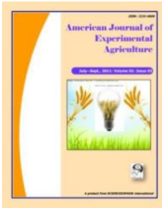

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# Evaluating the Impacts of Land Degradation on the Quality of Soils and Their Variations between Different Clusters in Mosiro Irrigation Scheme, Narok County, Kenya

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***Authors' contributions***

*This work was carried out in collaboration between all authors. Authors EMM and ALC designed the study, came up with the research protocol, coordinated the data collection processes and wrote the first draft of the manuscript. Authors VK, PMM, BKW and HG described and mapped out the study area, evaluated and rated different custers and assisted in writing the methodology. Authors EGT, JK and POO reviewed the experimental design, tabulated and synthesized the data and carried out statistical analysis. Authors VW, LSN and EM were responsible for quality control to ensure the flow of research materials from the introduction to conclusions and tallied the whole all the paper contents with what was expressed in the summary to make sure that there was consistency in the paper. All authors read and approved the final manuscript.*

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## ABSTRACT

**Aims:** To study the impact of land degradation on soil quality

**Study Design:** Comparative analysis of soil quality indicators in year 2002 and 2013 in Mosiro Irrigation Scheme.

**Methodology:** Changes in soil indicators determined in 2002 and 2013 were analyzed using ANOVA at 95% confidence level through Genstat Computer Software. The same indicators were applied to identify and characterize different clusters whose degree of variations were analysed using the same statistical method.

**Results:** The results showed that all the soil quality attributes changed in the range of 21.4 and 79.1%. The greatest change was recorded in potassium which decreased by 79.1%, followed by phosphorous (60% decrease).

The increase in sodium by 47% had a negative implication in terms of its increased potential to cause soil structural deterioration, while the increase of soil pH from 6.74 to 8.18 implied increased tendency of soil to fix most of the nutrients rendering them unavailable to plants. The soil organic carbon, nitrogen, phosphorous and potassium decreased by over 20%, which is much higher than the permissible threshold of 5% in ten years. The variations in soil characteristics between the five clusters identified were found to be significant for: cation exchange capacity ($P=0.002$), magnesium ($P=0.003$) and bulk density ($P=0.01$). There was no significant difference for calcium ($P=0.147$). All the textural characteristics of soil vary significantly with the highest being clay content ($P=0.001$), followed by silt ($P=0.0018$) and sand ($P=0.008$). For the micro-nutrients, the variation of manganese ($P<0.001$), zinc ($P=0.003$), copper ($P=0.008$) and iron ($P=0.031$) between different clusters was found to be significant.

**Conclusion:** Because the variations between different clusters in terms of both physical and chemical soil quality attributes was found to be significant except for calcium, each cluster must have different irrigation schedules and fertilizer inputs (except for calcium). This should form an important consideration in designing the irrigation water supply scheduling for all the clusters. Similarly, the prescription of the quantity of the micro-nutrients to apply should be clusters-specific. This is because the blanket recommendations across the clusters, where variations in terms of the levels of micro-nutrients are significant, would result into lower fertilizer use efficiency.


