Impact of irrigated and non-irrigated cropping systems on soil physicochemical properties in a small-scale irrigation farming system in Eastern Uganda

Issa Kaduyu¹ and Patrick Musinguzi²

¹Department of Agricultural and Biosystems Engineering, Botswana University of Agriculture and Natural Resources, Private Bag 0027, Gaborone, BOTSWANA
²Department of Agricultural Production, School of Agricultural Sciences, Makerere University, P.O Box 7062, Kampala, UGANDA

Citation of this article: Kaduyu, I., & Musinguzi, P. (2021). Impact of irrigated and non-irrigated cropping systems on soil physicochemical properties in a small-scale irrigation farming system in Eastern Uganda. Archives of Agriculture and Environmental Science, 6(3), 313-319, https://dx.doi.org/10.26832/24566632.2021.060308

INTRODUCTION

Globally, irrigation remains key to food supplies. Its importance will rise in future when the demand for food increases, whilst the reliability of yields from rain-fed agriculture may decline due to climate change. There has been an increase in climate scenarios in many agro-ecological regions globally (Lobell and Gourdji, 2011). The increasing intensity of climate change has significantly impacted global crop productivity (Lobell et al., 2011). Climate change has become a threat to food security, especially in developing countries. Therefore, tomorrow’s agriculture is challenged by increasing global demand for food, scarcity of arable lands, and resources alongside multiple environmental pressures, presenting the need to be managed smartly through sustainable and eco-efficient approaches.

Several farming communities have widely adopted irrigation practices to improve crop water availability during water scarcity induced by climate change. In recent decades, the amount of land irrigated, the type of irrigated cropping systems and the quantity of irrigation water used have increased substantially. These trends are expected to increase in the future. It is therefore ideal for assessing the impact of irrigation on soil quality. However, despite the varying nature of the impact of irrigation, most studies only assess impacts of water quality on soil properties (Abd-Elwahed, 2018, 2019; Alrajhi et al., 2017; Ayoub et al., 2016; Bastida et al., 2017; Che et al., 2021; Ganjegunte et al., 2017; Eid et al., 2021). Other studies assessed the variation of soil properties between irrigated and rain-fed (Makoi, 2016),
while others compare impacts across time intervals (Shang et al., 2019). The impact of irrigation across different cropping systems has attracted less attention.

The effects of cropping systems vary differently across different soil types and management practices (Nataliya and Lenssen, 2018). Variation of soil quality in different cropping systems has attracted increasing interest in assessing soil physicochemical and biological properties. Although the design of most cropping systems ensures maximum crop yields and returns, it is necessary to maintain soil health and productivity (Subhadi et al., 2019). Existing studies on cropping systems have majorly focused on crop yields as influenced by soil fertility and their effect on soil properties without considering management practices (Amsili et al., 2021; Mikha et al., 2006; Wienhold et al., 2006; Yang et al., 2020). Nataliya and Andrew (2018) compared the soil quality of fertilised and unfertilised cropping systems on different soil types in South-Central Uganda. Tesfahunegn and Gebru (2020) examined variation in soil properties across different cropping systems and land-use systems in northern Ethiopia. Tesfahunegn and Gebru (2019) also examined variation in soil properties in the long term irrigated and non-irrigated cropping and land-use systems in Ethiopia. However, the sustainability of cropping systems in maintaining soil quality is highly dependent on how farmers understand the response of their soils to site-specific land management practices.

Despite the numerous studies on irrigation and cropping systems, the environmental impact of irrigation is site-specific and highly variable yet, not well documented in developing countries. In Uganda, the effect of different land uses on the physiochemical soil properties is evident (Dissanayake et al., 2015; Mugagga, 2015). Nevertheless, knowledge of the variation of soil chemical and physical properties of irrigated soils under different cropping systems remains limited amongst farmers in Uganda. However, some of the impacts of irrigation and cropping systems can be severe, as demonstrated in different studies. Lack of knowledge about soil quality and management among farmers exacerbates farming communities’ food security challenges, putting at stake the livelihoods of over 90% of Ugandan farmers (Mutegi et al., 2012; Nkonya et al., 2004). In addition, the relationship between soil quality decline under different land-use practices in Uganda has attracted less attention among farmers. There is an urgent requirement to assess the impact of irrigation and cropping systems on soil properties in different parts of Uganda.

