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# Measuring Soil Quality Indicators under Different Climate-Smart Land Uses across East African Climate-Smart Villages

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**Abstract:** The present study assessed soil physical-chemical characteristics as reliable soil health indicators in six climate-smart land use types; agroforestry, community forest, cropland with soil and water conservation (SWC), crop land without SWC, grassland and control across climate-smart villages (CSVs) in Lushoto (Tanzania), Hoima (Uganda), Wote and Nyando (Kenya). Soils were sampled at three depths; 0–15 cm, 15–45 cm and 45–100 cm and then analyzed for bulk density (BD), pH, exchangeable bases (Ca, Mg, K, Na), extractable Fe, Mn, Zn, exchangeable acidity (ExAc), Electrical conductivity (EC), total carbon (TC), total nitrogen (TN) and cation exchange capacity (CEC). Land use types and sampling depths significantly affected soil properties ($p < 0.05$), High bulk density (BD) was measured at 45–100 cm depth in grassland (1.47 g/cm$^3$) and crop land (1.50 g/cm$^3$) in Kenya and Tanzania, respectively. BD in Ugandan grasslands was statistically lower ($p < 0.05$) than BD in other land use types at all depths. Soil pH of surface soil (0–15 cm) ranged from $6.67 \pm 0.67$ (agroforestry) to $6.27 \pm 0.85$ (grassland). Ex. bases (Ca, Mg, K and Na) and extractable Fe, Mn, Zn, ExAc, EC, TC, TN and CEC were significantly affected by land uses ($p \leq 0.05$). Soil properties were significantly correlated, a positive correlation between silt % ($p < 0.01$) and pH, sand and Ca ($p < 0.05$). EC and pH, exchangeable Ca, exchangeable bases, exchangeable K and C: N ratio was observed. There was a negative correlation ($p < 0.05$) between pH and clay. The study has shown that improving soil properties using land use systems leads to an increase in soil nutrients.

**Keywords:** climate-smart; land use type; physical-chemical properties; soil depth

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## 1. Introduction

The world population is projected to reach 8.9 billion people by 2050, and this will lead to increased demand for agricultural products [1]. Increase in population will make African countries more vulnerable to climate change, with crop yields predicted to decrease by at least 20% by 2050 [2]. This predicted decline in crop yields validates the need to intensify agricultural production using sustainable means by enhancing soil capacity and adjusting land use from low value crops to high yielding crops [3]. The new risks and vulnerabilities for smallholder farmers in East Africa (Kenya, Tanzania and Uganda), who depend mainly on rain fed agriculture for living condition are climate change variability and deteriorating soil quality [4]. Sustainable agricultural practices and increased crop production, while mitigating climate change and preserving agroecosystems, are considered as solution [1]. East African countries have great potential for agricultural production and have remained resilient to exploitation until the mid-20th century [5]. Both subsistence and surplus food production were adequately supported. Today, land degradation threatens the very foundation of agricultural systems [5]. Changes in soil properties have been linked to land use changes, and given the dire consequences of soil fertility deterioration caused by land use change, it is important to understand which specific soil quality parameters are affected by agricultural land use and which agricultural practices are responsible for the decline in soil quality parameters [6]. The advantages of sustainable land use strategies like agroforestry, community forestry and grassland management are well documented, but key aspects of these systems must be adjusted to the locations in which they are applied. The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) has developed the climate-smart village (CSV) research for development (R4D) approach, which focuses on improving local knowledge of climate risks and variability to inform farming decisions, with main goal of helping farmers respond to climate variability, reduce periodic hunger, ensure food security and enhance household incomes [7]. Sustainable agriculture and land management practices are widely discussed within the context of soil science/quality and agronomy [8]. Soil heath and soil quality are considered primary indicators of sustainability land management practices [9]. Soil health is a metric of natural capital that represents soil's ability to respond to agricultural management by sustaining both agricultural production and the provision of other ecosystem services [10], while soil quality encompasses characteristics such as physical, chemical and microbiological attributes of soil, thus the need to understand the linkages between management practices, observable soil properties and soil functions [11].

Soil health quality can be inferred from soil properties and soil behavior under controlled conditions [12] and from the fact that that soil health corresponds to dynamic soil qualities such as change with land use, management and disturbances over the human time scale and that soil quality includes both inherent (e.g., soil texture) and dynamic soil properties [13]. The choice of soil quality indicators adapted to local conditions represents important step towards sustainable soil management practices [14]. Several factors can easily lead to changes in soil quality, such as changes in land-use type from forest to arable land [15] as well as unsustainable agriculture [16]. Changes from different land-use types can be measured by monitoring soil organic carbon (SOC), total nitrogen (TN) and soil acidity (pH) [15] amongst other parameters. A number of studies have assessed soil quality indicators under different land use types [15,17,18]. Observations from these experiments seem to indicate that land-use type and management system are applicable procedures for assessing soil quality. Furthermore, changes in land-use significantly affect total organic carbon (TOC) dynamics in a way that conversion of natural soil to cropland or pasture affects C storage [17].

These soil health indicators must be sensitive to land management practices within a range of environments integrating diverse properties of soils [9] such as bulk density, clay, silt, sand, electric conductivity (ECd), exchangeable bases (ExBas), soil nitrogen (N), soil organic carbon (SOC), aluminum (Al), boron (B), calcium (Ca), potassium (K), magnesium (Mg), manganese (Mn), phosphorus (P) and pH [17,18]. In this study, we assessed selected soil properties as reliable soil health indicator from East African CSVs in Lushoto (Tanzania), Hoima (Uganda), Wote and Nyando (Kenya) to test the hypothesis of using the CSV as testbeds to support scaling up and out of Climate-Smart Agriculture (CSA) practices. Additionally, we compared changes in soil properties under different land use to evaluate effects of land use changes on the variability of selected soil properties.

## 2. Materials and Methods

### 2.1. Study Site

The study was carried out in four East Africa Climate-Smart Villages (CSV) in Lushoto (Tanzania), Hoima (Uganda), Nyando and Wote both from Kenya (Figure 1). The principal land use classes in the three counties are agroforestry, community forest, cropland with SWC, Crop land without SWC, grassland and control (Table 1). The Lushoto study site in north eastern Tanzania represent biodiversity hotspot in East Africa and lies within Western

Usambara Mountains (WUM) [19]. Lushoto has a mountainous topography of between 850 and 2300 m above sea level which makes it a degraded highland in East Africa [20]. The soil types in this region ranges from Regosols, Lithic Leptosols, Cutanic Acrisols and Ferralic Cambisols [19]. Agriculture is the main source of livelihood for the majority of households in Lushoto, and major crops include maize, beans, potatoes, cassava, vegetables, coffee and temperate fruits [21]. The population density per square kilometer is estimated at more than 134 people, with approximately 51% of the people living below the poverty line. As at 2011, about 96% of families had food deficit of one month per year, while 62% of households who depend on food from off-farm sources [20] experienced four months of hunger in a year [21].

**Table 1.** Description of land-use features in CSVs in Kenya, Tanzania and Uganda.

| Land Use Type | Landscape Features |
| --- | --- |
| Agroforestry | Multipurpose leguminous trees and shrubs, such as *Acacia anguistissima*, *Cajanus cajan*, *Gliricidia sepium*, *Leucaena collinsii*, *Sesbania sesban*, *Tephrosia candida* and *Tephrosia vogelii* |
| Community forest | Protected from both livestock and human disturbance, native trees, vegetation and grass cover. |
| Crop land with SWC [1] | Characterized by cultivation of crops (cereal–legumes rotation), irrigation. Minimum tillage and farmyard manure application. |
| Crop land without SWC [1] | Mixed-farming crop cultivation |
| Grass land | Rotational grazing, cut-and-carry system. Denuded of bushes and open for grazing |
| Control | Less disturbed land used as a reference |

[1] SWC = soil and water conservation.

Hoima is on the east side of Lake Albert in western Uganda. The landscape is generally undulating in relatively lowlands, alternating with wide mountains, with land degradation and decreased soil fertility as major challenges [22]. Elevations of Hoima average 1100 m above sea level, but on hills, it reaches 1300 m or more. The soil types in this region are Vertisols, which have 30% or more clay. The main source of livelihoods in Hoima is agriculture, and the farmers produce cassava, beans, sweet potatoes and maize. Livestock which includes chicken, pigs, cattle and goats are sources of food as well as income. The population density is approximately 160 people per km$^2$ with 22% of people living below the poverty line. During the entire year, most households receive their food from their own farms. The food deficiency months of March and April are when over 80% of households eat mainly off-farm. After several months of dry season, March and April also mark the beginning of long rains. About a third of households live safely in the year with a food shortage of two-thirds for at least one month a year [4].

The Nyando basin in western Kenya is a rich agricultural flood plain around the large Lake Victoria water mass. The Nyando River Basin in the Nyando Wetland has a general sub-humid climate with semi-arid characteristics with altitudes ranging from 1100 to 1800 meters [23]. The soil types are both fluviatile and lacustrine in origin and vary from colluviums to alluvium and lacustrine clays. The main source of livelihood remains agriculture, including growing staple cereals and sorghum in blends with legumes, such as beans and cow peas. In addition, local zebu cattle are kept with local poultry and small sheep and goat ruminants. It is one of the most populated rural towns in East Africa with a population density above 400 persons per square kilometer; 81% of families in the towns of Nyando experience 1–2 months of starvation in each year, while 17% of family members experience 3–4 months of hunger [7].

Wote is a semi-arid region in Eastern Kenya, with bimodal annual rainfall ranging from 480 to 800 mm [24]. The wooded bushland dominates the natural vegetation, and the soil types are Luvisols and interfluves developed on sandstones rich in ferro-magnesium minerals which range from sandy clay to clay [18]. Subsistence agriculture is the main source of livelihood, including bee keeping, small-scale trade, sand harvesting and charcoal burning. The area experiences flooding when it rains, and as a result, a quarter of the landscape has been eroded [24].

