices and factors that affect soil chemical quality, determined the effect of slope and slope cultivation on soil chemical quality and the potential strategies and interventions needed to mitigate the negative effects of slope cultivation on soil quality to enhance agricultural productivity and sustainability. The study utilized questionnaires, interviews, field observations, focus group discussions, and analysis of soil chemical properties at the Top, Middle, and Bottom slopes every 100 meters in a 0-20 cm depth range for both cultivated and uncultivated slopes. Inadequate agricultural practices negatively affected soil quality; only some effective soil conservation measures, such as terracing, were implemented. Intensive cultivation across the slopes (99.3%) was observed with minimal deep tillage to redistribute nutrients within the soil layers. Soil erosion was the major factor that affected soil chemical quality and reduced crop yield, leading to compensation through fertilizer application due to nutrient loss from the soil. Slope significantly affected soil chemicals, causing a reduction by (>50%) at the top slope except for PH (17.5%) and (>45%) in the middle slope except for PH (8.1%) and organic matter (20%) and (>40%)at the Bottom except for PH (9.3%) and total nitrogen (28.6%). slope cultivation affected pH ($p<0.01$), total nitrogen ($p<0.01$), magnesium ($p<0.01$), available phosphorous($p<0.01$.), calcium and potassium($p<0.01$) except organic matter levels. While slope gradients influenced variations in overall soil quality, milder gradients exhibited higher nutrient content than steeper ones. The findings concluded that: (1) Agricultural activities on cultivated slopes detrimentally affected soil quality. (2) Agricultural practices contributed to increased erosion, resulting in substantial loss of nutrients. (3) Cultivated areas displayed inferior health indicators relating to uniformly poor performance regarding their environmental well-being. (4) Variation occurred based on varying slope inclination affecting overall chemical attributes directly connected with specific distribution patterns' characteristics showcased by differentiating terrain conditions.

Keywords: Slope, Slope cultivation, Agricultural and Tillage practice, Soil chemical quality

Chapter One:
Introduction
Background to the Study
This study addressed cause of poor soil chemical quality due to the low concentration of essential micro nutrients of K, Ca, TN, AP, PH, OM which have gone low due to continuous slope cultivation and soil erosion. The potential strategies and interventions needed to mitigate the negative effects of slope cultivation on soil quality to enhance agricultural productivity and sustainability were documented,

practices and factors that affected soil chemical quality and effect of slope on soil chemical properties.
The decline of soil chemical properties significantly affected soil health and fertility, resulting in soil degradation. This was a form of soil chemical degradation, which was caused by slope cultivation and had led to low crop yield and, subsequently, hunger and famine. Soil chemical degradation is the decline in soil condition caused by improper use or poor management, usually for agricultural, industrial, or urban purposes. It is a serious environmental concern in hilly areas and may trigger soil erosion [84,85,86]. Soils are a fundamental natural resource and are the basis for all terrestrial life [32].
Soil chemical degradation was a serious global environmental problem caused by improper use, leading to a decline in soil quality and health [72]. It involved deteriorating chemical aspects, including loss of fertility, erosion, salinity, compaction, and build-up of dangerous chemicals [37]. Agricultural practices directly influence most of these types. Some standard agrarian practices contributing to soil degradation included excessive tillage, inadequate crop rotation, mono-cropping, and excessive use of fertilizers and pesticides [84]. Studies showed that, slope cultivation had been identified as one of the agricultural practices that can hurt soil chemical quality. The presence of slopes accelerated soil erosion, leading to the loss of topsoil, nutrients, and organic matter [1,12].
Globally, 33% of the world’s soils are degraded, of which Asia had 61% of its soils degraded. In comparison, Africa has 65% of its soils degraded [32], the European Union (60-70%) [34,26], Mid-Western US lost 57.6 trillion metric tonnes of soil according to the University of Massachusetts Amherst [97]. In Africa, soil chemical degradation had been cited in various countries and is a serious concern. It is 40% of the globally degraded soils in Africa. The worst affected countries include Sierra Leone, Liberia, Guinea, Ghana, Nigeria, Zaire, Central African Republic, and Senegal [32]. For example, studies about soil chemical degradation have been undertaken in Ethiopia [11,30] and Cameroon [67] among others.
In East Africa, Soil degradation is at an alarming rate, especially nutrient depletion [25]. It was estimated that 51%,41%,23%, and 22% of the land in Tanzania, Malawi, Ethiopia, and Kenya respectively had been degraded [48]. The current state of soil chemical degradation in East Africa is not yet documented, highlighting the urgent need for immediate action.
“[22], as cited by [23], 41% of Uganda’s total area is experiencing degradation, of which 12% is severely degraded. There was an unsustainable rate of soil erosion and degradation, the cost of which was unknown. This situation was not different in Nabweya Sub County Bududa District, which is mountainous with steep slopes, prone to landslides and soil erosion which has degraded the soils. The terrain makes it difficult for farming and has increased soil degradation. The practice of cultivating crops on sloping land has led to soil erosion, nutrient depletion and decreased soil fertility. The farming was purely subsistence in which farmers relied on the land for food and small income[95]. The steep slopes and intense rainfall made the area vulnerable to soil erosion which led to decreased soil chemical quality and fertility. Many farmers live below poverty line which made it difficult to adopt to sustainable agricultural practices. This tagged with limited access to credit, extension services, markets, hindered their ability to improve farming practices making farmers rely on traditional methods. However, high population growth is estimated at 3.8% per annum [65]. “[72]” revealed that 60% of the farmers in Bududa reported soil erosion as one of the causes of soil chemical decline, and 92 % acknowledged that soil fertility had been lost. The situation in this sub county is worse in which there is intense slope cultivation which have affected the soil chemical properties leading to low concentration of essential micro nutrients resulting into a very low for crop production. The crop yields have significantly dropped and farmers have started looking for better soils for farming in other areas.

Statement of the Problem

There has been a potential degradation of soil quality due to slope cultivation which has led to soil erosion, nutrient depletion and decreased soil fertility which have affected agricultural productivity and sustainability. Soil chemical quality has significantly decreased in the area for the last decade, affecting crop yields [72,81] due to intense slope cultivation. The low levels of essential micronutrients in the soil has affected agricultural production of crops. Measures to improve soil chemical quality, such as agroforestry, crop rotation, and contour farming, have been done on a small scale, but there has yet to be any improvement. Other methods to improve soil chemical quality, such as bund construction, cultivation along the slope, no-tillage, and permaculture, have yet to be implemented. "[22]"as cited by [23], reported that 41% of Uganda's total area is experiencing degradation, of which 12% is in a severe state of degradation. If not addressed, this problem may result in meagre crop yield, food shortage, or hunger. There needs to be literature on the effect of slope and slope cultivation on soil chemical degradation for Nabweya. Therefore, it was essential to investigate the effect of slope and slope cultivation on soil quality to identify potential solutions and mitigation measures for addressing the issue of soil quality and low crop yield. Conducting a comprehensive study on this matter using interviews, questionnaires, focused group discussions, and experiments provided valuable insights into the factors and practices contributing to decreasing soil chemical quality, such as soil erosion, and strategies to improve soil chemical quality and crop yield, such as bund construction and permaculture. This study aims to fill the research gap by providing data about slope cultivation and its effect on soil quality. Determining the extent to which slope cultivation practices had led to decreased soil chemical quality in the area was addressed by conducting field surveys and analyzing soils to assess the soil's chemical properties in slope cultivation areas and compare it to non-cultivated areas. Additionally, interviews with local farmers and land users conducted to gather information on cultivation practices, soil management techniques, and their perceptions of changes in soil quality over time. The study documented the factors and practices contributing to soil chemical degradation, slope effect on soil chemical properties, and potential strategies and innervations.

General Objective

The study aimed to assess the effects of slope cultivation on soil chemical quality parameters.

Specific Objectives of the Study

To evaluate the effect of slope cultivation on soil organic matter content.

1. To achieve this objective, soil organic matter was analyzed on different slopes with different cultivation practices and compared with soil quality of undisturbed slopes.
2. To evaluate the effect of slope cultivation on soil PH. To achieve this objective, soil PH was analyzed on different slopes with different cultivation practices and compared with soil quality of undisturbed slopes.
3. To investigate the relationship between slope cultivation and soil nutrient availability. To achieve this objective, soil nutrient availability was analyzed on different slopes with different cultivation practices and compared with soil quality of undisturbed slopes.
4. To investigate the relationship between slope cultivation and concentration of base cations. To achieve this objective, base cation concentration was analyzed on different slopes with different cultivation practices and compared with soil quality of undisturbed slopes.

Research questions

The following research questions guided the study

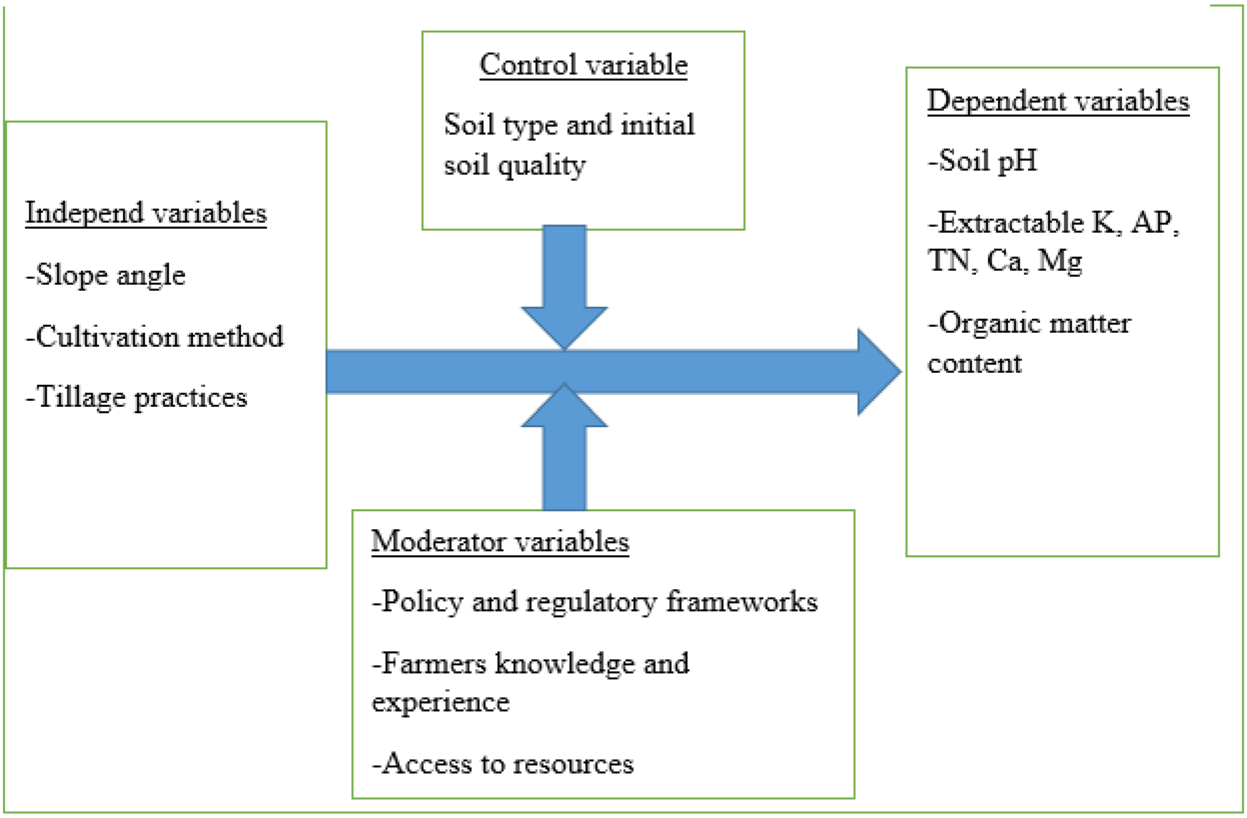
1. How does slope cultivation influence soil organic matter content and what are the implications for soil fertility and ecosystem services?
2. How does slope cultivation influence soil PH and what are the implications for soil fertility and ecosystem services?
3. What is the relationship between slope cultivation and soil nutrient availability and how does it impact crop yields and soil health?
4. What is the relationship between slope cultivation and concentration of base cation and how does it impact crop yields and soil health?

Hypotheses

1. Soil organic matter and PH will be lower on slopes with intensive cultivation practices compared with those with conservation or no tillage.
2. Soil nutrient availability will be higher on slopes with conservation tillage or no till practices

Conceptual /Theoretical Framework

Figure1.0 Conceptual Framework



Slope angle, cultivation method, tillage practices, and fertilizer and pesticide application change soil chemical properties such as soil PH, nutrient availability and organic matter. These chemical properties are further affected by soil erosion and slope angle. To measure the effect of slope cultivation, we use initial soil quality or an undisturbed sloped area and compare soil chemical properties with a current soil quality disturbed area under cultivation.

Significance of the Study

The findings will have contributed to a better understanding of the following:

The soil's most essential nutrients, such as nitrogen, phosphorus, and potassium, in this area had been degraded and needed replenishment.

The effect of slope on soil chemical properties.

Farmers' challenges in slope cultivation areas inform the development of sustainable agricultural practices that not only can improve crop yields but also hold the potential to significantly reduce nutrient degradation, offering a promising future for agriculture in hilly areas.

The research findings will play a crucial role as a basis for policy recommendations and interventions, underscoring the significance of our work in promoting soil conservation and sustainable agriculture in the region.

The findings will contribute to the existing knowledge on soil degradation in hilly areas and provide evidence-based recommendations for sustainable agriculture practices. Overall, this research aims to generate valuable data and recommendations that can support efforts to mitigate the negative impact of slope cultivation on soil quality and promote sustainable agricultural practices in hilly areas.

Justification

Bududa district is considered one of the global food baskets; it supplies food staff to all the East African countries. In recent years, the soil chemical quality has been low and declining with time. Therefore, a study of soil chemical quality is essential. Knowing which plant nutrient is below the minimum amount is urgent. If this study had not been done, the soils would have turned completely infertile, leading to low crop production. This, in turn, could have increased food insecurity, leading to malnutrition and hunger, culminating in climate change and, ultimately, famine

Scope of the Study

This study evaluated the influence of cultivating on slopes on soil quality. The analysis involved examining soil samples from various slopes to assess the degree of soil degradation and nutrient depletion. Additionally, the research explored the connection between slope steepness and soil erosion to determine the impact of intensive cultivation on steep slopes. Moreover, it also investigated how slope cultivation affected crop yields and its socio-economic implications for the local community. Genetic characterization of microbiota and bio-physical properties are not within the scope of this study.

