ORIGINAL RESEARCH ARTICLE

The effects of lake Ol'Bolossat's sediments application on soil-chemical characteristics and productivity of swiss chard *(Beta vulgaris* L.*)*

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ABSTRACT

Sediments dredged from the lakes have emerged as successful soil amendment solutions, especially in alleviating soil fertility problems in poor soils. This study aimed to assess the effect of sediments from lake Ol'Bolossat on soil quality and the growth and yield of Swiss chard *(Beta vulgaris* L.*)*. A pot experiment was carried out in January-April and July-October 2020 in a polyethylene greenhouse using a completely randomized design at the Jomo Kenyatta University of Agriculture and Technology. To achieve the study's objective, Swiss chard (Ford hook giant variety) was grown in pots, and five treatments were applied; (T1)-sediments from lake depth of 0-30 cm + soil, (T2)-sediments from lake depth of 30-60 cm + soil, (T3)-sediments from lake depth of 60-90 cm + soil, (T4)-inorganic fertilizer (NPK 150 kg/acre) + soil, (T5)-soil with no lake sediments or inorganic fertilizers, which acted as the control experiment. The sediments were mixed with soil at a ratio of 1:4.

The study's results showed that the lake sediments had a significant impact on the soil's major nutrients. After soil amendment, T1, T2, and T4 resulted in a significantly higher nitrogen value than T3 and T5 (0.38 mg/g, 0.38 mg/g, 0.26 mg/g, 0.29 mg/g, and 0.04 mg/g, respectively). T1 and T2 recorded significantly high levels of potassium (3.8% and 3.9%). T1 and T2 had the highest phosphorus content (3.8 mg/g and 4.2 mg/kg, respectively). Lake sediment treatments, T1, T2, and T3, had significantly high total organic carbon values (13 mg/g, 13 mg/g, and 11 mg/g, respectively). pH was lower in T4 (4.3) and electro conductivity (E.C) was higher in the same treatment (0.5) than in the other treatments.

This study also demonstrated significantly high values of plant height, leaf length, leaf width, and the number of leaves in T1 and T2 in both growing seasons. The average plant height values for the five treatments were 34.8cm, 34.9cm, 29.8cm, 29.6cm, and 24.8 cm, respectively, and the leaf length values were 25cm, 24.8cm, 23.9cm, 24.4 cm, and 23.1cm, respectively. The lake sediments obtained from 0-30cm and 30-60 cm depth had a significantly higher positive impact, and they resulted in better productivity and subsequently higher dry matter of Swiss chard (25.2g/plant and 25g/plant, respectively) compared to the productivity of Swiss chard grown using lake sediments from 60-90 cm depth, which was approximately

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ISSN 1561-7645 (online)
doi: 10.4314/jagst.v21i3.4

19g/plant. The study demonstrated that sediments play an essential role in improving the productivity of Swiss chard and the quality of agricultural soils.

Keywords: Lake sediment, *Beta vulgaris L.*, crop productivity, soil nutrient quality.

1.0 Introduction

Lake sediments amend the soil in sustainable agriculture as they are eco-friendly, sustainable, and less expensive. They contain living cells from different types of microorganisms (Darmody & Diaz, 2017). Studies show that lake sediments have critical nutrients that highly contribute to the soil's residue pool of organic nitrogen and phosphorus (Rather et al., 2018). Moreover, they are rich in organic matter, which is essential in improving soil fertility. Dredging the lake produces large amounts of sediments that can be utilized as fertilizer as an added value that can benefit many small-scale farmers while making the lake ecologically sustainable. The microorganisms in the lake sediments are responsible for mobilizing the present essential elements for crop nutrition (Fonseca et al., 2003). Soil amendment is central to socio-economic growth and agricultural production (Kashmir, 2010). Amending the soil with sediments from the lake is a viable way for farmers to increase output per unit area.

The use of lake sediments as a soil amendment is gaining momentum as they have been shown to boost soil fertility in poor soils (Shinde et al., 2018). They improve the soil's physical, chemical, and biological qualities while reducing the amount of inorganic fertilizers used by the farming community, subsequently bringing down production costs (Rahman et al., 2004). The application of lake sediments increases crop yield, helps with soil moisture retention, and improves soil structure. Studies have shown that sediments as soil amendment solutions give the soil a thicker topsoil depth and higher organic matter, and it helps reduce soil erosion (Ali et al., 2013).

Lake Ol'Bolossat, the only freshwater highland lake in central Kenya, is located in Nyandarua County. Apart from being a wetland-protected area, the lake is an important bird area (IBA) in Kenya and, therefore, a tourist attraction site. The ability and capacity of lake Ol'Bolossat's ecosystem to support and sustain livelihoods in Nyandarua and Laikipia counties in Kenya are threatened by continuous sedimentation and pollution. Farm activities and soil erosion around the lake are among the major contributors to sedimentation (Mathenge, 2013). The lake's water depth has been significantly reduced by sedimentation. To restore the lake volume, some of the proposed measures are integrated watershed management and dredging (dredging of silt). The dredged sediments are believed to be composed of organic matter and beneficial crop nutrients, which can be used as a soil amendment to boost soil fertility (Mathenge, 2013). Dredging activity in lake Ol' Bolossat aims to restore bird habitats and the aquatic ecosystem. This will restore the lake, and dredged sediments can provide an alternative soil amendment for small-scale farmers who depend on inorganic fertilizers.

In Kenya and other African countries, the constantly increasing food insecurity calls for urgent measures to curb the issues related to hidden hunger like low soil fertility, which lessens crop

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ISSN 1561-7645 (online)
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production (Hutchinson, 2011). In this study, Swiss chard (*Beta vulgaris L.*) was used as a test crop to study the effect of sediments obtained from lake Ol'Bolossat on the vegetable's productivity. Swiss chard is reputed to contribute significantly to the provision of essential micronutrients for a balanced diet. It has a short production cycle and high nutritional and medicinal value (Silveira et al., 2003). This vegetable is highly valued because it has good returns for small-scale farmers and its production has increased in the recent past because of increased demand and high returns per unit area (Silveira et al., 2003). In addition, Swiss chard's growth is nutritive demanding, sensitive to the soil's chemical qualities, and its productivity and quality are significantly influenced by the amount, frequency, and method of fertilization (Topalovic et al., 2018). The objectives of this study were (i) to assess the effect of sediments obtained from lake Ol'Bolossat on soil chemical quality and (ii) to determine the effects of the sediments on the growth and yield of Swiss chard.

2.0 Materials and methods

2.1 Sediments collection, site description, and sediments preparation

The lake is situated in Nyandarua County, Central Kenya, at 0°09'S latitude and 36°26'E longitude (Fig 1). The temperatures in this area range between 10°C and 28°C. The area receives a bimodal rainfall of 980mm annually between April and June and between October and November (Karuku & Mugo, 2019).

