

**EVALUATING THE IMPACTS OF LAND DEGRADATION ON THE  
QUALITY OF SOILS AND THEIR VARIATIONS BETWEEN DIFFERENT  
CLUSTERS IN MOSIRO IRRIGATION SCHEME**

**ABSTRACT**

The impact of land degradation on soil quality was studied through the analysis of the changes in soil quality indicators between the year 2002 and 2013 in Mosiro Irrigation Scheme. The same indicators were applied to identify and characterize different clusters whose variations were analyzed using ANOVA at 95% confidence level through Genstat Computer Software. 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 (71.8% 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 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 ( $P=0.008$ ). This was found to be an important consideration in designing the irrigation scheduling for different clusters. For the micro-nutrients, the variation of manganese ( $P<0.001$ ), zinc ( $P=0.003$ ), copper

28 (P=0.008) and iron (P=0.031) between different clusters was found to be significant.  
29 This had an important implication on the prescription of the quantity of these micro-  
30 nutrients for different clusters during implementation of the envisaged management  
31 strategies.

32

## 33 INTRODUCTION

34

35 Delineation of soils into clusters which vary to an extent that they would respond  
36 differently to management inputs is a preamble to precision agriculture, aimed at  
37 improved soil quality and water use efficiency (Muya et al., 2011). Soil is a key  
38 natural resource and its quality is as a result of integrated effects of all soil forming  
39 factors and management on soil properties that determine crop productivity and  
40 environmental sustainability (Sharma et al., 2004). As a result of human activities on  
41 land over time, the capacity of a given soil to produce goods and services is often  
42 decreased at much more rate than the formation of topsoil (Rijsberman, 1984). A  
43 cluster of soils or production systems are said to be biophysically sustainable if the  
44 compounded sufficiency of land quality attributes (productivity index) does not  
45 deteriorate over a realistic time horizon (Driessen, 1997). Indexing and monitoring  
46 soil productivity under crop and soil specific production system is the means to judge  
47 whether or not the system is sustainable in biophysical sense (Hurni, 1997).  
48 According to Muchangi et al. (2005), agricultural production from most irrigation  
49 schemes in Kenya have either reduced significantly over time or are far much below  
50 the level expected per unit of water supplied, and with advancement of agriculture  
51 under irrigation, soils are being degraded, thereby causing tremendous decline in their  
52 quality and productivity. Maintaining soil quality at a desirable level is a complex

53 issue due to involvement of the interactive actions of the soil forming factors on the  
54 parent materials to form soil properties that determine its quality and productivity  
55 (Prasad and Biswas, 1999). The results of these interactions are the vertical, spatial  
56 and temporal variations in soil properties or soil quality indicators within and between  
57 clusters of soils under different landforms. The assessment and evaluation of soil  
58 quality indicators and their variations are required, not only to determine the type and  
59 quantity of agricultural inputs to apply, but also soil and water management strategies  
60 for sustained ecosystem services under irrigated agriculture. In this regards, there is an  
61 urgent need to adopt appropriate soil and plant management practices to reduce land  
62 degradation and maintain soil quality at a desirable level, based on the evaluation of  
63 homogeneity and heterogeneity of the delineated clusters of soils under different  
64 landforms or slopes (Smith and Elliot, 1990). Low irrigation and fertilizer use  
65 efficiency as well as declining quality and productivity of soil in most of the schemes  
66 are exacerbated by the blanket fertilizer recommendations that ignore natural and  
67 biophysical diversity of production systems (Muya et al., 2012). For example,  
68 fertilizer recommendations in Kenya by Kenya Agricultural Research Institute were  
69 based on trials without detailed characterization and clustering of production systems,  
70 based on relevant soil quality indicators (Sanginga and Woomer, 2009). Soil quality  
71 assessment, indexing and clustering of production systems under different landforms  
72 and slopes is a new paradigm in soil science research that is applied in vertical, spatial  
73 and temporal evaluation of land degradation, aggregation and management effects on  
74 soil quality and productivity. The degree of land aggregation that caters for soil  
75 structural formation and stabilization are influenced by the factors of soil formation  
76 including geology (parent material), climate, topography, time and human activities.  
77 However, the degree of variations in the resulting soil properties depends on the scale.

