# Physical-Chemical Characterization of Soils in Selected Potato Growing Areas of Molo, Nakuru County Kenya

Francis M. Maingi[*1], Harun M. Mbuvi[2], Adamu Abdulhameed[2]

[1]*Department of Science Technology and Engineering, Kibabii University, Bungoma, Kenya*
[2]*Department of Chemistry, Kenyatta University, Nairobi, Kenya*

***ABSTRACT***
*Characterization of soils in selected potato growing farms of Molo, Nakuru County in Kenya was compelled by the decline in potatoes acreage yields observed in the study area over the years. In the pursuit of reasons behind the decline, this study determined levels of some key soil fertility indices in soil samples obtained from selected farms. Four farms that have been in intensive potatoes farming were used. The soil was randomly collected from a depth of 0-10 cm separately for all the investigated sites. Collected site-wise samples were air-dried, ground, and passed through a 2 mm sieve and stored in plastic containers ready for analysis. Analytical techniques employed were Walkley black for carbon, Kjeldahl for nitrogen, standard wet chem soil analysis, saturation method for water porosity, glass electrode determined soil pH, bulk density, particle density, water holding capacity were determined by methods of Keen box. The mean levels of essential soil fertility indices obtained were; soils pH (5.46 ± 0.43), soil bulk density (g/cm3) (1.03 ± 0.01), particle density (2.51 ± 0.08), water holding capacity (%) (36.07 ± 2.57), porosity (0.59 ± 0.01), exchangeable cations (uS/cm) (83.63 ± 14.22), cation exchange capacity (meq/100g) (18.48 ± 0.89), organic carbon (%) (3.50 ± 0.24), total nitrogen (%) (0.17 ± 0.03). Mean micro and macronutrients available (mg/Kg) were; phosphorous (7.11 ± 2.77), potassium (100.27 ± 8.32), calcium (198.2 ± 35.1), magnesium (20.97 ± 4.28), manganese (15.26 ± 1.12), sulphur (2.31 ± 1.88), copper (0.59 ± 0.12), boron (0.38 ± 0.07), zinc (12.96 ± 2.04), sodium (8.61 ± 0.51), iron (147.92 ± 4.10). These findings reveal the extent of some fertility indices depletion in the soils and will form a base for decreased acreage yield of potatoes in this region. The results further form the baseline for future research on the working acreage of key soil fertility indices required for remediation.*

**Keywords:** *Baseline, Characterization, Depletion, Fertility indices, Potatoes acreage yields.*

## I. INTRODUCTION

Molo is located on Mau Escarpment and its geographical coordinates are 0° 15' 0" South, 35° 44' 0" East. It is categorized as the second-largest producer of potatoes in Kenya according to the Kenyan National Potato Policy. Potato is a short season crop matures within three to four months, and can be grown twice and sometimes even thrice in one year depending on the variety and weather conditions among other factors[1]. Soil acidity causes a deficiency in Ca, Mg, and K. When soils are strongly acidic, there is increased solubility and subsequent excessive bioavailability of Al, Fe, and Mn micronutrients in toxic amounts. This also reduces bioavailable phosphates due to these minerals reacting with it to form insoluble phosphates. Soil acidity is corrected by liming it with $Ca(OH)_2$, however, care should be taken not to over-lime and make the soil alkaline. Soil alkalinity makes Fe, Mn, Zn, and Cu micronutrients bio-unavailable to plants[2]. Potatoes require an adequate supply of macro and micronutrients for them to grow well and make tubers. In Molo, potato growing is done mainly using Di-ammonium phosphate (DAP) fertilizer. Therefore, there is a need to establish the fertility status of the soil to determine its deficiencies and ultimately the corrective measures necessary for optimum potato production. In the present study physical-chemical characterization of soils sampled from potato growing areas has been undertaken in an attempt to address the dramatic decline in potato acreage yield in those areas over the years.

## II. MATERIALS AND METHODS

### *A. Soil Sampling*

Samples were obtained using a stainless metallic tube soil auger. They were collected in triplicates at depths of 0-10 cm from five points per site and soils mixed to form representative samples. The samples were placed in plastic bags and transported to Kibabii University laboratory where they were air-dried, ground, sieved through a 2 mm sieve size, and stored in stoppered plastic containers ready for analysis according to Scrimgeour[3].