Chapter Two

Literature Review

Introduction

Soil quality

Soil quality refers to the physical, chemical, and biological properties of soil and can be defined as the ability of the soil to sustain the productivity, diversity, and environmental services of terrestrial ecosystems [37]. Soil chemical decline is a serious global environmental problem caused by improper use, leading to a decline in soil quality and health [72,73]. It involves deteriorating chemical aspects, including loss of fertility, erosion, salinity, compaction, and build-up of dangerous chemicals [37,69]. Agricultural practices directly influence most of these types. Some standard agrarian practices contributing to soil chemical degradation include excessive tillage, inadequate crop rotation, mono-cropping, and excessive use of fertilisers and pesticides [84]. Slope cultivation has been identified as one of the agricultural practices that can hurt soil quality. The presence of slopes accelerates soil erosion, leading to the loss of topsoil, nutrients, and organic matter [12].

Causes of soil quality decline

There are several causes of soil chemical degradation, with agricultural practices playing a significant role. Improper land management, excessive use of chemical fertilizers and pesticides, overgrazing, and deforestation can all contribute to soil chemical degradation [52]. Agricultural practices in steep sloped areas have been found to affect soil quality significantly and cause degradation [101]. Additionally, soil erosion is considered one of the most significant contributors. Soil erosion occurs when topsoil is washed away or blown off by wind, leaving less fertile and nutrient-poor soils behind [27,44,88]. Steep slope cultivation has been identified as a significant factor in soil erosion and nutrient loss. Intensive cultivation on sloping land has been found to harm soil quality. Studies have shown intensive cultivation on steep slopes can lead to increased soil erosion, nutrient depletion, and reduced water-holding capacity [44]. This can result in decreased agricultural productivity, reduced crop yields, and increased vulnerability to drought and other environmental stresses.

Soil quality decline is a pervasive issue affecting agricultural productivity, ecosystem services, and environmental sustainability worldwide. The degradation of soil quality is attributed to various factors, which can be broadly categorized into natural and anthropogenic causes. Climate change is a significant driver of soil quality decline. Rising temperatures, altered precipitation patterns, and increased frequency of extreme weather events can lead to soil erosion, salinization, and nutrient depletion [88]. Soil erosion is a natural process exacerbated by climate change, deforestation, and land degradation. It leads to the loss of topsoil, nutrient depletion, and reduced water-holding capacity [53,54,55,56]. Intensive agricultural practices, such as monoculture, excessive tillage, and over-reliance on chemical fertilizers and pesticides, can degrade soil quality [58,59,60,61]. These practices can lead to soil compaction [52,53], erosion [55], and nutrient depletion [64,66,67]. Deforestation and land degradation can lead to soil quality decline by reducing vegetation cover, increasing soil erosion, and altering soil microclimate [38,62,63,64]. Soil quality decline is a complex issue resulting from the interplay of natural and anthropogenic factors [53,64]. Addressing soil quality decline requires a comprehensive approach that incorporates sustainable agricultural practices, conservation efforts, and policy interventions.

However, focus was primarily on global or general trends, with limited attention to regional or local-specific factors contributing to soil quality decline, largely qualitative, with limited quantitative analysis or synthesis of data from existing studies and does not explicitly address how soil quality decline changes over time, or how different factors contribute to these changes. Soil erosion and nutrient depletion is widely mentioned but does not adequately address the impact of soil quality decline on soil biodiversity. It also mentions climate change as a driver of soil quality decline, it does not provide a comprehensive discussion of strategies for mitigating these impacts. It primarily focuses on environmental factors contributing to soil quality decline, with limited attention to social and economic drivers. Lack of consideration of different land uses: The review does not explicitly address how different land uses (e.g., agriculture, forestry, urbanization) contribute to soil quality decline. Inadequate attention to soil type and properties: The review does not provide a comprehensive discussion of how different soil types and properties influence soil quality decline. Limited consideration of policy and governance factors: The review does not adequately address the role of policy and governance in driving or mitigating soil quality decline. They highlight the complexity of factors contributing to soil quality decline but does not provide a clear understanding of the causal relationships between these factors. It does not provide a comprehensive discussion of the thresholds and tipping points beyond which soil quality decline becomes irreversible. They highlight the need for sustainable land management practices but does not provide a comprehensive evaluation of the effectiveness of different mitigation strategies.

Indicators of Soil Chemical Degradation

Soil degradation signs include soil fertility loss, erosion, salinity, soil compaction, and accumulation of harmful substances [77]. These indicators can help evaluate the extent and severity of soil chemical degradation. One significant cause of soil erosion and associated degradation is the intensive cultivation of sloping land. The combined effects of changes in land cover and variations in slope gradient bring about substantial alterations in soil quality [101]. These alterations are evident in various soil parameters such as organic carbon, nitrogen (N), cation exchange capacity, potassium (K), clay content, and pH. Research in similar agricultural regions has observed comparable patterns where negative changes were noted following the conversion of forest land to other uses like shrubland or grazing land. For example, studies in the Agemi watershed of northwestern Ethiopia found that soil degradation indices such as organic carbon, nitrogen, phosphorus, potassium, and bulk density were significantly lower in cultivated and grazing land compared to forestland [6].

Practices and factors that have affected soil chemical quality

The major practices that have led to soil chemical degradation include among others, intensive cultivation [36,], forest fires, construction, deforestation [79] and [94], mining and misuse of fertilizers [96].

Major factors that contribute to soil chemical decline include soil erosion, salt affectedness, decline in soil fertility, and soil heavy metals contamination [7,28,101]. Soil management practices such as terracing [16,17], tree planting, minimum tillage or no tillage, intercropping, permaculture, bund construction among others improve soil chemical quality [52,53,54,68].

Slope Cultivation

Slope cultivation is cultivating crops on steep slopes, often needing to implement appropriate land management practices [36,74]. This practice poses significant challenges to soil quality and sustainability, exposing the soil to increased erosion and nutrient loss [109]. Steep slopes are more susceptible to erosion due to the force of gravity and the increased runoff of water [42,113]. As a result, the top layer of soil, rich in organic matter and nutrients, is easily washed away or carried downhill, leaving behind less fertile and nutrient-poor soil. This needs to be checked to see if it is typical of Nabweya Sub County.

Agricultural, tillage practices and slope cultivation

Agricultural practices play a crucial role in ensuring food security, reducing poverty, and promoting sustainable development. The world's population is projected to reach 9.7 billion by 2050, putting pressure on the agricultural sector to produce more food while minimizing its environmental impact. Current agricultural practices can be broadly categorized into conventional and sustainable agriculture. Conventional agriculture relies heavily on synthetic fertilizers, pesticides, and irrigation, which can lead to soil degradation, water pollution, and loss of biodiversity [90]. Sustainable agriculture, on the other hand, emphasizes the use of natural resources, conservation of biodiversity, and minimization of environmental impact [49]. Some agricultural practices include., Intensive tillage, monoculture, and lack of organic amendments can lead to soil erosion, nutrient depletion, and reduced fertility [78], Use of synthetic fertilizers and pesticides can contaminate water sources, posing risks to human health and aquatic ecosystems [46]. Loss of biodiversity, Monoculture and intensive farming practices can lead to loss of crop and animal diversity, compromising ecosystem services [35]. Several strategies can promote sustainable agriculture, including: Practices such as no-till, reduced-till, and cover cropping can reduce soil erosion, improve soil organic matter, and increase crop yields [45], Use of organic amendments, crop rotation, and biological pest control can reduce environmental impact and promote ecosystem services [70], Integrating trees into farming systems can promote biodiversity, improve soil fertility, and reduce environmental impact[43], Practices such as agroforestry, conservation agriculture, and irrigation management can help farmers adapt to climate change[57] . Agricultural practices have significant impacts on the environment, and there is a need to promote sustainable agriculture practices that minimize environmental impact while ensuring food security. Strategies such as conservation agriculture, organic farming, agroforestry [80], and climate-smart agriculture can promote sustainable agriculture and contribute to a more food-secure future.

Tillage practices are a crucial component of agricultural management, influencing soil physical, chemical, and biological properties [71]. The choice of tillage practice can significantly impact soil erosion, water quality, and crop yields. This literature review aims to provide an overview of current tillage practices, their effects on soil health and the environment, and strategies for sustainable tillage management. Conventional tillage practices involve intensive tillage, often using moldboard plows or disk harrows, to prepare the soil for planting. These practices can lead to soil degradation, erosion, and nutrient loss [78,120,121]. Conservation tillage practices, such as no-till, reduced-till, and mulch-till, aim to minimize soil disturbance and promote soil conservation. These practices can reduce soil erosion, improve soil organic matter, and increase crop yields [45,51,53,54,55,56]. Tillage practices can significantly impact soil physical, chemical, and biological properties. Intensive tillage can lead to: Soil erosion: Tillage can disrupt soil aggregates, making them more susceptible to erosion [45,120,121], Soil compaction: Repeated tillage can lead to soil compaction, reducing soil aeration and water infiltration [78] and Nutrient loss: Tillage can lead to nutrient loss through erosion and leaching [53]. Several strategies can promote sustainable tillage management, including: No-till or reduced-till farming: Minimizing soil disturbance can reduce soil erosion and improve soil health [45], Cover cropping: Planting cover crops can reduce soil erosion, improve soil organic matter, and increase crop yields [56], Mulch-till: Applying mulch to the soil surface can reduce soil erosion, improve soil moisture, and increase crop yields [120, 121]. Tillage practices play a critical role in agricultural management, influencing soil health, water quality, and crop yields. Sustainable tillage management strategies, such as no-till or reduced-till farming, cover cropping, and mulch-till, can promote soil conservation, reduce environmental impact, and improve crop yields.

Effect of Slope on soil chemical properties

Studies have shown that slope angle and length significantly impact soil chemical properties [16,17,21] Slopes with angles of 10% or greater are particularly susceptible to erosion, leading to changes in soil chemical properties [101,105]. Research has demonstrated that soil degradation increases with slope steepness[75]. For example, a study by “[4]” found that the upper slope (30-50%) was significantly more degraded than the middle slope (15-29%) and bottom slope (1-14%). Similarly, [18,19,20], reported that the bottom slope was less degraded than the middle and upper slopes. Several studies have investigated the impact of slope position on soil chemical properties. “[58,59]” found that soil pH did not differ significantly between upper, middle, and bottom slopes, although it changed from slightly acidic to strongly acidic. However, other soil chemical properties, such as total nitrogen, available phosphorus, exchangeable cations, and available potassium, were significantly higher in the middle slope than in the upper and bottom slopes. A similar study by [109] reported changes in soil chemical properties along the slope, with magnesium, calcium, and potassium decreasing significantly from top to bottom. The degradation index was highest for potassium (89%), followed by phosphorus (81%), and lowest for nitrogen (8%). Despite the growing body of research on the effect of slope on soil chemical properties, several gaps remain and these include; quantifying the impact of slope angle and length, more research is needed to quantify the impact of slope angle and length on soil chemical properties, particularly in regions with high relief energy. There is a need for more research on the effects of slope cultivation on soil erosion and soil chemical properties, particularly in regions with non-conservative management practices. Climate change is expected to alter rainfall patterns and soil moisture regimes, which could impact the relationship between slope and soil chemical properties. Future research should investigate these potential impacts. More research is needed to develop site-specific management practices that take into account the unique characteristics of each slope.

Soil PH and slope cultivation and Slope stability

Soil pH significantly influences slope stability, erosion, and overall soil health. Maintaining an optimal pH range is crucial for sustainable slope management and agricultural practices on sloped terrains. Several studies have explored the relationship between soil pH and slope stability. Research indicates that a pH range between 6.0 and 7.0 can reduce soil erosion and enhance soil fertility [91,104,117]. This optimal range promotes favorable soil structure and microbial activity, contributing to increased slope stability. Furthermore, soil pH affects nutrient availability for plant growth on slopes. Studies have demonstrated that pH significantly influences the availability of essential nutrients like nitrogen, phosphorus, and potassium [65,105]. Optimal nutrient availability is vital for healthy plant growth, which in turn reinforces the soil and enhances slope stability. However, the specific pH ranges for optimal nutrient availability can vary depending on the soil type and the specific nutrient in question. Further research is needed to establish precise pH recommendations for different soil and crop combinations. Soil pH also plays a critical role in soil erosion processes on slopes. Research suggests that soils with a pH between 5.5 and 6.5 are more susceptible to erosion [47,20]. Soils outside this range generally exhibit reduced erodibility.

While existing research has established a link between soil pH and slope stability, several gaps remain, these include, more research is needed to determine the optimal pH ranges for different soil types, crops, and climatic conditions. Soil pH interacts with other factors, such as soil texture, organic matter content, and slope gradient, to influence slope stability. Most studies have focused on short-term effects of pH on slope stability. Long-term studies are needed to assess the cumulative impacts of pH management practices on slope ecosystems. The role of soil microorganisms in mediating the effects of pH on slope stability is not fully understood. Climate change is expected to alter rainfall patterns and soil moisture regimes, which could influence the relationship between soil pH and slope stability. By addressing these research gaps, we can develop more effective strategies for managing soil pH and promoting sustainable slope management practices.

Soil organic matter and slope cultivation

Soil organic matter (SOM) plays a vital role in maintaining soil health, fertility, and overall ecosystem functioning. It influences various soil properties, including water retention, nutrient cycling, and structure [52]. However, slope cultivation, a common agricultural practice in hilly and mountainous regions, can significantly impact SOM levels. Several studies have demonstrated the negative impacts of slope cultivation on SOM levels. For instance, [115,116] found that slope gradient significantly affected soil organic carbon, a key component of SOM. Steeper slopes tends to experience higher rates of soil erosion, leading to the loss of topsoil rich in organic matter. A study by [102,103] highlighted the importance of cropland management practices in influencing SOC levels, as cropped soils have generally lost a significant percentage of their pre-cultivation SOC. "[60,61]" further emphasized the role of tillage and poor management practices in depleting SOM, particularly in agroecosystems with inherently low SOC content. While conventional tillage practices can exacerbate SOM loss on slopes, conservation tillage methods have shown promise in mitigating these negative effects. A study by [18,19] suggested that minimizing soil disturbance through practices like no-till farming can create ideal conditions for increased biomass and biological activity, leading to higher SOM levels. "[86]" also noted the importance of nutrient balance in maintaining SOM, and conservation tillage can contribute to improved nutrient cycling. A review by [50] found that conservation tillage practices can increase SOM levels by 10-20% compared to conventional tillage practices. Despite the growing body of research on SOM and slope cultivation, several gaps remain which includes among others; Quantifying the Impact of Specific Tillage Practices: More research is needed to quantify the effects of different conservation tillage practices (e.g., no-till, strip-till, cover cropping) on SOM levels across various slope gradients and soil types. Long-term studies are crucial to understanding the long-term impacts of slope cultivation and conservation tillage on SOM dynamics. Research should explore integrated approaches that combine conservation tillage with other soil management practices, such as crop rotation and organic amendments, to maximize SOM sequestration on slopes. Future research should investigate the interactions between climate change (e.g., changes in temperature and precipitation patterns) and slope cultivation on SOM dynamics. The impact of slope cultivation and conservation tillage on soil biodiversity and its relationship with SOM dynamics warrants further investigation.