*Keywords: Land degradation; soil quality, clusters and productivity.*

## 1. INTRODUCTION

Delineation of soils into clusters which vary in productivity to an extent that they would respond differently to management inputs is a preamble to precision agriculture, aimed at improved soil quality and water use efficiency [1]. Soil is a key natural resource and its quality is as a result of integrated effects of all soil forming factors and management [2]. As a result of human activities on land over time, the capacity of a given soil to produce goods and services is often decreased at much more rate than the formation of topsoil [3]. A cluster of soils or production systems are said to be biophysically sustainable if the compounded sufficiency of land quality attributes (productivity index) does not deteriorate over a realistic time horizon [4]. Indexing and monitoring soil productivity under crop and soil specific production system is the means to judge whether or not the system is sustainable in biophysical sense [5]. According to Muchangi et al. [6], agricultural production from most irrigation schemes in Kenya has either reduced significantly over time or is far much below the level expected per unit of water supplied, and with advancement of agriculture under irrigation, soils are being degraded, thereby causing tremendous decline in their quality and productivity. Maintaining soil quality at a desirable level is a complex issue due to involvement of the interactive actions of the soil forming factors on the parent materials to form soil properties that determine its quality and productivity [7,8]. The results of these interactions are the vertical, spatial and temporal variations in soil properties or soil quality indicators within and between clusters of soils under different landforms. The assessment and evaluation of soil quality indicators and their variations are required, not only to determine the type and quantity of agricultural inputs to apply, but also soil and water management strategies for sustained ecosystem services under irrigated agriculture. In this regards, there is an urgent need to adopt appropriate soil and plant management practices to reduce land degradation and maintain soil quality at a desirable level, based on the evaluation of homogeneity and heterogeneity of the delineated clusters of soils under different landforms or slopes [9]. Low irrigation and fertilizer use efficiency as well as declining quality and productivity of soil in most of the schemes are exacerbated by the blanket fertilizer recommendations that ignore natural and biophysical diversity of production systems [10]. For example, fertilizer recommendations in Kenya by Kenya Agricultural Research Institute were based on trials without detailed characterization and clustering of production systems, based on relevant soil quality indicators [11]. Soil quality assessment, indexing and clustering of production systems under different landforms and slopes is a new paradigm in soil science research that is applied in vertical, spatial and temporal evaluation of land degradation, aggregation and management effects on soil quality and productivity. The degree of land aggregation that caters for soil structural formation and stabilization are influenced by the factors of soil formation including geology (parent material), climate, topography, time and human activities. The degree of variations in the resulting soil properties depends on the scale. At farm level, the effects of climate and geology are generally insignificant, while the effects of topography and human activities on soils under different clusters over specified time becomes an important issue to examine at site specific scale. In this context, the objective of this research was to examine soil conditions within different topographical facets to evaluate the homogeneity of soils and the impacts of land degradation on their quality as a basis of formulating the cluster-specific interventions for improved nutrient and water use efficiency in Mosiro Irrigation Scheme. The homogeneity of different clusters of biophysical domains was assessed, based on the physical parameters and chemical characteristics which influence the availability of water and plant nutrients, while the impacts of land degradation on soil productivity was examined by indexing the dynamic and management dependant soil quality indicators.

## 2. MATERIALS AND METHODS

Mosiro Irrigation Scheme is situated South-West of Nairobi in Narok County, about 12 km South of Mosiro trading centre, and about 82 km from Ntulele Market Centre. The intersection of the grid line 36º 04’ E and 1º 28’ S marks approximately the centre of the scheme, at an elevation of approximately 1265 m above the sea level. The area lying to the North of the scheme is the main source of sediment, causing increased land degradation and siltation of irrigation channels [12]. Therefore, water use efficiency and biophysical sustainability of the scheme depends on the extent to which the excess flows are checked and soil aggregate stabilization is maintained [12]. The Physiography of the scheme comprises two major landforms, namely flat to gently undulating erosion plain and undulating old river alluvial plain. The soils of erosion plain are developed on volcanic tuff while those of river alluvial plain are derived from alluvium and volcanic ash mixtures respectively [13]. The study area was divided into five sampling areas, with slopes of 0-0.5%; 0.6-1.5%; 1.6-2.5%; 2.6-4.0% and 4.1-4.5%. Systematic soil investigation and mapping was done on transects across all the sampling areas from the upper erosion plain into the bottomlands of the river alluvial plain in the same area soil survey and mapping were carried in the year 2002. Clustering of the production systems was done, based on the visual assessment of observable soil parameters (soil colour, depth, texture, consistence and structure) across the five sampling areas. In each of the five sampling area, five representative soil profiles were identified for detailed description of vertical and spatial characteristics of soils. For the analysis of the impacts of land degradation on soil quality and productivity, composite soil samples were collected using a river auger at the depth of 0-20 cm around each of the representative soil profiles. The soil quality indicators (Table 1) selected for this purpose are those whose quantitative relationships with maize yield have been developed by Aune and Lal [14].

For the assessment of homogeneity of different clusters, calcium (Ca), magnesium (Mg), bulk density (BD) and particle size distribution (texture) were used. They were selected because they form an important measure of soil productivity as is explained by the merits indicated in Table 2 [15].