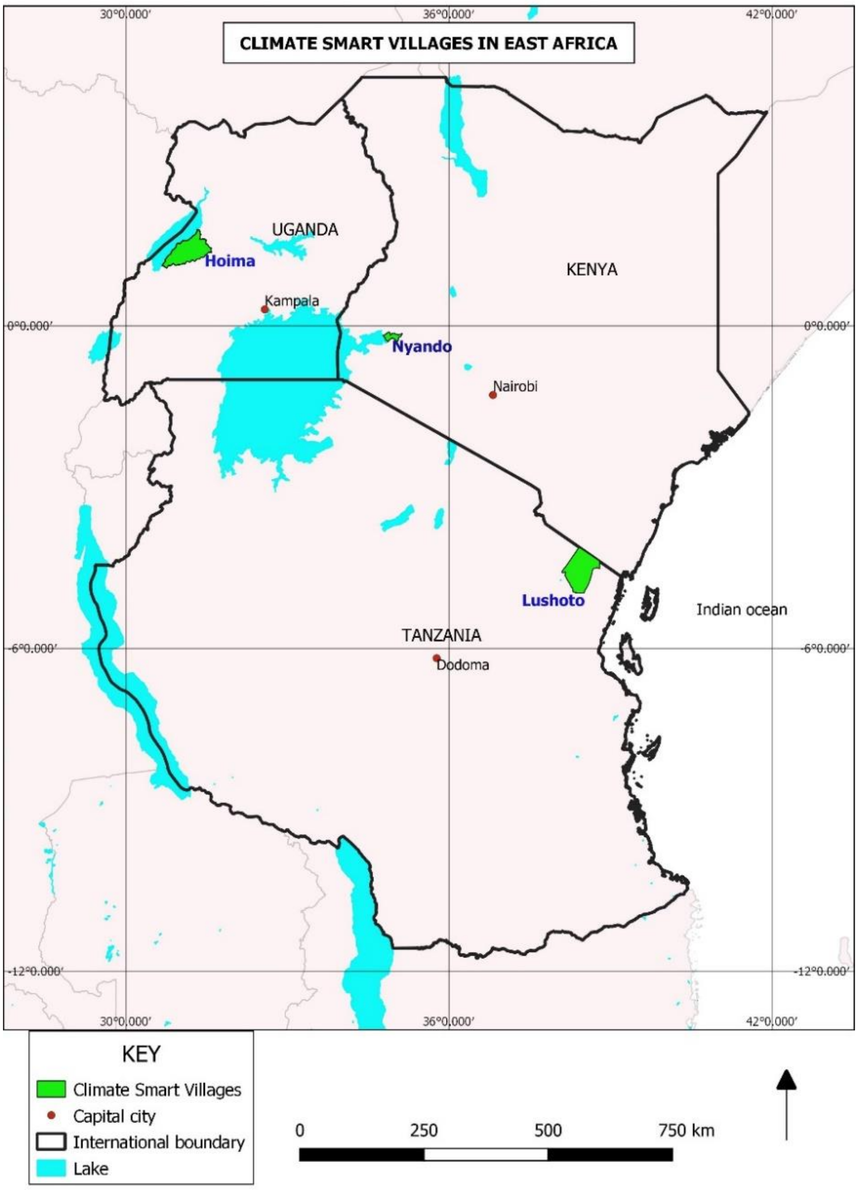


**Figure 1.** The Hoima, Nyando, and Lushoto Climate-Smart Villages study sites [25].

### 2.2. Soil Sampling and Preparation

Soil samples were collected using soil auger at three depths: 0–15 cm, 15–45 cm, and 45–100 cm from four East Africa CSVs in Lushoto (Tanzania), Hoima (Uganda) Nyando and Wote (Kenya). Control soil samples (no CSA practices) were collected adjacent to CSVs at three depths; 0–15 cm, 15–45 cm, and 45–100 cm. These climate-smart villages were launched in 2011. Soils were pooled together for each depth to obtain three composite samples at CSVs and three composite samples for control. For representativeness and to ensure similar edaphoclimatic conditions, each of the six control soil profiles per country in Lushoto (Tanzania), Hoima (Uganda), Nyando and Wote (Kenya) were located as close as possible in the same geographic area of the different CSA land use types [25]. Collected soil samples ($n$ =315) were oven-dried at 105 °C, finely ground to powder and passed through a 2 mm sieve, then analyzed by wet chemistry methods at Crop Nutrition Laboratory Services in Nairobi, Kenya for pH (analyzed in 1:2 $H_2O$ mixture) and Mehlich-3 soil tests for extractable P, K, Ca, Mg, Na, Mn, Fe, Cu, Zn, B, Mo, S, [26] and Al using inductively-coupled plasma spectroscopy (ICP)-OES (Model-Thermo iCAP6000 Series), ExBas-Exchangeable bases (sum of Mehlich exch Ca, Mg, K, Na), ExAc-Exchangeable acidity (unbuffered KCl extraction) and Ecd-Electrical conductivity (1:2 volume water extract). Total N and C (dry combustion method using an CN Elemental Analyzer) at World Agroforestry Centre (ICRAF), Soil–Plant Spectral Diagnostics Laboratory in Nairobi, Kenya.

### 2.3. Statistical Analysis

Land-use types, soil depths and country were used as independent variables and soil parameters as dependent variables. Descriptive statistics described soil quality indicators; the significance difference of soil quality indicators with land use types and soil depth was tested using one-way analysis of variance (ANOVA) at ($p \leq 0.05$). Prior to doing the ANOVA, all datasets on were tested for normality using the Kolmogorov–Smirnov test and visual examination of histograms. Tukey's honest significance difference (HSD) tested mean separation when analysis showed statistically significant differences ($p < 0.05$). Association between soil physical properties and chemical properties was measured using Pearson's correlation coefficient. All statistical analyses were performed using IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY, USA.

## 3. Results and Discussions

### 3.1. Bulk Density under Different Land Use Types

The soil bulk density is an indicator of soil compaction and a determinant of soil's mechanical resistance to root growth [27]. The mean soil bulk density under different land uses in Kenya were higher for control than agroforestry, community forest and cropland land uses ($p < 0.05$) (Figure 2). The highest mean bulk density was recorded at 45–100 cm depth in grassland (1.47 ± 0.03 g/cm$^3$) and control (1.46 ± 0.04 g/cm$^3$) although the two did not differ significantly ($p > 0.05$). Higher bulk density in control and grassland might have been as a result of soil compaction due to excessive livestock trampling [27]. The soil bulk density in Kenya increased with depth at different land use types. Agroforestry, community forest and cropland with SWC at soil surface (0–15 cm) had the lowest bulk density, which statistically differed from that of control and grassland.

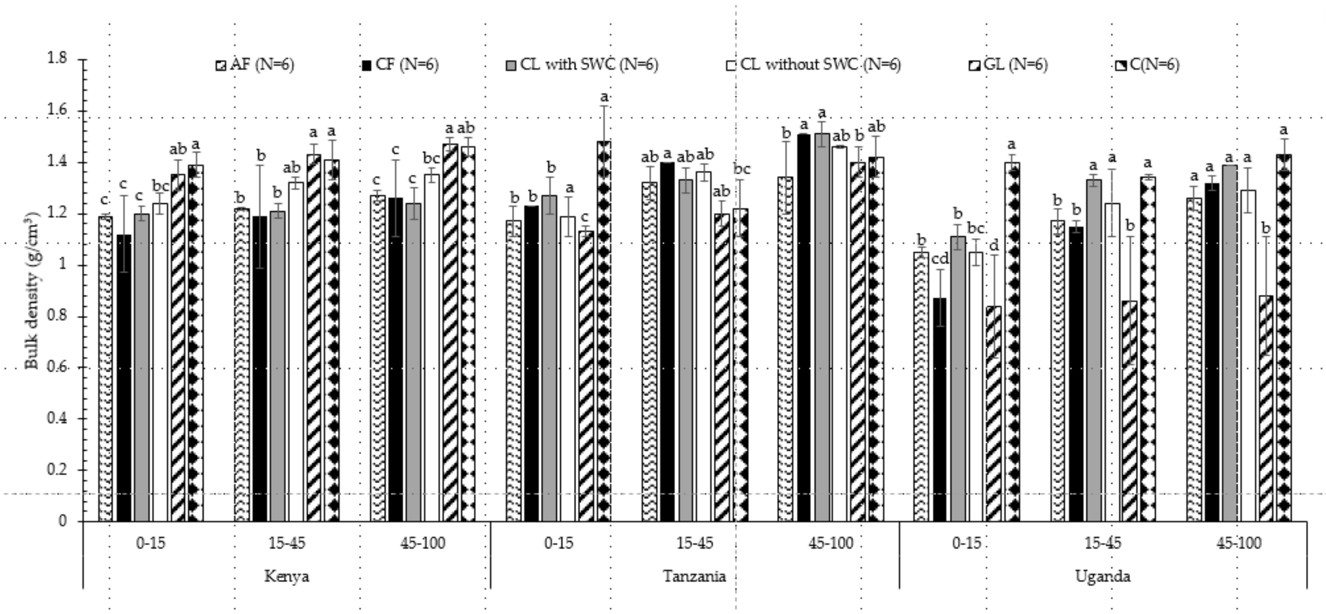


**Figure 2.** Bulk density (g/cm$^3$) physical soil quality indicator in relation to the country, land use and soil depths (Mean ± Std Dev). Means within Country followed by different letters (a, b, c, d) are significantly different ($p < 0.05$) with respect to land use and soil depths. AF—Agroforestry, CF—Community forest, CL with SWC—Cropland with soil and water conservation, CL without SWC—Cropland without soil and water conservation, GL—Grassland, C—Control.

In Tanzania, soil bulk density measured at 0–15 cm did not differ significantly with land use types except with control (Figure 2). Higher bulk densities above the recommended range were in control (1.48 ± 0.14 g/cm$^3$) at 0–15 cm and (1.42 ± 0.08 g/cm$^3$) at 45–100 cm. In addition, crop land without SWC at 45–100 cm had higher bulk density than the recommended mean of 1.46 ± 0.01 g/cm$^3$.

In Uganda, only control (1.43 ± 0.06 g/cm$^3$) land use at depth of 45–100 exceeded the recommended range for bulk density. The soil bulk density recorded in Uganda at 0–15, 45–100 and 15–45 cm for grasslands was statistically lower ($p < 0.05$) than those recorded for other land use types; this is contrary in Kenya and Tanzania for grasslands (Figure 2). The bulk density range (1.00–1.40 g/cm$^3$) has been suggested for maximum crop production and good root development [28]. However, increased bulk density values in grassland and control may be caused by excessive cattle trampling and continuous cultivation at low depths [29].

The interaction between the bulk density and land use type was significant regardless of the country of sampling ($p < 0.05$). In this regard, the soil bulk density for control (1.39 ± 0.10 g/cm$^3$) was significantly higher ($p < 0.05$) than the bulk density from other land use types, with minimum mean soil bulk density recorded for grassland (1.17 ± 0.28 g/cm$^3$). To a large extent, land use types in the three countries had bulk density within the recommended range [30], except for grassland (1.47 ± 0.03 g/cm$^3$) and control (1.46 ± 0.04 g/cm$^3$) at 45–100 cm depth in Kenya. Topsoil bulk-density values of 1.1–1.3 g/cm$^3$ are considered normal, whereas subsoil bulk-density values range from 1.3–1.7 g/cm$^3$ and are typically greater than topsoil values [30]. Furthermore, the bulk density of the substratum may be higher or lower than that of the subsoil. Higher bulk density for grassland than for cultivated lands could be due to continuous grazing all season unlike crop lands which are used for grazing only after harvest. A previous study by Kakaire et al. [31] showed that higher soil bulk density indicates less water stored in the soil, while lower soil bulk density indicates that the soils are less compacted and may hold more water. Soil bulk densities were higher in cropland, and control than in community forest, demonstrating that converting community forest to farmland and grassland increases soil bulk densities, possibly due to increased soil compaction.

### *3.2. Soil pH, Electrical Conductivity (EC) and Cation Exchange Capacity (CEC) across Land Uses*

In Kenya, the pH values from different land uses were significant at 45–100 cm sampling depth ($p < 0.05$). Significantly lower pH values were recorded in cropland with soil and water conservation (SWC) (6.19 ± 0.65) and community forest (6.94 ± 1.69), as compared to higher pH values in agroforestry (6.41 ± 0.76), cropland without soil and water conservation (7.91 ± 0.48), grassland (8.08 ± 0.59) and control (8.48 ± 0.30); Table 2. Conversely, in Tanzania, pH values from the six land use types, at different sampling depths did not differ significantly ($p > 0.05$), and the pH values were <7.00 at all land use types. In Uganda, pH values were only significant ($p < 0.05$) at 0–15 cm and 15–45 cm sampling depths. The surface soil (0–15 cm) for agroforestry land use system had significantly high ($p < 0.05$) pH than control, while grassland 5.13 ± 0.33 had the lowest pH at 15–45 cm depth. These soil pH ranges indicate moderately acidic soil condition under all the land use systems. The pH of productive soil is usually between 5.5 and 7.2, allowing the flora to access vital components and nutrients [32]. pH influences plants and crops nitrogen uptake, in acidic soils (pH < 6), microbial conversion of $NH_4^+$ to nitrate (nitrification) is usually slow, while at pH of 6 and 7, nitrification process is usually rapid, and nitrate uptake also increases [28].

