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# Effect of Different Land Use Types on Nutrient Distribution across Soil Depth in Busega Wetland, Uganda

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## Abstract

Wetlands play a number of vital roles in the ecosystem, such as serving as nutrient sinks, preventing floods, storing carbon, and filtering water. Encroachment on wetlands has led to substantial economic and environmental losses, including water quality degradation, loss of biodiversity and natural habitats, reduced climate mitigation as well as social and health risks. This study evaluated the effect of different land use types on nutrient stock distribution across varying soil depths in Busega wetland. The soil samples were collected in three different land uses (annually cultivated areas, perennially cultivated areas, and the undisturbed wetland area) at three different depths (0 - 10 cm, 10 - 20 cm, and 20 - 30 cm) in 2021. The soil samples were analyzed for physicochemical soil properties including soil texture and nitrogen, phosphorus, calcium, and potassium concentrations. The interaction between land use type and soil depth did not have a significant effect on nutrient distribution. However, our results showed that the main effects of land use type and soil depth influenced nutrient stock distribution across the wetland. Higher nutrient concentrations were observed under perennial cropping system than in both annual cropping system and the undisturbed wetland area. Soils under perennial cropping systems had the highest soil organic matter (1.45%), calcium (2.06 Cmol/Kg) and potassium (0.091 Cmol/Kg) levels. Higher soil organic matter (1.40%), nitrogen (0.22%), calcium (1.74 Cmol/Kg), and potassium (0.07 Cmol/Kg) were found at the mid-soil depth of 10 - 20 cm. Our results show substantial nutrient changes due to agricultural activities in the Busega wetland, suggesting further research is urgently needed to determine if these changes have adverse effects on biodiversity and water quality of the wetland and nearby water resources.

**Keywords**

Annual Cropping System, Perennial Cropping System, Undisturbed Wetland Area, Wetland Encroachment, Wetland Degradation

## 1. Introduction

Wetlands are essential components of natural resources that offer ecosystem services and ensure environmental sustainability if well managed [1] [2]. Globally, wetlands occupy 5% to 8% of the total earth's surface [3]. These are grouped as papyrus swamps, swamp forests, riverine wetlands, lake edges, flood plains, dambos and artificial wetlands [4]. In Uganda, wetlands cover about 13% of the total land area which is estimated at 30,105 $km^2$ land size [5] [6]. These wetlands are dominantly marshes, seasonal and permanently flooded swamps, and bogs [7]. Wetlands are a significant component of the ecosystem that promotes environmental quality through carbon sequestration, water purification, nutrient cycling, climate moderation, flood and erosion control, provide wildlife habitat and are a source of food, fuel and fresh water [3] [8].

Over the years globally, wetlands have been threatened by human encroachment and destruction resulting in sporadic wetland degradation. Almost half of the world's wetland area has been destroyed completely and the left wetland area is facing degradation [2]. Although the Government of Uganda enacted strict laws to protect wetlands from encroachment, wetland cover continues to decline, causing flooding, soil degradation, and water pollution [5]. The encroachment is mainly driven by population increase, industrialization, urbanization, and the unclear land ownership in the wetland areas [9]-[11]. The increasing population has exerted a lot of pressure on the available land for farming, increasing farmers' search for more farmland in the nearby wetland areas [12]. There is also limited knowledge by the locals of the importance of wetlands to the ecosystem and poor enforcement of stringent laws against wetland encroachment [5]. Wetland degradation has caused substantial land losses through soil erosion and nutrient loss, economic losses, and health risks [13] [14]. The degradation of wetlands through increased human agricultural activities is expected to increase the accumulation of nutrients mostly nitrogen (N) and phosphorus (P) in waterbodies such as Lake Victoria leading to eutrophication that is evidenced by growth of algal blooms [11].