78 At farm level, the effects of climate and geology are generally insignificant, hence the  
79 effects of topography and human activities on soils under different clusters over  
80 specified time becomes an important issue to examine at site specific scale. In this  
81 context, the soil conditions within different topographical facets were examined with  
82 the objective of evaluating the homogeneity of soils and the impacts of land  
83 degradation on their quality as a basis of formulating the cluster-specific interventions  
84 for improved nutrient and water use efficiency in Mosiro Irrigation Scheme. The  
85 homogeneity of different clusters of biophysical domains was assessed, based on the  
86 physical parameters and chemical characteristics which influence the availability of  
87 water and plant nutrients, while the impacts of land degradation on soil productivity  
88 was examined by indexing the dynamic and management dependant soil quality  
89 indicators.

90

## 91 **MATERIALS AND METHODS**

92

93 Mosiro Irrigation Scheme is situated South-West of Nairobi in Narok County, about  
94 12 km South of Mosiro trading centre, and about 82 km from Ntulele Market Centre.  
95 The intersection of the grid line 36° 04' E and 1° 28' S marks approximately the  
96 centre of the scheme, at an elevation of approximately 1265 m above the sea level.  
97 The area lying North of the scheme consists of steep, rolling and undulating  
98 landscapes and slopes with high potential for run-off, sediment yields and transport,  
99 thereby forming the major source of increased land degradation and siltation of  
100 irrigation channels. Therefore, water use efficiency and biophysical sustainability of  
101 the scheme depends on the extent to which the excess flows are checked and soil  
102 aggregate stabilization is maintained (Muya et al., 2013). 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 (Waruru et al., 2002). 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 at the depth of 0-20 cm around each of the representative soil profiles. The soil quality indicators selected for this purpose are those whose quantitative relationships with maize yield have been developed by Aune and Lal (1997) with other merits shown in Table 1.

120

121 **Table 1: Indicators for assessing soil productivity**

| Soil quality indicators             | Merits for selection                                                                                                                   |
|-------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| 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.                                                                                    |

122

123

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

**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 has 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.                                                                                                                                 |

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. (1980). Organic carbon was oxidized with concentrated  $\text{H}_2\text{SO}_4$  and  $\text{K}_2\text{CrO}_7$  and determined calorimetrically (Anderson and Ingram, 1993). Total N was determined using the method provided by Okaleb et al. (2002). 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 (Okaleb, 2002). Soil texture was determined using hydrometer method (Hinga et al., 1980). Indexing of soil productivity was done, using semi-quantitative land evaluation methods (Driessen and Konijn, 1992), where ranges 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 (Aune and Lal, 1997).

Productivity index (PI) was determined using parametric methods of land suitability assessment provided by Driessen and Konijn (1992) that involved 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.

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

| Soil quality indicator         | Ranges of numerical values | Assigned values in % | Ratings | Remarks                                                                             |
|--------------------------------|----------------------------|----------------------|---------|-------------------------------------------------------------------------------------|
| Soil pH                        | 5.6-6.8 or 4.8-5.5         | 100                  | 1       | 80% of the maximum yield of maize obtained from pH of 5.1 (Aune and Lal, 1997)      |
|                                | 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 where maize yield is 80% (Weeda, 1987) |
|                                | 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       | According to PIERCE et al (1986), bulk density of 1.0-1.4 gave sufficiency of 100%  |
|                                | 1.3-2-1.5                  | 100                  | 2       |                                                                                     |
|                                | >1.5                       | 75                   | 3       |                                                                                     |
| Potassium (m.e./100g)          | >0.5                       | 100                  | 1       | 80% of the maximum yield obtained by the value 0.7 (Aune and Lal, 1997)             |
|                                | 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) |
|                   | 21-60 | 90  | 2 |                                                                     |
|                   | 10-20 | 80  | 3 |                                                                     |
|                   | <20   | 70  | 4 |                                                                     |