**Table 2.** Soil quality indicators in relation to the land use and soil depths (Mean ± Std Dev) in Kenya, Tanzania and Uganda.

| Country | Property | Depth (cm) | Land Use | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Agroforestry (N = 6) | Community Forest (N = 6) | Crop Land with SWC (N = 6) | Crop Land without SWC (N = 6) | Grass Land (N = 6) | Control (N = 6) |
| Kenya | pH (Units) | 0–15 | 6.73 ± 0.89 [a] | 7.09 ± 0.73 [a] | 7.04 ± 0.73 [a] | 6.62 ± 0.89 [a] | 6.93 ± 1.08 [a] | 7.47 ± 0.89 [a] |
| | | 15–45 | 6.69 ± 0.99 [a] | 6.82 ± 1.54 [a] | 6.54 ± 0.59 [a] | 6.94 ± 0.85 [a] | 7.33 ± 1.13 [a] | 8.03 ± 0.62 [a] |
| | | 45–100 | 6.41 ± 0.76 [ab] | 6.94 ± 1.69 [bc] | 6.19 ± 0.65 [c] | 7.91 ± 0.48 [ab] | 8.08 ± 0.59 [ab] | 8.48 ± 0.30 [a] |
| | ExCa (cmolc $kg^{-1}$) | 0–15 | 18.34 ± 12.80 [a] | 28.78 ± 9.44 [a] | 18.69 ± 6.06 [a] | 17.32 ± 9.62 [a] | 22.92 ± 15.52 [a] | 25.43 ± 7.34 [a] |
| | | 15–45 | 15.36 ± 5.43 [a] | 23.23 ± 15.32 [a] | 13.70 ± 3.65 [a] | 18.15 ± 12.27 [a] | 23.48 ± 18.80 [a] | 30.50 ± 6.07 [a] |
| | | 45–100 | 11.22 ± 6.80 [b] | 23.40 ± 15.26 [ab] | 10.24 ± 4.38 [b] | 28.71 ± 9.43 [a] | 30.58 ± 9.84 [a] | 38.14 ± 6.29 [a] |
| | ExMg (cmolc $kg^{-1}$) | 0–15 | 3.68 ± 1.62 [a] | 5.97 ± 0.87 [a] | 4.33 ± 0.72 [a] | 3.07 ± 1.92 [a] | 3.34 ± 2.17 [a] | 3.98 ± 2.06 [a] |
| | | 15–45 | 4.09 ± 1.24 [a] | 4.79 ± 0.83 [a] | 5.02 ± 1.85 [a] | 3.20 ± 2.44 [a] | 3.33 ± 2.64 [a] | 30.50 ± 6.068 [a] |
| | | 45–100 | 3.67 ± 1.38 [a] | 4.48 ± 0.91 [a] | 5.54 ± 2.49 [a] | 4.82 ± 1.53 [a] | 4.92 ± 0.96 [a] | 4.48 ± 1.71 [a] |
| | ExNa (cmolc $kg^{-1}$) | 0–15 | 0.06 ± 0.05 [b] | 1.08 ± 1.36 [b] | 0.05 ± 0.03 [b] | 0.68 ± 0.26 [b] | 1.04 ± 0.38 [b] | 3.52 ± 2.22 [a] |
| | | 15–45 | 0.19 ± 0.17 [b] | 1.73 ± 2.12 [b] | 0.08 ± 0.06 [c] | 1.49 ± 1.13 [b] | 1.89 ± 1.44 [b] | 4.64 ± 2.41 [a] |
| | | 45–100 | 0.29 ± 0.30 [b] | 2.28 ± 2.28 [b] | 0.14 ± 0.13 [b] | 2.78 ± 1.52 [ab] | 3.21 ± 1.52 [ab] | 5.36 ± 2.90 [a] |
| | ExBases (cmolc $kg^{-1}$) | 0–15 | 23.32 ± 14.69 [a] | 37.85 ± 9.72 [a] | 25.62 ± 6.72 [a] | 21.98 ± 12.11 [a] | 28.22 ± 18.34 [a] | 34.52 ± 10.45 [a] |
| | | 15–45 | 21.07 ± 7.13 [a] | 31.07 ± 17.57 [a] | 20.66 ± 5.07 [a] | 23.72 ± 16.11 [a] | 29.46 ± 23.21 [a] | 41.48 ± 8.39 [a] |
| | | 45–100 | 16.94 ± 7.94 [b] | 31.31 ± 18.35 [ab] | 17.20 ± 6.51 [b] | 38.21 ± 11.82 [a] | 40.62 ± 11.14 [a] | 50.30 ± 7.05 [a] |
| | P (mg $kg^{-1}$) | 0–15 | 61.74 ± 61.97 [ab] | 5.51 ± 3.02 [b] | 68.95 ± 53.30 [a] | 5.58 ± 2.35 [b] | 2.96 ± 0.79 [b] | 6.27 ± 6.32 [b] |
| | | 15–45 | 13.91 ± 11.28 [a] | 3.00 ± 3.10 [a] | 17.72 ± 30.79 [a] | 2.37 ± 1.59 [a] | 2.48 ± 1.58 [a] | 12.24 ± 8.91 [a] |
| | | 45–100 | 15.52 ± 15.63 [a] | 3.92 ± 4.61 [a] | 2.28 ± 2.79 [a] | 5.71 ± 4.44 [a] | 3.33 ± 1.97 [a] | 26.22 ± 29.61 [a] |
| | Fe (mg $kg^{-1}$) | 0–15 | 168.40 ± 80.65 [a] | 153.00 ± 52.00 [a] | 145.50 ± 12.31 [a] | 221.67 ± 78.57 [a] | 217.88 ± 130.59 [a] | 145.40 ± 62.75 [a] |
| | | 15–45 | 189.17 ± 101.92 [a] | 170.30 ± 92.27 [a] | 124.35 ± 39.67 [a] | 166.50 ± 34.64 [a] | 153.00 ± 83.52 [a] | 92.47 ± 25.57 [a] |
| | | 45–100 | 163.83 ± 47.48 [a] | 153.90 ± 89.84 [ab] | 112.43 ± 20.22 [bc] | 83.00 ± 23.44 [bc] | 80.00 ± 29.26 [bc] | 61.20 ± 3.44 [c] |
| | Mn (mg $kg^{-1}$) | 0–15 | 338.67 ± 75.47 [a] | 269.50 ± 56.87 [ab] | 301.00 ± 81.19 [ab] | 169.97 ± 75.45 [b] | 194.00 ± 86.21 [b] | 252.83 ± 74.49 [ab] |
| | | 15–45 | 255.17 ± 107.79 [a] | 301.17 ± 61.11 [a] | 191.60 ± 90.40 [ab] | 105.85 ± 61.54 [a] | 175.27 ± 98.26 [a] | 265.50 ± 77.56 [a] |
| | | 45–100 | 221.00 ± 41.69 [a] | 304.17 ± 114.36 [a] | 132.82 ± 40.16 [a] | 155.10 ± 146.93 [a] | 190.98 ± 168.07 [a] | 250.00 ± 18.68 [a] |
| | Zn (mg $kg^{-1}$) | 0–15 | 8.71 ± 11.57 [ab] | 4.73 ± 3.91 [ab] | 12.97 ± 7.08 [a] | 2.34 ± 0.58 [b] | 1.71 ± 0.44 [b] | 1.16 ± 0.28 [b] |
| | | 15–45 | 2.99 ± 2.78 [a] | 2.35 ± 1.22 [a] | 4.33 ± 4.78 [a] | 2.94 ± 4.78 [b] | 0.94 ± 0.23 [b] | 2.43 ± 3.16 [b] |
| | | 45–100 | 1.30 ± 0.75 [a] | 1.63 ± 0.78 [a] | 0.66 ± 0.33 [a] | 0.78 ± 0.27 [a] | 0.85 ± 0.28 [a] | 3.50 ± 5.15 [a] |