### B. Determination of Soil pH

Soil pH was determined by the use of a glass electrode with calomel as standard[4]. About 5 g of soil was placed in 50 mL beakers and about 20 mL of deionized distilled water were then added. The contents were stirred for 30 minutes and then left standing for an hour. A combined electrode was carefully immersed into the clear supernatant solution, the meter allowed to stabilize, and the pH reading was taken.

### C. Porosity Determination

The determination of porosity was done using the saturation method[5]. 50 mL beakers were first filled to the mark with soil samples. Distilled water was slowly added into each of the beakers until it reached the top of each soil sample and the volume of water used to reach the top was determined. Soil porosity was determined by dividing the volume of water used to reach the top by the total volume of the soil using equation 1.

$$P = \frac{V_{void}}{V_{total}} X\ 100 \quad \text{.....1}$$

Where, $V_{void}$–pore space volume and $V_{total}$–total volume.

### D. Soil Bulk Density

Bulk density was determined using the weighing bottle method adopted from the laboratory manual[6]. An empty 50 mL beaker was weighed using an electronic balance with precision. The beaker was filled with soil ground and oven-dried at 105℃ for 48 hours up to the brim by tapping and then weighed. The exact volume of the beaker was determined by adding water to it using a burette. Bulk density was calculated by using equation 2.

$$Bulk\ density\ (g/cm^3) = \frac{M_2 - M_1}{V} \quad \text{.....2}$$

Where; $M_1$ = weight of the empty beaker (g)
$M_2$ = Weight of Beaker filled with oven-dried soil (g).
V = Exact volume of the empty beaker ($cm^3$).

### E. Particle Density

Particle density was determined from the results obtained on soil porosity and soil bulk density using the formula adopted from DIRD[ laboratory soil testing manual. Equation 3 was used in the determination of soil particle density.

$$Particle\ density = \frac{Bulk\ density}{1 - Porosity} \quad \text{.....3}$$

### F. Water Holding Capacity (WHC)

The water holding capacity of soil samples was determined using the Keen's box method[7] with slight modification. Perforated metallic cylinders of diameter 5 cm and a height of 8 cm were used instead of the kens box. The weight of the empty cylinders fitted with filter papers was taken using an electronic balance with accurate precision. The cylinders were filled tightly with the 2 mm sieved soil dried at 105° C for 12 hours and their weights recorded. The metallic cylinders were then kept over water up to a mark of its soil level for 5 hours. The cylinders and wet soil were then kept on dry filter papers for 30 minutes to remove loosely bound water. The water holding capacity of the soil was then determined by using equation 4.

$$WHC(\%) = \frac{(C-a) - (b-a)}{b-a} \quad \text{.....4}$$

Where; 'a'= Weight of empty cylinder + Filter paper
'b' = Weight of empty cylinder + Filter paper + dry soil.
'c' = Weight of empty cylinder + Filter paper + wet soil.

### G. Potassium, Nitrogen, Organic Carbon, Calcium, Magnesium and Sodium

The micro-Kjeldahl method was used to determine the total nitrogen according to International[8]. The organic carbon content was estimated using the procedure of Walkey and Black rapid titration adopted from Jackson[9]. The bio-available nutrients of magnesium, sodium, potassium, phosphorus, and calcium were determined as outlined in Walingo *et al*. [10].

### H. Boron, Iron, Copper, Manganese, and Zinc

The extraction procedure was adopted from De Campos Bernardi *et al*. [11] where 5 $cm^3$ of air-dried soil was added to 25 mL of extracting solution and then shaken for 5 min. Extractant containing (1:5 soil /extractant ratio) was obtained with Mehlich double acid method [0.05M HCl + 0.0125M $H_2SO_4$ solution]. Boron was determined using the spectrophotometric method. The presence of iron, copper, manganese, and Zinc was determined using atomic absorption spectrophotometer[,[.

### I. Available Phosphorus and Sulphur

The levels of available P were determined using Olsen's method[12] for neutral and alkali soils[13]. The levels of available sulfur which mainly occurs as adsorbed $SO_4^{2-}$ions were determined using procedure adopted from Motsara and Roy[.

## III. RESULTS AND DISCUSSIONS

### A. Physical Characteristics of Soil Samples

The mean values of key physical-chemical properties obtained for the soil samples are summarized in Table I. These properties are very important for sustainable agricultural production as they determine soil fertility. Plant growth depends on the amount and

rate of water, oxygen, and nutrients that the roots can absorb from the soil solution. The absorption of these ingredients by plants relies on the ability of soil to supply them to the roots. The physical-chemical parameters measured in this study greatly influence the availability of required ingredients to the roots for uptake by plants and have been discussed independently below.