Prior to laboratory analysis of the selected soil quality attributes, the soil samples were air dried and sieved through a 2-mm sieve. Soil pH was measured in 1:2.5 soil to water mixture, using the relevant electrodes according to Hinga et al. [16]. Organic carbon was oxidized with concentrated $H_2SO_4$ and $K_2CrO_7$ and determined calorimetrically. Total N was determined using the method provided by Okaleb et al. [17]. Cation exchange capacity (CEC) and exchangeable cations were extracted using 1N ammonium acetate at pH 7.0, followed by flame photometry for the determination Na, K, Mg and Ca, using flow analyzer [17]. Soil texture was determined using hydrometer method [18]. Indexing of soil productivity was done, using semi-quantitative land evaluation methods [19]. In this case, a range of numerical values of the selected soil quality indicators were rated and assigned fractions in percentage, being guided by the critical limits of the indicators. The critical limit of an indicator is defined as the numerical value of the soil property where crop yield is 80% of the maximum yield [14].

**Table 1. Indicators for assessing soil productivity**

| Soil quality indicators | Description |
|---|---|
| Soil pH | Controls several factors that influence soil's functions, toxicity of soil's internal environment and availability of micro-nutrients. |
| Soil organic carbon | Influences both nutrient availability and soil aggregate formation. |
| Nitrogen, phosphorous and potassium | They are macronutrients that determine crop growth. |

**Table 2. Indicators for evaluating the homogeneity of different clusters**

| Soil quality indicators | Merits for selection |
|---|---|
| Calcium and magnesium | The levels of these elements and their ratios determine the availability of potassium (one of the macro-nutrients). |
| Bulk density | It is one of the most important soil structure attributes that controls the circulation of air, water and nutrients between the soil media and plants, hence a principle determinant of soil health. |
| Particle size distribution | Determines the retention and availability of soil moisture to plants. |

*Source: Amacher et al. [15]*

Productivity index (PI) was determined using parametric methods of land suitability assessment provided by Driessen and Konijn [19]. This method involves: assigning ranges of numerical values and percentage fractions to each soil property selected as key soil quality indicators, ranking (Table 3) and combining all the single factor valuations in one mathematical equation that produces a numerical expression of the system performance or a relative index of performance (compounding) as follows:

$$PI=(SQ1/100) \times (SQ2/100) \times (SQ3/100) \times (SQn/100)$$

Where:

PI=Productivity index in % and SQ1, SQ2, SQ3, SQn are percentage ratings of soil quality indicator number 1, 2, and number n.

To assess the homogeneity of the identified clusters the variations in the selected soil quality attributes and PI within and between the clusters were evaluated by subjecting the data obtained from laboratory determinations (in the 2002 and 2012) to analysis of variance (ANOVA) at 95% confidence level where those soil quality indicators with significant levels were separated using Genstat Computer Software.

## 3. RESULTS AND DISCUSSIONS

### 3.1 Clusters Identified and Their Characteristics

Five clusters were identified and described as shown in Table 4.

### 3.2 The Impacts of land Degradation on Soil Quality and Productivity

All the soil quality attributes changed in the range of 21.4 and 79.1% between the year 2002 and 2012 (Fig. 1). According to Arshad and Martin [20], changes in the soil attributes could be used as measure of the impacts of land degradation on soil quality. The increase in soil pH from 6.74 to 8.18 implied an increased tendency of soils to fix phosphorous and render it unavailable to plants [21]. At soil pH above 8.0, the increased alkalinity triggers the release of aluminum, manganese and molybdenum to a toxic level that impairs the root uptake of micro-nutrients such as copper, zinc and iron [22]. Soil organic carbon, nitrogen, phosphorous and potassium decreased by over 20% which is much higher than the permissible threshold decrease of 5% in ten years [19,23]. The greatest percentage change was recorded in potassium which decreased by 79.1%, followed closely by phosphorous (60% decrease).

The increase in ESP by over 47% had a negative implication in terms of increased deterioration of soil structure by the increased accumulation of sodium [13].

### 3.3 Characteristics and Homogeneity of Different Clusters

The mean values of soil quality indicators for different clusters are presented in Table 5. The soil characteristics with the highest variation between the clusters is the clay (P<0.003) followed by CEC (P=0.002). Significant variations occur also in other characteristics, except calcium and sodium.