**Table 2.** *Cont.*

| Country | Property | Depth (cm) | Land Use | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Agroforestry (N = 6) | Community Forest (N = 6) | Crop Land with SWC (N = 6) | Crop Land without SWC (N = 6) | Grass Land (N = 6) | Control (N = 6) |
| | PSI (Units) | 0–15 | 61.66 ± 56.07 [b] | 136.00 ± 17.75 [a] | 89.55 ± 30.15 [ab] | 64.02 ± 32.80 [b] | 99.05 ± 20.06 [ab] | 99.88 ± 24.82 [ab] |
| | | 15–45 | 95.08 ± 46.19 [a] | 149.45 ± 50.47 [a] | 128.52 ± 42.29 [ab] | 68.67 ± 46.99 [b] | 78.98 ± 27.82 [ab] | 83.65 ± 19.92 [ab] |
| | | 45–100 | 111.23 ± 84.50 [ab] | 132.88 ± 60.88 [ab] | 165.23 ± 69.74 [a] | 63.40 ± 17.80 [b] | 94.23 ± 34.45 [ab] | 79.27 ± 7.05 [ab] |
| | EC (mS/cm) | 0–15 | 0.08 ± 0.05 [b] | 0.22 ± 0.14 [ab] | 0.12 ± 0.05 [ab] | 0.06 ± 0.02 [b] | 0.08 ± 0.03 [b] | 0.26 ± 0.17 [a] |
| | | 15–45 | 0.08 ± 0.06 [b] | 0.12 ± 0.10 [ab] | 0.06 ± 0.03 [b] | 0.12 ± 0.10 [ab] | 0.12 ± 0.07 [ab] | 0.25 ± 0.10 [a] |
| | | 45–100 | 0.06 ± 0.05 [b] | 0.12 ± 0.11 [ab] | 0.07 ± 0.08 [ab] | 0.21 ± 0.13 [ab] | 0.16 ± 0.07 [ab] | 0.31 ± 0.17 [a] |
| | TN (%) | 0–15 | 0.15 ± 0.06 [ab] | 0.24 ± 0.16 [a] | 0.23 ± 0.05 [ab] | 0.13 ± 0.06 [ab] | 0.15 ± 0.06 [ab] | 0.09 ± 0.02 [c] |
| | | 15–45 | 0.10 ± 0.02 [ab] | 0.10 ± 0.04 [ab] | 0.15 ± 0.05 [a] | 0.10 ± 0.05 [ab] | 0.07 ± 0.01 [b] | 0.07 ± 0.03 [b] |
| | | 45–100 | 0.05 ± 0.01 [a] | 0.07 ± 0.04 [a] | 0.09 ± 0.03 [a] | 0.06 ± 0.015 [a] | 0.05 ± 0.01 [a] | 0.06 ± 0.06 [a] |
| | TC (%) | 0–15 | 2.14 ± 0.89 [ab] | 3.88 ± 2.83 [a] | 3.22 ± 0.62 [ab] | 1.78 ± 0.78 [ab] | 2.12 ± 0.74 [ab] | 1.29 ± 0.40 [b] |
| | | 15–45 | 1.49 ± 0.42 [ab] | 1.66 ± 0.60 [ab] | 2.04 ± 0.65 [a] | 1.55 ± 0.61 [ab] | 1.23 ± 0.18 [ab] | 1.07 ± 0.59 [b] |
| | | 45–100 | 0.75 ± 0.23 [a] | 1.27 ± 0.62 [a] | 1.37 ± 0.67 [a] | 1.02 ± 0.28 [a] | 0.88 ± 0.10 [a] | 0.79 ± 0.29 [a] |
| | CEC (cmolc $kg^{-1}$) | 0–15 | 26.18 ± 14.16 [a] | 41.01 ± 8.86 [a] | 27.62 ± 5.66 [a] | 24.62 ± 11.00 [a] | 30.75 ± 17.43 [a] | 36.28 ± 10.15 [a] |
| | | 15–45 | 24.02 ± 5.56 [a] | 36.87 ± 13.36 [a] | 23.53 ± 3.74 [a] | 25.60 ± 16.26 [a] | 31.06 ± 23.28 [a] | 42.92 ± 8.54 [a] |
| | | 45–100 | 19.67 ± 6.97 [b] | 36.98 ± 14.09 [ab] | 21.15 ± 5.29 [b] | 39.62 ± 12.07 [a] | 42.02 ± 11.30 [a] | 51.85 ± 7.169 [a] |
| Tanzania | pH (Units) | 0–15 | 6.40 ± 0.25 [a] | 6.42 ± 0.22 [a] | 5.99 ± 0.46 [a] | 6.47 ± 0.48 [a] | 6.10 ± 0.42 [a] | 6.28 ± 0.53 [a] |
| | | 15–45 | 6.59 ± 0.34 [a] | 6.37 ± 0.13 [a] | 6.18 ± 0.52 [a] | 6.38 ± 0.40 [a] | 5.98 ± 0.48 [a] | 6.27 ± 0.71 [a] |
| | | 45–100 | 6.49 ± 0.59 [a] | 6.48 ± 0.17 [a] | 6.18 ± 0.47 [a] | 6.49 ± 0.36 [a] | 6.21 ± 0.40 [a] | 6.29 ± 0.86 [a] |
| | ExCa (cmolc $kg^{-1}$) | 0–15 | 10.56 ± 3.17 [a] | 11.92 ± 3.17 [a] | 7.89 ± 2.49 [ab] | 10.53 ± 3.48 [a] | 8.68 ± 3.20 [ab] | 4.78 ± 1.90 [b] |
| | | 15–45 | 8.23 ± 3.88 [a] | 7.97 ± 0.80 [a] | 6.63 ± 2.36 [a] | 7.52 ± 2.92 [a] | 8.40 ± 2.56 [a] | 4.29 ± 2.11 [a] |
| | | 45–100 | 4.99 ± 2.17 [a] | 5.46 ± 0.99 [a] | 5.59 ± 2.62 [a] | 5.17 ± 0.99 [a] | 6.65 ± 1.87 [a] | 3.94 ± 2.66 [a] |
| | ExMg (cmolc $kg^{-1}$) | 0–15 | 3.27 ± 0.12 [ab] | 3.88 ± 0.65 [a] | 2.52 ± 0.92 [ab] | 3.30 ± 1.18 [ab] | 3.00 ± 0.50 [ab] | 2.05 ± 0.99 [b] |
| | | 15–45 | 2.79 ± 0.66 [ab] | 3.96 ± 0.22 [a] | 2.40 ± 0.95 [ab] | 2.10 ± 0.59 [b] | 2.28 ± 0.86 [b] | 1.99 ± 1.16 [b] |
| | | 45–100 | 2.06 ± 0.74 [ab] | 3.67 ± 0.58 [a] | 2.29 ± 1.26 [ab] | 1.57 ± 0.51 [b] | 2.04 ± 0.81 [ab] | 1.85 ± 1.12 [b] |
| | ExNa (cmolc $kg^{-1}$) | 0–15 | 0.02 ± 0.01 [a] | 0.02 ± 0.00 [a] | 0.03 ± 0.03 [a] | 0.02 ± 0.015 [a] | 0.01 ± 0.01 [a] | 0.02 ± 0.01 [a] |
| | | 15–45 | 0.03 ± 0.02 [a] | 0.03 ± 0.00 [a] | 0.04 ± 0.04 [a] | 0.02 ± 0.01 [a] | 0.02 ± 0.03 [a] | 0.04 ± 0.02 [a] |
| | | 45–100 | 0.04 ± 0.015 [a] | 0.08 ± 0.012 [a] | 0.05 ± 0.07 [b] | 0.04 ± 0.03 [a] | 0.04 ± 0.03 [a] | 0.04 ± 0.02 [a] |

**Table 2.** *Cont.*

| Country | Property | Depth (cm) | Land Use | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Agroforestry (N = 6) | Community Forest (N = 6) | Crop Land with SWC (N = 6) | Crop Land without SWC (N = 6) | Grass Land (N = 6) | Control (N = 6) |
| | ExBases (cmolc $kg^{-1}$) | 0–15 | 14.11 ± 3.15 [a] | 15.95 ± 3.87 [a] | 10.61 ± 3.43 [ab] | 14.15 ± 5.00 [a] | 11.82 ± 3.42 [ab] | 6.92 ± 2.72 [b] |
| | | 15–45 | 11.11 ± 4.52 [a] | 12.04 ± 1.00 [a] | 9.11 ± 3.27 [a] | 9.72 ± 3.51 [a] | 10.77 ± 3.37 [a] | 6.33 ± 3.00 [a] |
| | | 45–100 | 7.11 ± 2.76 [a] | 9.29 ± 1.56 [a] | 7.95 ± 3.87 [a] | 6.80 ± 1.41 [a] | 8.77 ± 2.59 [a] | 5.84 ± 3.46 [a] |
| | P (mg $kg^{-1}$) | 0–15 | 2.39 ± 1.75 [a] | 2.53 ± 0.97 [a] | 5.80 ± 3.11 [a] | 15.74 ± 22.08 [a] | 4.49 ± 2.62 [a] | 0.44 ± 0.49 [a] |
| | | 15–45 | 0.93 ± 1.08 [ab] | 0.001 ± 0.00 [b] | 1.42 ± 1.81 [ab] | 2.75 ± 3.11 [ab] | 3.63 ± 2.22 [a] | 0.21 ± 0.42 [a] |
| | | 45–100 | 0.05 ± 0.12 [a] | 0.001 ± 0.00 [a] | 0.66 ± 0.84 [a] | 0.97 ± 01.09 [a] | 0.78 ± 0.95 [c] | 0.17 ± 0.19 [c] |
| | Fe (mg $kg^{-1}$) | 0–15 | 62.35 ± 10.23 [b] | 157.33 ± 41.31 [a] | 78.00 ± 18.57 [b] | 81.40 ± 37.31 [b] | 73.32 ± 18.43 [b] | 60.28 ± 13.19 [b] |
| | | 15–45 | 53.97 ± 11.77 [b] | 116.67 ± 9.50 [a] | 54.52 ± 17.50 [b] | 58.82 ± 11.2279 [b] | 77.03 ± 16.88 [b] | 57.98 ± 32.52 [b] |
| | | 45–100 | 42.85 ± 20.11 [b] | 91.30 ± 23.13 [a] | 43.15 ± 16.81 [b] | 39.38 ± 9.40 [b] | 56.42 ± 12.34 [b] | 46.13 ± 18.50 [b] |
| | Mn (mg $kg^{-1}$) | 0–15 | 306.33 ± 98.08 [a] | 348.67 ± 87.27 [ab] | 129.55 ± 97.34 [b] | 279.17 ± 124.67 [ab] | 159.37 ± 129.14 [ab] | 160.05 ± 113.86 [ab] |
| | | 15–45 | 194.90 ± 127.46 [ab] | 392.00 ± 124.90 [a] | 48.97 ± 30.32 [b] | 185.50 ± 127.83 [ab] | 134.30 ± 114.82 [b] | 110.69 ± 120.97 [b] |
| | | 45–100 | 35.22 ± 43.35 [b] | 233.77 ± 141.97 [a] | 21.55 ± 36.55 [b] | 59.63 ± 78.58 [b] | 75.33 ± 54.92 [b] | 73.62 ± 96.54 [b] |
| | Zn (mg $kg^{-1}$) | 0–15 | 7.32 ± 2.79 [a] | 7.24 ± 1.65 [a] | 2.98 ± 2.41 [ab] | 5.85 ± 1.96 [a] | 3.83 ± 3.27 [ab] | 0.47 ± 0.45 [b] |
| | | 15–45 | 3.35 ± 3.31 [a] | 3.21 ± 1.35 [a] | 0.56 ± 0.45 [a] | 1.93 ± 1.43 [a] | 2.7883 ± 3.54 [a] | 0.16 ± 0.28 [a] |
| | | 45–100 | 0.22 ± 0.27 [a] | 0.54 ± 0.63 [a] | 0.04 ± 0.085 [a] | 0.19 ± 0.16 [a] | 0.9818 ± 1.21 [a] | 0.24 ± 0.42 [a] |
| | PSI (Units) | 0–15 | 121.67 ± 28.20 [a] | 94.47 ± 17.59 [a] | 97.05 ± 6.71 [a] | 96.78 ± 30.02 [a] | 101.33 ± 14.60 [a] | 135.02 ± 39.39 [a] |
| | | 15–45 | 133.92 ± 27.43 [a] | 107.67 ± 5.69 [a] | 115.00 ± 12.55 [a] | 107.27 ± 35.80 [a] | 104.40 ± 25.07 [a] | 141.88 ± 53.08 [a] |
| | | 45–100 | 143.93 ± 41.59 [a] | 142.67 ± 29.67 [a] | 122.27 ± 20.81 [a] | 118.80 ± 25.23 [a] | 123.17 ± 19.46 [a] | 148.02 ± 56.09 [a] |
| | EC (mS/cm) | 0–15 | 0.07 ± 0.01 [a] | 0.09 ± 0.02 [a] | 0.04 ± 0.01 [bc] | 0.08 ± 0.03 [a] | 0.06 ± 0.01 [ab] | 0.03 ± 0.01 [c] |
| | | 15–45 | 0.05 ± 0.01 [a] | 0.05 ± 0.01 [a] | 0.04 ± 0.02 [a] | 0.04 ± 0.01 [a] | 0.05 ± 0.01 [a] | 0.03 ± 0.01 [a] |
| | | 45–100 | 0.03 ± 0.01 [a] | 0.04 ± 0.01 [a] | 0.04 ± 0.02 [a] | 0.03 ± 0.01 [a] | 0.04 ± 0.02 [a] | 0.03 ± 0.01 [a] |
| | TN (%) | 0–15 | 0.21 ± 0.04 [a] | 0.24 ± 0.05 [a] | 0.18 ± 0.03 [a] | 0.22 ± 0.05 [a] | 0.21 ± 0.04 [a] | 0.08 ± 0.03 [b] |
| | | 15–45 | 0.14 ± 0.05 [ab] | 0.13 ± 0.01 [b] | 0.12 ± 0.05 [ab] | 0.14 ± 0.05 [ab] | 0.20 ± 0.04 [a] | 0.07 ± 0.03 [b] |
| | | 45–100 | 0.05 ± 0.01 [b] | 0.07 ± 0.01 [ab] | 0.07 ± 0.04 [ab] | 0.06 ± 0.014 [ab] | 0.12 ± 0.05 [b] | 0.05 ± 0.03 [b] |
| | TC (%) | 0–15 | 2.64 ± 0.48 [b] | 2.76 ± 0.50 [b] | 2.24 ± 0.33 [b] | 2.61 ± 0.60 [bc] | 2.59 ± 0.43 [a] | 0.93 ± 0.23 [a] |
| | | 15–45 | 1.63 ± 0.64 [ab] | 1.40 ± 0.11 [b] | 1.42 ± 0.62 [ab] | 1.60 ± 0.55 [a] | 2.43 ± 0.60 [a] | 0.76 ± 0.27 [b] |
| | | 45–100 | 0.71 ± 0.24 [ab] | 0.69 ± 0.08 [b] | 0.91 ± 0.52 [a] | 0.81 ± 0.12 [a] | 1.45 ± 0.63 [a] | 0.71 ± 0.34 [ab] |