Relationship between slope cultivation and nutrient availability

Cultivating sloped land presents a complex interplay of factors influencing soil nutrient availability and overall soil health. The inherent instability of sloped terrain makes it susceptible to erosion, a key driver of nutrient loss and soil degradation [31,60,61]. Topsoil, rich in organic matter and essential nutrients, is readily transported downslope, diminishing the soil's capacity to support plant growth [102,103,106]. Soil nutrient availability, particularly of nitrogen and phosphorus, is crucial for plant growth and productivity. While the impact of slope cultivation on nutrient availability varies depending on soil type, cultivation practices, and fertilizer application, studies consistently demonstrate its negative effects [17,18,19,114,115,117]. For instance, research has shown that slope cultivation can significantly reduce soil organic carbon and total nitrogen[5,10], leading to declines in soil fertility and productivity [31,60,61,107]. The conversion of forestland to other uses, such as shrub land or grazing land, has been linked to a substantial decrease in vital soil nutrients [31,112]. This aligns with observations in regions where forested areas have been converted to farmland, resulting in diminished soil quality [31,114,115,117]. The deterioration of soil quality on slopes is often evident in negative degradation indices for key soil parameters, particularly in cultivated, grazed, and shrub-covered lands compared to undisturbed forestland [31,60,61]. Intensive agricultural practices, including up-down tillage, continuous cultivation, and crop residue burning, contribute to this decline [31,17,18,19] These practices disrupt the spatial distribution of organic matter, nitrogen, cation exchange capacity, potassium, clay content, and pH levels across different slope gradients [31,102,103,106]. Generally, lower slopes retain higher values for these parameters, while moderate and steeper slopes exhibit lower values [31,60,61]. Cultivated land typically shows the most significant deterioration, while shrub land experiences a less pronounced decline [31,114,115,117]. Addressing the challenges of slope cultivation requires a multi-pronged approach. Implementing appropriate soil and water conservation measures is crucial to minimize erosion and nutrient loss [102,103,106]. Promoting sustainable agricultural practices, such as minimizing tillage and retaining crop residues, can enhance soil health and nutrient retention [17,18,19,31]. Furthermore, integrating indigenous knowledge and local practices can provide valuable insights into effective slope management strategies [31,60,61].

Effect of Slope Cultivation on Soil Base Cations

Cultivating sloped land can significantly impact soil properties, including the concentration and balance of base cations (calcium, magnesium, potassium, and sodium). These cations play essential roles in soil structure, nutrient availability, and overall soil health [93]. Understanding how slope cultivation affects base cations is crucial for sustainable land management and agricultural practices. Effects of Slope Cultivation on Soil Base Cations includes; erosion and leaching are primary mechanisms through which slope cultivation affects base cations. When soil is disturbed on slopes, it becomes more susceptible to erosion by water and wind, removing topsoil rich in base cations and leading to their depletion in the remaining soil [102,103]. Increased water flow down slopes can enhance leaching, further removing base cations from the root zone [9]. The loss of base cations through erosion and leaching can disrupt nutrient balance in the soil[112]. Base cations play a crucial role in maintaining the cation exchange capacity (CEC) of the soil, which influences the availability of other essential nutrients [85]. A decrease in base cations can reduce CEC, limiting the soil's ability to retain and supply nutrients to plants. Slope cultivation can contribute to soil acidification, particularly in regions with high rainfall. The leaching of base cations leaves behind acidic ions, lowering the soil pH [33]. Soil acidification can further exacerbate nutrient deficiencies and negatively impact soil microbial communities. Base cations, particularly calcium and magnesium, contribute to soil aggregation and stability [76]. Their depletion due to slope cultivation can weaken soil structure, making it more prone to erosion and compaction. While the effects of slope cultivation on soil base cations are recognized, further research is needed to address several gaps for example; more research is needed to quantify the amount of base cations lost through erosion and leaching under different slope gradients, soil types, and management practices. Most studies have focused on short-term effects of slope cultivation. Long-term studies are needed to assess the cumulative impacts on base cation depletion and soil health. Slope cultivation interacts with other factors, such as climate, vegetation cover, and soil management practices, to influence base cation dynamics. Research is needed to identify and evaluate effective mitigation strategies to minimize base cation loss and maintain soil health in sloped agricultural systems. By addressing these research gaps, we can develop more sustainable land management practices that minimize the negative impacts of slope cultivation on soil base cations and overall soil health.

Comparative Analysis of Soil Quality Before and After Slope Cultivation

Slope cultivation significantly impacts soil quality, affecting its physical, chemical, and biological properties. A comparative analysis of soil samples from cultivated slopes and similar non-cultivated areas offers valuable insights into these effects. Recent studies have emphasized the importance of assessing multiple soil quality indicators to understand the impacts of slope cultivation. "[41]" proposed a minimum dataset for evaluating soil quality, highlighting the need for a comprehensive approach. "[82]" reviewed the effects of sloping farmland utilization on soil health, emphasizing the complex interplay between cultivation practices and soil properties. Research has shown that slope cultivation can lead to a decline in soil fertility, reduced nutrient retention, and increased soil erosion [29,108,109]. These changes can compromise agricultural productivity and environmental sustainability. To assess soil quality before and after slope cultivation, it is essential to focus on crucial indicators such as soil texture, organic carbon content, pH levels, nutrient availability, and water-holding capacity [40,70]. Longitudinal studies can provide valuable insights into the long-term effects of slope cultivation on soil quality, informing sustainable land management practices. Recent studies have also highlighted the importance of considering the impact of climate change on soil quality in slope cultivation scenarios [60,61,102,103,106]. Additionally, research has emphasized the need for integrated approaches that combine soil conservation measures with sustainable agricultural practices [53,54,56,114,115,119].

2.2.3: Methods used to assess the effect of slope cultivation on soil quality

Assessing the impact of slope cultivation on soil quality involves a multi-faceted approach, incorporating various physical, chemical, and biological indicators. Recent studies have emphasized the importance of integrating these indicators to gain a comprehensive understanding of soil quality. Physical indicators assess the structural and hydrological properties of the soil. Compaction, measured through bulk density and penetrometer readings, affects root penetration and water infiltration [15]. Erosion potential can be estimated through measurements of aggregate stability, infiltration rate, and surface runoff [53,55]. Soil moisture content, crucial for nutrient availability and biological activity, can be determined using gravimetric analysis and soil moisture sensors [102,103]. Chemical indicators evaluate the soil's chemical composition and nutrient content. Soil pH, influencing nutrient availability and microbial activity, can be accurately measured using standard pH meters [82,83]. Organic matter content, essential for soil health, can be determined through loss on ignition [41]. Nutrient availability, including macronutrients and micronutrients, can be analyzed using various laboratory techniques [114,115]. Biological indicators examine the soil's biological activity and diversity. Microbial biomass, measured through substrate-induced respiration and chloroform fumigation extraction, provides an indication of soil health [70]. Enzyme activity, crucial for nutrient cycling, can be measured by analyzing specific enzymes like dehydrogenase and phosphatase [58]. Earthworm counts, important indicators of soil health, can be determined through hand sorting and counting methods [105]. Field experiments are essential for evaluating the effects of different slope cultivation practices on soil quality, crop yields, and environmental sustainability. Long-term monitoring is crucial to understand the cumulative impacts of slope cultivation on soil health and productivity [53]. Remote sensing techniques can be employed to assess larger-scale changes in soil properties and vegetation cover [117]. Recent studies have highlighted the importance of integrating physical, chemical, and biological indicators to assess soil quality in slope cultivation scenarios. For example, a study by [54] used a comprehensive approach to evaluate the effects of different tillage methods on soil quality in a sloping agricultural watershed. Another study by [102] employed remote sensing techniques to assess changes in soil properties and vegetation cover in a slope cultivation area.

2.2.4: Strategies and interventions needed to mitigate the negative impacts of slope cultivation.

Slope cultivation can have detrimental effects on soil quality, including increased erosion, nutrient depletion, and reduced water-holding capacity. Studies have shown that intensive cultivation on sloping terrain can lead to soil degradation, reduced agricultural productivity, and environmental concerns [3,8]. To mitigate these negative impacts, a multi-faceted approach is necessary. Key strategies and interventions include: Implementing physical structures and practices like terracing, contour plowing, and vegetative barriers can effectively reduce soil erosion on slopes [87,100,101]. Terracing transforms steep slopes into level platforms, reducing water flow velocity and trapping eroded soil. Contour plowing follows the natural contours of the land, minimizing water runoff and erosion. Agroforestry techniques and crop rotation can improve soil fertility and nutrient cycling. Agroforestry systems enhance nutrient availability through nitrogen fixation, leaf litter decomposition, and improved soil structure [39]. Crop rotation diversifies nutrient demands and reduces pest and disease pressure, contributing to overall soil health [117,119,121]. Proper land management practices, such as fallowing and cover cropping, are essential for restoring soil health. Fallowing allows the soil to rest and regenerate, while cover crops protect the soil surface, suppress weeds, and improve soil organic matter content. The use of organic amendments, such as compost and manure, can further enhance soil fertility and structure [58,59,60,61]. Promoting sustainable land use planning and management practices at the local level is crucial for preventing further soil degradation. This involves integrating land use decisions with ecological considerations, ensuring that agricultural practices are compatible with the long-term health and productivity of the land. Participatory approaches involving local communities are essential for effective implementation [16,82]. Despite existing research, significant gaps remain in our understanding of slope cultivation and its impacts on soil quality. Most research has been conducted in temperate regions, with limited studies in tropical regions, where unique environmental conditions and agricultural practices may influence soil responses. Many studies are short-term, hindering a comprehensive understanding of the long-term impacts of slope cultivation on soil quality. Long-term monitoring is essential to assess the cumulative effects of different management practices. Most studies focus on individual aspects of soil quality, such as nutrient levels. Integrated assessments that consider multiple factors and their interactions are needed to provide a more holistic understanding of soil health. Climate change is expected to alter precipitation patterns, temperature, and soil moisture, potentially exacerbating soil degradation on slopes. Future research should incorporate climate change projections to assess its impacts on soil quality and develop adaptation strategies. While remote sensing and GIS have been used to assess soil data, there's limited use of advanced technologies like drones, sensors, and machine learning algorithms. Integrating these technologies can provide more precise and efficient soil monitoring and assessment.

Chapter Three
Methodology
Introduction

This chapter focuses on the study area, sampling strategy, experimental design, and data collection and analysis methods

Study Area

Agriculture is the principal livelihood of the people in Nabweya Sub County. The common crops grown in this area include coffee, beans, onions, cabbage, bananas, cassava, maize, potatoes, yams, tomatoes, and other green vegetables. The area is an important agricultural region with top hills being utilized for farming practices. The farming practices include mixed farming, intercropping, inorganic fertilizer, organic manure, contour plowing, mulching, and general use of agrochemicals. Various physical factors, including topography, soils, climate, vegetation, and land cover, set the stage for cultivation along the Nabweya hill slope.

Location

Nabweya Sub County is situated at 1°03'14 "N 34°22'14 "E, 1°03'14 "N 34°20'45" E, 1°02'18 "N 34°20'41 "E, 1°02'12 "N 34°22'14 "E to the west of Bududa district. It is approximately 23 kilometers (14 miles) by road, southeast of Mbale, the largest town in the sub-region.

Location of Nabweya Sub County

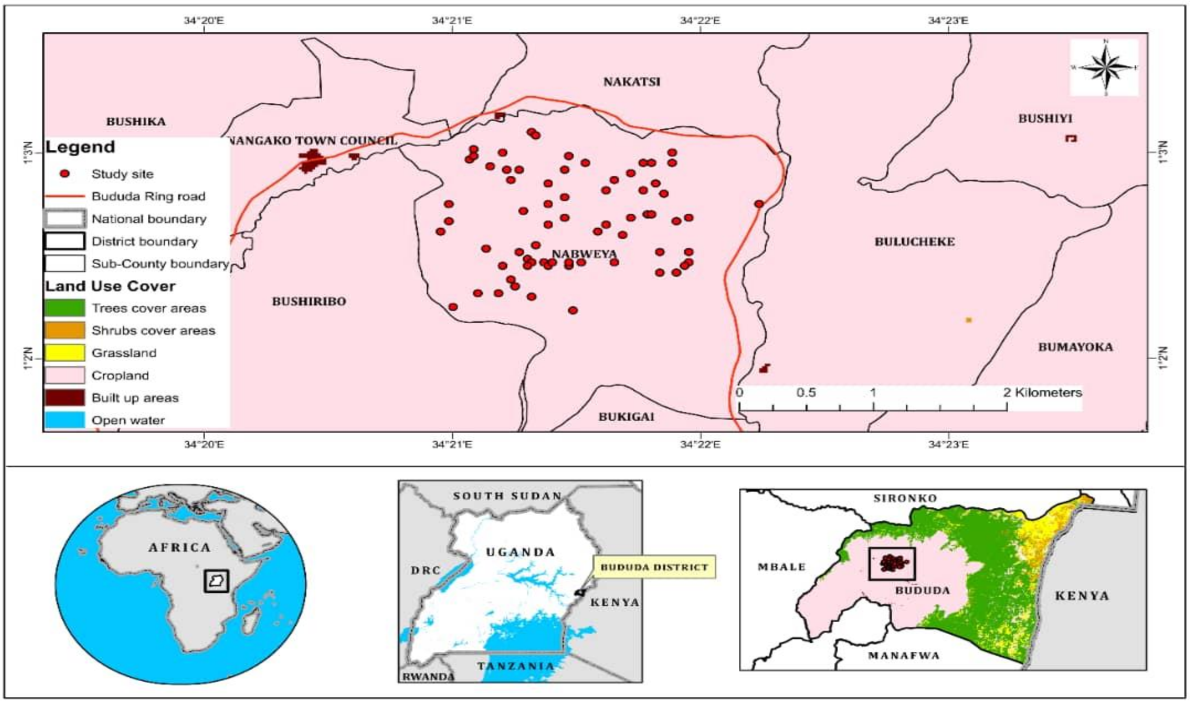


Figure 3.1 Location of Nabweya Sub County

(Source: Field source 2023/2024)

Research Design

The research used descriptive and experimental designs. Questionnaires, interviews, and observations were used to collect data to get a supportive idea about soil chemical degradation and farmers' perception of the cause and consequences of soil fertility decline. Moreover, focus group discussion (FGD) was conducted with different groups of society to get qualitative information about farmers' level of understanding regarding environmental protection and future sustainable land management options. Experiments were carried out on soil Samples. The results obtained were used to assess the soil quality.