Sediments were sampled from four different locations in lake Ol'Bolossat, as shown in Fig. 1 below. A Specialty Device, Inc. (SDI) Sediment Sampler Vibe Core and Accessories (Wylie, Texas, USA) were used to collect the samples from the lake depth. The collecting core pipes were sectioned into three levels after collection. The sections were three lake depths; depths of 0-30 cm, depths of 30-60 cm, and depths of 60-90 cm. Each of the three lake depths was considered an independent sample. The collecting pipes were transported to the Jomo Kenyatta University of Agriculture and Technology (JKUAT) laboratory and then were opened to collect the sediments from the different lake depths into separate bags. The plastic bags were zipped. A composite was made by combining sediments from the same lake depth at the four different collection sites. There was a 0–30 cm lake depth composite, a 30–60 cm lake depth composite, and a 60–90 cm lake depth composite.

The wet sediments were air-dried for seven days at the laboratory to prepare them for chemical quality analysis, as shown in Fig 2. After drying, the sediments were ground using a mortar and pestle and sieved using a 2 mm sieve. Sediment samples from the three depths (0–30 cm, 30–60 cm, and 60–90 cm) were then analyzed for the major crop nutrients: nitrogen, phosphorus, and potassium. They were also tested for total organic carbon, E.C., and pH. The analysis was carried out in the JKUAT Department of Horticulture and Food Security soil laboratory.

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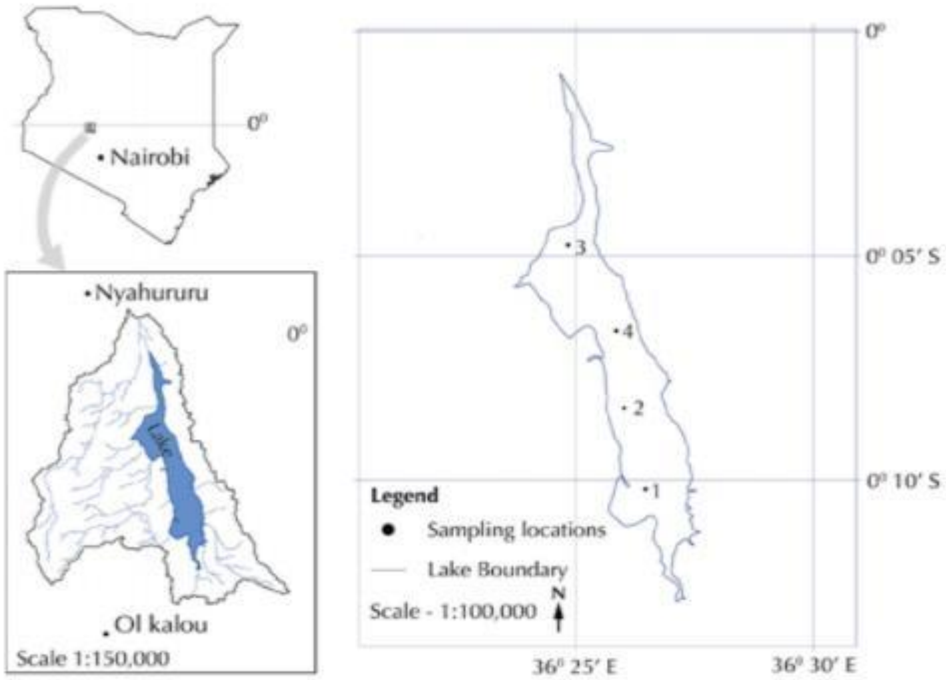

(a) (b)

Fig. 1. Lake Ol' Bolossat's location in Nyandarua County, Kenya (a) and the lake sampling sites 1, 2, 3, and 4 (b)

Figure 2: Drying, grinding, and sieving of the lake sediments in preparation for soil amendment.

Plate 1 (immediately after collection from the lake, locked in aluminum pipes), plate 2 (after opening the aluminum pipes), plates 3 & 4 (final product ready for amending the soil)

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2.2 Greenhouse experimental site and description

From January 2020 to October 2020 (two growing seasons), the pot experiment was conducted in a greenhouse at JKUAT (01°05′ S, 37° 00′ E; altitude of 1530 m) in Juja, Kenya. The site has a typical semiarid monsoon climate type, with an average annual temperature and annual precipitation of 19.8 °C and 675.8 mm, respectively (Luo et al., 2020). In this study, the first crop season was planted on January 24th, 2020, and harvested on April 27th, 2020, and the second crop season was planted on July 13th, 2020, and harvested on October 14th, 2020.

2.3 Experimental design and treatments

A completely randomized pot experiment was set up in the greenhouse. There were five treatments replicated five times. After the chemical quality analysis in the laboratory, the sediments from the different lake depths were separately mixed with soil at a ratio of 1:4. The different depths were considered three treatments. Additionally, the soil was mixed with NPK fertilizer at a rate of 150 kg/acre, as used by farmers as a positive control. To make five treatments, soil with no amendment was used as a negative control. Treatments in this experiment were designed as shown in Table 1 below.

Table 1: The different treatments in this study

Treatments	Treatment details
(T1)	Sediments from lake depth of 0-30cm + soil. Mixed at a ratio of 1:4 (sediments: soil)
(T2)	Sediments from lake depth of 30-60cm + soil. Mixed at a ratio of 1:4
(T3)	Sediments from lake depth of 60-90cm + soil. Mixed at a ratio of 1:4
(T4)	soil + NPK (150kg/acre)
(T5)	Control (soil with no sediments or inorganic fertilizer)

2.4 Methodology

2.4.1 Soil chemical analysis

Before the amendment, the soil was first analyzed for the available nitrogen, phosphorus, potassium, pH, E.C., and total organic carbon. After amending the soil with the lake sediments, chemical analysis was done before transplanting the Swiss chard seedlings, eight weeks after transplanting, and at the end of the season. Samples from each treatment were collected by making a composite from the five replicates. The colorimetric method was used to determine the levels of total organic carbon, and the Kjeldahl extraction method was used to determine the total nitrogen levels. The Mehlich double acid method was used to determine the levels of phosphorus and potassium were determined with a flame photometer (Corning M400, U.K.). The pH was determined using a pH meter by mixing 10 g of air-dried soil sample with 10 ml of distilled water at a ratio of 1:1. Standard buffers were used to measure the pH potentiometrically. The E.C. meter was used to determine the E.C levels after dissolving 10 g of the sample into 20 ml of distilled water at a ratio of 1:2.

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2.4.2 Swiss chard growth and morphological data

Swiss chard seedlings were raised using coco peat in seedling trays. The seedlings were constantly monitored with occasional watering depending on the amount of water in the coco peat. The amount of water in the coco peat was determined by dipping the index finger. The seedlings were not treated with any soil amendment before transplanting. Transplanting was done after four weeks, and the treatments were arranged using a completely randomized design in the greenhouse. The plants were irrigated twice a week, and routine cultural practices were observed.