Most government and non-government agencies have increased efforts to scale out irrigation on small-scale farms in Uganda. However, the lack of knowledge on its effect on soil properties jeopardises the sustainability of irrigated agriculture in Eastern Uganda. The effort to characterise the impact of irrigation practices under different cropping systems on a spatial and temporal scale is critical in understanding ecosystem changes and designing improved soil management practices to ensure sustainable production under irrigated agriculture. This study; i) evaluated the impact of irrigation on the physical and chemical soil properties and ii) determined the impact of irrigated and non-irrigated fields under annual and perennial cropping systems on physical and chemical soil properties in a small irrigation scheme in Jinja, Eastern Uganda. Therefore, farmers that might attain knowledge from this study would be aware of the effect of irrigation on soil quality and determine the best management of different irrigated cropping systems. Awareness of these impacts ensures the sustainability of irrigated agriculture and reduces the impact of irrigation and cropping systems on the environment.

MATERIALS AND METHODS

Description of the study area

The present study was conducted at Kyekide small scale irrigation farm in Eastern Uganda. The farm is located at 0°29’26 N and 33°10’32 E, 1148 m above sea level along Jinja-Kamuli High way in Kyekide village, Buwenda Parish, Mafubira Sub County, Jinja district. The irrigation scheme covers over twenty acres of land in the East of Jinja district. The favourable tropical climate is characterised by bimodal rainfall, and temperatures between 17 °C and 28 °C have favoured crop production. Irrigation practices ensure continuous productivity all year round. Clayey soils are the predominant soil type. Perennial and annual cropping has been carried out for over 20 years, both under sprinkler irrigation and rain-fed. Several perennial crops are grown at the farm, including; ivy gourd (Coccinia grandis), sugarcane (Saccharum officinarum), and coffee. On the other hand, annual crops grown include; maize (Zea mays), bitter gourd (Momordica charantia), eggplants (Solanum melongena), cucumber (Cucumis sativus), bottle gourd (Lagenaria siceraria), kale, spinach, common beans, sweet potatoes and tomatoes.

Experimental design and treatments

A completely randomised design was used for the study. Four treatments were considered for this study: Irrigated Perennial, Non-irrigated Perennial, Irrigated annual and non-irrigated annual fields. A single plot of ≥ 0.5 acres was selected for each of the treatments. A plot of irrigated ivy gourd (Coccinia grandis) was selected for irrigated perennial, irrigated bitter gourd (Momordica charantia) for the irrigated annual field, rain-fed maize (Zea mays) plot for non-irrigated annual field and a plot of rain-fed sugarcane (Saccharum officinarum) for the non-irrigated perennial field. The study plots were randomly selected, and the management history of the study plots was recorded for the previous years.

Soil sampling

At each study plot, four replicate plots, each measuring 20 m × 30 m, were demarcated before sampling. The soil was sampled randomly between plants and rows using soil core rings along a transect within each replicate plot. Samples were collected to a 0-30cm depth after removing litter and surface residues (Okalebo et al., 2002). The soil cores were air tightened and placed in plastic bags. Sixteen soil core rings (4 treatment plots × four replicate plots) were collected for bulk density and hydrau-
lic conductivity laboratory analyses. An additional four composite samples were collected using a soil auger to determine soil chemical properties in each plot. Four random samples were collected for each replicate plot, thoroughly mixed, and a composite sample was picked for analysis of soil textural, pH, electrical conductivity (EC), total soil organic carbon (SOC), total Nitrogen (TN), available phosphorous (P), Calcium (Ca\(^{2+}\)), Potassium (K\(^{+}\)), sodium (Na\(^{+}\)) and Magnesium (Mg\(^{2+}\)).

**Laboratory analysis**

Laboratory soil analysis was carried out using standard laboratory procedures at Makerere University Soil and plant analytical laboratory. Soil samples were sieved through a 2-mm mesh after air drying to discard roots and coarse plant debris. The soil hydraulic conductivity was determined using the constant head method (Diminescu et al., 2019), and bulk density (g cm\(^{-3}\)) was determined using the soil core rings and calculated according to the weight of the soil in the core ring of known volume after oven drying at 105 °C for 48 hours. Sieved (<2mm) air-dried soil was used to determine soil texture using the Bouyoucos hydrometer method (Okalebo et al., 2002).

The pH was measured with a pH meter at a ratio of distilled water: soil of 1:2.5, while EC was measured using a conductivity meter at a ratio of 1:1 of distilled water: soil. A Sieved (<0.02 mm) air-dried soil sample was used for the determination of SOM (%) using Walkley-Black oxidation and titration methods (Okalebo et al., 2002). Exchangeable cations (K, Mg, Ca, and Na) were extracted using ammonium acetate solution. Na and K were then determined using flame photometry, while Ca and Mg by atomic absorption spectrophotometry. Total phosphorus was determined using the colorimetric method (Okalebo et al., 2002).