**Table I:** Summary of Selected Physical Properties of Soil Samples

| Parameter | Units | Mean ± SD |
|---|---|---|
| pH | - | 5.46 ± 0.43 |
| EC | uS/cm | 83.63 ± 14.22 |
| Cation Exchange Capacity (CEC) | meq/100g | 18.48 ± 0.89 |
| Porosity | % | 59.0 ± 0.01 |
| Particle density | g/cm$^3$ | 2.51 ± 0.08 |
| Bulk density | g/cm$^3$ | 1.03 ± 0.01 |
| Water holding capacity (WHC) | % | 36.07 ± 2.57 |
| Organic carbon | % | 3.50 ± 0.24 |

1) ***Soil pH:*** The soil pH ranged from 5.07 to 6.02 with a mean of 5.46 ± 0.43 as shown in Table I. This indicates that all the soil samples were acidic. The recommended pH levels for normal plant growth lie within 5.0–5.5 according to Kadaja and Tooming[14]. This implies that the soil's pH of the studied area was within the recommended levels for the growth of potatoes.

2) ***Soil Porosity:*** Porosity is the main indicator of soil structural quality and therefore, its characterization is essential for assessing the impact of adding organic matter to a soil system. Reduced porosity results from the loss of larger pores and the increase of finer pores[15]. It dictates how much water a saturated soil sample can contain and has an important influence on the bulk properties of soil[16]. The soil porosity which describes the amount of negative space between soil particles ranged from 56.9 to 61.2 with a mean of 59 ± 0.01%. The porosity indices obtained was within the range of finer textured soils as per Hao *et al.*[17]. It also shows that the soils in studied areas are not densely compacted hence will allow for enough oxygen to reach the root systems of cultivated plants. The soils are also capable of allowing leaching of minerals and therefore reducing their availability for plants.

3) ***Soil EC:*** The electrical conductivity which is an indirect measure of total amounts of soluble salts in soil was found to range from 65.3-103.6 us/cm or 0.65-1.036 ds/m with a mean of 83.63 ± 14.22us/cm or 0.084ds/m. this is below the recommended threshold of 1.7ds/m[18] indicating that the soils are deficient in some important plants nutrients.

4) ***Cation Exchange Capacity:*** The soil samples were found to have a CEC mean of 18.48 ± 0.89 meq/100g as shown in Table I. The cation exchange capacity (CEC) is a very important soil fertility indicator because it measures the soil's ability to retain nutrients from fertilizers and avail them to plant roots[19]. The value when compared to those obtained by Hodges [20], indicates the soils contained illite type of clay and texture of clay loam. These soils can hold exchangeable cations for plants use if well supplied by proper fertilizer application.

5) ***Soil Water Holding Capacity:*** The mean water holding capacity obtained from this study was 36.07 ± 2.57%. The water holding capacity (WHC) is a measure of soil's ability to store water and hence its availability to plants. Soil porosity, which depends on soil texture and organic matter, is a key parameter that influences the soil water holding capacity. Silt and clay which have small particle sizes and large surface areas can hold more water compared to the large particle sizes and small surface areas sandy soils. This parameter determines soil's ability to supply water to crops during the dry period, and hence influences crop growth and rooting patterns[21].

6) ***Bulk Density and Particle Density:*** Bulk density and particle density are quantifying indicators of soil compaction. The mean bulk density and particle density obtained in this study are 1.03 ± 0.01 and 2.51 ± 0.08 g/cm$^3$ respectively. The mean bulk density obtained is within the recommended value for plant growth of below 1.10[22]. A high soil bulk density can adversely influence soil physical properties, and along these lines constrain microbial activity and biochemical processes, which are of significance in nutrient availability. High bulk density soils will favor shallow plant roots and poor plant growth and reduce vegetative cover available to protect soil from erosion. Potato crop being a tuber will have its yield reduced in highly compacted soils.

7) ***Organic Carbon:*** A mean of 3.50 ± 0.24% was obtained for the soil samples tested. The value is above the critical value of 3.0[23]. According to Bronick and Lal[24], soil organic carbon has a greater effect on assemblage, especially in coarse-textured soils. Organic carbon is one of the key components of soil structural stability, however, in agricultural soils; it is progressively being depleted by intensive cultivation, without adequate yield of plant biomass.