In this study, morphological data collection started three weeks after transplanting when the plants had more than two leaves. Plant height, leaf width, and the number of leaves per treatment were recorded every seven days. Plant height measurement was done from the ground level to the top of the longest leaf using a meter rule and recorded in centimeters. The number of leaves was counted per plant and recorded. The leaf width was measured across the leaf surface using a meter rule and recorded in centimeters. At 14 weeks after transplanting, the shoots were harvested and dried at 70 °C for 24 hours, and their weight was obtained and recorded as dry matter weight per plant.

2.4.3 Statistical analysis

The data were analyzed by one-way variance analysis (ANOVA). Fisher's Least Significant Difference (LSD) 0.05 test was used to separate the means of differences further when the ANOVA showed significance at the $p<0.05$ level. All statistical analysis was performed using Genstat 17th edition, VSN International Ltd (VSTi), the U.K. All graphs were plotted using Origin Lab 9.1 (the Origin Lab Corporation).

3.0 Results

3.1 Sediments and soil characteristics before the amendment

The lake sediments were found to be rich in nitrogen, phosphorus, potassium, and total organic carbon, as demonstrated in fig 3. Sediments from depths of 0-30cm, 30-60cm, and 60-90cm had 0.3mg/g, 0.35mg/g, and 0.2mg/g of nitrogen, respectively, and the reference soil had 0.1mg/g of nitrogen. The sediments were also rich in phosphorus compared to the soil. They had 6.33mg/kg, 5.33mg/kg, and 6.01mg/kg of phosphorus, while the soil had 0.56mg/kg. The sediments were saline with an average pH of 8. The soil had a pH of 4.7.

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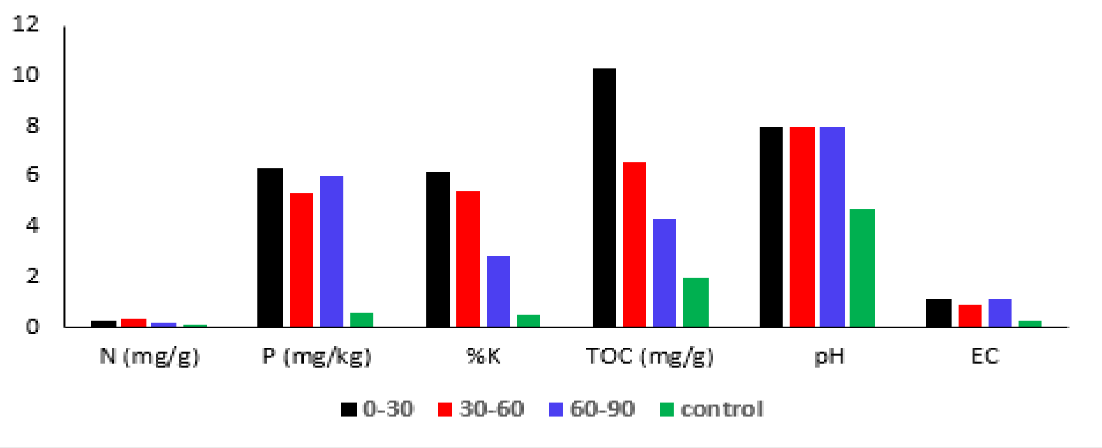
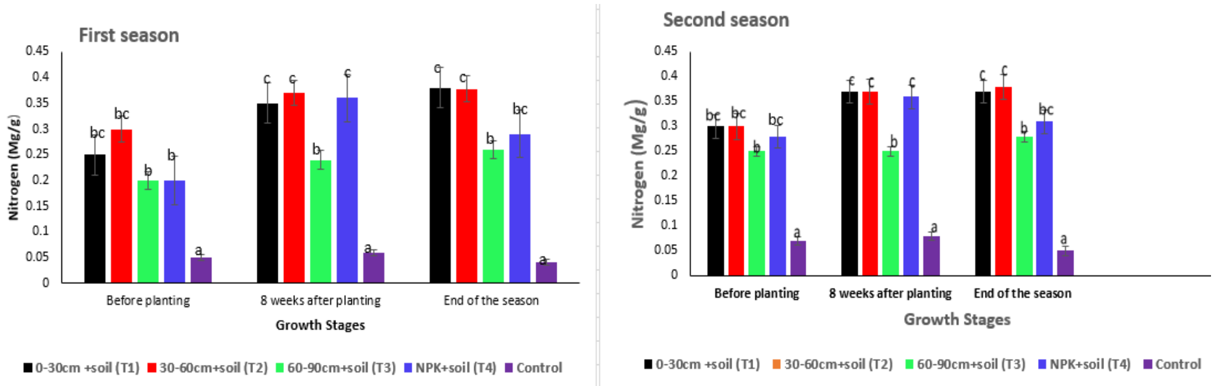


Figure 3: Chemical agricultural characteristics of the lake sediments and soil before the amendment

3.2 Soil quality dynamics under different treatments

3.2.1 Lake Ol'Bossat sediments and nitrogen dynamics

The effect of lake Ol'Bossat sediments on nitrogen dynamics in the first and second planting seasons is shown in Figure 4. The results show that in both growing seasons and all the growth stages, soil N in the control treatment (T5) was significantly lower. In the two seasons, T1 and T2 showed significantly higher levels of N at $p<0.05$ before transplanting. Similarly, T1 and T2 recorded significantly high N (0.38 mg/g) at the end of the first season. In the second season, T1, T2, and T4 recorded significantly higher nitrogen levels than T3 and T5.



(a) (b)

Figure 4: Soil N dynamics as influenced by lake sediments

Where (a) represents the first growing season and (b) represents the second growing season. The different letters on the error bars show significant differences at P<0.05

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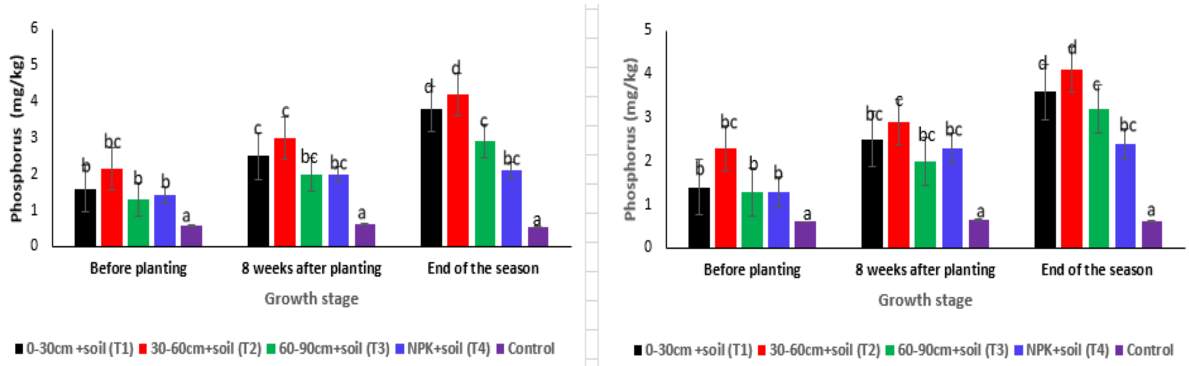
3.2.2 Phosphorous dynamics