**Data analysis**

A two-way analysis of variance (ANOVA) was conducted using Gen-stat 14th Edition (VSN International, 2011) to determine the differences in soil chemical and physical properties at a 5% probability level. The Least Significant Difference (LSD) was used to separate the means at a 95% confidence interval.

**RESULTS AND DISCUSSION**

**Impact on soil physical properties**

Soil texture: Generally, no significant differences (p > 0.05) in the impact of irrigation were observed on sand, clay and silt content. However, non-irrigated soils had more clay than irrigated soil; thus, the irrigated soils had more sand and silt than the non-irrigated soils (Table 1). Additionally, the interactive impact of irrigation and cropping systems showed no significant (p > 0.05) variation (Table 2). Overall, the soils at the study site of both irrigated and non-irrigated fields were sandy clay loam with greater than 30% clay and more than 50% sand content. The lower clay content in the irrigated plots could be due to the leaching effect associated with irrigation. These results do not align with those of (Tesfahunegn and Gebru, 2019), who found significant differences in soil texture in irrigated and non-irrigated land uses. The differences in soil type and management practices applied could explain the differences. Variation in soil quality, therefore, seems site-specific and is driven by existing management practices.

Non-irrigated annual cropped soils registered higher sand content than perennial non-irrigated soils, and this may be due to erosion that carries away the fine particles leaving sandy particles, especially for the annual cropping. Cropping systems such as perennial cropping increase soil organic carbon and reduce soil degradation due to erosion that results from continuous tillage in the annual cropping systems (Jin et al., 2021). These processes explain the higher sand content in annually cropped soils left after erosion impacts.

**Table 1. Variation in soil physical properties as influenced by irrigation.**

| Texture | Clay % | Sand % | Silt % | BD (mg/m²) | Ksat (cm/hr) |
|---------|--------|--------|--------|------------|--------------|
| Irrigated | 30.50 \(^a\) | 49.25 \(^a\) | 20.25 \(^a\) | 0.952 \(^a\) | 0.291 \(^a\) |
| Non-irrigated | 34.38 \(^a\) | 48.62 \(^a\) | 17.00 \(^a\) | 1.034 \(^a\) | 0.231 \(^a\) |
| LSD (5%) | 4.0488 \(^NS\) | 4.1454 \(^NS\) | 3.5649 \(^NS\) | 0.0998 \(^NS\) | 0.0564 \(^**\) |

* \(^**\) significant at p<0.05, NS Not significant.

**Table 2. Variation in soil physical properties as influenced by irrigation and cropping.**

| Texture | Clay (%) | Sand (%) | Silt (%) | BD (mg/m²) | Ksat (cm/hr) |
|---------|---------|---------|---------|------------|--------------|
| Irrig. Anl | 32.00 \(^a\) | 45.5 \(^a\) | 22.50 \(^a\) | 0.91 \(^a\) | 0.27 \(^ab\) |
| Irr. Pnl | 29.00 \(^a\) | 53.00 \(^b\) | 18.00 \(^ab\) | 0.98 \(^a\) | 0.31 \(^b\) |
| Non. irri. Anl | 32.625 \(^a\) | 50.00 \(^ab\) | 16.75 \(^b\) | 1.04 \(^a\) | 0.25 \(^ab\) |
| Non. Irri. Pnl | 32.625 \(^a\) | 47.25 \(^ab\) | 16.25 \(^b\) | 1.02 \(^a\) | 0.21 \(^a\) |
| LSD (5%) | 5.7259 \(^NS\) | 5.8624 \(^NS\) | 5.0416 \(^NS\) | 0.1411 \(^NS\) | 0.0797 \(^NS\) |

Irri- irrigated Nin-irri- Non-irrigated Anl- annual Pnl-perennial NS- Not significant.
Bulk density: Bulk density did not vary significantly (p > 0.05) with irrigation and cropping systems (Table 1). However, non-irrigated soils had higher bulk density than irrigated soils. Irrigated perennial cropped soils had a much lower bulk density than non-irrigated annual soil (Table 2). These results align with previous studies that reported non-significant bulk density variation with irrigation and cropping systems in Ethiopia (Tefahunegn and Gebru, 2019). The lower bulk density for irrigated perennial and annual soils could be due to the higher organic matter content that improves the soil physical properties (Table 2). The lower bulk density of perennial irrigated soils accounts for the higher saturated hydraulic conductivity. Perennial irrigated soils accumulate more organic matter than non-irrigated perennial cropped soils due to minimal soil disturbances, thus less compaction. The average bulk density (0.993 mg/m³) for the soil of the study area was above the critical range of 1.30 and 1.60 mg/m³ for fine-textured soils (Skopp, 2011).