### *B. Macronutrients in the Soil Samples*

The mean levels of macronutrients obtained for soil samples in this study are summarized in Table II. Macronutrients are required by plants in large quantities because they perform key roles in various metabolic processes. They also help in protecting plants from various abiotic and biotic stresses such as

stresses of heavy metals, drought, heat, UV radiations, and from diseases and insect pest attacks[25]. The supply of adequate amounts of macronutrients helps to increase crop yield, growth, and quality[26].

**Table II:** Summary of Macronutrients in the Soil Samples

| Nutrient | Unit | Mean ± SD |
|---|---|---|
| Total nitrogen | % | 0.17 ± 0.03 |
| Potassium | mg/Kg | 100.27 ± 8.32 |
| Phosphorous | mg/Kg | 7.11 ± 2.77 |
| Calcium | mg/Kg | 198.2 ± 35.1 |
| Magnesium | mg/Kg | 2.1 ± 0.43 |
| Sulphur | mg/Kg | 2.31 ± 1.88 |

1) ***Phosphorous:*** The mean concentration levels of available phosphorus were found to be 7.11 ± 2.77 mg/Kg. These levels were below the critical level of 10 mg/kg[. Phosphorus is a critical macronutrient whose deficiency affects plant growth, crop yield, and quality of the tuber[27]. Its deficiency can also delay the ripening of crops[28]. This can be corrected by proper quantitative application of phosphorous-based fertilizers by the farmers.

2) ***Nitrogen:*** The concentration levels of total nitrogen content obtained in this study were 0.17 ± 0.03%. The mean was below the critical levels of 0.25[. Nitrogen is required for plants in the greatest amount, which comprises about 1.5–2.0 % of plant dry matter, besides approximately 16 % of total plant protein[29]. Therefore, a sufficient amount of N availability in plants is required, as it is one of the major key factors of crop production[30]. An insufficient amount of nitrogen will affect the yield of potatoes. This deficiency of N can be addressed by the proper application of nitrogen-based fertilizers by the farmers.

3) ***Potassium:*** The concentration levels of potassium obtained from ammonium acetate extracts ranged from 89.6 to 110.3 mg/Kg and had a mean of 100.27 ± 8.32 mg/Kg. Potassium levels obtained from ammonium acetate extracts are considered as estimates of the amounts in the soil that are available for plant uptake. The values obtained were below the critical value of 160 mg/Kg[31]. This indicates that the available potassium in these soils is insufficient as far as the growth of potatoes is concerned. This is a key finding in this study because most farmers in Kenya assume farm soils contain adequate amounts of potassium and hardly replenish it. Indeed this the key reason for the continued decline in acreage yields of the produce. This effect is attributed to long-term continuous cropping without replenishing with potassium fertilizers. K plays a key role as a cationic inorganic element and plants cannot survive in its absence[32]. Farmers can address this soil nutrient deficiency by incorporating the use of potassium-based fertilizers such as MOP among others during the planting of the crop.

4) ***Calcium:*** The mean level of calcium obtained in this study was 198 ± 35.1 mg/Kg equivalent to 0.99 ± 0.18 Cmol/Kg. Low levels of calcium ions in the soil could be attributed to the low soil pH. Calcium macronutrient that boosts nutrient uptake improves the plant tissue's resistance, makes cell wall stronger, and contributes to normal root system development[33] it is also an essential regulator of plant growth and development and its deficiency causes yellow coloration and black spots on leaves. The farmer in this region should often lime their soils to increase levels of calcium.

5) ***Magnesium:*** The mean level of Mg in sample soils was 2.1±0.43 mg/Kg. Magnesium, a central atom of chlorophyll plays a major role in plant photosynthesis. Its deficiency degrades the chlorophyll content and causes chlorosis whereby leaves become yellow. An adequate supply of Mg is essential to plants as it enables sufficient production of food by photosynthesis hence making them healthy[34].

6) ***Sulphur:*** The sample soils contained sulphur mean level of 2.31 ± 1.88 mg/Kg. Sulphur is beneficial to all living organisms as it performs various dynamic roles for growth, development, and survival of plant life. Therefore, it is regarded as an essential plant nutrient necessary for maximum production. Further, S-rich protein is said to improve plant defense mechanisms against pathogens as it is related compounds that are closely connected to biotic stress resistance[35].