The control treatment (T5) recorded significantly lower P before transplanting in the two seasons, as shown in Fig 5. In the first season, T2 had higher P levels before planting (2.2mg/kg), but there was no significant difference in phosphorus levels between treatments T1, T3, and T4 (1.6mg/kg, 1.4mg/kg, and 1.5mg/kg, respectively). T1 and T2 had significantly high P levels at the end of the two seasons ($p<0.05$).

In the second growing season, treatment T2 showed significantly higher P before planting than the other treatments (2.3 mg/kg). P variations at the 8th week after planting showed that treatments T1, T3, and T4 had no significant differences in P levels. In general, there was a significantly higher P at $p<0.05$ in treatments T1, T4, T2, and T3 than in T5 across the Swiss chard growth stages in the two growing seasons.



(a) *(b)*

Figure 5: Soil P dynamics as influenced by lake sediments

Where (a) represents the first growing season and (b) represents the second growing season. The different letters on the error bars show significant differences at P<0.05

3.2.3 Potassium dynamics

In this study, potassium (K) variations among the treatments in the two growing seasons differed across the growth stages. It ranged from 1.2 to 4.3% in both seasons, as shown in Fig 6. Before planting, treatments T1 and T2 had significantly higher K levels than the other treatments in the two growing seasons. Treatments T3 and T4 did not significantly differ in K levels at $p<0.05$ before and after planting in the two growing seasons. Potassium levels in treatments T3 and T4 were significantly higher than in T5 before planting in the two growing seasons. Eight weeks after planting and at the end of the two seasons, K levels were not significantly different in treatments T1, T2, T3, and T4 at a $p<0.05$ significance level.

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ISSN 1561-7645 (online)
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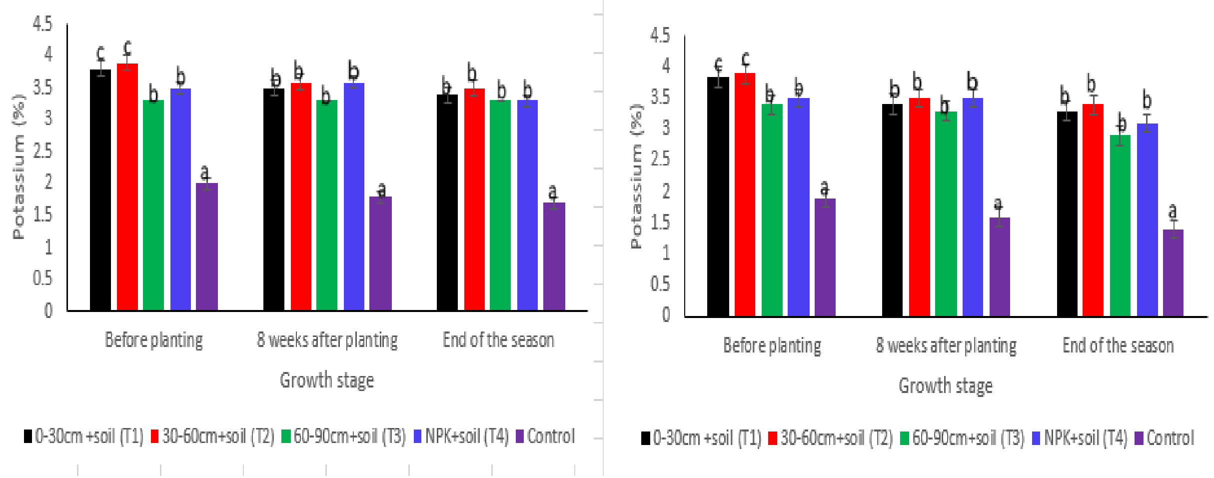
Journal of Agriculture Science & Technology
JAGST 21 (3) 2022, 30-48
(16th JKUAT Conference – Special Issue)



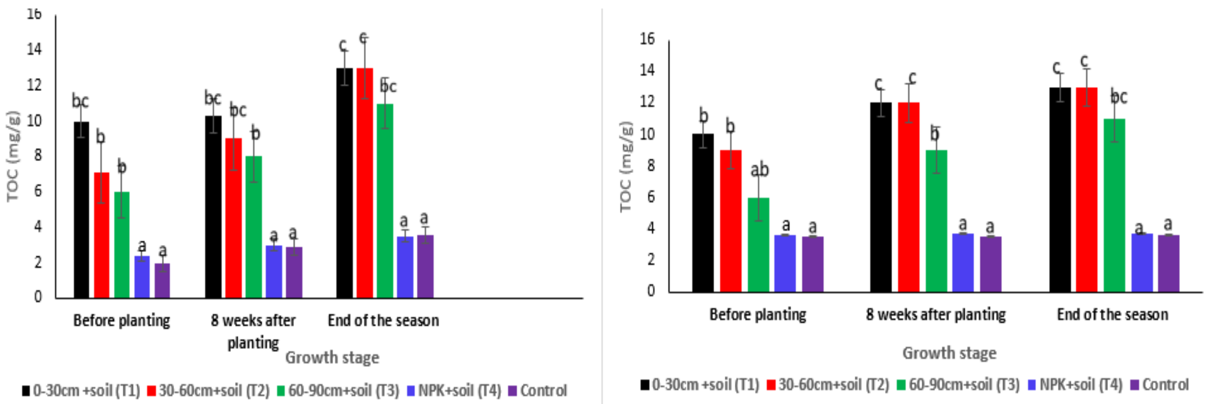
(a) (b)

Figure 6: Soil K dynamics among treatments

Where (a) represents the first growing season and (b) represents the second growing season. The different letters on the error bars show significant differences at P<0.05

3.2.4 Total organic carbon dynamics

In the two seasons, T1 and T2 had significantly high TOC levels at p<0.05. Their means were 10.8 and 11.3 mg/g, respectively. T5 recorded significantly low TOC levels than the other treatments in the two seasons, as shown in Fig 7.