161

162

163

164 To assess the homogeneity of the identified clusters the variations in the selected soil

165 quality attributes and PI within and between the clusters were evaluated by subjecting

166 the data obtained from laboratory determinations (in the 2002 and 2013) to analysis of

167 variance (ANOVA) at 95% confidence level where those soil quality indicators with

168 significant levels were separated using Genstat Computer Software.

169

## 170 RESULTS AND DISCUSSION

### 171 Clusters identified and their characteristics

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

173

174 **Table 4: 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, on relatively steep soils 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.                                                                                                                                                                                               |

175

176

### 177 The impacts of land degradation on soil quality and productivity

178

179 All the soil quality attributes changed in the range of 21.4 and 79.1% between the year

180 2002 and 2013 (Figure 1). According to Arshad and Martin (2002), changes in the

181 soil attributes could be used as measure of the impacts of land degradation on soil

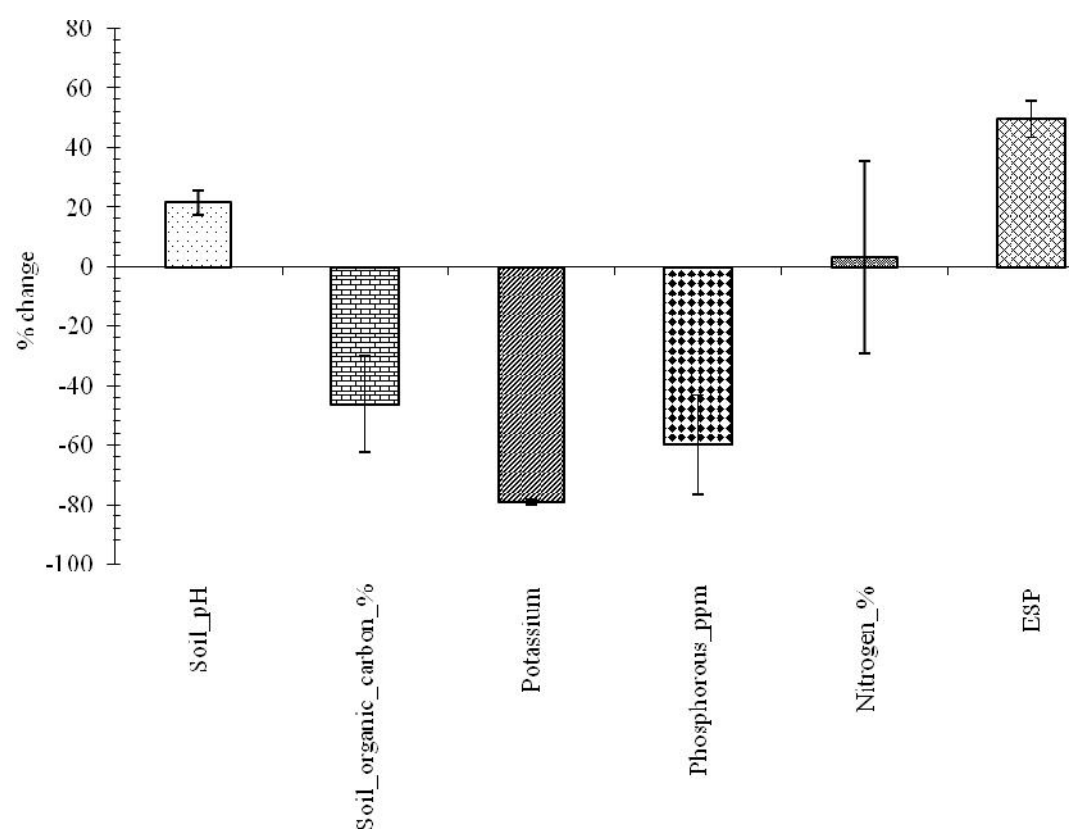
182 quality. The increase in soil pH from 6.74 to 8.18 implied an increased tendency of