### *C. Selected Micronutrients Studied in the Soil Samples*

The mean levels of selected micronutrients in the studied soil samples are summarized in Table III. Although micronutrients are required by plants in small amounts in comparison to macronutrients, they play many complex roles in plant nutrition and the functioning of several enzyme systems. However, the specific functions that the various micronutrients play in plants and microbial growth processes vary considerably.

**Table III:** Summary of Selected Micronutrients in the Soil Samples

| Nutrient | (Mean ± SD) (mg/Kg) |
|---|---|
| Manganese | 15.26 ± 1.12 |
| Copper | 0.59 ± 0.12 |
| Boron | 0.38 ± 0.07 |
| Zinc | 12.96 ± 2.04 |
| Sodium | 8.61 ± 0.51 |
| Iron | 147.92 ± 4.10 |

1) ***Zinc:*** The mean concentration values of zinc obtained from soil samples was 12.96 ± 2.04mg/Kg. This value is above the upper critical limit of 5.0 as per Siva Prasad et al. [36]. Low levels of nitrogen in the soils hinder the plants from absorbing zinc increasing its bio-availability. The high levels can be regulated by increasing the concentration of available nitrogen in the soils. Excess organic matter may also increase the levels of zinc. Though needed by plants in small amounts, it is a crucial micronutrient to plant development. It is a key constituent of many enzymes and proteins that play important roles in a wide range of processes, such as growth hormone production and internode elongation. Its deficiency leads to reduced growth, tolerance to stress, and chlorophyll synthesis[37],[38].

2) ***Iron:*** This study obtained a mean concentration of 147.92± 4.10 mg/Kg. The iron (Fe) micronutrient is not only required for the formation of chlorophyll in plant cells but also serves as an activator for biochemical processes such as respiration, photosynthesis, and symbiotic nitrogen fixation. Iron deficiency can be induced by high levels of manganese or high lime content in soils[39]. Iron deficiency has been reported to adversely affect certain crops like corn, sorghum, certain soybean varieties, turf, and certain tree crops and ornamentals[.

3) ***Manganese:*** The mean concentration value of Mn obtained was 15.26 ± 1.12 mg/Kg. This is above the critical level of 8.0[. Manganese nutrient helps to activate enzymes in growth processes as well as assist iron during the formation of chlorophyll[. Symptoms of its deficiency include interveinal chlorosis of young leaves, gradation of pale green coloration with darker color next to veins among others.

4) ***Boron:*** The sample soils contain boron at a mean concentration of 0.38 ± 0.07 mg/Kg. The mean levels are slightly below the lower critical level of 0.5 as per Siva Prasad *et al*. [. Boron functions in plants in the differentiation of meristem cells. Usually, low levels of B are attributed to the high rainfall. Under high rainfall conditions, boron is readily leached from soils as $B(OH)_3$ according to Lohry[. Some of the symptoms of boron deficiency include the discoloring or drying of terminal buds or youngest leaves, and dropping of buds, flowers, and developing fruits leading to reduced crop yields.

5) ***Copper:*** The sample soils contain copper at a mean concentration of 0.59 ± 0.12 mg/Kg. This was within the acceptable levels of between 0.1-10[. The copper nutrients in plants are found in complex forms and act as activators of several enzyme systems in plants. They also function in electron transport and energy capture by oxidative proteins and enzymes and may play a role in vitamin A production. The copper deficiency interferes with protein synthesis.

6) ***Sodium:*** The sample soils contain copper at a mean concentration of 8.61 ± 0.51 mg/Kg. Sodium is not an essential element for plants but can be used in small quantities, similar to micronutrients, to aid in the metabolism and synthesis of chlorophyll.

## IV. CONCLUSION

The physical-chemical characterization of soils in potato growing areas of Molo was undertaken in the present study. The results revealed that the soils were deficient on the three macronutrients N, P, and K. Deficiency of potassium is a key finding of this work because Kenyan farmers, in general, assume that the soils have sufficient amount and therefore hardly replenish it. This may be the main reason for the decline in acreage yield of potatoes over the years. This calls for appropriate information to be passed on to farmers on how to correct these deficiencies. The findings are consistent with the FAO[40] report. Therefore, farmers need to be educated on better methods of soil fertilization to raise the levels of the deficient macro and micronutrients to boost their crop production. The results obtained will further form the baseline for future research on the working acreage of key soil fertility indices required for remediation.