Busega wetland (as it is locally known) in Uganda, a tropical perennial wetland covering 1200 m in surface area with around 450 $km^2$ of drainage catchment area, has been severely encroached upon and degraded. The encroachment has resulted in various introduced land uses in Busega wetland, including agriculture with different cropping systems, animal and fish rearing, bricklaying, sand mining, and industrialization [15]. Depending on the type of land use, soil physical, chemical, and biological properties are affected [16], which could interact to affect the wetland's soil quality and capacity to provide ecosystem services such as improved water quality, erosion control, and flood protection in Kampala city and surrounding areas. In addition, land use types such as cropping affect the distribution and availability of nutrients in the soil, which is influenced by several factors such as soil depth, tillage, fertilizer application and changes in nutrient cycling [17]-[19]. Although reports show that the shift of parts of Busega wetland from natural ecosystem to farmland owing to its fertile soils, water availability to crops throughout the year [20] has significantly lowered the wetland's soil and water quality due to intensive fertilizer and pesticide use [21] [22], there is still no documentation on the impact of different land use types especially cultivation on the soil status across the soil profile of Busega wetland. One possible way of determining the effects of these introduced land use practices on wetland quality is to assess the soil physical and chemical properties [8] under different land use types currently undertaken in the wetland. The present study examined how different land use types affect nutrient stock distribution across varying soil depths in Busega wetland. We hypothesized that cropped land would have increased nutrient concentrations compared to the undisturbed wetland area across the varying soil depth in Busega wetland.

## 2. Materials and Methods

### 2.1. Site Description

The study was conducted in Busega wetland found in Wakiso district, Busiro county, Wakiso subcounty, Ssuumbwe parish, Buleenga A Kikaaya in central Uganda (00˚18'36" N 32˚31'12" E) at an elevation of 1158 m above main sea level. The study area has a drainage catchment area of 40 $km^2$ [23]. Busega wetland was naturally covered by swampy vegetation dominated by *Echinochloa pyramidalis, Paspalum scrobiculatum, Cyperus papyrus, Typha capensis and Thelypteris acuminata* species [23].

The wetland area receives a bimodal type of rainfall with total annual rainfall ranging from 1200 mm to 1700 mm in seasons of March to May and September to December. The average daily temperatures received range from 17˚C to 27˚C throughout the year [24]. Soils in the wetland are characterized by intermittent wetting and drying in the wet and dry seasons respectively, clayey in nature with greyish and dark soils and are classified as Gleysols [25]. Busega wetland, a reserved natural ecosystem is currently under threat by anthropogenic activities including agriculture. Farmers have encroached on the wetland growing mainly maize (*Zea mays L.*), sweet potatoes (*Ipomea batatas L.*), bananas (*Musa spp*), sugarcanes (*Saccharum officinarum*), and yams (*Dioscoreaceae spp.*) [26].

### 2.2. Field Selection and Soil Sampling

A preparatory reconnaissance transect survey was conducted across the wetland in December 2021 through which the main cropping systems in the wetland were identified. Both annual and perennial cropping systems were observed in the encroached area of the wetland. Annual cropping system in this study includes crops that complete their life cycle within one growing season, and the dominant annual crop grown in the studied area was maize (*Zea mays*). On the other hand, perennial cropping system includes crops that can live for more than two years without being replanted each year. Banana (*Musa spp*) was the dominant perennial crop in the studied area. Part of the land is undisturbed, which refers to the part of the wetland still in its natural state and has never been encroached with any human activities. In this study, the two systems of cultivation (annual and perennial) as well as the undisturbed area are referred to as the three types of land use (LU). There was no overlap among the three land use types.

For this study, purposive sampling was done separately to identify areas under annual and perennial cropping systems, and the undisturbed wetland area. For the two cropping systems, various fields were selected from the upper, middle, and lower areas of the wetland which represented three different blocks. Soil sampling was done during the dry season in December 2021 when the wetland was not very wet. Soil samples for analysis were collected using a 2.1-inch diameter auger following the zigzag method in the cropped land and the undisturbed area. Three soil samples at varying depths of 0 - 10 cm, 10 - 20 cm, and 20 - 30 cm from each cropping system and the undisturbed area per block were collected (**Table 1**). The study site and soil sampled area are shown in **Figure 1**. Soil clods, stones and objects were carefully removed using hands. The soil in the bucket was mixed thoroughly and a representative sample taken. All soil samples were packed in plastic bags and taken to Makerere Soil Science Laboratory, Kampala for soil laboratory analysis (during December 2021 to May 2022). All soil samples were placed on trays and hand crushed to avoid sticking together. The soil was air-dried at room temperature in an open-air space room for 14 days. The dried soil was crushed further using a mortar and pestle and sieved through a 2 mm sieve to get rid of gravels and plant roots.