**Table 2.** *Cont.*

| Country | Property | Depth (cm) | Land Use | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Agroforestry (N = 6) | Community Forest (N = 6) | Crop Land with SWC (N = 6) | Crop Land without SWC (N = 6) | Grass Land (N = 6) | Control (N = 6) |
| | CEC (cmolc kg$^{-1}$) | 0–15 | 16.40 ± 3.16 $^{a}$ | 18.43 ± 4.10 $^{a}$ | 13.68 ± 2.95 $^{ab}$ | 16.05 ± 4.50 $^{a}$ | 14.67 ± 2.81 $^{ab}$ | 8.35 ± 2.59 $^{b}$ |
| | | 15–45 | 12.41 ± 4.71 $^{ab}$ | 14.10 ± 1.10 $^{a}$ | 11.15 ± 3.04 $^{ab}$ | 11.31 ± 3.49 $^{ab}$ | 13.98 ± 2.73 $^{ab}$ | 7.67 ± 2.81 $^{b}$ |
| | | 45–100 | 8.21 ± 2.44 $^{a}$ | 10.69 ± 1.85 $^{a}$ | 9.69 ± 3.89 $^{a}$ | 7.75 ± 1.20 $^{a}$ | 10.60 ± 2.32 $^{a}$ | 6.901 ± 3.38 $^{a}$ |
| Uganda | pH (Units) | 0–15 | 6.89 ± 0.72 $^{a}$ | 6.03 ± 0.87 $^{abc}$ | 6.46 ± 0.29 $^{ab}$ | 6.32 ± 0.25 $^{abc}$ | 5.79 ± 0.52 $^{bc}$ | 5.31 ± 0.59 $^{b}$ |
| | | 15–45 | 6.59 ± 0.84 $^{a}$ | 5.71 ± 0.54 $^{a}$ | 6.46 ± 0.10 $^{a}$ | 6.17 ± 0.53 $^{a}$ | 5.13 ± 0.33 $^{b}$ | 5.05 ± 0.62 $^{a}$ |
| | | 45–100 | 6.28 ± 0.74 $^{a}$ | 5.84 ± 1.18 $^{a}$ | 6.11 ± 0.50 $^{a}$ | 5.88 ± 0.68 $^{a}$ | 5.06 ± 0.26 $^{a}$ | 5.12 ± 0.66 $^{a}$ |
| | ExCa (cmolc kg$^{-1}$) | 0–15 | 18.21 ± 7.51 $^{a}$ | 14.23 ± 7.22 $^{ab}$ | 12.15 ± 2.49 $^{abc}$ | 14.41 ± 1.89 $^{ab}$ | 7.96 ± 4.72 $^{bc}$ | 4.77 ± 3.12 $^{b}$ |
| | | 15–45 | 10.17 ± 3.73 $^{a}$ | 7.13 ± 4.42 $^{ab}$ | 9.68 ± 3.28 $^{a}$ | 10.33 ± 2.78 $^{a}$ | 2.03 ± 2.16 $^{b}$ | 2.76 ± 1.68 $^{b}$ |
| | | 45–100 | 5.72 ± 3.38 $^{a}$ | 5.17 ± 2.71 $^{a}$ | 6.01 ± 2.13 $^{a}$ | 5.43 ± 2.86 $^{a}$ | 0.62 ± 0.30 $^{b}$ | 2.58 ± 1.83 $^{ab}$ |
| | ExMg (cmolc kg$^{-1}$) | 0–15 | 5.50 ± 0.79 $^{a}$ | 5.17 ± 2.13 $^{a}$ | 3.25 ± 0.71 $^{ab}$ | 4.14 ± 0.42 $^{ab}$ | 3.11 ± 2.13 $^{ab}$ | 2.13 ± 0.91 $^{b}$ |
| | | 15–45 | 4.20 ± 1.16 $^{a}$ | 3.67 ± 1.70 $^{a}$ | 3.10 ± 0.82 $^{ab}$ | 3.07 ± 0.30 $^{bc}$ | 0.83 ± 1.15 $^{c}$ | 1.47 ± 0.68 $^{bc}$ |
| | | 45–100 | 1.83 ± 1.03 $^{ab}$ | 4.28 ± 3.12 $^{a}$ | 2.83 ± 0.56 $^{ab}$ | 2.10 ± 1.11 $^{abc}$ | 0.26 ± 0.23 $^{c}$ | 1.01 ± 0.60 $^{bc}$ |
| | ExNa (cmolc kg$^{-1}$) | 0–15 | 0.03 ± 0.01 $^{a}$ | 0.12 ± 0.18 $^{a}$ | 0.02 ± 0.023 $^{a}$ | 0.03 ± 0.02 $^{a}$ | 0.06 ± 0.02 $^{a}$ | 0.26 ± 0.45 $^{a}$ |
| | | 15–45 | 0.05 ± 0.03 $^{a}$ | 0.78 ± 1.71 $^{a}$ | 0.02 ± 0.006 $^{a}$ | 0.05 ± 0.02 $^{a}$ | 0.07 ± 0.05 $^{a}$ | 0.05 ± 0.01 $^{a}$ |
| | | 45–100 | 0.03 ± 0.01 $^{a}$ | 2.120 ± 4.71 $^{a}$ | 0.02 ± 0.01 $^{a}$ | 0.04 ± 0.01 $^{a}$ | 0.04 ± 0.02 $^{a}$ | 0.06 ± 0.02 $^{a}$ |
| | ExBases (cmolc kg$^{-1}$) | 0–15 | 24.65 ± 8.66 $^{a}$ | 20.37 ± 9.25 $^{ab}$ | 16.59 ± 3.66 $^{abc}$ | 19.13 ± 2.07 $^{ab}$ | 11.53 ± 6.74 $^{bc}$ | 7.73 ± 3.72 $^{b}$ |
| | | 15–45 | 15.23 ± 4.77 $^{a}$ | 12.05 ± 5.82 $^{a}$ | 13.25 ± 3.48 $^{a}$ | 13.71 ± 3.16 $^{a}$ | 3.06 ± 3.27 $^{b}$ | 4.42 ± 2.22 $^{b}$ |
| | | 45–100 | 9.69 ± 4.24 $^{a}$ | 11.88 ± 9.48 $^{a}$ | 9.09 ± 2.16 $^{ab}$ | 7.69 ± 3.93 $^{ab}$ | 1.01 ± 0.45 $^{b}$ | 3.84 ± 2.50 $^{ab}$ |
| | P (mg kg$^{-1}$) | 0–15 | 22.52 ± 45.35 $^{a}$ | 14.45 ± 8.43 $^{a}$ | 6.08 ± 4.26 $^{a}$ | 2.57 ± 0.46 $^{a}$ | 3.63 ± 0.89 $^{a}$ | 4.91 ± 8.09 $^{a}$ |
| | | 15–45 | 1.28 ± 1.03 $^{ab}$ | 3.34 ± 2.34 $^{a}$ | 1.61 ± 2.50 $^{ab}$ | 0.53 ± 0.34 $^{b}$ | 1.29 ± 0.84 $^{ab}$ | 0.23 ± 0.28 $^{b}$ |
| | | 45–100 | 0.61 ± 0.53 $^{ab}$ | 1.16 ± 0.94 $^{a}$ | 0.11 ± 0.28 $^{b}$ | 0.001 ± 0.00 $^{b}$ | 0.63 ± 0.47 $^{ab}$ | 0.15 ± 0.23 $^{b}$ |
| | Fe (mg kg$^{-1}$) | 0–15 | 75.08 ± 9.67 $^{b}$ | 193.50 ± 104.62 $^{a}$ | 100.02 ± 22.71 $^{b}$ | 96.62 ± 20.25 $^{b}$ | 141.38 ± 55.80 $^{ab}$ | 91.08 ± 29.77 $^{b}$ |
| | | 15–45 | 92.27 ± 9.40 $^{ab}$ | 196.43 ± 136.02 $^{a}$ | 120.40 ± 28.20 $^{ab}$ | 109.78 ± 13.02 $^{ab}$ | 103.38 ± 50.45 $^{ab}$ | 70.35 ± 22.24 $^{b}$ |
| | | 45–100 | 103.15 ± 23.37 $^{ab}$ | 130.12 ± 69.57 $^{a}$ | 118.45 ± 29.32 $^{ab}$ | 100.60 ± 21.47 $^{ab}$ | 76.25 ± 33.43 $^{ab}$ | 57.25 ± 8.67 $^{b}$ |
| | Mn (mg kg$^{-1}$) | 0–15 | 468.83 ± 74.49 $^{a}$ | 200.38 ± 154.90 $^{a}$ | 557.00 ± 62.53 $^{a}$ | 398.83 ± 51.47 $^{ab}$ | 104.23 ± 122.66 $^{a}$ | 252.22 ± 140.10 $^{bc}$ |
| | | 15–45 | 390.83 ± 129.82 $^{a}$ | 128.95 ± 119.65 $^{b}$ | 519.17 ± 123.35 $^{a}$ | 358.00 ± 90.40 $^{a}$ | 33.06 ± 41.91 $^{b}$ | 152.43 ± 106.79 $^{b}$ |
| | | 45–100 | 331.83 ± 167.95 $^{a}$ | 99.99 ± 104.02 $^{bc}$ | 392.00 ± 143.57 $^{a}$ | 275.00 ± 78.22 $^{ab}$ | 18.06 ± 21.25 $^{c}$ | 85.67 ± 40.90 $^{c}$ |