### 3.4 Variations in Soil Textural Characteristics and Their Management Implications

As is indicated in Fig. 2, the textural characteristics of soils, namely sand, silt and clay content vary significantly between different clusters, and this has an important implication in irrigation water management. Muya [24] showed significant relationships between these attributes and available soil moisture holding capacity, which may be applied in designing the irrigation water scheduling for different clusters. For example, cluster five has the highest sand content, implying the need for lighter and more frequent irrigation, while cluster one has the highest clay content, meaning more and less frequent water application than any other clusters.

### 3.5 Variations in Soil Micro-nutrients and Their Management Implications

The variations of the micro-nutrients between different clusters were found to be significant for all the micro-nutrients except sodium (Table 6). The variation of manganese (P<0.001), zinc (P=0.003), copper (P=0.008) and iron (P=0.031) between different clusters was found to be significant. This had an important implication on the prescription of the quantity of these micro-nutrients for different clusters during implementation of the envisaged management strategies. According to White and Zasoski [26], precision agriculture, aimed at improved nutrient

**Table 3. Ratings of soil quality indicators**

| Soil quality indicator | Ranges of numerical values | Assigned values in % | Ratings | Remarks |
|---|---|---|---|---|
| Soil pH | 4.8-5.5 or 5.6-6.8 or | 100 | 1 | 80% of the maximum yield of maize obtained from pH of 5.1 (Aune and Lal, 1997) [14] |
| | 4.8-5.5 or 6.9-7.5 | 80 | 2 | |
| | 4.0-4.7 or 7.6-8.7 | 60 | 3 | |
| | 3.5-4.5 or 8.7-10.0 | 40 | 4 | |
| | <3.5 or >10.0 | 20 | 5 | |
| Exchangeable sodium percentage | <2.0 | 100 | 1 | The permissible environmental threshold is 6 while maize yield is 80% (Waruru et al., 2002).[13] |
| | 2.1-10.0 | 80 | 2 | |
| | 10.1-20.0 | 60 | 3 | |
| | 20.1-35.0 | 40 | 4 | |
| | >35.0 | 20 | 5 | |
| Bulk density (g/cc) | <1.2 | 100 | 1 | Bulk density changes according to the degree of erosion and values of 1.0-1.4 gave sufficiency of 100%, (Pierce et al., 1983) [25] |
| | 1.3-2-1.5 | 100 | 2 | |
| | >1.5 | 75 | 3 | |
| Potassium (m.e.%) | >0.5 | 100 | 1 | 80% of the maximum yield obtained by the value 0.7 (Aune and Lal, 1997) [14] |
| | 0-2-0.5 | 80 | 2 | |
| | 0.1-0.2 | 60 | 3 | |
| | <0.1 | 40 | 4 | |
| Phosphorous (ppm) | >60 | 100 | 1 | 7.6 ppm gave 80% of the maximum yield of maize (Aune and Lal, 1997) [14] |
| | 21-60 | 90 | 2 | |
| | 10-20 | 80 | 3 | |
| | <20 | 70 | 4 | |

use efficiency should be based on the understanding of the variations in the levels of micro-nutrients as a basis of prescribing the soil and site specific types and quantity of micro-nutrients required as is normally done for macro-nutrients.

**Table 4. Identified clusters and their characteristics**

| Clusters | | Description |
|---|---|---|
| **Cluster no** | **Physiographic unit** | |
| C1 | Upper level structural plains | Very deep clay, in places, has crusting, causing surface water stagnation, especially, on bare ground, showing high susceptibility to disruptive external forces including animal trapping and raindrop impacts. |
| C2 | Lower level structural plains | Shallow to moderately deep sandy clay loam to clay, in places gravelly, pale yellow to reddish brown clay over murrum. |
| C3 | Old alluvial plain | Moderately structured and deep clay loam to clay with relatively high carbonate concentration, in places shallow and highly calcareous |
| C4 | Highly degraded, gently sloping structural plains | Dominantly shallow sandy loam to loam soils, on relatively steep slopes towards the low-lying area with low water uptake and retention capacity, being extremely calcareous, saline, sodic and highly degraded with relatively low productive capacity. |
| C5 | On alluvial flood plains | Extremely deep stratified sandy clay loam to loam. |