Hydraulic conductivity: The hydraulic conductivity varied significantly (p < 0.05) with irrigation practices. Irrigated soils had a significantly higher saturated hydraulic conductivity than non-irrigated soils (Table 1). However, the interactive impact of irrigation and cropping had no significant impact on hydraulic conductivity (Table 2). The significant impact of irrigation suggests that irrigation rather than cropping has a considerable effect on hydraulic conductivity. These results do not align with Alrajhi et al. (2017), who found no significant differences in soil hydraulic conductivity for different irrigation scenarios. Soils with a low bulk density have more macrospores that allow more water through infiltration than soils with higher bulk density. Thus, the significantly higher Hydraulic conductivity of irrigated soils could be due to the low bulk density induced by the improved physical properties. The improved physical properties could be explained by the higher soil organic matter observed in irrigated soils. Availability of soil organic matter significantly reduces soil compaction resulting in improved hydraulic conductivity (Amsili et al., 2021). These results, therefore, suggest an increase in macro-porosity in irrigated soils which accounts for the higher hydraulic conductivity.

Impact on chemical properties: Organic matter, total nitrogen and phosphorus: Results from the ANOVA indicate that Organic matter varied significantly (p < 0.05) with the impact of irrigation (Table 3).

Irrigated fields had significantly higher organic matter compared to non-irrigated fields. The higher SOM in irrigated soils could be due to the all-year crop growth enhanced by irrigation compared to rain-fed fields. Additionally, the increased cropping leads to more crop residues that decompose into soil organic matter. The accumulation of organic matter in the irrigated soils dramatically improves the soil chemical properties. The TN and P content varied significantly with the impact of irrigation. The TN and P content were higher in irrigated soils than non-irrigated soils. Irrigated soils had 0.064% more N and 88% more P than non-irrigated soils (Table 3). High organic matter content in the soils leads to higher soil nutrients and pH. For example, soils with high organic matter have higher N content released from the mineralisation process of organic matter.

Table 4 indicates the variations of chemical properties with irrigation and cropping system. The impact of irrigation on SOM had no significant differences (p > 0.05) under annual and perennial cropping. However, the higher SOM content observed in irrigated perennial and annual cropped soil is more noteworthy than non-irrigated perennial and annual cropped soils (Table 4). These results are consistent with previous studies showing more significant organic carbon in perennial cropped soils than annual ones (Sprunger et al., 2019). Shang et al. (2019) also observed increased organic carbon in perennial forages for dry soils compared to annual crops. The significant increase is attributed to the continuous growth that enhances the below-ground biomass carbon pool (Shang et al., 2019).

Total N and available P did not vary significantly (p > 0.05) with irrigation and cropping system. Perennial irrigated soils had a higher non-significant level of total N and P (Table 4). The higher TN and P implies that the above-ground crop residue in perennial cropped soils favoured the cycling of N and P compared to annually crops (Ferrarini et al., 2021; Liu et al., 2021). The increased recycling could be due to the increased microbial activity in perennial cropped and irrigated soils compared to annually cropped soils (Ferrarini et al., 2021; Pascazio et al., 2018; Sprunger et al., 2019). These results suggest that irrigation in cropping systems improves nitrogen and phosphorus availability, which are essential nutrients for crop growth. However, soils of the study area were moderately deficient in N and severely deficient in P with the mean values of 0.175% N and 1.183 mg kg⁻¹ P compared with the critical values of 0.2% N and 15 mg kg⁻¹ P, respectively (Okalebo et al., 2002).

| Table 3. Variation in soil chemical properties as influenced by irrigation. |
|---------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| SOM (%)             | TN (%) | pH   | EC (µS/cm) | P (ppm) | K⁺ | Ca²⁺ | Mg²⁺ | Na⁺ (cmol/kg) |
| Irrigated           | 4.147ᵃ  | 0.21ᵃ  | 6.62ᵃ  | 1.91ᵃ  | 3.30ᵃ  | 3.49ᵃ  | 19.45ᵃ  | 6.42ᵃ  | 3.52ᵃ  |
| Non-irrigated       | 3.02ᵇ  | 0.14ᵇ  | 5.81ᵇ  | 1.08ᵇ  | 0.37ᵇ  | 2.09ᵇ  | 12.50ᵇ  | 4.13ᵇ  | 2.39ᵇ  |
| LSD (5%)            | 0.439*** | 0.034** | 0.465** | 0.252** | 1.286*** | 0.270** | 4.351*** | 1.436** | 0.351*** |