This helped to give a deep insight into the level of slope degradation. This helped to draw logical conclusions on the effect of slope cultivation on soil quality.

Sample Size and Population

A population refers to all members of a clearly defined group. A sample is a group that is selected from the population. The sample size is the number of subjects in a study or sample [2]. Nabweya Sub County have a total of 1200 farmers, according to the Bududa District Agricultural officer and sub-county agricultural extension worker. To determine the sample size, I followed the methods described by [24] in which a total of 300 farmers were selected out of 1200. The respondents were selected using a purposive and later systematic sampling technique. This gave every fourth farmer along the slope a chance to be chosen.

Methods of Collecting Data/Research Instruments

Methods of collecting data for Slope cultivation and tillage practices

Questionnaire

A questionnaire is a set of printed or written survey documents with questions to gather information from individuals for research [2]. The questionnaires were administered to 90 respondents who can read and write. This is because some respondents could read and write and have attained a certain level of education, which could give a clear picture of the status and magnitude of the problem.

Interview

Interviews are a qualitative research technique involving individual interviews with a few respondents to explore their perspectives on a particular idea, program, or situation . It can be defined as a qualitative research technique that involves asking open-ended questions to converse with respondents and collect elicit data about a subject[2,14] . In most cases, the interviewer is the subject matter expert who intends to understand respondents' opinions in a well-planned and executed series of answers. Interviews were carried out with 210 respondents who could not read and write. This is because most of the farmers were illiterate. The same questionnaire was used as an interview guide to avoid bias and ambiguity when asking questions.

Focus Group Discussions (FGD)

A focus group discussion (FGD) is a qualitative research method in which people from similar backgrounds or experiences discuss a specific topic of interest [2]. The group of participants is guided by a moderator (or group facilitator) who introduces topics for discussion and helps the group to participate in a lively and natural discussion amongst themselves. Focus group discussions of 6 farmers per parish were organized to harmonize findings obtained from the questionnaire, interview, and observation. This provided a deep insight into the type of agricultural practices and how they have affected soil quality.

Method of collecting data for objectives one, two, three and four.

Effect of slope and slope cultivation on soil chemical quality

Experiment

Soil samples were analyzed for Total Nitrogen (%), Organic matter (%), Phosphorus (ppm), Calcium (ppm), and Magnesium (ppm) for both cultivated slopes and undisturbed slopes. The results were compared and then correlated with the observed nature and physiology of crops growing in the study area fields, which is a guide for making conclusions. Soil samples were triplicated during analysis to obtain consistency in results regarding nutrient composition, and finally, means were used to determine the significance level between study sites.

Observation

Observation is a way of collecting data [2]. The observation data collection method is classified as a participatory study because the researcher has to immerse in the setting where respondents are while taking notes and recording. An observation was carried out across the study area of Nabweya Sub County in Bududa district to observe the soils, vegetation, and physiological appearance physically, the type of crops farmers was growing, and the nature of the soils. Observations were made and noted to compare laboratory soil results with available literature to deduce logical conclusions. Additionally, focus group discussions (FGD) were also used.

Soil sampling procedures

Nabweya Sub-county has a diversity of slopes. Slopes with angles were selected for the study. Soil samples at a depth of 0-20 cm were collected using a metallic soil auger in a transect of 100m by 100m in the four geographical directions: north, east, west, and south at regular intervals of 100m using both zigzag and diagonal methods along the slopes, branded as A-Top slope (30-60%) (Upper Terrace), B- Middle slope (15-30%) (middle Terrace), C- Bottom slope (10-15%) (bottom Terrace). The samples were picked from the selected farm holdings where cultivation had been ongoing for five years and beyond. The uncultivated area/control (D) was a forest land that had never been disturbed for five to ten years. The assumption was that the properties of soils in that forest were once similar to those of a less disturbed mountain forest [63] . The soils were thoroughly mixed to form composite samples at each spot and depth. The samples were then packed in well-labeled polythene bags and transported to Kawanda.

Research Laboratories for Analysis.

Soil samples were analyzed for various physicochemical properties using standardized methods. Soil pH was determined in both water and potassium chloride (KCl) suspension using a 1:2.5 soil-liquid ratio, as described by [98]. Organic carbon content was estimated using the wet digestion method developed by [99]. Organic matter content was subsequently calculated by multiplying the organic carbon content by a factor of 1.724. Total nitrogen was measured through Kjeldahl digestion, distillation, and titration, following the procedure outlined by [13]. Available phosphorus (P) was analyzed using the standard Olsen method. Briefly, 5 cm^3 of soil (<2 mm) was extracted with 100 cm^3 of 0.5 M $NaHCO_3$ solution (pH adjusted to 8.5) for 30 minutes. The phosphate concentration of the solution was then measured colorimetrically and expressed as mg P per liter of soil. Exchangeable bases were determined using the ammonium acetate method at pH 7.0. Exchangeable calcium (Ca) and magnesium (Mg) levels were analyzed using an atomic absorption spectrometer (AAS). Sodium (Na) and potassium (K) concentrations were assessed through flame photometry, according to [92].

Data Analysis and Interpretations

The quality of the soil was evaluated by analyzing its physical and chemical properties. The analysis aimed to determine the impact of changes in land cover and slope gradient on various soil quality parameters. For this purpose, a two-way analysis of variance (ANOVA) was carried out using SPSS version 20. The analysis revealed significant main effects ($P \leq 0.05$). To determine significantly differing treatment means, Fisher's least significant difference (LSD) was used. Further, a Pearson correlation coefficient analysis was conducted to determine the relationship between soil variables, land cover types, and slope gradients. Household perceptions were analysed using the statistical frequency distribution analysis method to understand the causes and consequences of soil degradation. A qualitative analysis of focus group participant data was also performed to substantiate the results obtained through a questionnaire.

Ethical Considerations

This study was approved by the Department of Environmental Science, Faculty of Science of the Islamic University in Uganda, under the supervision of the Center for Postgraduate Studies. The respondents voluntarily participated and were informed of consent by signing before providing any information. Anonymity and confidentiality were observed to prevent potential harm and biases in communication and results.

Limitations of the study

In this study, some limitations were found:

Funding was not sufficient to carry out tests on all soil chemical properties of the soil samples. This was overcome by carrying out tests on only essential soil chemical nutrients such as nitrogen, phosphorous, potassium organic matter, calcium, soil PH and magnesium which are responsible for soil fertility and healthy.

Soil laboratory tests were done without my participation which could easily alter actual results. However, Kawanda Research Laboratories is one of the certified soil science laboratories. which gave guarantee of the results.

Chapter Four

Data Presentations

Analysis, and Discussion of Findings

Introduction

This chapter shows results from the data collection methods used which included questionnaires, interviews, focus group discussions and experiments.

Results from interviews and questionnaires

Practices and factors that have affected soil chemical quality.

Table 4.1.0: Shows Agricultural Practices

Cultivation practices	Practiced	%	Not practiced	%
Terracing	65	21.6	235	78.3
Crop Rotation	199	66.4	101	33.6
Mulching	221	73.7	79	26.3
Fertilizer Application	86	28.6	214	71.4
Manure Application	278	92.6	22	7.4
Tree Planting	107	35.7	193	64.3
Cultivating along the slope	37	12.3	263	87.7
Cultivating across the slope	261	87	39	13

(Source: Field source 2023/2024)

The results from our research, which involved observation, FGD, interviews, and a questionnaire (Table 4.1.0), underscore the urgency of addressing the current agricultural practices used during slope cultivation. These practices, including terracing, crop rotation, mulching, fertilizer application, organic manure application, tree planting cultivation along the slopes, and cultivation across the slope, are contributing to soil chemical decline. The detrimental impact of intensive cultivation, fertilizer misuse, and improper agricultural practices on soil health is a pressing issue that requires immediate attention and action. By engaging in sustainable agricultural practices, we can mitigate these effects and ensure the future of our soil and agriculture.

Factors that have contributed to soil chemical degradation

Table 4.1.1: Shows Soil erosion and Crop Yield

	Agreed	%	Disagreed	%
Effect of soil erosion on gardens	206	68.7	94	31.3
Effect of soil erosion on crop yield	206	68.7	94	31.3

(Source: Field Source 2023/2024)

Table 4.1.1: Shows the significant factors contributing to soil chemical decline in the Nabweya sub-county. Soil erosion was the primary factor. The highest number of farmers agreed to the fact that soil erosion affects soil quality and crop yield.

Soil laboratory test results

Effect of slope position and slope cultivation on soil chemical properties

Table 4.1.2 Mean soil chemical properties at Terrace Positions

		Top(A)	Middle(B)	Bottom(C)
K(ppm)	**Y**	12.9	14.7	36.1
	D	197.3	203.6	229.6
Ca(ppm)	**Y**	130.8	556.3	666.8
	D	2664.3	2861.5	3708.7
AP(ppm)	**Y**	15	18	30
	D	56	58	58
Mg(ppm)	**Y**	16.7	82.2	80.8
	D	160.1	177.5	180.5
OM(%)	Y	4.2	6.6	6.8
	D	4.8	6.8	7.2
TN(%)	Y	0.2	0.2	0.5
	D	0.7	0.7	0.7
PH	Y	5.2	5.82	5.94
	D	6.3	6.33	6.55

(Source: Field Source 2023/2024)

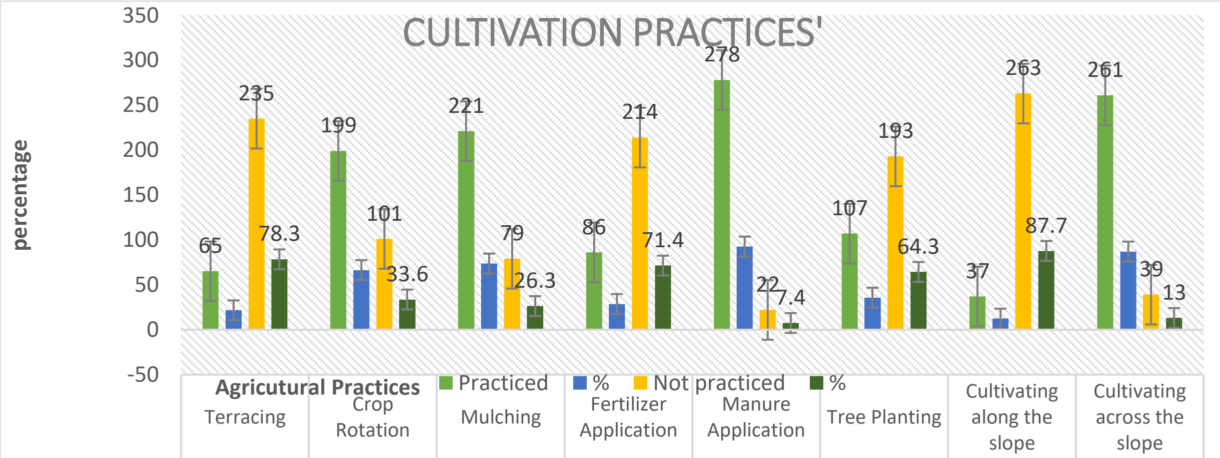
C=low terrace position; B= middle terrace position; A= upper terrace position. Y= cultivated slopes, D=uncultivated slope.

The average soil chemical properties of the soils in Nabweya generally decreased as you moved from the top slope to the bottom in cultivated slopes and undisturbed slopes (Table 4.1.2). Total nitrogen showed no changes in undisturbed slope

Analysis of results.

practices and factors affecting soil chemical quality.

Figure 4.1: comparison of Slope cultivation practices

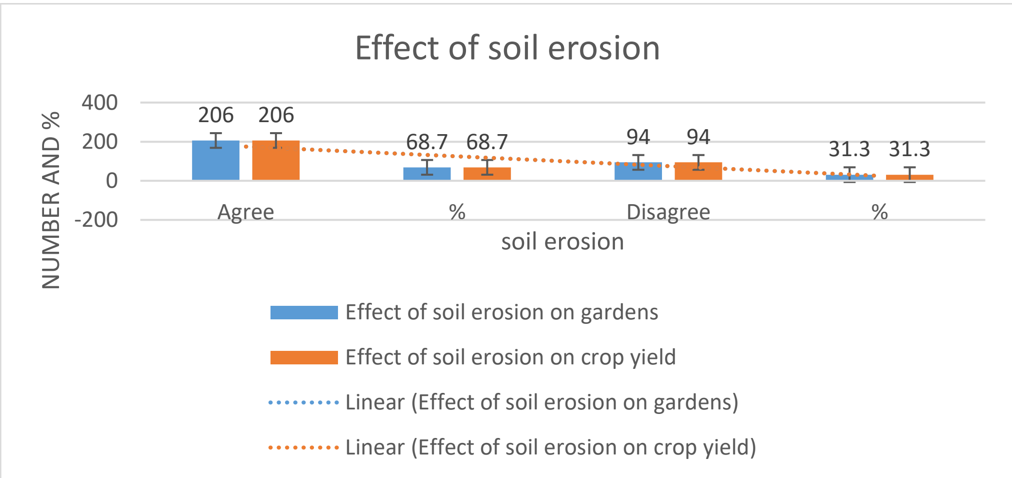


	Terracing	Crop Rotation	Mulching	Fertilizer Application	Manure Application	Tree Planting	Cultivating along the slope	Cultivating across the slope
Practiced	65	199	221	86	278	107	37	261
%	21.6	66.4	73.7	28.6	92.6	35.7	12.3	87
Not practiced	235	101	79	214	22	193	263	39
%	78.3	33.6	26.3	71.4	7.4	64.3	87.7	13

(Source: Field Source 2023/2024)

Slope cultivation practices such as mulching and crop rotation were practiced by many farmers. (figure 4.1). The other good practices such as terracing, manure application, and tree planting, though less common, hold significant potential for improving soil health. Cultivation along the slope was also found to be beneficial. However, intensive cultivation across the slope and misuse of fertilizers were found to contribute to soil chemical decline.