(a) (b)

Figure 7: Variations in Total Organic Carbon (TOC) among the treatments

Where (a) represents the first growing season and (b) represents the second growing season. The different letters on the error bars show significant differences at P<0.05

3.2.5 Effect on pH and electrical conductivity (E.C.)

The pH levels were significantly high in T1, T2, and T3, as demonstrated in figure 8 below. In general, the average pH for the treatments with lake sediments ranged from 6.0 to 6.2, while that of NPK+SOIL and control treatments was 4.0 to 4.5, respectively. A similar trend was

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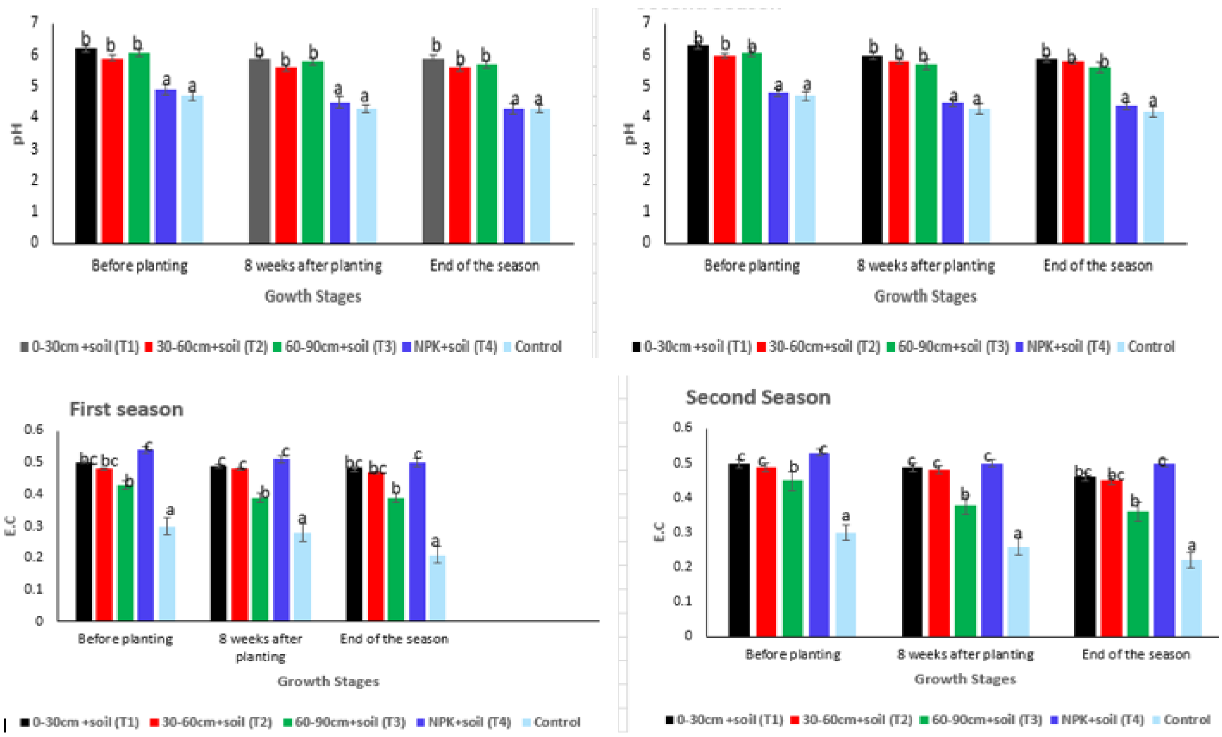
observed in the second season regarding the pH dynamics among this study's treatments. E.C. showed significant differences among the treatments ($p<0.05$). T4 had a significantly higher E.C. in season 1. T1 and T2 did not show significant differences in E.C. levels in the first and second seasons. T1, T2, and T4 did not significantly differ in E.C. 8 weeks after transplanting. In the two seasons, the lowest E.C levels were recorded in T5.



(a) (b)

Figure 8: pH and E.C. dynamics among treatments

Where (a) represents the first growing season and (b) represents the second growing season. The different letters on the error bars show significant differences at P<0.05.

3.3 Effect of the sediments on swiss chard productivity

3.3.1 Plant height variations

The plant height variations under different treatments are shown in figure 9 below. The study showed significant differences in plant height at $p<0.05$ among the five treatments in both growing seasons. In the first season, three weeks after transplanting, plant height under treatments T1, T2, and T4 was not significantly different at $p<0.05$, while T3 and T5 recorded significantly low plant height values in the same period. Significantly high plant heights were recorded in T1 and T2 at the end of seasons 1 and 2. T5 recorded the lowest plant height values in seasons 1 and 2.

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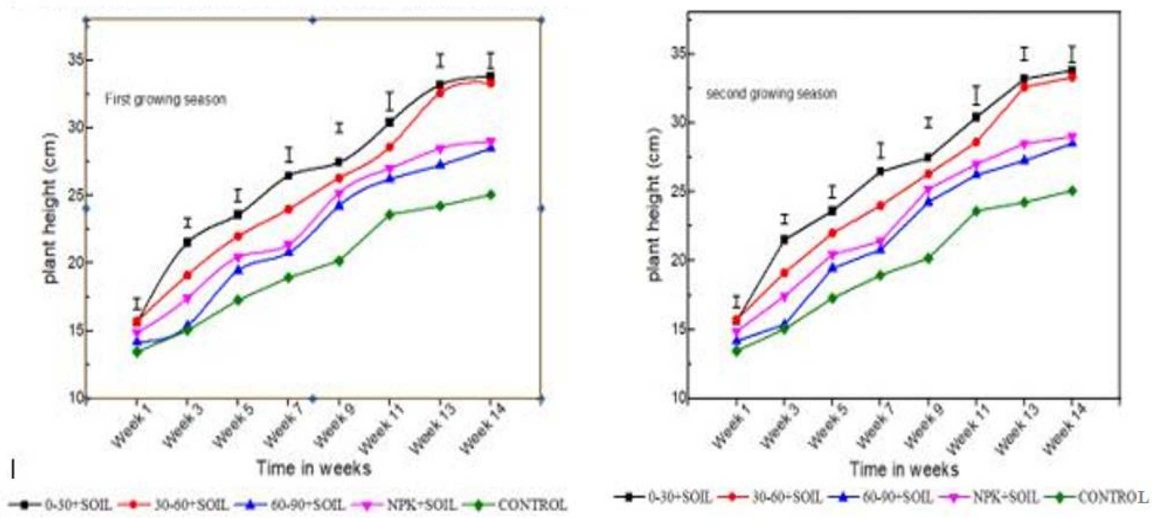

(a) *(b)*

Figure 9: Plant height variations among the treatments in two growing seasons
Where (a) represents the first growing season and (b) represents the second growing season.