** significant at p<0.05 *** significant at p<0.001.
Leaving the soil under crop cover for more extended periods leads to the accumulation of organic carbon in the irrigated perennial cropped soil compared to annually cropped soils with seasonal tillage and harvesting (Sprunger et al., 2019). Previous studies have reported that long-standing vegetation increases organic matter content compared to short-lived vegetation (Overstreet and DeJong-Hughes, 2009). The lower SOM content in non-irrigated annual cropped soils could be due to the soil disturbances through tillage leading to increased SOM turnover due to soil aggregate breakdown (Sánchez–González et al., 2017). The increased aggregate breakdown results in increased soil erosion, lower carbon sequestration and reduced nutrient availability (Rodrigo-Comino et al., 2018).

**ph and electrical conductivity:** The soil pH and electrical conductivity also varied significantly (p<0.05) with the impact of irrigation (Table 3). Irrigated soils had a significantly higher pH (6.62±0.151) compared to non-irrigated soils (5.80±0.1783). Electrical conductivity was 43.13% higher for irrigated soils compared to non-irrigated soils. The higher pH in irrigated soils could be explained by improved SOM content than non-irrigated soils, while the higher EC could be due to increased salt accumulation in irrigated soils. The soil pH varied significantly (p<0.05) with the impact of irrigation and cropping, while electrical conductivity showed no significant variation (Table 4). Irrigated perennial and annually cropped soils had a significantly higher pH compared to non-irrigated cropped soils. The significantly lower pH values in non-irrigated annual cropped soils may be due to the lower organic matter than perennial cropped non-irrigated soils (Table 4).

The grand mean pH of 6.22 for soils of the study area is still within the range of 5.5-6.5 that can favour crop growth (Okalebo et al., 2002). This study’s results agree with those of Alrajhi et al. (2017), who found significant variations in soil pH for different irrigation water qualities, although irrigation scenarios had no significant effects. It appears like irrigation practices improve soil pH, attributed to the increase in soil organic matter that buffers soil acidity. The higher EC observed for irrigated soils is attributed to the increased accumulation of salts enhanced by irrigation.

**Basic cations:** The K+, Mg2+, Ca2+ and Na+ content were significantly (p<0.05) impacted by irrigation (Table 3). Irrigated fields had higher K+, Mg2+, Ca2+ and Na+ than non-irrigated soils. Irrigated soils had 40% higher K than non-irrigated soils. Similarly, irrigated soils had 35.74% more Ca and 35.72% more Mg than non-irrigated soils. Additionally, there were no significant differences (p > 0.05) in the impact of irrigation under perennial and annual cropping on the content of K+, Ca2+ and Mg2+ of the soils under perennial and annual cropping (Table 4). However, irrigation and cropping had had significant impacts on the level of Na+ of the soils under perennial and annual cropping (Table 4). Soils under irrigation had significantly higher basic cations K+, Mg2+, Ca2+ and Na+ content, and this could also be due to the soil management practices such as the addition of animal manure. Farmers that irrigate their fields tend to adopt more improved cropping practices. Makone et al. (2021) also found that irrigation technologies improved agricultural production practices in Kenya. However, results from this study do not align with Adejumobi et al. (2014), who indicated that a decrease in Mg2+ and Ca2+ content in irrigated soils. The study area soils had a high K+ content with a mean of 2.79 cmol/kg K compared to the critical level of 0.3-0.7 cmol kg⁻¹ (Hazleton and Murphy, 2017). Additionally, the mean Mg2+ and Ca2+ for the study area soils were above critical levels with 5.75 cmol/kg and 15.975 cmol/kg compared to the critical levels of 1-3 cmol kg⁻¹ and 5-10 cmol kg⁻¹, respectively (Hazleton and Murphy, 2017). The average Na+ observed for the study area was 2.93 cmol of Na/kg, which appears to be far greater than the recommended level of 0.1 cmol/kg for successful crop growth. The high sodium content for irrigated soils may be attributed to the study site’s poor drainage and irrigation practices, as salts tend to accumulate in the topsoil over time. Several previous studies have also reported an increased salt accumulation with irrigation (Che et al., 2021; Makoï, 2016). High sodium levels have a dispersing impact in the soil leading to poor soil structure by dispersing soil colloids such as organic matter and clay (Awedat et al., 2021). Additionally, increased electrical conductivity due to salt accumulation due to irrigation also affects plant growth and other essential processes in the soil. These results suggest the need to ensure appropriate salt content of the irrigation water to prevent further accumulation of salts.