**Table 1.** Experimental field layout.

| Blocks (replicate) | Perennial (P) and depth (banana) | Annual (A) and depth (maize) | Undisturbed part (U) |
|---|---|---|---|
| 1 | P1 P1 P1 | A1 A1 A1 | U1 U1 U1 |
| 2 | P2 P2 P2 | A2 A2 A2 | U2 U2 U2 |
| 3 | P3 P3 P3 | A3 A3 A3 | U3 U3 U3 |

Where, P is perennial (banana), A is annual (maize) and U is undisturbed whereby P1 = (0 - 10) cm, P2 = (20 - 30) cm, P3 = (20 - 30) cm, A1 = (0 - 10) cm, A2 = (10 - 20) cm, A3 = (20 - 30) cm, U1 = (0 - 10) cm, U2 = (10 - 20) cm, U3 = (20 - 30) cm.

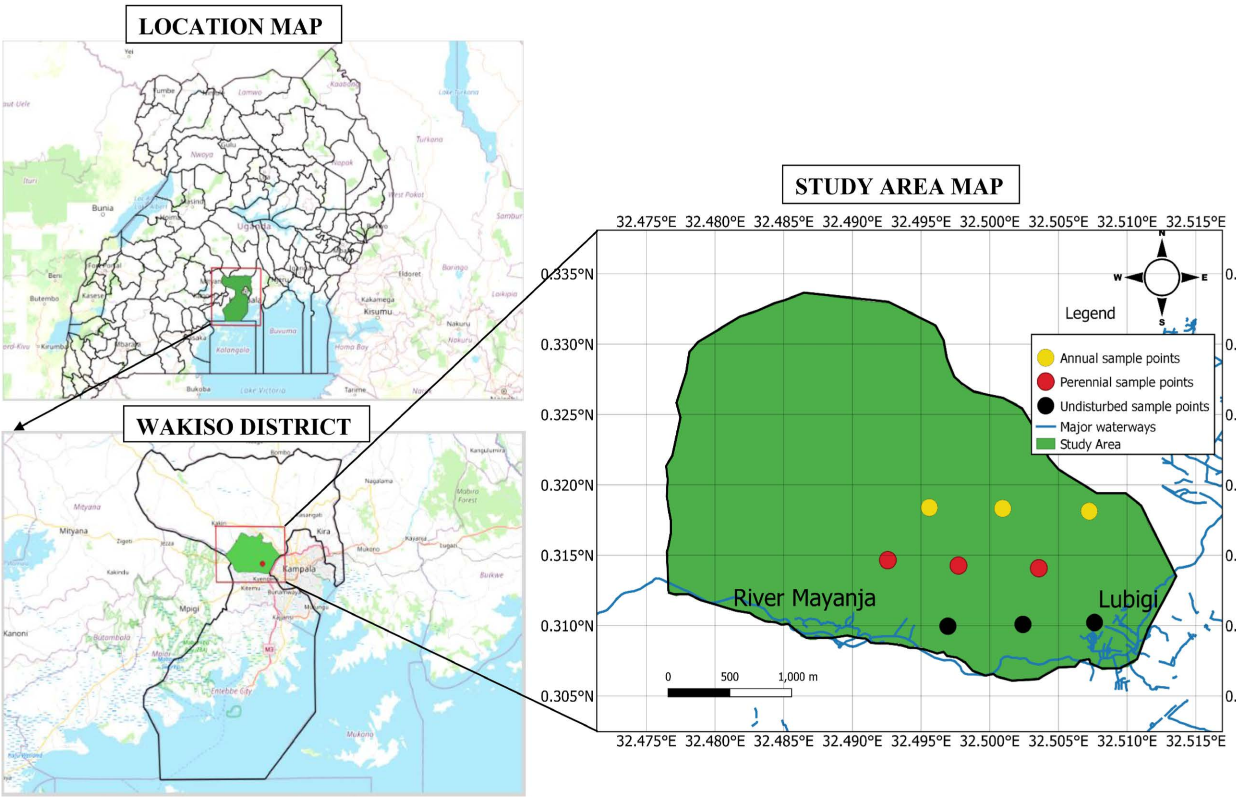



**Figure 1.** Study area map of Busega wetland. Red, yellow and black bold circles represent the fields sampled in this study.