3.3.2 Variations in the Number of Leaves

Fig. 10 shows the effects of lake sediments on the number of leaves in Swiss Chard plants. T2 recorded a significantly high number of leaves at the end of season 1 ($p<0.05$), but a significant difference in the number of leaves in T1 and T2 was not observed at the end of season 2. As in the other parameters, T5 recorded a significantly low number of leaves in the two seasons. T1, T2, T3, and T4 did not show significant differences in the number of leaves in the first five weeks after transplanting. In the first three weeks, no significant difference at $p<0.05$ was recorded among all the treatments in the second growing season. In the two growing seasons, the average number of leaves per plant was 8, 9, 6, 8, and 5 cm in treatments T1, T2, T3, T4, and T5, respectively.

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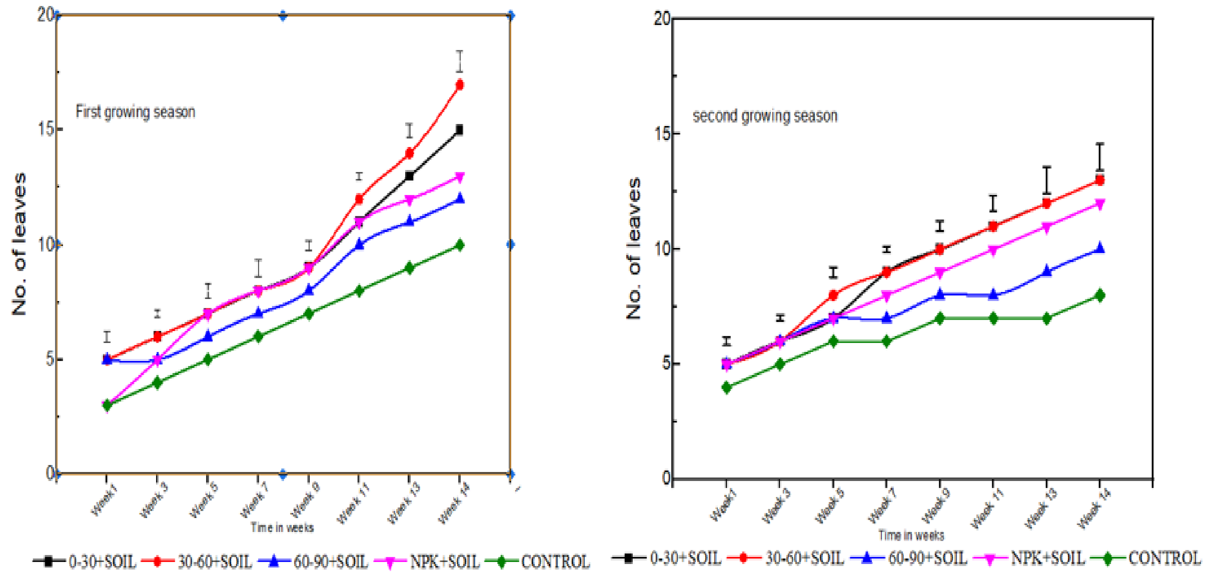

(a) *(b)*

Figure 10: Variations in the number of leaves among the treatments
Where (a) represents the first growing season and (b) represents the second growing season.

3.3.3 Leaf length dynamics

The variation in leaf length in the two growing seasons is shown in Fig.11 below. Swiss chard leaf length under T5 was significantly lower ($P<0.05$) than in the other treatments. In the first season, the first seven weeks after transplanting did not show significant differences in treatments between T1, T2, T3, and T4. T2 recorded a significantly higher mean leaf length in weeks 13 and 14. T1 and T2 showed significantly higher leaf length in season 2. Treatment T2 recorded the highest leaf length of 24.4 cm, and treatments T1, T3, T4, and T5 recorded a leaf length of 22.8, 19.8, 21.2, and 17 cm, respectively, in season 2.

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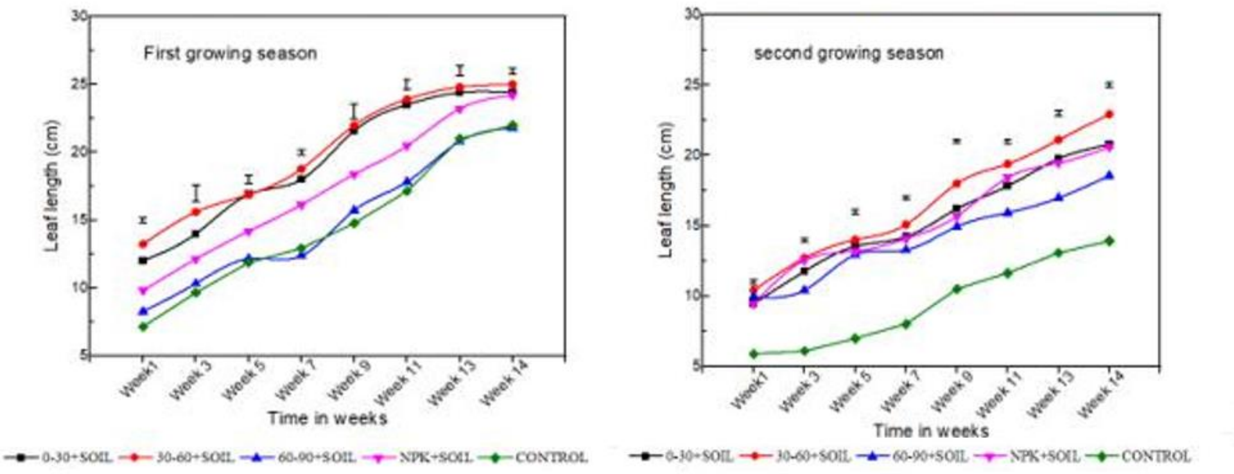


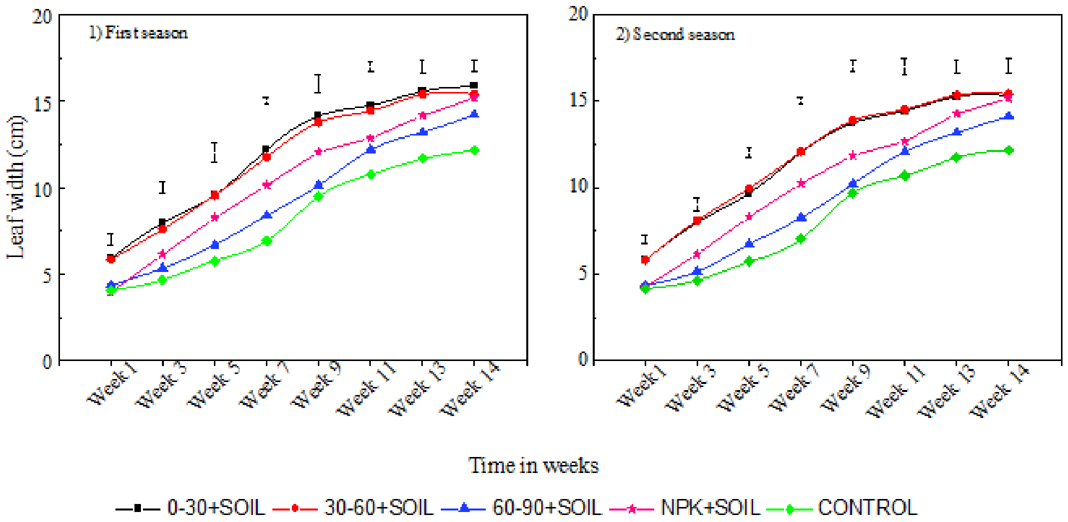
(a) (b)

Figure 11: Leaf length variation among the treatments

Where (a) represents the first growing season and (b) represents the second growing season.