**Conclusion**

The cropping systems influence the sustainability of irrigation practices carried out for given land use. Hence, farming communities should adopt soil quality monitoring under a

---

**Table 4. Variation in soil chemical properties as influenced by irrigation and cropping.**

| SOM | N | pH | EC (µS/cm) | P | K⁺ | Ca²⁺ | Mg²⁺ | Na⁺ |
|-----|---|----|------------|---|----|------|------|-----|
| ----|---|----|------------|---|----|------|------|-----|
| Irrig. Annual | 4.02 a | 0.19 a | 7.01 a | 1.81 a | 2.77 ab | 2.87 a | 21.40 a | 7.06 a | 4.06 a |
| Irri. Perennial | 4.27 b | 0.23 b | 6.24 ab | 2.00 b | 3.84 b | 4.10 b | 17.50 b | 5.78 ab | 2.99 b |
| Non. irri. Anl | 2.66 b | 0.12 b | 5.44 b | 0.98 b | 0.15 b | 1.92 a | 11.34 b | 3.74 b | 1.96 ab |
| Non. Irrg. Prnl | 3.37 ab | 0.17 a | 6.18 ab | 1.19 b | 0.58 ab | 2.26 b | 13.66 b | 4.51 ab | 2.83 b |
| LSD (5%) | 0.621 NS | 0.048 NS | 0.658 ** | 0.777 NS | 1.819 NS | 1.176 NS | 6.153 NS | 2.03 NS | 0.49 NS |

**Not significant.**

---

**NS** significant at p<0.05; **NS** significant at p<0.001; NS-Not significant.
specific cropping system, and irrigation practice is critical. This study revealed that irrigated perennial cropped soils had better chemical properties and hydraulic conductivity than non-irrigated soils. Irrigation and perennial cropping seem to improve soil chemical properties better than rain-fed and annual cropping. Soils in the study area were adequate in basic cations (K\textsuperscript{+}, Ca\textsuperscript{2+} and Mg\textsuperscript{2+}) but moderately deficient in TN and severely deficient in P content. Increased soil accumulation in irrigated soils was evident in the study area. This study recommends continuous monitoring of soil properties to track the effect of irrigation and cropping systems on the environment. The study also recommends further investigation on the effect of irrigation and cropping systems for different irrigation methods and schemes to establish the variations in soil quality and prevent further soil degradation due to salt accumulation.

Open Access: This is an open access article distributed under the terms of the Creative Commons Attribution NonCommercial 4.0 International License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author(s) or sources are credited.

REFERENCES

Abd-Elwahed, M. S. (2018). Influence of long-term wastewater irrigation on soil quality and its spatial distribution. Annals of Agricultural Sciences, 63(2), 191–199. https://doi.org/10.23937/2018.11.004

Abd-Elwahed, M. S. (2019). Effect of long-term wastewater irrigation on the quality of alluvial soil for agricultural sustainability. Annals of Agricultural Sciences, 64 (2), 151–160. https://doi.org/10.23937/2019.10.003

Adejumobi, M. A., Ojediran, J. O., & Olabiyi, O. O. (2014). Effects of Irrigation Practices on Some Soil Chemical Properties on OMI Irrigation Scheme. Journal of Engineering Research and Applications, 4(10), 29–35.

Airahi, A., Beecham, S., & Hassanii, A. (2017). Effects of partial root-zone drying irrigation and water quality on soil physical and chemical properties. Agricultural Water Management, 162, 117–125. https://doi.org/10.1016/j.agwat.2016.12.011

Amulli, J. P., van Es, H. M., & Schindelbeck, R. R. (2021). Cropping system and soil texture shape soil health outcomes and scoring functions. Soil Security, 4, 100012. https://doi.org/10.1016/j.soisoec.2021.100012

Awedat, A. M., Zhu, Y., Bennett, J. M., & Raine, S. R. (2021). The impact of clay and organic amendments on soil chemical properties better than rainfed arable soil. Journal of Soils and Tillage Research, 117, 103870. https://doi.org/10.1016/j.jstol.2020.103870

Bastida, F., Torres, I. F., Romero-Trigueros, C., Baldrian, P., Větrovský, T., Bayona, J. M., Alarcón, J. J., Herrández, T., García, C., & Nicolás, E. (2017). Combined effects of reduced irrigation and water quality on the soil microbial community of a citrus orchard under semi-arid conditions. Soil Biology and Biochemistry, 104, 226–237. https://doi.org/10.1016/j.soilbio.2016.10.024