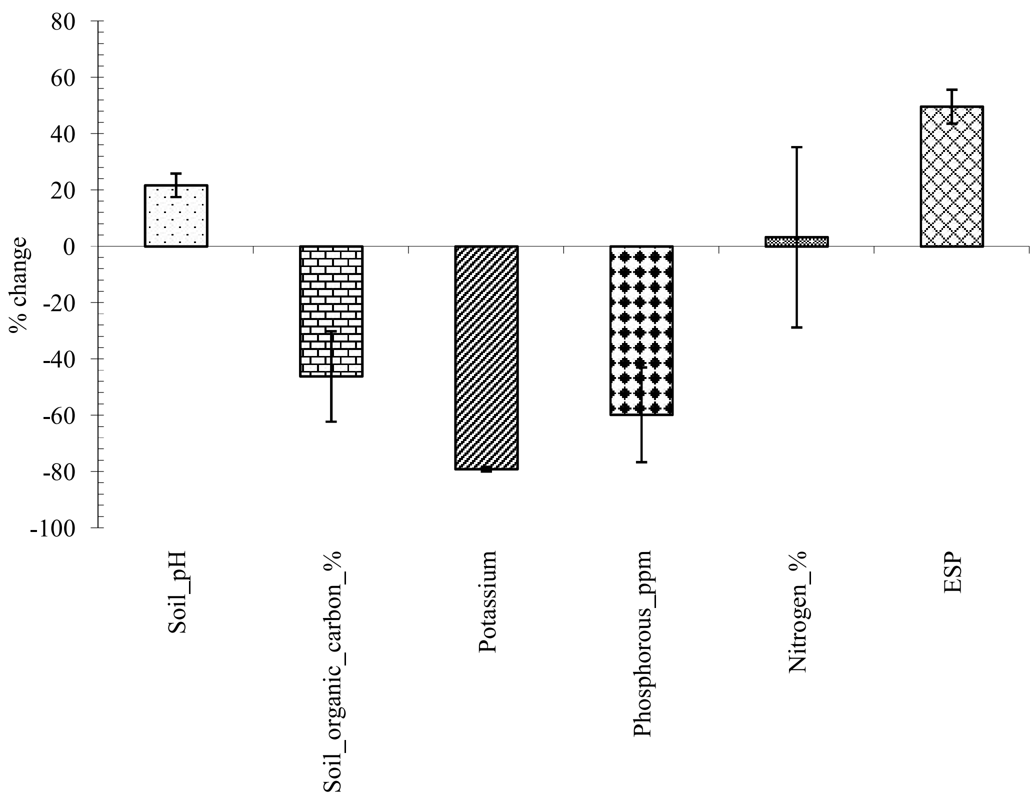


**Fig. 1. The impacts of land degradation on soil quality**

**Table 5. Physical and chemical characteristics of different clusters**

| Clusters | Physical and chemical characteristics of soils | | | | | | |
|---|---|---|---|---|---|---|---|
| | Bulk density (g/cc) | Textural characteristics | | | Ca me% | Mg me% | CEC me% |
| | | % Sand | % Silt | % Clay | 52.7 | 4.1a | 23.6a |
| C1 | 1.34b | 17.3c | 19.3c | 63.3a | 52.8 | 2.7b | 22.1a |
| C2 | 1.27c | 42.0ab | 28.7bc | 29.3bc | 63.2 | 3.1ab | 24.5a |
| C3 | 1.28c | 36.0b | 28.0bc | 36.0b | 33.5 | 0.7c | 26.8a |
| C4 | 1.56a | 54.0a | 31.3ab | 14.7d | 36.0 | 2.4b | 13.1b |
| C5 | 1.18d | 36.0b | 41.3a | 22.7cd | 26.6 | 1.3b | |
| P | <0.01 | 0.008 | 0.018 | 0.001 | | | |

*Key: g/cc=grams/cubic centimetre; Ca=Calcium, Mg=Magnesium; CEC=Cation exchange capacity; ME=Miliequivalent*