## 2.3. Soil Analysis

Soil texture was determined by the hydrometer (Bouyoucos) method. Briefly, 50 g of air-dried sieved soil were saturated with distilled water and 10 ml of 10% sodium hexametaphosphate (Calgon solution) in a buffer cup [27]. The percentage of sand, silt and clay were used to determine the textural classes of the soil samples using the USDA-soil textural triangle [28]. Total N was determined using the Kjeldahl digestion and distillation method. Briefly, a mixture of 0.3 g of sieved soil and 2.5 ml of the digestion mixture was digested at 110˚C, followed by steam distillation using 40% sodium hydroxide [29]. The Bray 1 method was used to determine available P where 1 g of air-dried sieved soil was extracted using 10 ml of Bray1 extractant (0.025 M HCl and 0.03 M $NH_4F$) and shaken for 5 minutes. The concentrations of extracted P were measured colorimetrically at a wavelength of 880 nm [30]. Total organic carbon was determined using the Walkley-Black method. Briefly, 5 ml of potassium dichromate solution and 7.5 ml of concentrated sulphuric acid were added to 0.5 g of ground soil for carbon oxidation and digested for 30 minutes at a temperature of 155˚C. The excess volume of potassium dichromate was titrated with 0.5 M ferrous ammonium sulphate. The sample and blank titres were used in calculation of % carbon [31]. Soil pH was measured using the 1:2.5 (w/v) soil to water ratio method. This involved adding 50 ml of distilled water to 20 g of air-dried sieved soil. The mixture was vigorously shaken using a mechanical shaker. The pH values were read from the pH meter of model

(AD1000, Adwa, Romania) [32]. Exchangeable cations of potassium (K) and calcium (Ca) were determined by adding 100 ml of 1M ammonium acetate to 5 g of air-dried sieved soil and shaken for 30 minutes. The extracts were filtered using No.42 Whatman paper and the concentration of K and Ca analyzed using flame photometry and atomic absorption spectrophotometry respectively [33].

### 2.4. Data Analysis

Statistical analyses were performed using R version 4.3.1 (R Core Team, 2023). Prior to data analysis, data normality was tested using the Shapiro Wilk test. Data transformation was done on data that was not normally distributed to meet assumptions of ANOVA. Two-factor Analysis of Variance (ANOVA) was conducted (Land Use Type (LU), Depth (D) and Land Use * Depth interaction) and blocks as a random effect. Treatment means that were significantly different were separated using Tukey's Honestly Significant Difference (HSD) test at $p \leq 0.05$.

## 3. Results

### 3.1. Effect of Land Use Type and Depth on Soil Texture

**Table 2.** Effect of land use type and depth on soil texture in Busega wetland.

| Land use type | Annual | | | Perennial | | | Undisturbed | | | $LSD_{0.05}$ | CV% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (cm) | 0 - 10 | 10 - 20 | 20 - 30 | 0 - 10 | 10 - 20 | 20 - 30 | 0 - 10 | 10 - 20 | 20 - 30 | | |
| Sand % | 75.0 | 76.3 | 78.3 | 65.0 | 61.7 | 57.7 | 69.0 | 62.3 | 73.0 | 10.8 | 3.5 |
| Silt % | 15.7 | 14.3 | 11.7 | 21.7 | 23.0 | 25.7 | 23.7 | 29.7 | 15.7 | 8.0 | 7.2 |
| Clay % | 12.7 | 12.7 | 10.0 | 18.7 | 19.3 | 22.7 | 15.3 | 22.0 | 16.0 | 7.0 | 28.8 |

There was no interactive effect of land use type * depth on the sand ($p = 0.277$) and clay ($p = 0.877$) soil proportions (**Table 2**). However, the interaction was slightly significant for silt ($p = 0.054$) showing inconsistent changes in silt content in the different land use types at the various soil depths. Increase in soil depth (from 0 - 10 cm to 10 - 20 cm to 20 - 30 cm) resulted in a decrease in silt content under annual cropping system (15.7% to 14.3% to 11.7%) respectively. In contrast, an increase in soil depth (from 0 - 10 cm to 10 - 20 cm to 20 - 30 cm) resulted in an increase in silt content (21.7% to 23% to 25.7%) respectively under perennial cropping systems. For the undisturbed wetland area, silt content increased from 23.7% to 29.7% and decreased to 15.7% as soil depth increased down the soil profile. Land use types significantly affected sand ($p = 0.0004$), clay ($p = 0.001$) and silt ($p = 0.0005$) content. Sand proportions were significantly higher than silt and clay content under all land use types. The annual cropping system had the highest sand proportion = 76.5% compared to both the perennial cropping system (61.4%) and the undisturbed wetland area (68.1%) (**Table 2**) although the trends under different cropping systems were inconsistent. Perennial cropping system had the highest silt content (23.46%), followed by the undisturbed wetland area (23.03%) while the lowest silt content (13.9%) was found under the annual cropping system. Clay content significantly varied across the different land use types with more clay (15.1%) under perennial cropping system and the least clay content (10%) under annual cropping system (**Table 2**). The main effect of soil depth alone had no significant effect on sand ($p = 0.543$), clay ($p = 0.231$) and silt ($p = 0.129$) proportions.