Che, Z., Wang, J., & Li, J. (2021). Effects of water quality, irrigation amount and nitrogen applied on soil salinity and cotton production under mulched drip irrigation in arid Northwest China. Agricultural Water Management, 247, 106738. https://doi.org/10.1016/j.agwat.2021.106738

Dinizescu, M.-A., Dumitranc, G.-E., & Vvăul, L.-I. (2019). Experimental methods to determine the hydraulic conductivity. EJS Web of Conferences, 85, 06010. https://doi.org/10.1051/e3conf/20198506010

Dissanayake, D. M. M. R., Seneviratne, H. J. T., & Sumanasankara, V. D. W. (2015). Influence of the land use on dynamic soil quality; a review. NBRO Symposium 2015–Innovations for Resilient Environment, 6.

Eid, E. M., Kumar, P., Adelodun, B., Choi, K. S., Singh, J., Kumari, S., & Kumar, V. (2021). Modeling of mineral elements uptake and localization in cabbage

influence (Brassica oleracea var. capitata) grown on sugar mill pressmud-amended soils. Environmental Monitoring and Assessment, 193(9), 1–13.

Ferrarin, A., Martani, E., Fornasier, F., & Amaducci, S. (2021). High C input by perennial energy crops boosts belowground functioning and increases soil organic P content. Agriculture, Ecosystems & Environment, 308, 107247. https://doi.org/10.1016/j.agee.2020.107247

Ganjegunte, G., Uleri, A., Niu, G., & Wu, Y. (2017). Effects of treated municipal wastewater irrigation on soil properties, switchgrass biomass production and quality under arid climate. Industrial Crops and Products, 99, 60–69. https://doi.org/10.1016/j.indcrop.2017.01.038

Hazelton, P., & Murphy, B. W. (2017). Interpreting Soil Test Results: What Do All the Numbers Mean? (3rd edition). CSIRO Publishing, Clayton, Australia. pp. 80-91.

Jin, V. L., Wienhold, B. J., Minik, M. M., & Schnier, M. R. (2021). Cropping system partially offsets tillage-related degradation of soil organic carbon and aggregate properties in a 30-yr rainfed agroecosystem. Soil and Tillage Research, 209, 104968. https://doi.org/10.1016/j.still.2021.104968

Liu, C., Wang, Q.-W., Jin, Y., Tang, J., Lin, F., & Olatunji, O. A. (2021). Perennial cover crop biomass contributes to regulating soil P availability more than rhizosphere P-mobilizing capacity in rubber-based agroforestry systems. Geoderma, 402, 115218. https://doi.org/10.1016/j.geoderma.2021.115218

Lobb, D. B., & Gourdon, S. M. (2012). The Influence of Climate Change on Global Crop Productivity. Plant Physiology, 160(4), 1686–1697. https://doi.org/10.1104/pp.111.208298

Lobb, D. B., Schlenker, W., & Costa-Roberts, J. (2011). Climate Trends and Global Crop Production Since 1980. Science, 333(6042), 616–620. https://doi.org/10.1126/science.1204531

Makon, H. J. H. R. (2016). Assessment of Soil Chemical Properties and Fertility in Some Traditional Irrigation Schemes of the Babtati District, Manyara Region, Tanzania. Agriculture, Forestry and Fisheries, 5(6), 249-260. https://doi.org/10.1016/j.jafif.2016.05.016

Makone, S. M., Bawwell, E. A., & Buwattawa, D. K. (2021). Effects of Irrigation Systems on Farming Practices: Evidence from Oluch-Kîmira Scheme, Homa Bay County, Kenya. Asia Journal of Advanced Research and Reports, 26, 35. https://doi.org/10.9734/ajar/2015150355

Mikha, M. M., Vigil, M. F., Liebig, M. A., Bowman, R. A., McConkey, B., Deibert, E. J., & Pilk, J. L. (2006). Cropping system influences on soil chemical properties and soil quality in the Great Plains. Renewable Agriculture and Food Systems, 21(1), 26–35, https://doi.org/10.1017/SFRA20051213

Mugagga, F. (2015). The Effect of Land Use on Carbon Stocks and Implications for Climate Variability on the Slopes of Mount Elgon, Eastern Uganda. International Journal of Regional Development, 2(1), 58-75, https://doi.org/10.5296/ijrd.v2i1.7537

Mutegi, E. M., Kungu, J. B., Muna, M., Pieter, P., & Mugendi, D. N. (2012). Complementary effects of organic and mineral fertilisers on maize production in the smallholder farms of Meru South District, Kenya. Agricultural Science, 03(02), 221-229. https://doi.org/10.4236/as.2012.32026