183 soils to fix phosphorous and render it unavailable to plants (Silveria, 2012). At soil pH

184 above 8.0, the increased alkalinity triggers the release of aluminum, manganese and

185 molybdenum to a toxic level that impairs the root uptake of micro-nutrients such as  
 186 copper, zinc and iron (Whiting and Reeder, 2009). Soil organic carbon, nitrogen,  
 187 phosphorous and potassium decreased by over 20% which is much higher than the  
 188 permissible threshold decrease of 5% in ten years (Amacher et al., 2005). The greatest  
 189 percentage change was recorded in potassium which decreased by over 79%, followed  
 190 closely by phosphorous (71.8% decrease). The increase in ESP by over 47% had a  
 191 negative implication in terms of increased deterioration of soil structure by the  
 192 increased accumulation of sodium (Waruru and Muya, 2002).

193



194  
 195  
 196  
 197  
 198  
 199  
 200  
 201

**Figure 1: The impacts of land degradation on soil quality**

## 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.

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

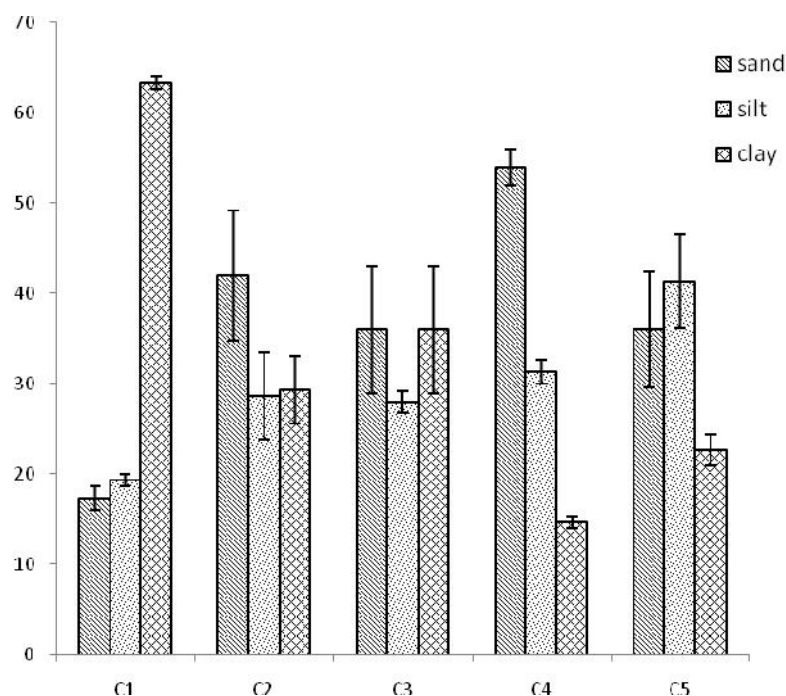
| Clusters | Physical and chemical characteristics of soils |                          |        |        |        |        |         |
|----------|------------------------------------------------|--------------------------|--------|--------|--------|--------|---------|
|          | Bulk density (g/cc)                            | 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 | 0.147  | 0.003  | 0.002   |
| P        | <0.01                                          | 0.008                    | 0.018  | 0.001  |        |        |         |

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

## Variations in soil textural characteristics and their management implications

As is indicated in Figure 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 (1996) 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

223 lighter and more frequent irrigation, while cluster one has the highest clay content,  
 224 meaning more and less frequent water application than any other clusters.  
 225