**Table 2.** *Cont.*

| Country | Property | Depth (cm) | Land Use | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Agroforestry (N = 6) | Community Forest (N = 6) | Crop Land with SWC (N = 6) | Crop Land without SWC (N = 6) | Grass Land (N = 6) | Control (N = 6) |
| | Zn (mg kg$^{-1}$) | 0–15 | 3.25 ± 1.27 $^{a}$ | 3.27 ± 1.48 $^{a}$ | 3.24 ± 0.59 $^{a}$ | 1.88 ± 1.42 $^{ab}$ | 0.76 ± 0.35 $^{b}$ | 0.76 ± 1.17 $^{b}$ |
| | | 15–45 | 0.89 ± 0.52 $^{b}$ | 0.68 ± 0.31816 $^{b}$ | 1.59 ± 0.83 $^{b}$ | 0.69 ± 0.26 $^{b}$ | 0.39 ± 0.13 $^{a}$ | 0.19 ± 0.15 $^{ab}$ |
| | | 45–100 | 0.39 ± 0.23 $^{a}$ | 0.34 ± 0.17 $^{a}$ | 0.49 ± 0.35 $^{a}$ | 0.28 ± 0.04 $^{a}$ | 0.18 ± 0.19 $^{a}$ | 0.24 ± 0.25 $^{a}$ |
| | PSI (Units) | 0–15 | 89.83 ± 17.08 $^{ab}$ | 94.95 ± 53.41 $^{ab}$ | 64.78 ± 14.51 $^{b}$ | 108.05 ± 42.91 $^{ab}$ | 220.35 ± 164.81 $^{a}$ | 223.00 ± 104.40 $^{a}$ |
| | | 15–45 | 134.55 ± 50.11 $^{bc}$ | 140.35 ± 80.11 $^{bc}$ | 101.97 ± 27.29 $^{c}$ | 158.50 ± 53.09 $^{bc}$ | 346.83 ± 172.25 $^{a}$ | 275.33 ± 72.81 $^{ab}$ |
| | | 45–100 | 170.63 ± 50.87 $^{b}$ | 172.52 ± 101.91 $^{b}$ | 176.67 ± 48.27 $^{b}$ | 253.17 ± 69.94 $^{ab}$ | 391.33 ± 136.02 $^{a}$ | 290.33 ± 66.70 $^{ab}$ |
| | EC (mS/cm) | 0–15 | 0.10 ± 0.02 $^{c}$ | 0.11 ± 0.04 $^{a}$ | 0.09 ± 0.03 $^{a}$ | 0.06 ± 0.01 $^{a}$ | 0.04 ± 0.016 $^{a}$ | 0.22 ± 0.27 $^{a}$ |
| | | 15–45 | 0.06 ± 0.03 $^{ab}$ | 0.05 ± 0.02 $^{ab}$ | 0.05 ± 0.02 $^{ab}$ | 0.04 ± 0.01 $^{ab}$ | 0.02 ± 0.01 $^{b}$ | 0.07 ± 0.04 $^{a}$ |
| | | 45–100 | 0.04 ± 0.02 $^{a}$ | 0.06 ± 0.06 $^{a}$ | 0.04 ± 0.01 $^{a}$ | 0.03 ± 0.01 $^{a}$ | 0.01 ± 0.004 $^{a}$ | 0.06 ± 0.05 $^{a}$ |
| | TN (%) | 0–15 | 0.22 ± 0.03 $^{ab}$ | 0.36 ± 0.13 $^{a}$ | 0.20 ± 0.05 $^{ab}$ | 0.23 ± 0.03 $^{ab}$ | 0.32 ± 0.25 $^{ab}$ | 0.13 ± 0.05 $^{ab}$ |
| | | 15–45 | 0.13 ± 0.04 $^{a}$ | 0.16 ± 0.05 $^{a}$ | 0.13 ± 0.03 $^{a}$ | 0.15 ± 0.03 $^{a}$ | 0.23 ± 0.24 $^{a}$ | 0.11 ± 0.09 $^{a}$ |
| | | 45–100 | 0.09 ± 0.05 $^{a}$ | 0.11 ± 0.02 $^{a}$ | 0.08 ± 0.01 $^{a}$ | 0.09 ± 0.01 $^{a}$ | 0.17 ± 0.16 $^{a}$ | 0.07 ± 0.02 $^{a}$ |
| | TC (%) | 0–15 | 3.08 ± 0.32 $^{ab}$ | 4.50 ± 1.66 $^{a}$ | 2.68 ± 0.76 $^{ab}$ | 3.40 ± 0.32 $^{ab}$ | 4.82 ± 3.47 $^{a}$ | 1.35 ± 0.73 $^{b}$ |
| | | 15–45 | 1.76 ± 0.54 $^{a}$ | 2.06 ± 0.73 $^{a}$ | 1.57 ± 0.64 $^{a}$ | 2.13 ± 0.20 $^{a}$ | 3.28 ± 2.95 $^{a}$ | 1.26 ± 1.24 $^{a}$ |
| | | 45–100 | 1.09 ± 0.87 $^{ab}$ | 1.18 ± 0.36 $^{ab}$ | 0.75 ± 0.26 $^{ab}$ | 0.96 ± 0.093 $^{ab}$ | 2.15 ± 1.68 $^{a}$ | 0.70 ± 0.22 $^{b}$ |
| | CEC (cmolc kg$^{-1}$) | 0–15 | 26.97 ± 8.07 $^{a}$ | 26.68 ± 9.96 $^{a}$ | 19.50 ± 3.39 $^{ab}$ | 22.67 ± 2.31 $^{ab}$ | 15.41 ± 6.64 $^{b}$ | 12.79 ± 4.56 $^{b}$ |
| | | 15–45 | 17.55 ± 3.81 $^{a}$ | 16.94 ± 8.76 $^{ab}$ | 15.25 ± 3.86 $^{ab}$ | 16.95 ± 1.72 $^{ab}$ | 5.45 ± 4.62 $^{c}$ | 8.61 ± 3.52 $^{bc}$ |
| | | 45–100 | 11.95 ± 4.95 $^{ab}$ | 16.14 ± 9.42 $^{a}$ | 11.41 ± 1.18 $^{ab}$ | 9.99 ± 3.77 $^{abc}$ | 2.13 ± 1.13 $^{c}$ | 7.10 ± 3.52 $^{bc}$ |

Means within a row followed by different letters (a, b, c, d) are significantly different ($p < 0.05$) with respect to land use and soil depths. PSI—Phosphorus sorption index; ExNa—Exchangeable Na; ExCa—Exchangeable Ca; ExMg—Exchangeable Mg; ExK—Exchangeable K; ExBas—Exchangeable bases (sum of Mehlich exch Ca, Mg, K, Na); EC—Electrical conductivity; ExAc—Exchangeable acidity; TN—Total nitrogen, TC—Total carbon, BD—Bulk density.

Soil pH and electrical conductivity vary slowly in most soils, with the exception of localized variations in and near a fertilizer band or those associated with manure or liming material treatments. Electrical conductivity significantly differed among land use types in different countries at different soil depths ($p < 0.05$); Table 2. In Kenya, soils under agroforestry and soils from cropland with no soil and water conservation at the surface layer (0–15 cm) had significantly ($p < 0.05$) lower EC values, while in Tanzania, significant differences in EC values at the surface (0–15 cm) layer were found between soils under cropland with soil and water conservation and soils under other land uses (Table 2). Additionally, Ugandan agroforestry (0.10 $\pm$ 0.02) land use had significantly low EC values than other land uses at the surface (0–15 cm) (Table 2). In general, the results show that EC values varied significantly ($p < 0.05$) with land use and soil depths and were not above the normal values (EC > 0.15 cmolc kg$^{-1}$) [33]. These results are in line with the findings of Tellen et al. [34] who reported that EC varied significantly ($p > 0.01$) with land use. Despite the fact that EC represents soil soluble salt components, soils under croplands land with/without soil and water conservation did not show higher EC values than normal; studies have found higher EC in grassland soils than in cultivated lands and other land use types [35]. Higher EC > 0.15 mS/cm affects plant growth and development; however, higher EC value under the grazing land have been attributed to increase in exchangeable Na content, whereas lower EC value under the cultivated land have been attributed to loss of base forming cations ($Ca^+$ and $Mg^+$) through exhaustive farming [36].

Soils with acceptable cation exchange capacity (CEC) values are expected to hold more nutrients, have greater water holding capacity, and buffer rapid changes in soil solution levels of these nutrients more effectively [32]. CEC (cmolc/kg) decreased from the surface soils (0–15 cm) to subsoils (45–100 cm) for all the land use types in three countries studied. Although CEC was not significant amongst land uses in Kenyan surface soils (0–15 cm), the soils had high CEC (>25 cmolc/kg), an indication of more fertile soils which can provide more nutrients and water to plants; these type of soils can hold a lot of cation nutrients and probably have a lot of clay and/or organic matter [36]. The main climate-related risks in these areas include high rainfall variability at the expected onset, long dry spells and extreme flooding at the late onset. Extensive soil erosion has resulted in land degradation that affects approximately 40% of the landscape [37]. The benefits of these climate-smart land uses such as agroforestry on soil quality may increase the rate of adoption of the promoted CSA practices in the study area. CEC determines overall nutrient dynamics in soils; in Tanzania, significantly higher CEC contents were observed in the surface soil (0–15 cm) layer of agroforestry (16.40 cmolc/kg), community forest (18.43 cmolc/kg), cropland with/without water and soil conservation and the lowest CEC (8.35 cmol(+)/kg) of control land. Mengiste et al. [36] reported high cation exchange capacity (CEC) values under grassland and grazing land compared to cultivated land/crop lands, while Chemeda et al. [38] reported significant difference in CEC contents due to the interaction of land use and soil depth. Rainfall variability, late expected onset and early cessation, long dry spells, land degradation through erosion, and floods in lowlands were identified as the main climate-related risks in Lushoto (study area in Tanzania) [37]. Lushoto suffers from high soil erosion, which affects CEC content; CEC content for different land uses in these regions at the surface soil (0–15 cm) was significantly higher than that of the control (Table 2). Cation exchange capacity (CEC) helps soils hold nutrients and buffer pH, making it essential for maintaining basic terrestrial ecosystem functions. CEC loss can be caused by soil acidification, a decrease in SOC content, overgrazing, and cultivation [39]. Physical SWC practices (stone bund, soil bund, and check dam) and biological SWC practices (mulching and crop residue, area closure, and plantation on bund) contribute to reduced runoff and sediment loss, as well as increased soil moisture conservation [40].

At all sampling depths, the CEC content of soils in Hoima Uganda was significantly ($p < 0.05$) higher than soils from the control (Table 2). CEC increased in the following order at the surface layer (0–15 cm): Agroforestry > Community forest > cropland without soil and water conservation (SWC) > soil and water conservation (SWC) > grassland > control.

Tellen et al. [34] reported non-significant differences in CEC at the surface (0–15 cm) layer under different land uses. Climate-related risks in Hoima have been identified as rainfall variability, late onset, long dry spells, and lowland floods. Soil erosion is widespread, affecting 20% of the landscape, and soil fertility is declining [39]. Soil fertility levels in both agroforestry and community forests may be due to plant residues, which are sources of $Ca^{2+}$, $K^{+}$, P, $Mg^{2+}$, and have a relatively higher organic matter content [39]. Previous research found that SWC measures had a positive effect on soil CEC content [39].

### 3.3. Exchangeable Bases (Ca, Mg, K and Na), Extractable Fe, Mn, Zn, Total Carbon (TC), Total Nitrogen (TN) and C:N Ratio across Land Uses

Exchangeable bases (K, Ca, Mg and Na) significantly differed due to influence of different land uses ($p \leq 0.05$). Without stratifying into countries, there was significant difference between soil properties and land use type as determined by one-way ANOVA ($p < 0.05$). A Tukey post hoc test showed that the soil depth was statistically significant for C:N ratio ($F(5, 309) = 2.512$, $p = 0.030$), Total C stock ($F(5, 306) = 5.933$, $p = 0.000$), PSI ($F(5, 309) = 4.901$, $p = 0.000$), Al ($F(5, 309) = 3.644$, $p = 0.003$), Zn ($F(5, 309) = 3.600$, $p = 0.004$), Mn ($F(5, 309) = 8.439$, $p = 0.000$), Fe ($F(5, 309) = 8.593$, $p = 0.000$), S ($F(5, 309) = 3.390$, $p = 0.005$), P ($F(5, 309) = 2.980$, $p = 0.012$), ExAc ($F(5, 309) = 4.667$, $p = 0.000$), Exchangeable Na ($F(5, 309) = 7.855$, $p = 0.000$), Exchangeable Mg ($F(5, 309) = 9.807$, $p = 0.000$), P ($F(5, 309) = 2.980$, $p = 0.012$). There was a slight difference in ExCa among different land-use types at different sampling depths, and these differences were not statistically significant ($p > 0.05$). The results show that agricultural land use is linked to variations in total nitrogen, organic and reactive carbon, magnesium, calcium and iron levels (Table 2), Mengiste et al. [36] reported a range of 0.56–0.24 $dSm^{-1}$ for grazing and cultivated land use types, respectively, much higher than what this study reports.