Figure 4.2 Shows Soil erosion and soil quality

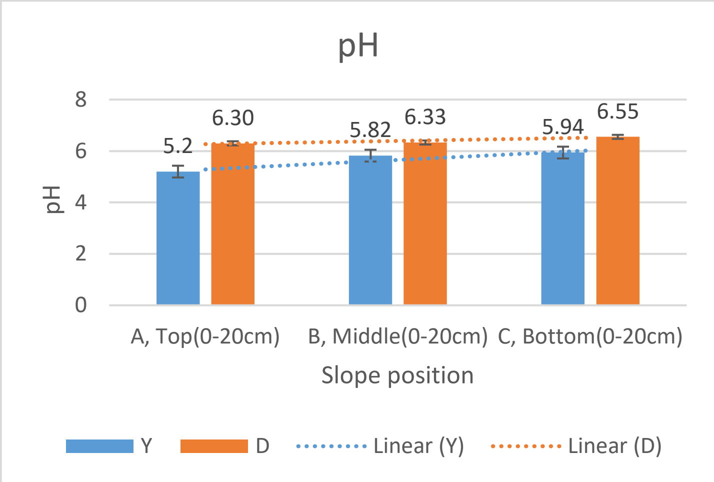


(Source: Field Source 2023/2024)

Soil erosion affected crop yields and gardens and was identified as one of the major factors affecting soil chemical quality (Figure 4.2). It is seen as an accelerator of nutrient loss during heavy rains.

Analysis of results for objective two: Effect of slope on soil chemical quality

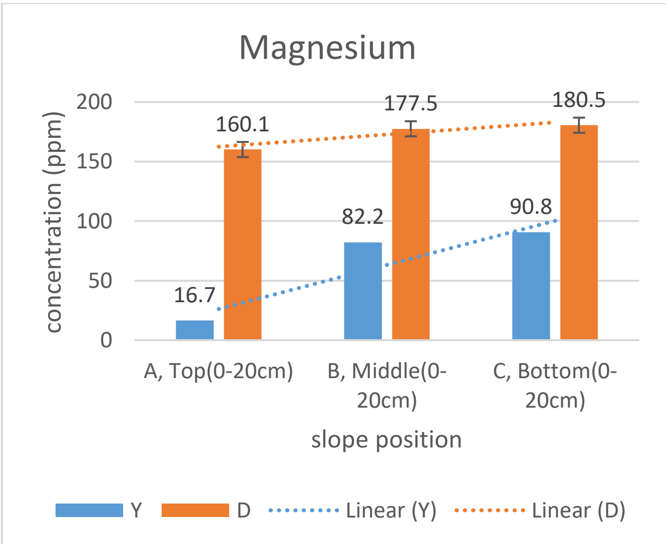
Figure 4.3 Shows Comparisons of PH at different terrace position



percentage reduction
Top:17.5%
Middle:8.1%
Bottom:9.3%
Source: Field source 2023/2024

The soil pH was reduced by 17.5 % at the top,8.1% in the middle, and 9.3 % at the bottom, showing a general reduction in pH (Figure 4.3). Undisturbed slopes had a high pH compared to disturbed slopes.

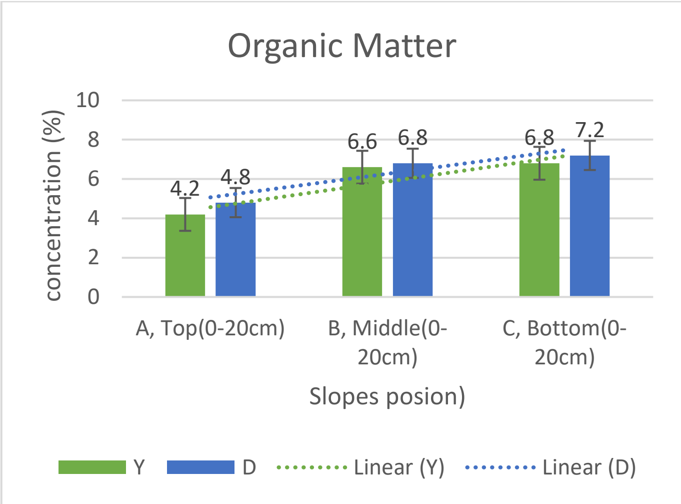
Figure 4.4: Shows Comparisons of Magnesium at different terrace positions



Top:89.6%
Middle:48.1%
Bottom:49.7%
Source: Field source 2023/2024

The available Magnesium concentrations were reduced by 89.6 % at the top,48.8% at the middle, and 49.7% at the bottom. This reduction was both in cultivated and uncultivated slopes(figure:4.4).

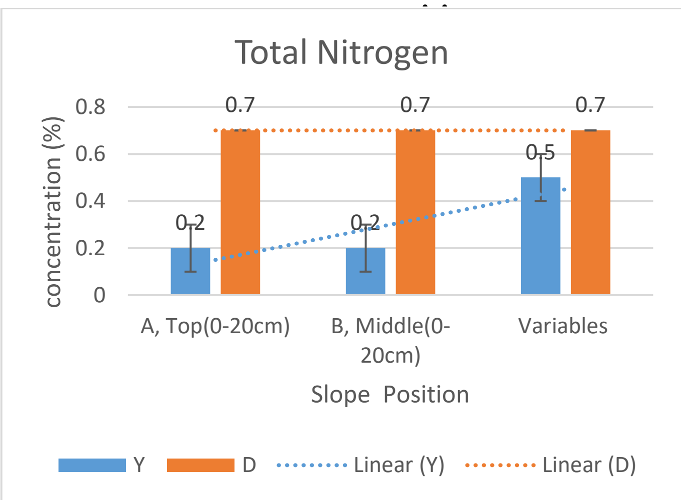
Figure 4.5: comparisons of organic matter at different terrace positions



Percentage reduction
Top:60%
Middle:20%
Bottom:40%
Source :Field source 2023/2024

The Organic matter concentrations were reduced by 60 % at the top,20% at the middle, and 40% at the bottom. The reduction was for both cultivated and uncultivated slopes. (figure 4.5).

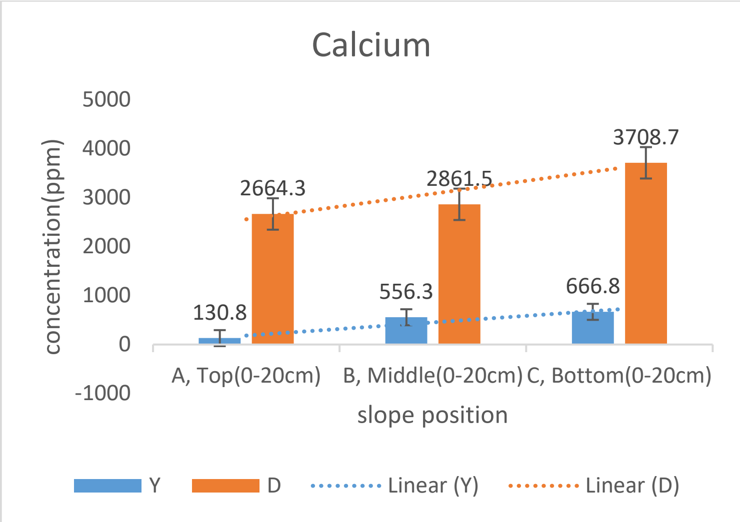
Figure 4.6 Shows Comparisons of Nitrogen at different terrace



percentage reduction
Top:71.4%
Middle:71.4%
Bottom:28.6%
Source: Field source 2023/2024

The Total Nitrogen concentrations were reduced by 71.4 % at the top,71.4% at the middle, and 28.6% at the bottom. (figure :4.6). However, the concentration remained constant for the uncultivated slopes.

Figure 4.7 Shows comparisons of calcium at different terrace position



(Source: Field Source 2023/2024

Percentage reduction

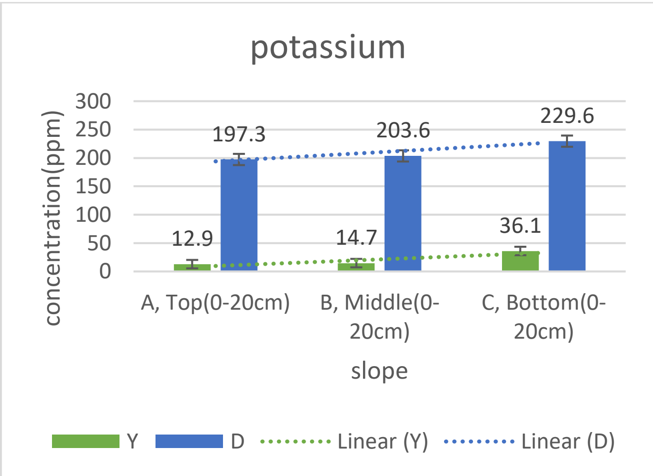
Top: 95.1%

Middle:80.6%

Bottom: 82.0%

The available calcium concentrations were reduced by 95.1% at the top, 80.6% at the middle, and 82.0% at the bottom. (Figure 4.7)

Figure 4.8 Shows comparisons of Potassium at different terrace position



Source: Field source 2023/2024

Percentage reduction

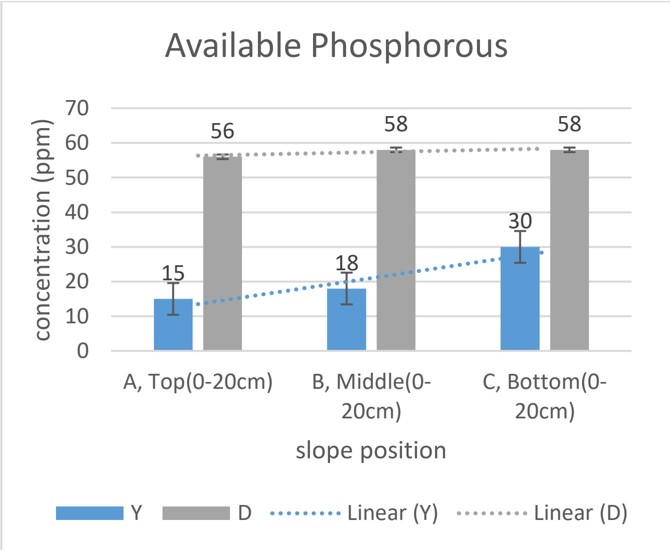
Top:92.5%

Middle:92.7%

Bottom:84.3%

The available potassium concentrations were reduced by 92.5 % at the top,92.7% at the middle, and 84.3% at the bottom. (figure 4.8).

Figure:4.9: Shows the comparison of available Phosphorous at different terrace position



Source: Field source 2023/2024

Percentage reduction

Top: 73.2 %

Middle: 68.9%

Bottom: 48.7%

The available phosphorous concentrations were reduced by 73.2 % at the top,68.9% in the middle, and 48.7% at the bottom (Figure 4.9). The cultivated slopes showed low concentrations compared to the undisturbed areas.

Pearson correlation coefficients for soil chemical properties across the slope for January, April, and July.

Table 4.1.3: Shows Correlation for Potassium(k) between different months across the slope

	K1(C)	K4 (C)	K7(C)	K1(UC)	(UC)	K7(UC)
K1(C)	1	1	0.61	1	0.99	1
K4(C)	1	1	0.63	1	0.99	1
K7(C)	0.61	0.63	1	0.64	0.49	0.64
K1(UC)	1	1	0.64	1	0.98	1
K4(UC)	0.99	0.99	0.49	0.98	1	0.98
K7(UC)	1	1	0.64	1	0.98	1

Table where,1=January,4=april,7=July, C=Cultivated Slopes, UC=Uncultivated Slopes (Source: Field Source 2023/2024)

There was a positive correlation coefficient for Potassium (table 4.1.3) between January and April, April and July and January and July.

International Journal for Multidisciplinary Research (IJFMR)

E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Table 4.1.4: Shows **Correlation** for Calcium(Ca) between different months across the slope

	Ca1(C)	Ca4 (C)	Ca7(C)	Ca1(UC)	Ca4(UC)	Ca7(UC)
Ca1(C)	1	0.78	1	0.78	1	0.78
Ca4(C)	0.78	1	0.78	1	0.78	1
Ca7(C)	1	0.78	1	0.78	1	0.78
Ca1(UC)	0.78	1	0.78	1	0.78	1
Ca4(UC)	1	0.78	1	0.78	1	0.78
Ca7(UC)	0.78	1	0.78	1	0.78	1

Table where,1=January,4=april,7=July, C =Cultivated Slopes, UC=Uncultivated Slopes (Source: Field Source 2023/2024)

There was a positive correlation coefficient for Calcium (table 4.1.4) between January and April, April and July and January and July.

Table 4.1.5: shows Correlation for Magnesium(Mg) between different months across the slope

	Mg1(C)	Mg4 (C)	Mg7(C)	Mg1(UC)	Mg4(UC)	Mg7(UC)
Mg1(C)	1	1	1	1	1	1
Mg4(C)	1	1	1	1	1	1
Mg7(C)	1	1	1	1	1	1
Mg1(UC)	1	1	1	1	1	1
Mg4(UC)	1	1	1	1	1	1
Mg7(UC)	1	1	1	1	1	1

Table where,1=January,4=april,7=July, C=Cultivated Slopes, UC=Uncultivated Slopes (Source: Field Source 2023/2024)

There was a positive correlation coefficient for Magnesium (table 4.1.5) between January and April, April and July and January and July.

Table 4.1.6: Shows Correlation for Organic Matter(OM) between different months across the slope

	OM1(C)	OM4 (C)	OM7(C)	OM1(UC)	OM4(UC)	OM7(UC)
OM1(C)	1	1	1	1	1	1
OM4(C)	1	1	0.99	1	0.99	0.99
OM7(C)	1	0.99	1	0.98	1	1
OM1(UC)	1	1	0.98	1	0.98	0.99
OM4(UC)	1	0.99	1	0.98	1	1
OM7(UC)	1	0.99	1	0.99	1	1

Table where,1=January,4=april,7=July=Cultivated Slopes, UC=Uncultivated Slopes (Source: Field Source 2023/2024)

There was a positive correlation coefficient for OM (table 4.1.6) between January and April, April and July and January and July.