Nataliyi, A., & Lennsen, W. A. (2018). Cropping systems and soil quality and fertility in south-central Uganda. African Journal of Agricultural Research, 13(15), 792–802. https://doi.org/10.5897/AJAR2018.13056

Nkonya, E., Pender, J., & Kaizzi, C. (2004). Determinants of Soil Nutrient Balances and the Dynamics of Soil Nutrient Flow: Evidence from Smallholder Farms of Meru South District, Kenya. Agriculture, Ecosystems & Environment, 104(1), 21–32. https://doi.org/10.1016/j.agee.2003.11.003

Okalebo, J. R., Gathua, J. W., & Woomer, P. L. (2002). Laboratory Methods of soil analysis: A Working Manual (Second Edition). TSBF CIAT and CIAT and SACRED Africa, Nairobi, 20 June,17,2021 from https://doi.org/10.5296/ijrd.v2i1.7537

Pascasio, S., Crecchio, C., Scaglioni, M., Mininni, A. N., Dichiio, B., Xiloyannis, C., & Sofo, A. (2018). Microbial-based soil quality indicators in irrigated and rain-fed soil portions of Mediterranean olive and peach orchards under sustainable management. Agricultural Water Management, 195, 172–179. https://doi.org/10.1016/j.agwat.2017.10.014

Rodrigo-Comino, J., Martínez-Hernández, C., Isieroh, T., & Cerdà, A. (2018). Contrasted Impact of Land Abandonment on Soil Erosion in Mediterranean Agriculture Fields. Pedosphere, 28(4), 617–631. https://doi.org/10.1016/j.педосф.2018.04.017

Sánchez-González, A., Chapela-Lara, M., Germán-Venegas, E., Fuentes-García, R.,
Río-Portilla, F. del, & Siebe, C. (2017). Changes in quality and quantity of soil organic matter stocks resulting from wastewater irrigation in formerly forested land. Geoderma, 306, 99–107. https://doi.org/10.1016/j.geoderma.2017.07.009

Shang, Z. H., Cao, J. J., Degen, A. A., Zhang, D. W., & Long, R. J. (2019). A four year study in a desert land area on the effect of irrigated, cultivated land and abandoned cropland on soil biological, chemical and physical properties. CATENA, 175, 1–8. https://doi.org/10.1016/j.catena.2018.12.002

Skopp, J. M. (2011). Physical Properties of Primary Particles. Handbook of Soil Sciences Properties and Processes, CRC Press, pp. 1–20.

Sprunger, C. D., Culman, S. W., Peralta, A. L., DuPont, S. T., Lennon, J. T., & Snapp, S. S. (2019). Perennial grain crop roots and nitrogen management shape soil food webs and soil carbon dynamics. Soil Biology and Biochemistry, 137, 107573, https://doi.org/10.1016/j.soilbio.2019.107573

Subhadip, P., Neha Chatterjee, Bohra, J. S., Singh, S. P., Dutta, D., Singh, R. K., & Rakshit, A. (2019). Soil Health in Cropping Systems: An Overview. In M. Hasanuzzaman (Ed.), Agronomic Crops (pp. 45–66). Springer Singapore. https://doi.org/10.1007/978-981-32-9151-3_4

Tesfahunegn, G. B., & Gebru, T. A. (2019). Variation in Soil Properties under Long-Term Irrigated and Non-Irrigated Cropping and Other Land-Use Systems in Dura Catchment, Northern Ethiopia [Preprint]. Ecology. https://doi.org/10.1101/755256

Tesfahunegn, G. B., & Gebru, T. A. (2020). Variation in soil properties under different cropping and other land-use systems in Dura catchment, Northern Ethiopia. PLOS ONE, 15(2), e0222476, https://doi.org/10.1371/journal.pone.0222476

VSN International. (2011). Genstat for Windows 14th Edition. VSN International. https://www.vsni.co.uk/software/genstat/

Wienhold, B. J., Pikul, J. L., Liebig, M. A., Mikha, M. M., Varvel, G. E., Doran, J. W., & Andrews, S. S. (2006). Cropping system effects on soil quality in the Great Plains: Synthesis from a regional project. Renewable Agriculture and Food Systems, 21(1), 49–59. https://doi.org/10.1079/RAF2005125

Yang, T., Siddique, K. H. M., & Liu, K. (2020). Cropping systems in agriculture and their impact on soil health-A review. Global Ecology and Conservation, 23, e01118, https://doi.org/10.1016/j.gecco.2020.e01118