### 3.2. Effect of Land Use Type and Depth on Soil Organic Matter

The interactive effect of land use type * depth on soil organic matter (SOM) was not significant while the main effect of land use type significantly ($p = 0.005$) influenced SOM. Soils under perennial cropping system had the highest SOM content (1.45%) compared to the annual cropping system (0.56%) and the undisturbed wetland areas (1.25%) (**Table 3**). The main effect of depth highly ($p = 0.012$) influenced SOM. At 0 - 10 cm soil depth, SOM (1.60%) under perennial cropping system was more than twice as that found in annual cropping system (0.68%). Soil organic matter at 10 - 20 cm soil depth for perennial cropping system and annual cropping systems area almost doubled that obtained under the undisturbed wetland area at the same depth. At 20 - 30 cm soil depth, SOM under perennial cropping system was significantly higher than SOM under annual cropping system and the undisturbed wetland area. The amount of SOM was in order of Undisturbed < Annual < Perennial land use type when averaged across the three soil depths (**Table 3**).

**Table 3.** Effect of land use type and depth on soil organic matter (%) and soil pH.

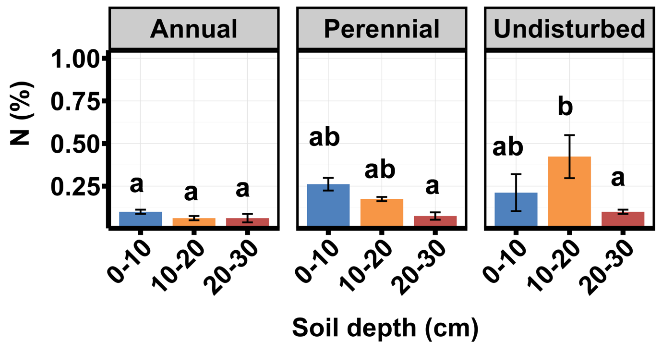
| Land use type | Annual | | | Perennial | | | Undisturbed | | | $LSD_{0.5}$ | CV% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (cm) | 0 - 10 | 10 - 20 | 20 - 30 | 0 - 10 | 10 - 20 | 20 - 30 | 0 - 10 | 10 - 20 | 20 - 30 | | |
| SOM (%) | 0.68 | 1.58 | 1.44 | 1.60 | 1.88 | 1.71 | 0.41 | 0.87 | 0.59 | 0.88 | 4.60 |
| Soil pH | 6.57 | 6.77 | 6.17 | 5.89 | 6.05 | 6.38 | 5.60 | 5.50 | 5.76 | 8.00 | 0.48 |

### 3.3. Effect of Land Use Type and Depth on Soil pH

The interactive effect of land use type * depth significantly ($p = 0.043$) affected soil pH (**Table 3**). The highest (6.77) soil pH was observed under annual cropping system at 10 - 20 cm soil depth. Similarly, the lowest (5.50) soil pH was observed at 10 - 20 cm soil depth but in the undisturbed wetland area. There were inconsistent changes in soil pH with increment in soil depth across the different land use types. For example, as soil depth increased from 0 - 10 cm to 10 - 20 cm, there was an increase in soil pH *i.e.* (6.57 to 6.77), and (5.89 to 6.05) in annual and perennial cropping systems respectively. Contrastingly, this trend was not observed under the undisturbed wetland area. Soil pH decreased with increase in depth with higher soil pH (5.60) obtained at 0 - 10 cm and lower pH (5.50) recorded at 10 - 20 cm. Soil pH increased with depth for perennial cropping system (from 6.05 to 6.38 for 10 - 20 cm to 20 - 30 cm) and under the undisturbed wetland area (5.50 to 5.76 from 10 - 20 cm to 20 - 30 cm soil depth). In contrast, soil pH decreased (from 6.77 to 6.17) under annual cropping system from soil depths at 10 - 20 cm to 20 - 30 cm (Table 3).