Table 4.1.7: shows Correlation for Organic Matter(OM) between different months across the slope

	TN1(C)	TN4 (C)	TN7(C)	TN1(UC)	TN4(UC)	TN7(UC)
TN1(C)	1	0	1	0	1	0
TN4(C)	0	1	0	1	0	1
TN7(C)	1	0	1	0	1	0
TN1(UC)	0	1	0	1	0	1
TN4(UC)	1	0	1	0	1	0
TN7(UC)	0	1	0	1	0	1

where,1=January,4=april,7=July, C=Cultivated Slopes, UC=Uncultivated Slopes (Source: Field Source 2023/2024)

There was a positive correlation coefficient for Total Nitrogen (table 4.1.7) between January and April, April and July and January and July.

Table 4.1.8: shows Correlation for PH between different months across the slope

	PH1(C)	PH4 (C)	PH7(C)	PH1(UC)	PH4(UC)	PH7(UC)
PH1(C)	1	0.8	1	0.71	1	0.34
PH4(C)	0.8	1	0.74	0.99	0.83	0.84
PH7(C)	1	0.74	1	0.65	0.99	0.25
PH1(UC)	0.71	0.99	0.65	1	0.75	0.9
PH4(UC)	1	0.83	0.99	0.75	1	0.39
PH7(UC)	0.34	0.84	0.25	0.9	0.39	1

where,1=January,4=april,7=July, C=Cultivated Slopes, UC=Uncultivated Slopes (Source: Field Source 2023/2024)

There was a positive correlation coefficient for PH (table 4.1.8) between January and April, April and July and January and July. Though positive a small correlation shown July between cultivated and uncultivated slope

Table 4.1.9: shows Correlation for Available Phosphorous (AP) between different months across the slope

	AP1(C)	AP4 (C)	AP7(C)	AP1(UC)	AP4(UC)	AP7(UC)
AP1(C)	1	0.78	0.99	0.97	1	-0.18
AP4(C)	0.78	1	0.87	0.9	0.78	-0.76
AP7(C)	0.99	0.87	1	1	0.99	-0.35
AP1(UC)	0.97	0.9	1	1	0.97	-0.41
AP4(UC)	1	0.78	0.99	0.97	1	-0.18
AP7(UC)	-0.18	-0.76	-0.35	-0.41	-0.18	1

Where,1=January,4=april,7=July, C=Cultivated Slopes, UC=Uncultivated Slopes (Source: Field Source 2023/2024)

There was a positive correlation coefficient for AP (table 4.1.9) between January and April, April and July and January and July for cultivated slopes except for uncultivated slopes.

Post-hoc Tukey HSD Results on Soil Chemical Properties

Table 4.2.0: Shows Potassium

K(pmm)	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference
A_Y vs. B_Y	2.8925	0.3360984	insignificant
A_Y vs C_Y	4.3168	0.0432766	* p<0.05
A_Y vs A_D	34.4409	0.0010053	** p<0.01
A_Y vs B_D	35.6182	0.0010053	** p<0.01
A_Y vs C_D	40.4769	0.0010053	** p<0.01
B_Y vs C_Y	1.3295	0.8999947	insignificant
B_Y vs. A_D	31.4535	0.0010053	** p<0.01
B_Y vs. B_D	32.6309	0.0010053	** p<0.01
B_Y vs. C_D	37.4896	0.0010053	** p<0.01
C_Y vs. A_D	31.1814	0.0010053	** p<0.01
C_Y vs. B_D	32.4000	0.0010053	** p<0.01
C_Y vs. C_D	37.4293	0.0010053	** p<0.01
A_D vs. B_D	1.2186	0.8999947	insignificant
A_D vs. C_D	6.2479	0.0010053	** p<0.01
B_D vs C_D	5.0293	0.0117916	* p<0.05

P<0.05 and p<0.01 Shows Significant differences between the means across different slope terraces. p>0.05 shows no significant difference between the means across different slope terraces. A_Y (cultivated Top slope), B_Y (cultivated Middle slope), C_Y (cultivated Bottom slope),A_D uncultivated Top slope),B_D (uncultivated Middle slope),C_D (uncultivated Bottom slope). (Source: Field source 2023/2024

There was a significant difference (p<0.05) in the potassium concentrations except for top-middle, middle–bottom for cultivated and top-bottom for uncultivated slopes.

Table 4.2.1: Shows Calcium (Ca)

Ca(ppm)	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference
A_Y vs. B_Y	11,417.3634	0.0010053	** p<0.01
A_Y vs. C_Y	14,382.3897	0.0010053	** p<0.01
A_Y vs A_D	67,980.9407	0.0010053	** p<0.01
A_Y vs B_D	73,272.3721	0.0010053	** p<0.01
A_Y vs C_D	96,005.1343	0.0010053	** p<0.01
B_Y vs C_Y	2,965.0262	0.0010053	** p<0.01
B_Y vs. A_D	56,563.5772	0.0010053	** p<0.01
B_Y vs. B_D	61,855.0087	0.0010053	** p<0.01
B_Y vs. C_D	84,587.7708	0.0010053	** p<0.01
C_Y vs. A_D	53,598.5510	0.0010053	** p<0.01
C_Y vs. B_D	58,889.9824	0.0010053	** p<0.01
C_Y vs. C_D	81,622.7446	0.0010053	** p<0.01

A_D vs. B_D	5,291.4314	0.0010053	** p<0.01
A_D vs. C_D	28,024.1936	0.0010053	** p<0.01
B_D vs C_D	22,732.7622	0.0010053	** p<0

P<0.05 and p<0.01 Shows Significant differences between the means across different slope terraces. p>0.05 shows no significant difference between the means across different slope terraces. A_Y (cultivated Top slope), B_Y (cultivated Middle slope), C_Y (cultivated Bottom slope),A_D uncultivated Top slope),B_D (uncultivated Middle slope),C_D (uncultivated Bottom slope). (Source: Field source 2023/2024)

There was a significant difference (p<0.05) in the Calcium concentrations between the cultivated slopes and undisturbed slopes, and between all the slope positions

Table 4.2.2:0rganic matter

OM(%)	**Tukey HSD Q statistic**	**Tukey HSD p-value**	**Tukey HSD inference**
A_Y vs. B_Y	196	0.0010053	** p<0.01
A_Y vs. C_Y	16.0641	0.0010053	** p<0.01
A_Y vs A_D	2.9208	0.3473699	Insignificant
A_Y vs B_D	14.4577	0.0010053	** p<0.01
A_Y vs C_D	16.2102	0.0010053	** p<0.01
B_Y vs C_Y	2.0445	0.6796636	Insignificant
B_Y vs. A_D	11.0989	0.0010053	** p<0.01
B_Y vs. B_D	0.4381	0.8999947	Insignificant
B_Y vs. C_D	2.1906	0.6244705	Insignificant
C_Y vs. A_D	13.1434	0.0010053	** p<0.01
C_Y vs. B_D	1.6064	0.8452351	Insignificant
C_Y vs. C_D	0.1460	0.8999947	Insignificant
A_D vs. B_D	11.5370	0.0010053	** p<0.01
A_D vs. C_D	13.2894	0.0010053	** p<0.01
B_D vs. C_D	1.7525	0.7900454	Insignificant

P<0.05 and p<0.01 Shows Significant differences between the means across different slope terraces. p>0.05 shows no significant difference between the means across different slope terraces. A_Y (cultivated Top slope), B_Y (cultivated Middle slope), C_Y (cultivated Bottom slope),A_D uncultivated Top slope),B_D (uncultivated Middle slope),C_D (uncultivated Bottom slope). (Source: Field source 2023/2024)

Our research, conducted with meticulous attention to detail, uncovered a significant difference (p<0.01) in the OM concentrations. However, it's equally noteworthy that no significant difference was found in the concentrations between various slope pairs, as detailed in the table 4.2.2.

Table 4.2.3: Total Nitrogen

TN(%)	**Tukey HSD Q statistic**	**Tukey HSD p-value**	**Tukey HSD inference**
A_Y vs. B_Y	0.0000	0.8999947	Insignificant
A_Y vs. C_Y	60,397,977.6000	0.0010053	** p<0.01
A_Y vs A_D	100,663,296.0000	0.0010053	** p<0.01

A_Y vs B_D	100,663,296.0000	0.0010053	** p<0.01
A_Y vs C_D	100,663,296.0000	0.0010053	** p<0.01
B_Y vs C_Y	60,397,977.6000	0.0010053	** p<0.01
B_Y vs. A_D	100,663,296.0000	0.0010053	** p<0.01
B_Y vs. B_D	100,663,296.0000	0.0010053	** p<0.01
B_Y vs. C_D	100,663,296.0000	0.0010053	** p<0.01
C_Y vs. A_D	40,265,318.4000	0.0010053	** p<0.01
C_Y vs. B_D	40,265,318.4000	0.0010053	** p<0.01
C_Y vs. C_D	40,265,318.4000	0.0010053	** p<0.01
A_D vs. B_D	0.0000	0.8999947	Insignificant
A_D vs. C_D	0.0000	0.8999947	Insignificant
B_D vs. C_D	0.0000	0.8999947	Insignificant

P<0.05 and p<0.01 Shows Significant differences between the means across different slope terraces. p>0.05 shows no significant difference between the means across different slope terraces. A_Y (cultivated Top slope), B_Y (cultivated Middle slope), C_Y (cultivated Bottom slope),A_D uncultivated Top slope),B_D (uncultivated Middle slope),C_D (uncultivated Bottom slope). (Source: Field source 2023/2024

A significant difference in Total nitrogen concentration (p<0.01) was noted. However, no significant difference was observed between slope positions in the uncultivated slopes and between the top and bottom slopes in the cultivated slope table 4.2.3

Table 4.2.4:PH

PH	**Tukey HSD Q statistic**	**Tukey HSD p-value**	**Tukey HSD inference**
A_Y vs. B_Y	11.1860	0.0010053	** p<0.01
A_Y vs. C_Y	14.1223	0.0010053	** p<0.01
A_Y vs A_D	20.1348	0.0010053	** p<0.01
A_Y vs B_D	20.8339	0.0010053	** p<0.01
A_Y vs C_D	25.7278	0.0010053	** p<0.01
B_Y vs C_Y	2.9363	0.3418815	insignificant
B_Y v.s A_D	8.9488	0.0010053	** p<0.01
B_Y vs. B_D	9.6479	0.0010053	** p<0.01
B_Y vs. C_D	14.5418	0.0010053	** p<0.01
C_Y vs. A_D	6.0125	0.0054267	** p<0.01
C_Y vs. B_D	6.7116	0.0019049	** p<0.01
C_Y vs. C_D	11.6055	0.0010053	** p<0.01
A_D vs. B_D	0.6991	0.8999947	insignificant
A_D vs. C_D	5.5930	0.0101518	* p<0.05
B_D vs. C_D	4.8939	0.0283470	* p<0.05

P<0.05 and p<0.01 Shows Significant differences between the means across different slope terraces. p>0.05 shows no significant difference between the means across different slope terraces. A_Y (cultivated Top slope), B_Y (cultivated Middle slope), C_Y (cultivated Bottom slope),A_D uncultivated Top slope),B_D (uncultivated Middle slope),C_D (uncultivated Bottom slope). (Source: Field source 2023/2024

A significant difference in total nitrogen concentration (p<0.01) was noted. However, no significant difference was observed between slope positions in the uncultivated slopes and between the top and bottom slopes in the cultivated slope table 4.2.4.

Table 4.2.5: Magnesium

Mg(ppm)	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference
A_Y vs. B_Y	145.3110	0.0010053	** p<0.01
A_Y vs. C_Y	164.0769	0.0010053	** p<0.01
A_Y vs A_D	318.9093	0.0010053	** p<0.01
A_Y vs B_D	356.3303	0.0010053	** p<0.01
A_Y vs C_D	363.0838	0.0010053	** p<0.01
B_Y vs C_Y	18.7659	0.0010053	** p<0.01
B_Y vs. A_D	173.5982	0.0010053	** p<0.01
B_Y vs. B_D	211.0193	0.0010053	** p<0.01
B_Y vs. C_D	217.7728	0.0010053	** p<0.01
C_Y vs. A_D	154.8324	0.0010053	** p<0.01
C_Y vs. B_D	192.2534	0.0010053	** p<0.01
C_Y vs. C_D	199.0069	0.0010053	** p<0.01
A_D vs. B_D	37.4211	0.0010053	** p<0.01
A_D vs. C_D	44.1746	0.0010053	** p<0.01
B_D vs. C_D	6.7535	0.0017880	** p<0.01

P<0.05 and p<0.01 Shows Significant differences between the means across different slope terraces. p>0.05 shows no significant difference between the means across different slope terraces. A_Y (cultivated Top slope), B_Y (cultivated Middle slope), C_Y (cultivated Bottom slope),A_D uncultivated Top slope),B_D (uncultivated Middle slope),C_D (uncultivated Bottom slope). (Source: Field source 2023/2024

There was a significant difference(p<0.05) in magnesium concentrations across all slope positions (table 4.2.5).

Table 4.2.6: Available phosphorous

AP(ppm)	Tukey HSD Q statistic		Tukey HSD p-value	Tukey HSD inference
A_Y vs. B_Y	552		0.5622337	insignificant
A_Y vs. C_Y	10.2621		0.0010053	** p<0.01
A_Y vs A_D	27.2535		0.0010053	** p<0.01
A_Y vs B_D	28.2629		0.0010053	** p<0.01
A_Y vs C_D	29.1041		0.0010053	** p<0.01
B_Y vs C_Y	7.9069		0.0010053	** p<0.01
B_Y vs. A_D	24.8983		0.0010053	** p<0.01
B_Y vs. B_D	25.9077		0.0010053	** p<0.01
B_Y vs. C_D	26.7488		0.0010053	** p<0.01
C_Y vs. A_D	16.9914		0.0010053	** p<0.01

C_Y vs. B_D	18.0008		0.0010053	** p<0.01
C_Y vs. C_D	18.8419		0.0010053	** p<0.01
A_D vs. B_D	1.0094		0.8999947	insignificant
A_D vs. C_D	1.8505		0.7529727	insignificant
B_D vs. C_D	0.8412		0.8999947	insignificant

P<0.05 and p<0.01 Shows Significant differences between the means across different slope terraces. p>0.05 shows no significant difference between the means across different slope terraces. A_Y (cultivated Top slope), B_Y (cultivated Middle slope), C_Y (cultivated Bottom slope),A_D uncultivated Top slope),B_D (uncultivated Middle slope),C_D (uncultivated Bottom slope). (Source: Field source 2023/2024

A significant difference in the Available phosphorous (p<0.05) across different slope positions. No significant difference was observed along the three slope positions of the uncultivated slope and Between top cultivated and middle cultivated slopes (table 4.2.6).