Total N contents varied significantly with land use types ($p < 0.05$) and soil depths (0–15 cm and 15–45 cm). Equally, the top surface (0–15 cm) TN under community forest land ($0.29 \pm 0.14\%$) is statistically higher than agroforestry land ($0.19 \pm 0.05$) and control ($0.10 \pm 0.04$) (Table 2); the increased amount of TN in community forest soil could be attributed to increased plant residue and a low rate of decomposition. At 15–45 cm, TN was significantly higher ($p < 0.05$) for grassland than control (Table 2); higher TN content in the grass land maybe attributed to continuous grazing and accumulation of biomass below-ground. When land is converted from natural, perennial use to annual cropping, the synchronization between plant need for N and N mineralization supply is disrupted, resulting in higher N leaching losses [41]. It is envisaged that practices like agroforestry systems aid in the recovery of nitrogen from subsurface layers inaccessible to crop roots [41] and because trees have deep root systems, they are able to access nutrient reserves at depth in the soil profile, which is one of the proposed benefits of agroforestry. These findings for total nitrogen and carbon are consistent with those of other authors [42–44], who all found that when soil in a formerly forested area is cultivated, a significant amount of organic carbon and nitrogen is lost during crop harvest. Tadesse et al. [45] demonstrated that different land uses have different soil carbon stocking capacities and that integrating climate-smart agricultural practices at the farm level with other land-use systems, such as agroforestry, grasslands, and forests, is required to maximize soil carbon stock and improve ecological health.

The concentration of exchangeable K in the soil significantly varied with land use types and soil depths. At the soil surface (0–15 cm), higher values of K were observed for cropland compared to low value of K for grassland. This could be attributed to farmers use of chemical fertilizers and herbicides in the farms, which could have also influenced the level of Ca in the soils. However, some factors that could influence K, Ca and Mg include deposits of ash on the soil surface after slash-and-burn practice, basic cations (K, Ca and Mg), and waste and other forms of manure applications to soil [3].The C: N ratio is a measure of the relative nitrogen concentration of organic materials and is used as a nutrient immobilization and mineralization indicator [27].

### 3.4. Correlation between Soil Nutrients

The result of the Pearson's correlation analysis between soil properties is presented in Table 3. In Kenya, soil pH ($H_2O$) showed positive correlation ($p < 0.01$) with land use as well as exchangeable (Ca, Mg and K) cation exchange capacity (CEC), Cu and electrical conductivity. A significant positive correlation between exchangeable (Ca, Mg and K) and soil pH indicates that increasing soil pH results in increased cation availability. These findings are consistent with those of Zhao et al. [46], who reported a positive relationship between soil pH and exchangeable Ca, Mg, Zn and Cu. Similar positive correlations between soil pH and exchangeable (Ca, Mg and K) were observed in soils from Tanzania and Uganda (Table 3), indicating that soil pH is an important factor in soil fertility. We found a significant negative relationship ($p < 0.01$) between soil pH and Fe, Al, total carbon and total nitrogen in Kenyan soils and a negative correlation ($p < 0.05$) between soil pH and total carbon in Tanzania. Ugandan soils did not show any significant correlation with total carbon and total nitrogen. Lower soil pH has also been linked to smaller number of exchangeable Ca ions used by the plants [46].

Bulk density ($g/cm^3$) showed positive correlation with soil pH ($H_2O$), exchangeable Ca, Na and CEC in Kenya and a negative correlation ($p < 0.05$) with total carbon and total nitrogen in both Tanzania and Uganda. m3. P was positively correlated with Boron and Zn for soils in Kenya (B; Pearson correlation = 0.355 **; $p < 0.01$: Zn; Pearson correlation = 0.573 **; $p < 0.01$), Tanzania (B; Pearson correlation = 0.347 **; $p < 0.01$: Zn; Pearson correlation = 0.349 **; $p < 0.01$) and Uganda (B, Pearson correlation = 0.355 **; $p < 0.01$: Zn; Pearson correlation = 0.573 **; $p < 0.01$). The low level of boron could be due to fixation in kaolinite soil types as well as continuous cropping that reduces soil organic matter content and further decreases B level. Zhao et al. [46] reported that P can be reduced through facile absorption of phosphoric acid and slow reaction of fixed Fe, Al colloids forming phosphates. Correlation analysis showed that land use types were significantly correlated with bulk density and soil electrical conductivity (EC) (Table 3). Similarly, a significant positive correlation was observed between EC and pH ($H_2O$), exchangeable Ca, exchangeable bases, exchangeable K, and C: N ratio (Table 3), indicating that increase in electrical conductivity results in the increases of these soil chemical properties, while a significant negative correlation between electrical conductivity and exchangeable acidity were observed. Aciego et al. [47] reported a negative correlation between pH and total N while Purnomo et al. [48] reported a positive correlation between soil pH and organic carbon and total N; however, the study did report a negative correlation of soil pH with organic C: N ratio similar to what our study reported for Tanzanian soils.

**Table 3.** Pearson's correlation analysis between selected soil quality indicators in Kenya, Tanzania and Uganda.

| | BD | pH | ExCa | ExK | ExMg | ExNa | ExBas | ExAc | CEC | P | S | B | Cu | Fe | Mn | Zn | Al | PSI | EC | TN | TC | C:N Ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kenya | | | | | | | | | | | | | | | | | | | | | | |
| pH | 0.687 ** | | | | | | | | | | | | | | | | | | | | | |
| ExCa | 0.587 ** | 0.885 ** | | | | | | | | | | | | | | | | | | | | |
| ExK | −0.076 | 0.305 ** | 0.206 * | | | | | | | | | | | | | | | | | | | |
| ExMg | 0.121 | 0.471 ** | 0.598 ** | 0.268 ** | | | | | | | | | | | | | | | | | | |
| ExNa | 0.686 ** | 0.746 ** | 0.662 ** | 0.073 | 0.212 * | | | | | | | | | | | | | | | | | |
| ExBas | 0.587 ** | 0.899 ** | 0.991 ** | 0.260 ** | 0.651 ** | 0.711 ** | | | | | | | | | | | | | | | | |
| ExAc | −0.280 ** | −0.416 ** | −0.301 ** | −0.114 | −0.161 | −0.175 | −0.295 ** | | | | | | | | | | | | | | | |
| CEC | 0.523 ** | 0.840 ** | 0.979 ** | 0.237 * | 0.669 ** | 0.695 ** | 0.989 ** | −0.211 * | | | | | | | | | | | | | | |
| P | −0.106 | 0.185 | 0.068 | 0.259 ** | 0.030 | −0.069 | 0.062 | −0.118 | 0.029 | | | | | | | | | | | | | |
| S | 0.043 | 0.018 | 0.029 | −0.013 | −0.098 | 0.106 | 0.026 | −0.043 | 0.020 | −0.018 | | | | | | | | | | | | |
| B | 0.100 | 0.495 ** | 0.555 ** | 0.246 * | 0.579 ** | 0.102 | 0.549 ** | −0.234 * | 0.526 ** | 0.355 ** | −0.080 | | | | | | | | | | | |
| Cu | 0.323 ** | 0.544 ** | 0.573 ** | 0.052 | 0.692 ** | 0.217 * | 0.584 ** | −0.229 * | 0.561 ** | 0.273 ** | −0.092 | 0.582 ** | | | | | | | | | | |
| Fe | −0.482 ** | −0.721 ** | −0.646 ** | −0.438 ** | −0.505 ** | −0.515 ** | −0.682 ** | 0.123 | −0.645 ** | −0.058 | −0.090 | −0.385 ** | −0.390 ** | | | | | | | | | |
| Mn | −0.226 * | 0.124 | 0.244 * | 0.169 | 0.197 * | 0.064 | 0.240 * | 0.067 | 0.285 ** | 0.175 | 0.028 | 0.270 ** | 0.048 | −0.164 | | | | | | | | |
| Zn | −0.275 ** | 0.049 | 0.083 | 0.254 ** | 0.143 | −0.239 * | 0.064 | −0.076 | 0.064 | 0.573 ** | −0.084 | 0.530 ** | 0.236 * | 0.034 | 0.242 * | | | | | | | |
| Al | −0.543 ** | −0.639 ** | −0.546 ** | 0.202 * | −0.089 | −0.440 ** | −0.508 ** | 0.535 ** | −0.433 ** | −0.274 ** | 0.064 | −0.300 ** | −0.316 ** | 0.179 | 0.025 | −0.100 | | | | | | |
| PSI | −0.387 ** | −0.407 ** | −0.227 * | 0.149 | 0.163 | −0.226 * | −0.191 * | 0.572 ** | −0.105 | −0.369 ** | 0.011 | −0.077 | −0.143 | −0.039 | 0.169 | −0.173 | 0.805 ** | | | | | |
| EC | 0.479 ** | 0.675 ** | 0.678 ** | 0.209 * | 0.354 ** | 0.743 ** | 0.711 ** | −0.225 * | 0.696 ** | 0.111 | 0.490 ** | 0.369 ** | 0.298 ** | −0.544 ** | 0.204 * | −0.002 | −0.361 ** | −0.159 | | | | |
| TN | −0.546 ** | −0.323 ** | −0.193 * | 0.122 | 0.037 | −0.388 ** | −0.202 * | −0.040 | −0.174 | 0.281 ** | −0.040 | 0.365 ** | −0.024 | 0.304 ** | 0.118 | 0.553 ** | 0.133 | 0.099 | −0.083 | | | |
| TC | −0.521 ** | −0.280 ** | −0.105 | 0.074 | 0.114 | −0.329 ** | −0.115 | −0.016 | −0.074 | 0.192 * | −0.116 | 0.363 ** | 0.002 | 0.286 ** | 0.114 | 0.530 ** | 0.095 | 0.138 | −0.082 | 0.941 ** | | |
| C:N Ratio | 0.319 ** | 0.364 ** | 0.468 ** | −0.209 * | 0.308 ** | 0.453 ** | 0.473 ** | 0.009 | 0.501 ** | −0.145 | −0.227 * | 0.071 | 0.253 ** | −0.197 * | 0.026 | −0.062 | −0.405 ** | −0.058 | 0.215 * | −0.244 * | 0.017 | |
| LU | 0.677 ** | 0.420 ** | 0.366 ** | 0.055 | −0.071 | 0.567 ** | 0.373 ** | −0.224 * | 0.339 ** | −0.185 | 0.035 | −0.002 | 0.061 | −0.241 * | −0.215 * | −0.194 * | −0.217 * | −0.213 * | 0.396 ** | −0.216 * | −0.235 * | 0.038 |
| Tanzania | | | | | | | | | | | | | | | | | | | | | | |
| pH | 0.099 | | | | | | | | | | | | | | | | | | | | | |
| ExCa | −0.417 ** | 0.443 ** | | | | | | | | | | | | | | | | | | | | |
| ExK | −0.328 ** | 0.270 ** | 0.572 ** | | | | | | | | | | | | | | | | | | | |
| ExMg | −0.253 * | 0.464 ** | 0.719 ** | 0.500 ** | | | | | | | | | | | | | | | | | | |
| ExNa | 0.222 * | 0.285 ** | 0.004 | −0.086 | 0.259 ** | | | | | | | | | | | | | | | | | |
| ExBas | −0.400 ** | 0.475 ** | 0.984 ** | 0.606 ** | 0.831 ** | 0.071 | | | | | | | | | | | | | | | | |
| ExAc | 0.144 | −0.432 ** | −0.258 ** | −0.077 | −0.188 | −0.067 | −0.252 * | | | | | | | | | | | | | | | |
| CEC | −0.477 ** | 0.274 ** | 0.963 ** | 0.579 ** | 0.791 ** | 0.007 | 0.973 ** | −0.217 * | | | | | | | | | | | | | | |
| P | −0.309 ** | 0.044 | 0.371 ** | 0.750 ** | 0.257 * | −0.166 | 0.379 ** | −0.050 | 0.395 ** | | | | | | | | | | | | | |
| S | 0.019 | −0.604 ** | −0.431 ** | −0.167 | −0.304 ** | −0.026 | −0.420 ** | 0.629 ** | −0.338 ** | −0.062 | | | | | | | | | | | | |
| B | −0.176 | 0.579 ** | 0.663 ** | 0.576 ** | 0.561 ** | 0.053 | 0.680 ** | −0.119 | 0.582 ** | 0.347 ** | −0.295 ** | | | | | | | | | | | |
| Cu | −0.356 ** | 0.339 ** | 0.763 ** | 0.523 ** | 0.413 ** | −0.168 | 0.719 ** | −0.105 | 0.689 ** | 0.358 ** | −0.249 * | 0.612 ** | | | | | | | | | | |
| Fe | −0.227 * | −0.020 | 0.446 ** | 0.334 ** | 0.490 ** | −0.136 | 0.482 ** | −0.119 | 0.543 ** | 0.402 ** | −0.175 | 0.171 | 0.258 * | | | | | | | | | |
| Mn | −0.249 * | 0.290 ** | 0.703 ** | 0.370 ** | 0.571 ** | −0.106 | 0.706 ** | −0.147 | 0.694 ** | 0.076 | −0.286 ** | 0.460 ** | 0.624 ** | 0.499 ** | | | | | | | | |
| Zn | −0.493 ** | 0.188 | 0.818 ** | 0.576 ** | 0.542 ** | −0.164 | 0.796 ** | −0.103 | 0.818 ** | 0.349 ** | −0.218 * | 0.459 ** | 0.757 ** | 0.392 ** | 0.758 ** | | | | | | | |
| Al | −0.107 | −0.735 ** | −0.308 ** | −0.150 | −0.312 ** | −0.177 | −0.326 ** | 0.341 ** | −0.178 | 0.086 | 0.439 ** | −0.377 ** | −0.225 * | −0.044 | −0.303 ** | −0.202 * | | | | | | |
| PSI | 0.233 * | −0.080 | −0.181 | −0.207 * | −0.004 | 0.025 | −0.150 | 0.397 ** | −0.177 | −0.259 ** | 0.427 ** | 0.144 | −0.053 | −0.178 | −0.043 | −0.243 * | 0.180 | | | | | |
| EC | −0.517 ** | 0.117 | 0.714 ** | 0.589 ** | 0.574 ** | −0.204 * | 0.721 ** | −0.121 | 0.759 ** | 0.482 ** | −0.200 * | 0.456 ** | 0.600 ** | 0.506 ** | 0.594 ** | 0.764 ** | −0.149 | −0.191 | | | | |
| TN | −0.583 ** | −0.155 | 0.695 ** | 0.496 ** | 0.362 ** | −0.386 ** | 0.650 ** | −0.142 | 0.767 ** | 0.481 ** | −0.194 | 0.276 ** | 0.557 ** | 0.566 ** | 0.571 ** | 0.778 ** | 0.096 | −0.332 ** | 0.753 ** | | | |
| TC | −0.595 ** | −0.199 * | 0.668 ** | 0.493 ** | 0.311 ** | −0.398 ** | 0.616 ** | −0.111 | 0.739 ** | 0.491 ** | −0.161 | 0.240 * | 0.556 ** | 0.503 ** | 0.508 ** | 0.779 ** | 0.142 | −0.348 ** | 0.743 ** | 0.988 ** | | |