## ACKNOWLEDGEMENTS

The authors give special thanks to the Department of Science Technology and Engineering of Kibabii University, Department of Chemistry of Kenyatta University and Cropnuts laboratory services for their services and technical assistance offered during the study.

## REFERENCES

[1] Z. Ekin, "Some analytical quality characteristics for evaluating the utilization and consumption of potato (Solanum tuberosum L.) tubers," *African Journal of Biotechnology*, 2011

[2] S. M. Kanyanjua and G. O. Ayaga, "A guide to choice of mineral fertilisers in Kenya," *KARI Technical Note*, 2006

[3] C. Scrimgeour, *Soil Sampling and Methods of Analysis (Second Edition). Edited by M. R. Carter and E. G. Gregorich. Boca Raton, Fl, USA: CRC Press (2008), pp. 1224, £85.00. ISBN-13: 978-0-8593-3586-0.*, vol. 44, no. 3. 2008.

[4] W. Van Lierop and A. F. Mackenzie, "Soil Ph Measurement And Its Application To Organic Soils," *Canadian Journal of Soil Science*, vol. 57, no. 1, pp. 55–64, 1977

[5] S. T. Netto, "Pore-Size Distribution in Sandstones," *American Association of Petroleum Geologists Bulletin*, 1993

[6] DIRD, "Directorate of Irrigation Research and Development Water Resources Department Directorate of Laboratory Testing Procedure for Soil & Water Sample Analysis Soil & Water Sample Analysis," 2009.

[7] G. W. Okalebo, "Laboratory methods of soil and plant analysis: a working manual.," *Researchgate.Net*, 2002.