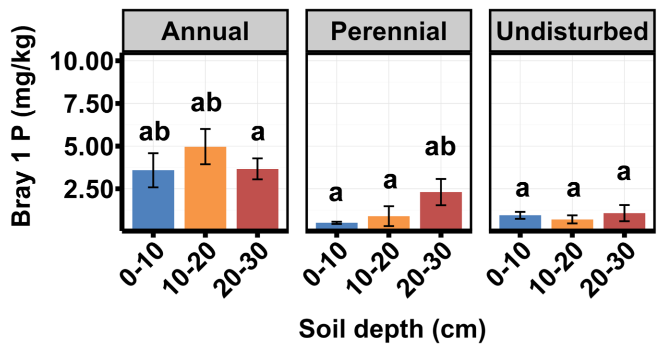
### 3.4. Effect of Land Use Type and Depth on N and P Concentrations

The interaction of land use type * depth had no significant effect on N stock ($p = 0.067$). We observed significant differences of N among different land use types ($p = 0.011$). The annual cropping systems recorded significantly lower N (0.073%) followed by perennial (0.170%) and the undisturbed wetland area (0.244%). The main effect of depth alone significantly influenced soil N levels ($p = 0.025$) with 10 - 20 cm depth recording the highest N (0.220%) and the lowest N (0.078%) at 20 - 30 cm soil depth (Figure 2).




Means followed by the same letter are not significantly different according to Tukey's honestly significantly different test ($p \leq 0.05$).

**Figure 2.** Mean interactive effect of land use type and depth on N levels in Busega wetland as of December 2021.




Means followed by the same letter are not significantly different according to Tukey's honestly significantly different test ($p \leq 0.05$).

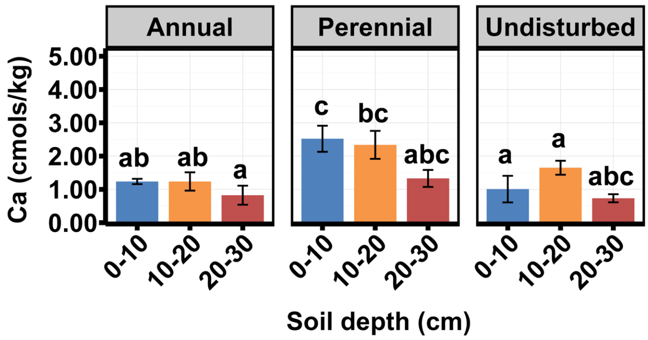
**Figure 3.** Mean interactive effect of land use type and depth on available P in Busega wetland as of December 2021.

The interaction of land use type * depth had no significant effect on P concentrations (Figure 3). However, P concentrations significantly varied ($p < 0.001$)

within different land use types. The P concentrations were significantly higher under the annual cropping system but decreased by about 40% to 20% within perennial cropping system and the undisturbed wetland area respectively. The P concentrations did not vary across soil depths ($p = 0.492$). Overall, the P levels were low in the soils of the study area.

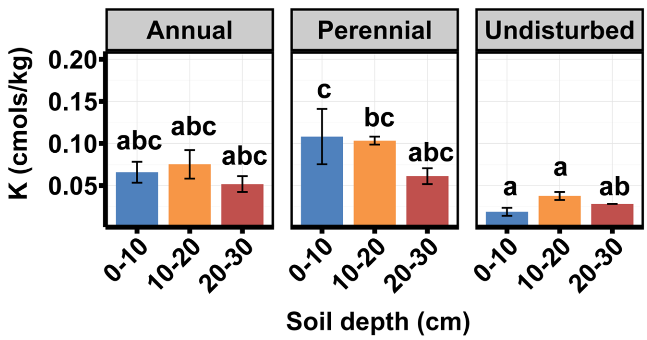
### 3.5. Effect of Land Use Type and Depth on Ca and K Concentrations

The interaction between land use type * depth on Ca concentrations was not significant ($p = 0.256$) (**Figure 4**). In contrast, the main effect of land use type was strongly significant on soil Ca concentrations ($p < 0.001$). High Ca levels were obtained under the perennial cropping system while annual cropping system and the undisturbed wetland area had relatively lower Ca levels. Soil Ca concentrations significantly differed across the various soil depths ($p = 0.003$). Higher Ca concentration was observed in the topsoil of 0 - 10 cm, 10 - 20 cm than in deeper soils of 20 - 30 cm. Averaging all land use types, the highest Ca levels were obtained at 10 - 20 cm soil depth (1.741 Cmol/Kg) while the lowest Ca (0.963 Cmol/Kg) was found at the 20 - 30 cm soil depth (**Figure 4**).




Means followed by the same letter are not significantly different according to Tukey's honestly significantly different test ($p \leq 0.05$).