226

227 **Figure 2: Textural variations between different clusters**

228

## 229 **Variations in soil micro-nutrients and their management implications**

230

231 The variations of the micro-nutrients between different clusters were found to be  
 232 significant for all the micro-nutrients except sodium (Table 6). The variation of  
 233 manganese ( $P < 0.001$ ), zinc ( $P = 0.003$ ), copper ( $P = 0.008$ ) and iron ( $P = 0.031$ ) between  
 234 different clusters was found to be significant. This had an important implication on  
 235 the prescription of the quantity of these micro-nutrients for different clusters during  
 236 implementation of the envisaged management strategies. According to White and

Zasoski (1999), precision agriculture, aimed at improved nutrient 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 6: Variations in Micro-nutrients between different clusters**

| Clusters | Micro-nutrients |           |           |           |           |
|----------|-----------------|-----------|-----------|-----------|-----------|
|          | Mn<br>me%       | Cu<br>Ppm | Fe<br>Ppm | Zn<br>Ppm | Na<br>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**

## CONCLUSIONS

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 (C1, C2, C3, C4 and C5) were described as: very deep clay with crusts that caused water stagnation on the surface (C1); shallow to moderately deep sandy clay loam to clay in places gravelly over murrum (C2);

261 moderately structured and deep clay loam to clay with high carbonate concentration  
 262 (C3); Shallow and highly degraded sandy loam to loam (C4) and extremely deep,  
 263 stratified sandy clay loam to clay loam (C5). The variations in soil characteristics  
 264 between the five clusters were found to be significant for cation exchange capacity  
 265 ( $P=0.002$ ), magnesium ( $P=0.003$ ) and bulk density ( $P=0.01$ ). There was no significant  
 266 difference for calcium ( $P=0.147$ ). All the textural characteristics of soil vary  
 267 significantly with the highest being clay content ( $P=0.001$ ), followed by silt  
 268 ( $P=0.0018$ ) and sand ( $P=0.008$ ). This was found to be an important consideration in  
 269 designing the irrigation scheduling for different clusters.

270

271 The variation of manganese ( $P<0.001$ ), zinc ( $P=0.003$ ), copper ( $P=0.008$ ) and iron  
 272 ( $P=0.031$ ) was found to be significant. This had an important implication on the  
 273 prescription of the quantity of these micro-nutrients for different clusters during  
 274 implementation of the envisaged management strategies.

275

276

277

278

279

280

## 281 **REFERENCES**

282

283 [1] Amacher, M.C., Katherine, P.O. and Charles, H.P. 2007. Soil Vital Signs: A New  
 284 Soil Quality Index for assessing forest soil health, USDA, department of agriculture  
 285 and forest service

- 286  
287 [2] Arshad, M.A. and Martin, S. 2002. Identifying critical limits of key soil quality  
288 indicators in agro-ecosystems. *Agricultural Ecosystems and Environment*, Vol. 88, pp  
289 153-160
- 290  
291 [3] Aune, J.B. and Lal, R. 1997. Agricultural productivity in the tropics and critical  
292 limits of properties of Oxisols, Ultisols and Alfisols. *Trop. Agric. (Trinidad)* Vol. 74.  
293 No 2, pp 96-102.
- 294  
295 [3] Anderson, J.M. and Ingram, J.S.L. 1993. *Tropical Soil Biology and Fertility: A*  
296 *handbook of Methods*, CAB International, Wallingford [4] Doran, J.W., Jones, A.J.,  
297
- 298 [4] Arshad, M.A. and Gilley, J.E. 1999. Determinants of soil quality and health. In:  
299 *Soil quality and soil erosion* (R. Lal, ed.). CRC Press. Soil and Water Conservation  
300 Society, Iowa.
- 301  
302
- 303 [5] Diessen, P.M. 1997. Biophysical sustainability of land use systems. *ITC Journal*,  
304 pp 243-247.
- 305
- 306 [6] Driessen, P.M. and Konijn, N.T. 1992. *Land use systems analysis. Lecture Notes*,  
307 *Wageningen Agricultural University*.
- 308
- 309 [7] Hurni, H. 1997. Concepts of sustainable land management. *ITC Journal*, pp 210-  
310 214
- 311