3.3.4 Leaf width variations

In season 1, the study revealed that leaf width under the control treatment was significantly lower ($p<0.05$) than in other treatments, as demonstrated in Fig. 12. Plants in treatments T3 and T5 did not show significant differences in leaf width in the second season. Plants in treatments T1 and T2 did not show a significant difference in leaf length at the end of season 1. The two treatments recorded significantly high leaf width values at the end of the season but showed no significant differences between them. The leaf width in all the treatments increased with time.



(a) *(b)*

Figure 12: Leaf width variation among the treatments

Where (a) represents the first growing season and (b) represents the second growing season.

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3.3.5 Shoot Dry Matter

Swiss chard dry matter was significantly impacted by lake sediments. At p<0.05, treatments T1 and T2 recorded significantly higher dry matter (g/plant) compared to the other treatments. T3 and T4 did not have a significant difference in dry matter content. The order of increasing Swiss chard dry matter was T5<T3=T4<T1=T2.

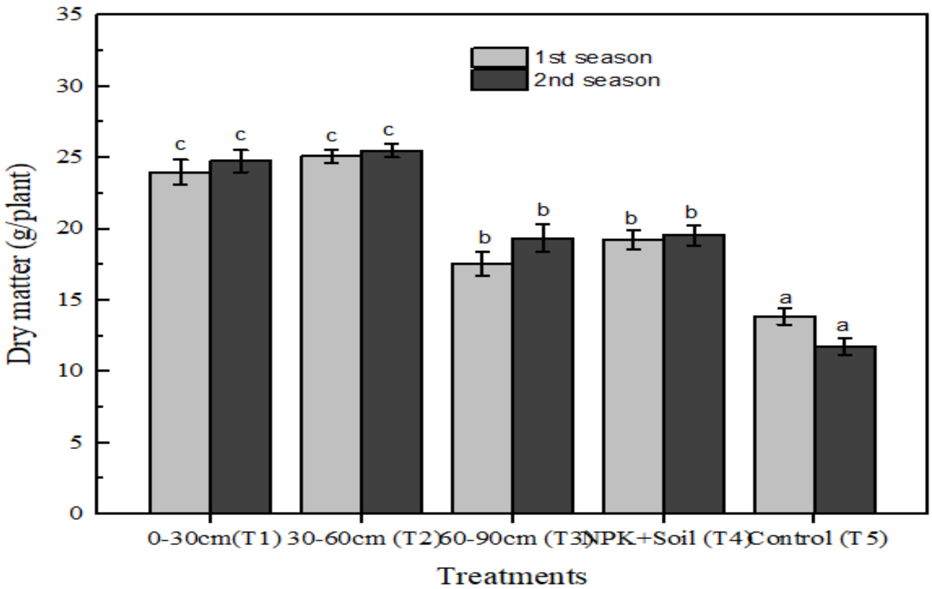

Figure 13:Dry matter variation among the treatments in the two growing seasons. The different letters on the error bars show significant differences at p<0.05

4.0 Discussion

The study has shown that sediments from different lake depths directly affect soil quality and Swiss chard growth characteristics. Sediments positively affected the vegetable's growth characteristics due to the improved soil quality when used as a soil amendment. Through this study, the sediments were found to be rich in the plant's major nutrients (N, P, and K), as shown in fig 3. The effects of the sediments depended on the depth of the lake at which the sediments were obtained. Swiss chard and soil chemical characteristics at lake depths of 0–30 cm (T1) and 30–60 cm (T2) had the highest impact on the soil chemical characteristics and Swiss chard's production. The lake sediments increased the reference soil's nitrogen, phosphorus, and potassium content. According to the results, the sediments had a continuous positive effect on the soil chemical quality throughout the season compared to treatment T4, which had the NPK. However, the effect of the sediments decreased with increasing lake depth because the nitrogen, phosphorus, and potassium levels reduced as the lake depth increased, as shown in figures 4, 5, and 6.

The sediments' positive impact could also be attributed to the presence of phosphate-solubilizing and nitrogen-fixing bacteria, as found by Wafula & Murunga (2020). Their research on the isolation and identification of the beneficial bacteria in lake Ol'Bolossat sediments

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doi: 10.4314/jagst.v21i3.4

identified nitrogen-fixing and phosphate-solubilizing bacteria whose count decreases with increasing lake depth. Moreover, the highest microbial counts were found in the upper layer of the lake sediments. Sediments have inherent fertility due to their high content of macronutrients N, P, and K. Currently, dredged sediments are directly used as fertilizers or soil amendments because they are known to improve soil fertility and increase crop production. Directly reusing nutrient-rich sediments has decreased the quantity of P-fertilizers utilized in agriculture. The sediments upsurge the soil's organic matter and cation exchange capacity, improving the soil's chemical, physical, and microbiological fertility (Renella et al., 2021).

In this study, nitrogen (N) content in treatments T1 (depth 0-30cm+soil), T2 (depth 30-60cm+soil), and T4 (NPK+soil) ranged from 0.1 to 0.4 mg/kg in both growing seasons. There were significant ($p<0.05$) treatment effects on the residual soil N concentration (Fig.4). Soil N levels associated with treatments T1 and T2 were significantly higher than those in treatments T4, T5 (with no amendment or inorganic fertilizer), and T3 (60-90 cm depth) at $p<0.05$, suggesting that the plants did not exhaust N from these added amendments. The high N content observed in soil with lake sediments could be due to the slow release of nutrients through mineralization from the lake materials (Basapuram, 2018). The results were in line with Baksiene's results. In his research, he aimed to assess the effect of lake sediments on the fertility of Cambisol. He found that lake sediments increased the total soil nitrogen by 0.002-0.021 percentage units (Baksiene, 2009). The NPK fertilizer application significantly increased N content compared to treatments T5 and T3. The highest N concentration was observed in T2 in both growing seasons.