**Figure 4.** Mean interactive effect of land use type and depth on Ca levels in Busega wetland as of December 2021.




Means followed by the same letter are not significantly different according to Tukey's honestly significantly different test ($p \leq 0.05$).

**Figure 5.** Mean interactive effect of land use type and depth on K levels in Busega wetland as of December 2021.

Similarly to Ca, the interactive effect of land use type * depth was not significant on K concentrations ($p = 0.424$). (**Figure 5**). In contrast, the main effect of land use type had a great significant effect on K concetrations ($p < 0.001$). Perennial cropping system had significantly higher K concetrations, followed by the annual cropping system and the undisturbed wetland area. The main effect of soil depth alone was not significant on K concentrations in the present study ($p = 0.110$).

## 4. Discussion

### 4.1. Effects of Land Use Types and Soil Depth on Soil Texture

The lack of significant interactive effect of depth and land use type on sand and clay proportions justifies that soil texture is an inherent stable physical property. Soil texture is also one of the physicochemical soil properties that does not change easily in a short time and is characterized by its stability to withstand mechanical pressures [34] [35]. The inconsistent trends in silt content under the different land use types at the varying soil depths was due to the susceptibility of silt particles to erosive forces and differences in vegetative cover under the various land use types. Literature has reported that the small nature of silt particles compared to sand makes silt more prone to soil erosion [36]. The differences in clay, silt and sand contents in the different land use types is due to the difference in crops grown, agronomic practices such as manure additions and tillage. The higher clay content in perennial cropping system and the undisturbed wetland area could be due to clay deposition caused by limited cultivation and soil erosion. The higher sand content under annual cropping system is attributed to seasonal land preparation that promotes loss of clay and silt proportions through soil erosion. Results from many studies showed that soil texture varied across different land use types owing to differences in weather condition, agronomic practices, the cropping system duration, and topographical variations [36]-[38]. The absence of soil depth effects on soil texture could be explained by the same parent material from which soils of the wide region of the wetland developed. Busega wetland soils are Gleysols characterized by intermittent wetting and drying, that developed from clayey parent material with a higher percentage of sand soil proportions [39]. In contrast to our results, other studies found significant changes in clay, silt, and sand proportions across various depths within soil profiles [40] [41].

### 4.2. Effects of Land Use Types and Soil Depth on Soil Organic Matter

The higher amount of SOM under perennial cropping system is due to limited cultivation and the accumulation of organic materials that later decompose to form SOM [42] [43]. Under annual cropping systems, low SOM values result from repeated cultivation, which increases topsoil loss through soil erosion and facilitates microbial organic matter breakdown [44] [45]. The unexpected low SOM in the undisturbed wetland area could have been a result of limited plant litter. Another reason for low SOM in the undisturbed wetland area is the anaerobic soil conditions (since this part is still covered by water) that are known to lower the decomposition of plant litter which builds SOM [46] [47]. The lower SOM at 0 - 10 cm soil depth could be due to increased mineralization of the SOM into energy and nutrients for plant utilization. On the other hand, the higher SOM at 10 - 20 cm is due to accumulation of organic materials such as dried leaves, dead leaves, grasses, and other decomposed organic matter common at this depth leading to SOM accumulation. Furthermore, the higher SOM at 10 - 20 cm soil depth could be related to the much root density growing in this range of soil depth. A reduction in SOM down the soil profile can be attributed to a reduced deposition of plant materials that form SOM and reduced microbial activity in deeper soils. This lower SOM at a depth of 20 - 30 cm indicates that the soil in the studied area (**Figure 1**) has a well-developed soil profile that separates the upper and subsequent soil layers.

### 4.3. Effects of Land Use Types and Soil Depth on Soil pH, N and P

The significant interactive effect of land use type and depth on soil pH indicates the importance of these two studied factors in determining acidity and alkalinity of the soil solution. Higher soil pH values under annual cropping systems could be attributed to a range of factors including the high sand content, agronomic practices such as fertilizer application for example calcium phosphate and lime that increases soil pH [36] [48]. The lowest soil pH under the undisturbed wetland area could have been due to increased clay content compared to other land use types. High clay content reduces hydrogen ions on the clay colloidal surfaces resulting in low soil pH. This occurs when base cations replace hydrogen ions responsible for acidity on the clay surfaces leading to an increase of hydrogen ions in the soil solution [49]. Overall, the abrupt changes in soil pH in different land uses at different depths can be attributed to the soil's buffering capacity. Soil pH is a sensitive parameter, and soils tend to resist changes in their pH caused by external forces [50] [51].