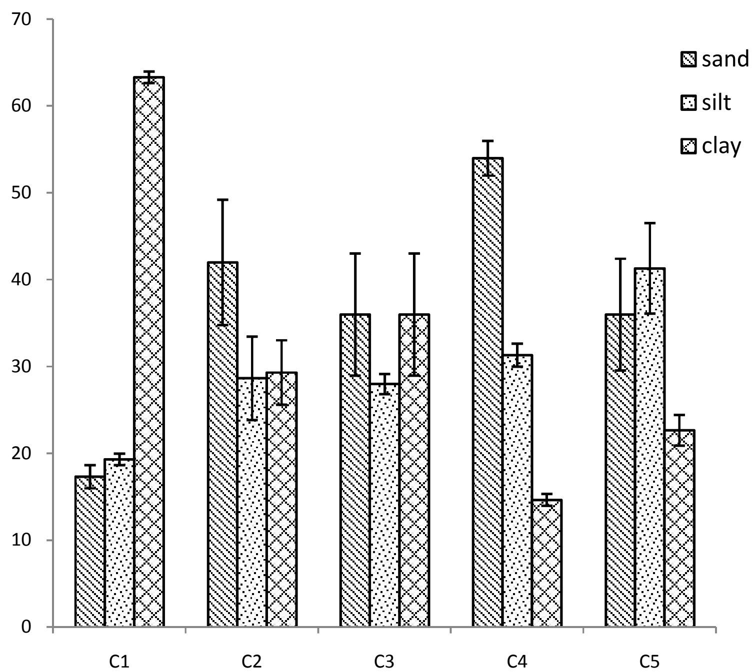


**Fig. 2. Variations in % sand, silt and clay contents between different clusters**

**Table 6. Variations in Micro-nutrients between different clusters**

| Clusters | Micro-nutrients | | | | |
|---|---|---|---|---|---|
| | Mn me% | Cu ppm | Fe ppm | Zn ppm | Na me% |
| C1 | 4.0a | 0.5c | 65.4a | 7.1b | 0.7 |
| C2 | 0.9b | 0.6bc | 23.8b | 4.6b | 1.1 |
| C3 | 0.8b | 0.8ab | 30.7b | 6.6b | 0.5 |
| C4 | 0.1d | 0.5c | 11.8b | 0.4c | 0.7 |
| C5 | 0.4c | 0.9a | 39.9ab | 4.7a | 0.8 |
| P | <0.001 | 0.008 | 0.031 | 0.003 | 0.155 |

*Key: Mn=Manganese; Cu=Copper; Zn=Zinc; Na=Sodium; me=Miliequivalent; ppm=parts per million*

## 4. CONCLUSION

The study demonstrated the impacts of land degradation on soil quality in terms of the change in soil quality attributes between the year 2002 and 2013. The change in all the soil quality attributes examined was found to be in the range of 21.4 to 79.1%. The increase in soil pH from

6.74 to 8.18 implied an increased tendency of soil colloids to fix nutrients and render them unavailable to plants, which could explain the decreased availability of nutrients. The decrease in phosphorous, potassium, nitrogen and soil organic carbon by over 20% was found to be much higher than 5%, which is the value permissible (threshold) within 10 years.

The five clusters identified were described as: C1: very deep clay with crusts that caused water stagnation on the surface; C2: shallow to moderately deep sandy clay loam to clay in places gravelly over murrum; C3: moderately structured and deep clay loam to clay with high carbonate concentration; C4: Shallow and highly degraded sandy loam to loam; and C5: extremely deep, stratified sandy clay loam to clay loam. The variations in soil characteristics between the five clusters were found to be significant for cation exchange capacity (P=0.002), magnesium (P=0.003) and bulk density (P=0.01). There was no significant difference for calcium (P=0.147). All the textural characteristics of soil varied significantly with the highest being clay content (P=0.001), followed by silt (P=0.0018) and sand (P=0.008). This meant that the design of irrigation scheduling for different clusters should be based on their textural differences, which have an important bearing on their water uptake and retention capacities.