- 312 [8] Hinga, G., Muchena, F.N. and Njihia, C.M. 1980. Physical and chemical methods  
313 of soil analysis.  
314
- 315 [9] Muya, E.M., Nafula, L.S., Macharia, E. and Owenga, P. 2013. Land suitability  
316 assessment for improved crop production and environmental sustainability in Mosiro  
317 Irrigation Scheme, Narok County: A Technical Report  
318
- 319 [10] Muya, E.M., Njeru, E., Maingi, P.M., Chek, A.L. and Otipa, M. 2012. Irrigation  
320 suitability assessment for improved soil quality and water use efficiency. A technical  
321 Report  
322 .
- 323 [11] Muya, E.M., P.M. Maingi, A.L. Chek, G.N. Gachini, M. Otipa, P. Kahiga, E.  
324 Njeru, E. Kilonzo, J.J. Anyango, E. Macharia, J.V. Yegon, V. Kirigua, L. Lusike and  
325 B. Atonya. 2011. Analysis of soil quality, irrigation system and cluster-specific  
326 interventions for improved production of high value vegetables. A Technical Report  
327
- 328 [12] Muchangi, P., Sijali, I., Wendot, H. and Lemperiere, P. 2005. Irrigation systems,  
329 their operation and maintenance: Training Source Book  
330
- 331 [13] Muya, E.M. 1996. An investigation into numerical relationships between soil  
332 water contents at several suctions and other soil properties. MSc Thesis. Cranfield  
333 University, U.K  
334
- 335 [14] Okaleb, J.R., Gathua, K.W. and Woomer, P.L. 2002. Laboratory methods of soil  
336 analysis: A working manual (second edition).

337

338 [15] Prasad, R.N. and Biwas, P.P. 1999. Soil Resources of India. In: Fifty Years of  
339 Natural Resource Management Research, Natural Resource Management Division,  
340 India Council for Agricultural Research, New Delhi, pp. 13-30.

341

342 [16] Silveria, M. 2012. Effects of soil acidity on nutrient use efficiency. A technical  
343 report, Soil and Water Science Programme, University of Florida.

344

345 [17] Sanginga, N. and Woomer, P.L. (eds). 2009. Integrated Soil Fertility  
346 Management in Africa: Principles, Practices and Development Processes. Tropical  
347 Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture  
348 (TSBF-CIAT).

349

350 [18] Sharma, K.L., Mandal, U.K., Srinivas, K., Vittal, K.P.R, Mandal, B., Grace, J.K.  
351 and Ramesh, V. 2004. Long-term management effects on crop yields and soil quality  
352 in dryland Alfisol. Soil and Tillage Research, Vol 83, pp 246-259.

353

354 [19] Steer, A. 1998. Making development sustainable. Adv. Geo.Ecol. 31, 857-865

355

356 [20] Smith, J.L. and Elliott, L.F. 1990. Tillage and residue management effects on  
357 soil organic matter dynamics in semi arid regions. Adv. Soil Sci. 13, 69-85.

358

359 [21] Whiting, D. and Reeder, J. 2009. Soil pH and its effects on nutrient availability.  
360 Colorado Master Gardener Programme and extension document.

361

362 [22] White, J.G. and zasoski, R.J. 1999. Mapping soil micronutrients. Field Crop  
363 Research, Volume 60, Issues 1-2, pp 11-26, Elsevier.

364

365 [23] Waruru, B.K., Muya, E.M. Gicheru, P.T. and Wanjogu, S.N. 2002. The soils and  
366 their suitability for surface irrigation in the proposed Mosiro Irrigation Scheme, Mau  
367 Division, Narok District. Detailed Soil Survey Report No D74.

368

369

370

371

372