The low quantities of N in the annual cropping system can be attributed to N being one of the most limiting nutrients, readily utilized by crops such as maize that is widely grown in Busega wetland. In addition, over cultivation under annual cropping systems may facilitate N loss through water runoff, leaching and volatilization as the land is tilled repeatedly every season. These results are consistent with previous studies which reported that N is very mobile in the soil and is easily lost through different pathways with an increase in land clearing and tillage [52] [53]. It is possible that the higher N content in perennially cropped areas can be attributed to the higher SOM accrued from decomposition of plant matter and limited land cultivation in perennial crops. Several studies have reported an increase in N levels with an increase in SOM [42] [43]. As expected, N input and outputs influenced N concentrations in different soil layers across the soil profile with upper soil layers recording higher N stock due to SOM accumulation. Our results are in agreement with those of [54] who reported that N accumulated in upper soil layers where high SOM was found. The lower N stock in the lower soil layers could be due to plant nitrate utilization by the crop in the upper layers and low SOM leading to limited nitrate leaching.

The higher P concentrations under annual cropping system could be attributed to fertilizer application, given that soil P levels were low in the studied area. Another reason for these high P levels could be because of higher sand: clay ratio found under annual cropping system. In literature, soils with high clay content provide large surface area to strongly adsorb phosphate [55]-[57]. Contrarily, some studies found that the concentrations of available P were lower under annual cropping system than perennial cropping system as a result of water runoff, and crop removal [36] [58] [59]. The lower available P in perennial cropping system and the undisturbed wetland area is caused by the higher clay content that provides a large surface for phosphate sorption. Soil phosphate sorbed to clay surfaces makes it unavailable to be detected in the soil solutions [60]. Contrary to our study, [54] obtained higher levels of P under perennial cropping system which was attributed to reduced soil erosion and increased SOM. Available P was generally lower in the presently studied soils than the critical value of 30 kg·P·ha$^{-1}$ which is a characteristic of most Ugandan soils. This is because of phosphate sorption from high Fe and Al hydroxides dominant in these soils which causes low soil phosphate concentrations in the soil solution [54]. The low P levels are beneficial for the natural wetland soils to avoid increased risks of P loss to nearby water bodies in which Busega wetland discharges its water.

### 4.4. Effects of Land Use Types and Soil Depth on Base Cations, Ca and K

Unlike N and P, we found higher Ca and K levels under perennial cropping system than under annual cropping system and the undisturbed wetland area. The accumulation of Ca and K in the upper soil layers is explained by weathering of soil minerals which is a primary source of base cations and atmospheric deposition in topsoil [61]-[63]. Furthermore, higher amount of Ca and K in the surface layers may be due to management practices such as mulching, limited cultivation that promote soil and water conservation which reduce leaching of the base cations. The significant amount of Ca and K under perennial cropping systems as compared to annual and the undisturbed wetland area is explained by the functions of deeper root systems on recovering cations like Ca and K to upper soil layers through plant nutrient cycling [61] [62]. The results of this study show significant alterations in nutrient distribution across the varying soil depths under different land use types in the wetland calling for sustainable practices to maintain this natural ecosystem. However, soil samples used for this study were collected from the wetland during the dry season. To minimize the effects of seasonal variability on the results, the authors recommend that future studies collect soil samples during both the wet and dry seasons of the year.

## 5. Conclusion

The different land use types affected nutrient distribution across the varying soil depth in Busega wetland. The land use type and soil depth interaction had no significant effect on soil texture, SOM, N, P, Ca, and K except for soil pH. The different land use types had more significant influence on the soil nutrient distribution than soil depth. Overall, higher nutrient concentrations were observed under perennial cropping system than in both annual cropping system and the undisturbed wetland area. Soils under perennial cropping systems had higher SOM (1.45%) and N (0.170%) content than SOM (0.68%) and N (0.073%) under annual cropping systems. Our results show alteration in SOM and original nutrient stocks when cultivation is introduced in the wetland which could in turn affect the original capacity of this wetland to perform its ecosystem functions. Based on the findings of this preliminary study in Busega wetland, it becomes clear that wetland conservation is necessary due to their ecosystem-critical importance. Unlike perennial and annual crops currently grown in encroached areas of the Busega wetland, natural marshes and papyrus help conserve soil and water by purifying water, cycling nutrients, controlling floods, and minimizing erosion. We suggest further research to better understand the effects of cultivation introduced to this natural wetland on water quality.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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