The variation of manganese (P<0.001), zinc (P=0.003), copper (P=0.008) and iron (P=0.031) was found to be significant, meaning that the quantities of the fertilizers applied to supply these nutrients should be different for different clusters as opposed to the current blanket recommendations that ignore these differences. This had an important implication on the prescription of the quantity of these micro-nutrients for different clusters during implementation of the envisaged management strategies.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

1. Muya EM, Maingi PM, Chek AL, Gachini GN, Otipa M, Kahiga P, Njeru E, Kilonzo E, Anyango JJ, Macharia E, Yegon JV, Kirigua V, Lusike L, Atonya B. Analysis of soil quality, irrigation system and cluster-specific interventions for improved production of high value vegetables. A Technical Report; 2011.
2. Sharma KL, Mandal UK, Srinivas K, Vittal, KPR, Mandal B, Grace JK, Ramesh V. Long-term management effects on crop yields and soil quality in dryland Alfisol. Soil and Tillage Research. 2004;83:246-259.
3. Rijberman P. Effects of erosion on land and agricultural productivity. A review paper; 1984.
4. Driessen PM. Biophysical sustainability of land use systems. ITC Journal. 1997;243-247.
5. Hurni H. Concepts of sustainable land management. ITC Journal. 1997;210-214.
6. Muchangi P, Sijali I, Wendot H, Lemperiere P. Irrigation systems, their operation and maintenance: Training Source Book; 2005.
7. Prasad RN, Biswas PP. Soil Resources of India. In: Fifty Years of Natural Resource Management Research, Natural Resource Management Division, India Council for Agricultural Research, New Delhi. 1999;13-30.
8. Arshad MA and Gilley JE. Determinants of soil quality and health. In: Soil quality and soil erosion (R. Lal, ed.) CRC Press. Soil and Water Conservation Society, Iowa; 1999.
9. Smith JL, Elliott LF. Tillage and residue management effects on soil organic matter dynamics in semi arid regions. Adv. Soil Sci. 1990;13:69-85.
10. Muya EM, Njeru E, Maingi PM, Chek AL, Otipa M. Irrigation suitability assessment for improved soil quality and water use efficiency. A technical Report; 2012.
11. Sanginga N, Woomer PL. (eds). Integrated Soil Fertility Management in Africa: Principles, Practices and Development Processes. Tropical Soil Biology and Fertility Institute of the International Centre

for Tropical Agriculture (TSBF-CIAT); 2009.

12. Muya EM, Nafula LS, Macharia E, Owenga P. Land suitability assessment for improved crop production and environmental sustainability in Mosiro Irrigation Scheme, Narok County: A Technical Report. 2013;3.
13. Waruru BK, Muya EM, Gicheru PT, Wanjogu SN. The soils and their suitability for surface irrigation in the proposed Mosiro Irrigation Scheme, Mau Division, Narok District. Detailed Soil Survey Report No D74; 2002.
14. Aune JB, Lal R. Agricultural productivity in the tropics and critical limits of properties of Oxisols, Ultisols and Alfisols. Trop. Agric. (Trinidad). 1997;74(2):96-102.
15. Amacher MC, Katherine PO, Charles HP. Soil vital signs: a new soil quality index for assessing forest soil health. USDA, department of agriculture and forest service. A Handbook. 2007;1.
16. Anderson JM, Ingram JSL. Tropical Soil Biology and Fertility: A handbook of Methods, CAB International, Wallingford [4] Doran JW, Jones, AJ. 1993;1.
17. Okaleb JR, Gathua KW, Woomer PL. Laboratory methods of soil analysis: A working manual (second edition); 2002.
18. Hinga G., Muchena FN, Njihia CM. Physical and chemical methods of soil analysis. A Handbook. 1980;1.
19. Driessen PM, Konijn NT. Land use systems analysis. Lecture Notes, Wageningen Agricultural University; 1992.
20. Arshad MA, Martin S. Identifying critical limits of key soil quality indicators in agro-ecosystems. Agricultural Ecosystems and Environment. 2002;88:153-160.
21. Silveria M. Effects of soil acidity on nutrient use efficiency. A technical report, Soil and Water; 2012.
22. Whiting D, Reeder J. Soil pH and its effects on nutrient availability. Colorado Master Gardener Programme and extension document; 2009.
23. Steer A. Making development sustainable. Adv. Geo. Ecol. 1998;31:857-865.
24. Muya EM. An investigation into numerical relationships between soil water contents at several suctions and other soil properties. MSc Thesis. Cranfield University, U.K; 1996.
25. Pierce FJ, Larson WE, Downdy RHG. The relationships between land quality and crop performance (unpublished information); 1983.
26. White JG, zasoski RJ. Mapping soil micronutrients. Field Crop Research. 1999;60(1-2):11-26. Elsevier.




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