**Table 3.** *Cont.*

| | BD | pH | ExCa | ExK | ExMg | ExNa | ExBas | ExAc | CEC | P | S | B | Cu | Fe | Mn | Zn | Al | PSI | EC | TN | TC | C:N Ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C:N Ratio | 0.097 | −0.265 ** | −0.327 ** | −0.134 | −0.441 ** | −0.084 | −0.371 ** | 0.303 ** | −0.362 ** | −0.028 | 0.299 ** | −0.268 ** | −0.115 | −0.427 ** | −0.444 ** | −0.129 | 0.169 | −0.015 | −0.200 * | −0.224 * | −0.092 | |
| LU | 0.074 | −0.169 | −0.271 ** | −0.142 | −0.316 ** | −0.088 | −0.297 ** | 0.183 | −0.283 ** | 0.029 | 0.189 | −0.202 * | −0.105 | −0.113 | −0.219 * | −0.303 ** | 0.239 * | 0.024 | −0.288 ** | −0.145 | −0.151 | 0.045 |
| Uganda | | | | | | | | | | | | | | | | | | | | | | |
| pH | 0.001 | | | | | | | | | | | | | | | | | | | | | |
| ExCa | −0.185 | 0.727 ** | | | | | | | | | | | | | | | | | | | | |
| ExK | 0.007 | 0.538 ** | 0.321 ** | | | | | | | | | | | | | | | | | | | |
| ExMg | −0.080 | 0.708 ** | 0.773 ** | 0.293 ** | | | | | | | | | | | | | | | | | | |
| ExNa | 0.057 | 0.230 * | −0.034 | −0.036 | 0.368 ** | | | | | | | | | | | | | | | | | |
| ExBas | −0.148 | 0.798 ** | 0.957 ** | 0.398 ** | 0.900 ** | 0.213 * | | | | | | | | | | | | | | | | |
| ExAc | −0.083 | −0.575 ** | −0.466 ** | −0.189 | −0.439 ** | 0.036 | −0.465 ** | | | | | | | | | | | | | | | |
| CEC | −0.156 | 0.642 ** | 0.915 ** | 0.323 ** | 0.907 ** | 0.192 * | 0.960 ** | −0.416 ** | | | | | | | | | | | | | | |
| P | −0.158 | 0.331 ** | 0.541 ** | 0.310 ** | 0.338 ** | 0.014 | 0.516 ** | −0.109 | 0.501 ** | | | | | | | | | | | | | |
| S | 0.151 | −0.256 ** | −0.210 * | 0.014 | −0.094 | 0.067 | −0.168 | 0.068 | −0.087 | 0.073 | | | | | | | | | | | | |
| B | −0.212 * | 0.570 ** | 0.668 ** | 0.415 ** | 0.454 ** | −0.119 | 0.628 ** | −0.299 ** | 0.535 ** | 0.367 ** | −0.202 * | | | | | | | | | | | |
| Cu | 0.047 | 0.621 ** | 0.587 ** | 0.185 | 0.660 ** | 0.435 ** | 0.681 ** | −0.293 ** | 0.620 ** | 0.183 | −0.099 | 0.404 ** | | | | | | | | | | |
| Fe | −0.106 | −0.008 | 0.101 | −0.090 | 0.349 ** | 0.269 ** | 0.191 * | 0.037 | 0.330 ** | 0.088 | 0.017 | −0.079 | 0.177 | | | | | | | | | |
| Mn | 0.233 * | 0.566 ** | 0.562 ** | 0.191 * | 0.376 ** | −0.183 | 0.500 ** | −0.528 ** | 0.413 ** | 0.101 | −0.105 | 0.381 ** | 0.498 ** | −0.083 | | | | | | | | |
| Zn | −0.241 * | 0.492 ** | 0.772 ** | 0.363 ** | 0.505 ** | −0.076 | 0.720 ** | −0.299 ** | 0.683 ** | 0.535 ** | −0.172 | 0.662 ** | 0.510 ** | 0.084 | 0.498 ** | | | | | | | |
| Al | −0.268 ** | −0.701 ** | −0.734 ** | −0.304 ** | −0.707 ** | −0.059 | −0.754 ** | 0.582 ** | −0.704 ** | −0.230 * | 0.142 | −0.505 ** | −0.636 ** | −0.141 | −0.684 ** | −0.569 ** | | | | | | |
| PSI | −0.157 | −0.579 ** | −0.688 ** | −0.224 * | −0.731 ** | −0.125 | −0.729 ** | 0.480 ** | −0.733 ** | −0.193 * | 0.029 | −0.392 ** | −0.743 ** | −0.328 ** | −0.621 ** | −0.573 ** | 0.908 ** | | | | | |
| EC | 0.140 | 0.114 | 0.168 | 0.300 ** | 0.225 * | 0.224 * | 0.242 * | −0.125 | 0.278 ** | 0.291 ** | 0.756 ** | 0.166 | 0.164 | −0.001 | 0.142 | 0.205 * | −0.167 | −0.205 * | | | | |
| TN | −0.604 ** | 0.089 | 0.315 ** | 0.081 | 0.194 * | −0.014 | 0.287 ** | −0.143 | 0.317 ** | 0.200 * | −0.033 | 0.369 ** | −0.003 | 0.136 | −0.083 | 0.359 ** | 0.179 | 0.147 | 0.112 | | | |
| TC | −0.632 ** | 0.103 | 0.360 ** | 0.076 | 0.201 * | −0.062 | 0.315 ** | −0.153 | 0.338 ** | 0.201 * | −0.105 | 0.361 ** | 0.029 | 0.139 | −0.074 | 0.380 ** | 0.153 | 0.104 | 0.025 | 0.975 ** | | |
| C:N Ratio | −0.414 ** | 0.105 | 0.345 ** | 0.006 | 0.122 | −0.194 * | 0.258 ** | −0.069 | 0.242 * | 0.102 | −0.254 ** | 0.147 | 0.251 ** | 0.137 | 0.021 | 0.284 ** | −0.042 | −0.164 | −0.266 ** | 0.263 ** | 0.444 ** | |
| LU | 0.077 | −0.551 ** | −0.466 ** | −0.290 ** | −0.588 ** | −0.099 | −0.531 ** | 0.223 * | −0.486 ** | −0.196 * | 0.164 | −0.283 ** | −0.511 ** | −0.245 * | −0.404 ** | −0.366 ** | 0.467 ** | 0.517 ** | 0.064 | −0.037 | −0.038 | −0.068 |

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). ExBs—Exchangeable bases; TC—total carbon in stock; BD = Bulk density; ExCa—Exchangeable Ca; ExMg—Exchangeable Mg; ExK—Exchangeable K; ExBas—Exchangeable bases (sum of Mehlich exch Ca, Mg, K and Na); EC—Electrical conductivity; ExAc—Exchangeable acidity; CEC—Cation exchange capacity.

## 4. Conclusions

This study was designed to determine the usefulness of the Climate-Smart Agriculture (CSA) interventions on soil quality under different land uses. Soil properties in all climate-smart land use types did not show significant degradation of soil quality, and the quality indicators were within recommended ranges for productive soils [49]. However, electrical conductivity (EC) and other properties of topsoils (0–15 cm) from agroforestry, community forest, cropland with soil and water conservation (SWC), and grassland land use types varied significantly. The soil pH as a critical characteristic for agricultural production did not show significant difference at different depths across land-use types and was within the productive range of between 5.5 and 7.2 [32]. Additionally, correlation analyses showed that the soils physical and chemical properties were significantly correlated. Sustainable land use systems involving climate smart villages need to be strengthened for their potential to partially mitigate the effects of long-term soil health. Additionally, less disturbed community forests and grasslands can be promoted to support more diverse soil communities than intensively managed croplands.

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