Discussion of Results:

Agricultural Practices, tillage practices and slope

Only 21.6% of farmers practiced terracing, which was a crucial technique for reducing soil erosion on slopes, 66.4% of farmers practiced crop rotation, which could help improve soil fertility and structure,73.7% of farmers used mulching, which could reduce soil erosion and improve soil moisture,28.6% of farmers applied fertilizers, which indicated limited use of external inputs,92.6% of farmers applied manure which suggested a reliance on organic amendments,35.7% of farmers planted trees, which could help stabilize slopes and improve soil quality, 12.3% of farmers cultivated along the slope, which could increase erosion risk and 87% of farmers cultivated across the slope, which was a more sustainable practice. The findings suggest ed that farmers were adopting some sustainable practices, such as mulching and manure application, which could improve soil quality. However, the limited use of terracing and fertilizer application indicated a need for improved soil conservation and fertility management practices. Cultivating along the slope could increase erosion risk, while cultivating across the slope was a more sustainable practice. The high percentage of farmers cultivating across the slope suggested that they were aware of the importance of reducing erosion risk.

The findings were consistent with other studies, which highlighted the importance of sustainable agricultural practices, such as conservation tillage, crop rotation, and organic amendments, in improving soil quality and reducing erosion risk [45,52,53]. These studies emphasized the need for integrated soil fertility management practices, which involved combining organic and inorganic amendments to improve soil fertility [78]. Furthermore, research had shown that conservation agriculture practices, such as no-till or reduced-till farming, can improve soil health, reduce soil erosion, and increase crop yields. The findings are closely linked to agricultural and tillage practices, as they highlighted the importance of sustainable cultivation practices in improving soil quality and reducing erosion risk. Conservation tillage practices, such as reduced tillage or no-till, can help reduce soil disturbance and promote soil conservation [78]. Additionally, research shown that crop rotation and organic amendments can improved soil fertility and structure, while reducing the need for synthetic fertilizers [52,53].

Intensive slope cultivation is one of the practices that led to soil chemical degradation in the Nabweya sub-county. It has exposed the soil to all types of erosion and has developed the potential to destroy soil structure and make soils more prone to other forms of degradation, such as erosion. The incorrect use of cultivation can cause a reduction in soil chemical properties. There is a decline in soil structure. Similar studies have shown a decline in organic matter [36,101]. In this study (87.7%) practised intensive cultivation. Additionally, improper fertilizer use is another practice that has led to soil chemical decline. The indiscriminate application of some agrochemical fertilizers has led to eutrophication. A study on improper fertilizer use found eutrophication as one of the effects [96]. This effect also spreads to neighboring parts of this sub-county.

Terracing was rarely used, posing a significant risk of soil erosion due to inadequate water pathways. Terracing is one of the slope cultivation practices that prevents soil chemical degradation. Similar studies such that [30,58,59109], cited terracing as a practice that can stop the loss of soil nutrients. Additionally, [18,19] found that areas that do not implement terracing to stop nutrient loss suffer degradation. The Nabweya situation has few farmers implementing this practice.

It is crucial to understand that the use of mulch needs to be increased to counter the force of surface runoff during heavy rains, which can lead to soil erosion. This, combined with the underutilization of terracing, underscores the gravity of the situation and the urgent need for action. Moreover, fragmentation posed a significant challenge due to uncontrolled intercropping systems, leading to varying crop rotation practices among respondents. The presence of animals and poultry contributes to the high use of organic fertilizers. To tackle soil erosion and improve long-term soil wellness in the area, suitable land management approaches like terracing, contour farming, permaculture, bund construction, and cover crops must be enforced. The cultivation of these inclines notably diminished the soil quality within this locality.

Soil erosion is one of the factors contributing to soil chemical degradation and nutrient loss in slope cultivation areas in the Nabweya sub-county. This is accelerated by inadequate water pathways, insufficient use of mulch, uncontrolled intercropping systems, heavy use of inorganic fertilizers, and limited adoption of effective agronomic practices. These factors have decreased soil fertility, reduced crop yields, and increased erosion risk.

Soil erosion resulting from slope cultivation had a detrimental effect on soil quality. The erosion reduced crop yields, decreased soil fertility, land degradation, displacement of population, loss of residential houses and farm crops, changed drainage patterns, and increased sedimentation in nearby water bodies. Additionally, the erosion exposed the subsoil, which often has lower nutrient content and less organic matter than the topsoil', further exacerbating soil degradation and reducing overall land productivity. These findings agree with [36,96,109]. They said intensive cultivation and misuse of fertilizers were the significant causes of soil chemical decline accelerated by soil erosion as a factor. In conclusion, slope cultivation has harmed and hurt soil quality.

Soil erosion and slope cultivation

The findings indicate that a significant proportion of respondents (68.7%) agree that soil erosion had a negative impact on gardens and crop yield, while 31.3% disagreed. The results suggested that soil erosion is perceived as a significant threat to garden productivity and crop yield. This was consistent with the other studies, which highlighted the negative impacts of soil erosion on soil fertility, structure, and overall productivity [51,78]. The findings supported the other studies, which emphasized the importance of sustainable soil management practices to mitigate soil erosion and promote soil health. It highlighted the need for integrated soil fertility management practices, which involve combining organic and inorganic amendments to improve soil fertility. The findings also align with other studies on the importance of conservation agriculture practices, such as no-till or reduced-till farming, in reducing soil erosion and promoting soil health [45].

Effect of Slope position on soil chemical properties

The findings indicated that slope position had a significant impact on soil chemical properties, with the bottom terrace position (C) generally having higher concentrations of potassium (K), calcium (Ca), available phosphorus (AP), magnesium (Mg), organic matter (OM), and total nitrogen (TN) compared to the top (A) and middle (B) terrace positions. The results also showed that cultivated slopes (Y) had lower concentrations of soil chemical properties compared to uncultivated slopes (D). This was consistent with the other studies, which suggested that cultivation can lead to soil degradation and nutrient depletion [45,78]. The findings suggested that slope position has a significant impact on soil chemical properties. The bottom terrace position (C) had higher concentrations of nutrients and organic matter, which can be attributed to the accumulation of sediment and nutrients at the bottom of the slope [4,109,120]. In contrast, the top terrace position (A) had lower concentrations of nutrients and organic matter, which was attributed to soil erosion and nutrient depletion [51]. The findings are consistent with other studies, which suggested that slope position had a significant impact on soil chemical properties. For example, [120] found that the bottom of a slope tends to have higher concentrations of nutrients and organic matter compared to the top of the slope. Similarly, [51] and [58,59] found that soil erosion and nutrient depletion tend to be more severe at the top of a slope compared to the bottom. In conclusion, the findings suggested that slope position had a significant impact on soil chemical properties, with the bottom terrace position (C) generally having higher concentrations of nutrients and organic matter compared to the top (A) and middle (B) terrace positions. The findings also suggest that cultivated slopes (Y) have lower concentrations of soil chemical properties compared to uncultivated slopes (D). These findings are consistent with the literature, which suggests that slope position and cultivation can have significant impacts on soil chemical properties.

Effect of slope cultivation on soil chemical properties

Findings showed a general positive correlation ($0.25 \leq r \leq 1$)for soil chemical properties between January, April, and July, both cultivated slopes and uncultivated slopes, except for available phosphorous, Which gave a negative correlation for uncultivated slope between April and July ($r = -0.45$), January and July($r=-0.18$). The negative correlation was due to heavy rains, which carried away soils at the bottom and deposited them in water streams.

Effect of slope cultivation on soil organic matter content(OM)

The results presented in Table 4.3.3 show the effects of slope cultivation on organic matter (OM) content. The findings indicated that there were significant differences ($p<0.01$) in OM concentrations between cultivated and uncultivated slopes, as well as between different slope positions. The results showed that cultivated slopes (A_Y, B_Y, and C_Y) have lower OM concentrations compared to uncultivated slopes (A_D, B_D, and C_D). This was consistent with other studies, which suggested that cultivation can lead to soil degradation and nutrient depletion, including OM loss [1,51]. The results also showed that there are significant differences in OM concentrations between different slope positions. For example, the bottom slope position (C_Y and C_D) had higher OM concentrations compared to the top (A_Y and A_D) and middle (B_Y and B_D) slope positions. This is consistent with other studies, which suggested that soil erosion and nutrient depletion tend to be more severe at the top of a slope compared to the bottom [116]. The results also showed that there are no significant differences in OM concentrations between certain slope pairs. For example, there is no significant difference between the OM concentrations of the cultivated middle slope (B_Y) and the uncultivated middle slope (B_D). This suggests that the effects of cultivation on OM concentrations may be influenced by other factors, such as soil type, climate, and land use history. The findings are consistent with other studies which suggested that slope cultivation can have significant impacts on OM concentrations. For example, [51] found that cultivation can lead to OM loss and soil degradation, while [120], found that conservation agriculture practices can help to maintain OM concentrations and promote soil health. "[119,120,121] found that soil erosion and nutrient depletion tend to be more severe at the top of a slope compared to the bottom, which is consistent with the findings of this study. Similarly, [45] found that conservation agriculture practices can help to maintain OM concentrations and promote soil health, particularly in sloping landscapes.

A study by [120,121] found that slope cultivation can lead to significant losses of organic matter, particularly in areas with high erosion rates. He suggested that conservation tillage practices, such as no-till or reduced-till, can help to mitigate these losses. Conservation tillage can reduce soil erosion and increase soil organic matter content, which is essential for maintaining soil fertility and promoting sustainable agriculture [120,121]. Another study by [53,54,55] found that the effects of slope cultivation on organic matter content can vary depending on the slope position. The authors found that the bottom slope position tends to have higher organic matter content compared to the top slope position. The results suggest that the bottom slope position has a higher potential for soil organic matter accumulation, which can be attributed to the sedimentation of organic matter and nutrients [55]. "[45]" discussed the importance of conservation agriculture practices, including conservation tillage, in promoting soil health and reducing erosion. He emphasized the need for sustainable agriculture practices that prioritize soil conservation and organic matter management. Conservation agriculture is a key strategy for promoting soil health, reducing erosion, and increasing crop yields. It involves the use of conservation tillage, crop rotations, and cover crops to promote soil organic matter management [45]. In conclusion, the findings of this study suggested that slope cultivation had significant impacts on OM concentrations, in which cultivated slopes had lower OM concentrations compared to uncultivated slopes. The findings also suggested that the effects of cultivation on OM concentrations may be influenced by other factors, such as soil type, climate, and land use history. The study's findings are consistent with other studies, which suggested that conservation agriculture practices can help to maintain OM concentrations and promote soil health, particularly in sloping landscapes.

Effect of slope cultivation on soil PH

The results presented in Table 4.3.5 showed that slope cultivation had a significant impact on soil pH. The Tukey HSD test revealed that the cultivated top slope (A_Y) had a significantly lower pH compared to the cultivated middle slope (B_Y) and cultivated bottom slope (C_Y) ($p<0.01$). Similarly, the cultivated top slope (A_Y) had a significantly lower pH compared to the uncultivated top slope (A_D), uncultivated middle slope (B_D), and uncultivated bottom slope (C_D) ($p<0.01$). These results suggested that slope cultivation had led to soil acidification, particularly in the top slope position. This is consistent with studies that suggests that soil erosion and nutrient depletion could lead to soil acidification [45,109,56]. "[56]" found that slope cultivation can lead to significant changes in soil pH, particularly in areas with high erosion rates. The studies suggested that conservation tillage practices, such as no-till or reduced-till, can help to mitigate soil acidification. Soil acidification is a major concern in cultivated slopes, particularly in areas with high erosion rates. Conservation tillage practices can help to mitigate soil acidification by reducing soil erosion and promoting soil organic matter management [54]. Another study by [118] found that the effects of slope cultivation on soil pH can vary depending on the slope position. The study found that the bottom slope position tends to had a higher pH compared to the top slope position. The results suggested that the bottom slope position had a higher pH compared to the top slope position, which could be attributed to the sedimentation of basic cations and nutrients [120,56]. Overall, the results of this study suggested that slope cultivation had led to soil acidification, particularly in the top slope position. These findings are consistent with the literature, which suggests that conservation tillage practices can help to mitigate soil acidification and promote soil health.

Effect of slope cultivation on available soil nutrients

Effect of slope cultivation on potassium (K)

The results presented in Table 4.3.1 showed the effects of slope cultivation on potassium (K) concentrations. The Tukey HSD test revealed significant differences ($p<0.05$) in K concentrations between cultivated and uncultivated slopes, except for the top-middle, middle-bottom, and top-bottom slope positions. The findings suggested that slope cultivation has led to significant changes in K concentrations, particularly in the top and bottom slope positions. This is consistent with the literature, which suggests that soil erosion and nutrient depletion can lead to changes in soil K concentrations [45,53]. A study by [54] found that conservation tillage practices can help to maintain soil K concentrations by reducing soil erosion and promoting soil organic matter management. Conservation tillage practices can help to maintain soil K concentrations by reducing soil erosion and promoting soil organic matter management. This is particularly important in sloping landscapes where soil erosion can lead to significant nutrient losses [53,54]. Another study [115] found that the effects of slope cultivation on soil K concentrations can vary depending on the slope position. The studies found that the bottom slope position tends to have higher K concentrations compared to the top slope position. The results suggested that the bottom slope position has higher K concentrations compared to the top slope position, which can be attributed to the sedimentation of nutrients and organic matter [115,120]. Overall, the findings of this study suggested that slope cultivation had led to significant changes in soil K concentrations, particularly in the top and bottom slope positions. These findings are consistent with the literature, which suggests that conservation tillage practices can help to maintain soil K concentrations and promote soil health.