[8] A. International, "AOAC: Official Methods of Analysis,

1980," *Association of Official Agricultural Chemists. Washington, D.C.*, 1980.
[9] M. L. Jackson, "Soil Chemical Analysis," *Journal of Agricultural and Food Chemistry*, 1959.
[10] J. J. V. Walingo, L., Vark, W., Van Houba, V. J. G., and Lee, "Soil and plant analysis (Part 7). Plant analysis procedures. Syllabus. Wageningen Agricultural University, Neatherlands.," 1989.
[11] A. C. De Campos Bernardi, C. A. Silva, D. Vidal Pérez, and N. D. A. Meneguelli, "Analytical quality program of soil fertility laboratories that adopt Embrapa methods in Brazil," *Communications in Soil Science and Plant Analysis*, 2002.
[12] S. R. Olsen, C. V Cole, F. Watandbe, and L. Dean, "Estimation of Available Phosphorus in Soil by Extraction with sodium Bicarbonate," *Journal of Chemical Information and Modeling*, 1954.
[13] M. R. Motsara and R. N. Roy, *Guide to laboratory establishment for plant nutrient analysis*. 2008.
[14] J. Kadaja and H. Tooming, *Potato production model based on principle of maximum plant productivity*, vol. 127, no. 1–2. 2004..
[15] A. C. Barbera, C. Maucieri, V. Cavallaro, A. Ioppolo, and G. Spagna, "Effects of spreading olive mill wastewater on soil properties and crops, a review," *Agricultural Water Management*. 2013.
[16] V. Matko, "Porosity Determination by Using Stochastics Method," *Journal of Automatika*, vol. 44, no. 3–4, pp. 155–162, 2003
[17] X. Hao, B. C. Ball, J. L. B. Culley, M. R. Carter, and G. W. Parkin, "Chapter 57: Soil density and porosity," *Soil sampling and methods of analysis*, no. June, pp. 743–760, 2006.
[18] R. M. A. Machado and R. P. Serralheiro, "Soil salinity: Effect on vegetable crop growth. Management practices to prevent and mitigate soil salinization," *Horticulturae*, vol. 3, no. 2, 2017.
[19] B. . Hazelton, P.A and Murphy, "'Interpreting Soil Test Results What Do All The Numbers Mean' CSIRO Publishing: Melbourne," 2007.
[20] S. C. Hodges, "Basics of Soil Fertility," *Soil Fertility Basics: NC Certified Crop Advisor Training*, pp. 1–75, 2013.
[21] P. Deb, P. Debnath, and S. K. Pattanaaik, "Physico-chemical properties and water holding capacity of cultivated soils along altitudinal gradient in South Sikkim, India," *Indian Journal of Agricultural Research*, vol. 48, no. 2, pp. 120–126, 2014
[22] C. Gardi, M. Tomaselli, V. Parisi, A. Petraglia, and C. Santini, "Soil quality indicators and biodiversity in northern Italian permanent grasslands," *European Journal of Soil Biology*, vol. 38, no. 1, pp. 103–110, 2002.
[23] H. Mbuvi, O. Kenyanya, and J. Muthengia, "Determination of Potassium Levels in Intensive Subsistence Agricultural Soils in Nyamira County, Kenya," *International Journal of Agriculture and Forestry*, vol. 3, no. 7, pp. 294–302, 2013.
[24] C. J. Bronick and R. Lal, "Soil structure and management: A review," *Geoderma*. 2005.
[25] V. B. Shanker AK, "Abiotic stress in plants-mechanisms and adaptations. Tech Publisher," p. pp 1–428, ISBN 978-953-307-394-1, 2011
[26] J. B. Morgan and E. L. Connolly, "Plant - Soil Interactions : Nutrient Uptake," *Nature Education Knowledge*, 2013.
[27] C. Y. Huang, N. Shirley, Y. Genc, B. Shi, and P. Langridge, "Phosphate utilization efficiency correlates with expression of low-affinity phosphate transporters and noncoding RNA, IPS1, in Barley," *Plant Physiology*, 2011.
[28] J. B. Morgan and E. L. Connolly, "Plant - Soil Interactions : Nutrient Uptake," *Nature Education Knowledge*, 2013.
[29] J. M. Alvarez, E. A. Vidal, and R. A. Gutiérrez, "Integration of local and systemic signaling pathways for plant N responses," *Current Opinion in Plant Biology*. 2012.
[30] S. M. Nadeem, M. Ahmad, Z. A. Zahir, A. Javaid, and M. Ashraf, "The role of mycorrhizae and plant growth promoting rhizobacteria (PGPR) in improving crop productivity under stressful environments," *Biotechnology Advances*. 2014
[31] H. Al-Zubaidi, A., and Pagel, "Content of different forms of potassiumin some Iraq soils," *Iraq Journal of Agricultural Science*, vol. 14, pp. 214–240, 1979.
[32] K. Mengel, "Potassium. In: Barker AV, Pilbeam DJ (eds) Handbook of plant nutrition. Taylor & Francis, Boca Ratan, pp91–120," 2007.
[33] M. J. Berridge, P. Lipp, and M. D. Bootman, "The versatility and universality of calcium signalling," *Nature Reviews Molecular Cell Biology*. 2000.
[34] C. Hermans, M .Vuylsteke,. F. Coppens, S. M. Cristescu, F. J. M. Harren, D. Inzé, and N.Verbruggen, "Systems analysis of the responses to long-term magnesium deficiency and restoration in Arabidopsis thaliana," *New Phytologist*, 2010.
[35] R. Hell and H. Hillebrand, "Evaluation of future developments in agrobiotechnology: The potential roles of protein nitrogen and sulfur for better crop plants," *Landbauforschung Volkenrode*, 2008.
[36] P. N. Siva Prasad, C. T. Subbarayappa, M. R. Reddy, and H. M. Meena, "Development of Critical Limits for Different Crops Grown in Different Soils and Its use in Optimizing Fertilizer Rates," *International Journal of Current Microbiology and Applied Sciences*, vol. 6, no. 6, pp. 241–249, 2017.
[37] M. Kawachi, Y. Kobae, H. Mori, R. Tomioka, Y. Lee, and M. Maeshima, "A mutant strain arabidopsis thaliana that lacks vacuolar membrane zinc transporter MTP1 revealed the latent tolerance to excessive zinc," *Plant and Cell Physiology*, 2009
[38] S. Lee, S. A. Kim, J. Lee, M. Lou Guerinot, and G. An, "Zinc deficiency-inducible OsZIP8 encodes a plasma membrane-localized zinc transporter in rice," *Molecules and Cells*, 2010.
[39] R. Lohry, "Micronutrients : Functions , Sources and Application Methods," *Indiana CCA Conference Proceedings*, no. Cl, p. 15, 2007.
[40] FAO (Food and Agricultural Organization), "Gateway to land water information Kenya National Report. http//www.fao.org/reports/ke.htm.," 2004.