Phosphorus (P) content in treatments with lake sediments ranged from 1.0 to 4.4 mg/g in the two growing seasons. P content was significantly higher in treatments with lake sediments, as demonstrated in fig 5. According to Fonseca et al. (2003), available forms of phosphorus in lake sediments exceed the values for soils. The high levels are attributed to Fe-P and Al-P being the major phosphorus combinations in the lake sediments. These fractions are the major sources of soluble P. Moreover, lake sediments have mineralogical and chemical conditions essential to organic matter solubility and the mineralization of adsorbed P on organic/mineral particle surfaces (Fonseca et al., 2003).

The lake sediments had high levels of total organic carbon. The upsurge could be due to organic matter decomposition, soil erosion from neighboring farmlands, or atmospheric deposition. TOC and total nitrogen content are essential parameters when determining the quality of sediments for agricultural use. The organic carbon in sediments is majorly derived from the decomposition of plants, animals, plankton, or anthropogenic sources like organic-rich wastes in the lake. In pots treated with lake sediments, soil residual K was higher than in the control treatment (T5). The most increased soil residual K was observed in pots where soil sediments were obtained from 0–30 and 30–60 cm lake depths.

In this study, pH was significantly ($p<0.05$) affected by different sediment treatments. The soil used as a control had a pH of 4.7, which was significantly lower than in the other treatments.

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ISSN 1561-7645 (online)
doi: 10.4314/jagst.v21i3.4

The application of lake sediments increased the soil pH to an average of 6. These results indicate that lake sediments have a liming effect that is critical in improving low soil pH areas. According to Rahman & Ranamukhaarachchi (2004), using sediments as amendments increases soil pH and enhances the availability of nutrients. Moreover, Darmody & Diaz (2017) showed an increase in soil pH from 5.4 to 7.2 after applying lake sediments as a soil amendment in research to determine the dredged sediments' effect on corn and soybean production. The low pH and low nutrient content in the control treatment (T5) could have enhanced the low Swiss chard productivity because soil acidity is hazardous to crop production. Some hazards are inhibited plant nutrient uptake, repressed root growth, and reduced water uptake (Mugai et al., 2008).

In this study, there was a positive effect of lake sediments on the productivity of Swiss chard as shown by better crop performance, particularly in the Swiss chard dry matter in treatments with soils amended with lake sediments than in those without the amendments. The positive effects on Swiss chard productivity under treatments T1 (0–30 cm+soil) and T2 (30–60 cm+soil) could be attributed to the higher macronutrient levels observed in the sediments. A study conducted on Dongting lake suggested that the impact of lake sediments on agricultural soils and their macronutrient content depends on the depth of sediment extraction and the rate applied to the soil (Wang et al., 2014). Sediments contain a high quantity of fine particles rich in soil organic matter, nitrogen, and potassium to enhance crop productivity. Lake sediments have a less complex physical structure as compared to agricultural soils. Organic matter in these sediments is solely from surface deposits sorted into well-defined layers by the overlying water in the lake (Lim et al., 2011). Studies have shown that oxygen in lakes enhances biogeochemical processes, resulting in enhanced sediment quality due to defined physiochemical layers (Groffman & Bohlen, 1999). Human activities such as crop growing and grazing along the banks of the lake have increased the level of nitrogen loading in lake Ol'Bolossat (Karuku, 2019).

Using lake sediments as a soil amendment improved soil quality and enhanced crops' effective uptake of soil nutrients. The efficient uptake of crop nutrients increased the Swiss chard production by approximately 30% compared to the reference soil. This was realized through the recorded high plant height (fig 9), leaf length (fig 10), leaf width (fig 11), number of leaves per plant (fig 12), and the dry matter content, as demonstrated in fig 13, throughout the two seasons. In previous studies, sediments led to an over 40% increase in wheat production when used as a soil amendment (Mao et al., 2018). The increase in yield due to the effect of the lake sediments in the current study is similar to what Darmody (2017) found out after conducting field research on tomatoes, beetroot, carrots, and turnips, in which the yield increased by 35%. The sediment's fertility influenced this increased production because it is rich in the plant's major nutrients, N, P, and K.

Plants and other lake sediment enhancement in lake Ol'Bolossat improved soil structure and fertility. The deposits impact soil air and water movement, increase humus content, and enhance the soil's practical nitrogen and phosphorus cycling. Using lake sediments as a soil

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amendment improves the soil's moisture storage capacity and results in high porosity, resulting in improved crop productivity by 9–15% (Murunga et al., 2020). Deposits from lake Ol'Bolossat obtained from 0–60 cm depth improved crop yield, as shown in this study. The results confirmed that sediments play an imperative role in improving the quality of soils and agricultural productivity.

5.0 Conclusion

Lake sediments mixed with soil positively affected net growth indices and productivity of Swiss chard (*Beta vulgaris* L.), as evidenced by the positive effect on Swiss chard dry matter compared to a single application of NPK fertilizer and soil without sediment amendments. Besides, using sediments as soil amendments leads to improved soil fertility, as evidenced by high N, P, K, and TOC contents in treatments with lake sediments. Lake sediments can improve soil fertility and provide the required plant nutrition in less fertile farmlands, making them efficient components for soil amendment programs to boost fertility, especially in smallholder agriculture. Further, amending the soil with lake sediments is an excellent measure of reducing soil acidity. In this study, sediments increased the soil pH to make it more favorable for Swiss chard growth. This study has shown that farmers can use sediments from lake Ol'Bolossat to amend the soil, improve soil fertility, and increase crop yield.

6.0 Acknowledgements

6.1 Funding

This study was part of a master's thesis and was partly financed by the Japan International Cooperation Agency (JICA) through the AFRICA-ai-JAPAN Project Innovation towards improving food security through innovative biotransformation and value addition of major locally available biological resources [Project number: JFY 2019/2020].

6.2 Analysis and Research

The analysis and research were conducted in the Department of Horticulture and Food security soil laboratory and greenhouse, at Jomo Kenyatta University of Agriculture and Technology.

6.3 Presentation of the study, findings, and a portion of the work

These preliminary findings were presented in abstract communication and poster presentation at the 16th JKUAT scientific, technological, and industrialization conference held at Jomo Kenyatta University of agriculture and technology, Kenya, from March 24 to 25, 2022. This paper's abstract may be found at: https://drive.google.com/file/d/1pCiWvu_euU7VfS-_Q4krXYViWSeFelml/view from the 16th JKUAT and 1st Hybrid Scientific Conference.

6.4 Declaration of interest

All authors declare that they have no conflict of interest. The authors retain the copyright of this work.

This paper's opinions, assessments, knowledge, and conclusions are exclusively the authors' and they are responsible for the content, editing decisions, manuscript composition,

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ISSN 1561-7645 (online)
doi: 10.4314/jagst.v21i3.4

viewpoints expressed, acceptance of the final content, and consent to publish if any errors remain. The manuscript studies were organized in a chosen manner based on their relevance to the subject matter and predicted work quality, rather than being exhaustive in fulfillment of the requirements for obtaining the degree "MSc in Horticulture."

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