Effect of slope cultivation on Total Nitrogen (TN)

The results presented in Table 4.3.4 revealed significant differences in total nitrogen (TN) concentrations across various slope terraces. The Tukey HSD test indicated that cultivated slopes (A_Y, B_Y, and C_Y) have significantly higher TN concentrations compared to uncultivated slopes (A_D, B_D, and C_D) ($p < 0.01$). This finding was consistent with previous studies, which have shown that cultivation practices can impact soil nitrogen dynamics [45,53]. The results also showed that TN concentrations varied significantly across different slope positions accounting for a maximum of 0.7% in uncultivated slopes and 0.2% in cultivated slopes - representing a reduction of 71.43% as a depletion of nitrogen due to conversion from uncultivated sloped forest to cultivation. The average nitrogen content decreased in the cultivated slopes from 0.5% in the gentler slopes to 0.2% in the steep slopes, which reduced nitrogen by about 60% in steep sloped areas. The bottom slope position (C_Y) has significantly higher TN concentrations compared to the top slope position (A_Y) ($p < 0.01$). This finding was in line with previous research, which has demonstrated that slope position can impact soil nitrogen concentrations due to factors such as soil erosion and nutrient redistribution [59,115]. The findings of this study had important implications for soil fertility and ecosystem health. Soil nitrogen is an essential nutrient for plant growth, and changes in TN concentrations can impact ecosystem productivity and biodiversity. The results of this study suggest that cultivation practices and slope position can significantly impact soil nitrogen dynamics, highlighting the need for sustainable land use management strategies that promote soil conservation and ecosystem productivity [103,110]. The findings of this study are consistent with previous research on soil nitrogen dynamics. For example, a study by [54] found that conservation tillage practices would helped maintain soil TN concentrations by reducing soil erosion and promoting soil organic matter management. Similarly, a study by [115] found that slope cultivation led to significant changes in soil TN concentrations, particularly in the top and bottom slope positions. In conclusion, the results of this study demonstrated significant differences in TN concentrations across various slope terraces. The findings are consistent with previous research on soil nitrogen dynamics and highlight the need for sustainable land use management strategies that promote soil conservation and ecosystem productivity.

Effect of slope cultivation on Available Phosphorous (AP)

Table 4.3.7 revealed significant differences in available phosphorus (AP) concentrations across various slope terraces with the peak of 58ppm and a low of 15ppm (table 4.3). A closer examination of the Tukey HSD test results indicated that, AP concentrations were significantly higher in cultivated slopes (A_Y, B_Y, and C_Y) compared to uncultivated slopes (A_D, B_D, and C_D) ($p < 0.01$). AP concentrations varied significantly across different slope positions, with the bottom slope (C_Y) showing higher concentrations than the top slope (A_Y) ($p < 0.01$). Middle Slope: The middle slope (B_Y) exhibited significantly higher AP concentrations than the top slope (A_Y) ($p < 0.01$). No significant differences in AP concentrations were observed among uncultivated slopes (A_D, B_D, and C_D) ($p > 0.05$). No significant differences in AP concentrations were found between the top (A_D) and middle (B_D) uncultivated slopes ($p > 0.05$). These findings suggested that cultivation practices and slope position significantly impact AP concentrations. The results were consistent with previous studies, which have shown that soil erosion and nutrient depletion can lead to changes in soil AP concentrations [45,53]. Research has shown that cultivation practices can significantly affect soil phosphorus concentrations. For example, a study by [54] found that conservation tillage practices helped maintain soil AP concentrations by reducing soil erosion and promoting soil organic matter management. Similarly, a study by [117] found that slope cultivation had led to significant changes in soil AP concentrations, particularly in the top and bottom slope positions. Slope position has also been shown to impact soil phosphorus dynamics. A study by [59,109] found that slope position and land use affected soil phosphorus fractions in a subtropical region, with the bottom slope position tended to having higher AP concentrations compared to the top slope position, which was consistent with the findings. The findings of this study have important implications for soil fertility and ecosystem health. Soil phosphorus is an essential nutrient for plant growth, and changes in soil AP concentrations can impact ecosystem productivity and biodiversity. The results of this study suggest that conservation tillage practices and sustainable land use management strategies can help maintain soil fertility and promote ecosystem health. The cultivation of slopes had led to a significant decrease in available phosphorus levels, with a reduction of approximately 60% from lower to higher regions. This decline in available phosphorus was attributed to the shift from uncultivated to cultivated slopes and factors such as erosion-deposition processes. In conclusion, the results of this study demonstrated significant differences in AP concentrations across various slope terraces. These findings are consistent with previous studies that have investigated the impact of cultivation practices and slope position on soil phosphorus dynamics. The results of this study have important implications for soil fertility and ecosystem health, and highlight the need for sustainable land use management strategies that promote soil conservation and ecosystem productivity.

Effect of slope cultivation on exchangeable base cations

Effect on Calcium (Ca)

Table 4.3.2 indicated significant differences in calcium (Ca) concentrations across various slope terraces. Specifically, the Tukey HSD test revealed that cultivated slopes (A_Y, B_Y, and C_Y) exhibit significantly higher Ca concentrations compared to uncultivated slopes (A_D, B_D, and C_D) ($p < 0.01$). This finding is consistent with previous studies, which had demonstrated that cultivation practices can substantially impact soil Ca dynamics [45,53]. Furthermore, the results showed that Ca concentrations varied significantly across different slope positions. Notably, the bottom slope position (C_Y) exhibits significantly higher Ca concentrations compared to the top slope position (A_Y) ($p < 0.01$). This finding aligns with previous studies, which have demonstrated that slope position can influence soil Ca concentrations by 80.3% from the bottom to the top due to factors such as soil erosion and nutrient redistribution [60,115]. The findings of this study had important implications for soil fertility and ecosystem health. Calcium is an essential nutrient for plant growth, and changes in soil Ca concentrations can impact ecosystem productivity and biodiversity. The findings suggested that cultivation practices and slope position had significantly impacted soil Ca dynamics, highlighting the need for sustainable land use management strategies that promote soil conservation and ecosystem productivity [105,110]. The findings of this study are consistent with previous research on soil Ca dynamics. For instance, a study by [54] found that conservation tillage practices could help maintain soil Ca concentrations by reducing soil erosion and promoting soil organic matter management. Similarly, a study by [115] [found that slope cultivation led to significant changes in soil Ca concentrations, particularly in the top and bottom slope positions. In conclusion, the results of this study demonstrate significant differences in Ca concentrations across various slope terraces. The findings are consistent with previous research on soil Ca dynamics and highlighted the need for sustainable land use management strategies that promote soil conservation and ecosystem productivity. The overall decline of calcium in the cultivated soils can also be attributed to high concentration of hydrogen ions that displace calcium.

Effect of slope cultivation on Magnesium (Mg)

Table 4.3.6 revealed a significant variation in magnesium (Mg) concentrations across different slope terraces. Notably, the Tukey HSD test indicates that cultivated slopes (A_Y, B_Y, and C_Y) exhibited significantly higher Mg concentrations than uncultivated slopes (A_D, B_D, and C_D) ($p < 0.01$). This finding corroborates previous studies, which have shown that cultivation practices can substantially influence soil Mg dynamics [45,53,54,56]. The results also demonstrated that Mg concentrations differ significantly across various slope positions by 81.6%. Specifically, the bottom slope position (C_Y) exhibits higher Mg concentrations than the top slope position (A_Y) ($p < 0.01$). This finding is consistent with previous studies, which have demonstrated that slope position can impact soil Mg concentrations due to factors such as soil erosion and nutrient redistribution [59,117]. The findings of this study had significant implications for soil fertility and ecosystem health. As an essential nutrient for plant growth, changes in soil Mg concentrations can impact ecosystem productivity and biodiversity. The results suggested that cultivation practices and slope position have significantly influenced soil Mg dynamics, emphasizing the need for sustainable land use management strategies that promote soil conservation and ecosystem productivity [105,107]. The findings of this study align with previous research on soil Mg dynamics. For example, [55] found that conservation tillage practices could maintain soil Mg concentrations by reducing soil erosion and promoting soil organic matter management. Similarly, [117,111] observed that slope cultivation could lead to significant changes in soil Mg concentrations, particularly in the top and bottom slope positions.

Implications of Changes in Soil Properties Due to Slope Cultivation

The impact of slope cultivation on soil properties has important implications for agriculture and environmental sustainability. While organic manure and crop residues help maintain and increase organic matter content, crucial nutrients like nitrogen and phosphorus have decreased significantly. Reducing available phosphorus levels can negatively affect plant growth and soil quality, while decreasing total nitrogen content poses challenges for maintaining soil fertility and nutrient cycling. In addition, the decline in exchangeable magnesium and potassium concentrations can limit plant nutrient availability. The intricate relationship among slope farming, soil characteristics, and land management methods requires additional study to create specific approaches for minimizing potential adverse effects while maximizing soil fertility and agricultural sustainability in the area.

Fertility and Health of the soil in cultivated sloped and non-cultivated sloped areas.

Soil fertility was low, while soil health was poor. A significant difference between the uncultivated slopes and the cultivated slopes was observed. Crop production was low in the areas since potassium, nitrogen, and phosphorus were low yet essentially required in large amounts for crop production. This explains why many inorganic fertilizers containing potassium were overused to compensate for nutrient loss. The low nutrient levels were also presumed to be due to leaching and high rainfall intensity.

Focus group discussion about the effect of slope cultivation on soil quality

The focus group discussion uncovered significant soil properties alterations due to slope cultivation practices. While using organic manure and crop residues has helped maintain and increase the content of organic matter in the soil, crucial nutrients such as nitrogen and phosphorus have experienced notable reductions due to this type of cultivation. Moreover, the steep gradient has posed challenges for agricultural production by causing erosion, loss of fertile topsoil, and increased runoff, leading to land degradation and reduced crop yields. The lack of proper land management practices like fallowing and terracing further exacerbates these issues resulting from slope cultivation. Farmers expressed concerns about decreased soil fertility but recognized the need for alternative farming techniques, such as contour ploughing and agroforestry, to minimize erosion effects on sloped lands.

Potential mitigation strategies and interventions

Strategies

1. Terracing:

One effective strategy to mitigate soil erosion on slopes is the construction of terraces. Terracing involves creating a series of leveled platforms on the slope to slow down water runoff and prevent soil erosion. The terraces can be constructed using stones, logs, or other materials to stabilize and prevent soil erosion.

2. Agroforestry:

Implementing forestry practices, such as planting trees or shrubs on the slopes, can help reduce soil erosion and improve soil quality. The roots of trees and shrubs help bind the soil together, reducing the chances of erosion.

3. Cover cropping:
Planting cover crops on sloping fields can help improve soil structure and reduce erosion. The cover crops act as protective layers, preventing rainfall from directly impacting the soil surface and reducing erosion risk.
4. Conservation tillage:
Conservation tillage practices like minimum or no-till farming can help retain soil moisture and reduce slope erosion.
5. Soil erosion control structures:
Installing soil erosion control structures, such as contour bunds or check dams, can help slow down water flow and trap sediment, reducing soil erosion on slopes
6. Soil and water management:
Proper soil and water management practices, such as mulching, contour plowing, and drainage systems, can help alleviate slope cultivation's negative impacts on soil quality and enhance agricultural productivity and sustainability. Drainage systems, such as contour ditches or trenches, can help redirect excess water and prevent slope erosion.
7. Crop rotation and diversification:
Implementing crop rotation and diversification strategies can help improve soil fertility and reduce the risk of nutrient depletion.
8. Education and awareness:
Promoting education and awareness among farmers about the negative impacts of slope cultivation on soil quality and providing them with training and resources on sustainable agricultural practices can empower them to make informed decisions and adopt strategies to mitigate soil erosion and improve soil quality on slopes. By implementing these strategies, farmers in Nabweya Sub County can reduce soil erosion and improve soil quality, ultimately enhancing agricultural productivity and sustainability.

Interventions

Regular monitoring of soil quality and erosion levels in areas with slope cultivation is essential to assess the effectiveness of implemented mitigation strategies and make necessary adjustments. This can help ensure agricultural lands' long-term sustainability and productivity on slopes

Chapter Five
Summary Conclusions and Recommendations
Introduction

This section summarizes all earlier parts of this dissertation before making conclusions about the research. That is to say, it includes the background information. It also looks at the research problem, which assesses the effects of slope cultivation on soil chemical quality along the slopes at Nabweya Sub County. It summarizes findings on the agricultural practices and evaluates their effect on soil quality in Nabweya Sub County, Bududa district.

Conclusion

The cultivation of steep slopes, have significantly affected soil quality. The slope cultivation practices and factors contributing to soil chemical degradation include intensive cultivation and misuse of fertilizers.

Soil erosion is one of the factors contributing to soil chemical decline accelerated by limited good cultivation practices such as terracing and bund construction.

Slope and slope cultivation reduced the soil chemical properties of total nitrogen, available phosphorous, pH, calcium, magnesium, and potassium, and organic matter. This is evident through the decline in essential nutrients such as nitrogen and phosphorus and the decrease in exchangeable magnesium and potassium concentrations. These changes have reduced plant nutrient availability and increased susceptibility to erosion and land degradation.

The following are the potential mitigation strategies: terracing and bund construction, permaculture, agroforestry, cover cropping, conservation tillage, Soil erosion control structures, Soil and water management, Crop rotation and diversification, and Education and awareness. Regular monitoring of soil quality and erosion levels is the best intervention.

Overall, slope cultivation without proper land management techniques has decreased soil chemical properties and agricultural productivity in the area, leading to poor crop yields.

Recommendations

Evidence from this study has unequivocally shown that slope cultivation is severely impacting soil quality, leading to a significant decline in agricultural production. This urgent situation necessitates immediate action, and it is on these premises that the following recommendations are made.

Firstly, the successful implementation of soil conservation measures such as contour ploughing, terracing, bund construction, and slope cultivation largely depends on the active involvement of the farmer's associations and their executive committee in each village. Their role in enforcing these measures can significantly reduce erosion, retain soil moisture, prevent the loss of topsoil, and improve the overall quality of the soil.

Secondly, promoting agroforestry practices can be beneficial in slope cultivation. Planting trees and perennial crops on slopes can help to stabilize the soil, reduce erosion, and improve soil fertility. Additionally, incorporating crop rotation and fallow periods can minimize nutrient depletion and improve soil health. The district agricultural and environmental office should constitute a committee and distribute trees to offer a permaculture environment.

Thirdly, promoting sustainable land management practices such as organic farming and using natural fertilizers can help improve soil quality. Organic farming methods and natural fertilizers can help replenish soil nutrients and improve overall soil health. The farmers' association is in a better position to implement these practices.

Lastly, raising farmers' awareness of the importance of soil conservation and sustainable land management practices is crucial for addressing soil degradation in slope cultivation. By providing farmers with education and training on soil conservation techniques, they can better understand the importance of preserving soil quality and implement practices that promote long-term sustainability and productivity. The government should recruit more agricultural environmental extension personnel to champion such practices.

Additionally, further research should be conducted to assess the long-term effects of slope cultivation on soil bio-physical quality and explore additional mitigation measures that can be implemented in the area.

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