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Soil Fertility Characterization in Mvumi and Mbogo - Komtonga Irrigation Schemes in Kilosa and Mvomero Districts, Morogoro Region, Tanzania.

Joachim HJR Makoi[1*] and Halima Mmbaga[2]

[1]Freelance Consultant, P.O. Box 1771, Moshi, Tanzania
[2]National Irrigation Commission, Morogoro Zonal Irrigation Office, P.O. Box 652, Morogoro, Tanzania

Abstract— *Soil samples from three (3) mapping units in Mvumi and four (4) mapping units in Mbogo Komtonga representing two irrigation schemes in Kilosa and Mvomero Districts in eastern Tanzania were collected and analyzed for different mineral elements. Using zigzag sampling techniques, 9 composite samples with three replicates were collected at depth 0 – 30 cm from the delineated pedogeomorphic units at a radius of 20 m around the soil pits. Soil samples from each soil type were bulked, thoroughly mixed, sub sampled to obtain a representative composite sample, packed and sent to Mlingano National Soil Service laboratory (NSS), Tanga, Tanzania for the determination of physical chemical fertility indicators. The data showed overall significant ($P \leq 0.05$) difference in fertility status in the selected irrigation schemes. The pH of top soils in Mvumi and Mbogo - Komtonga irrigation schemes ranged from 4.4 to 6.3. These were rated as extremely and/or strongly acid to slightly acid. Of the total area studied in Mvumi and Mbogo Komtonga irrigation schemes, 25.5 % is slightly acid, 40.2 % is medium acid, 31.0 % is extremely acid and 3.3 % extremely acid. Similarly, results of organic carbon (OC) determination from the top soil (0 - 30 cm) samples ranged from 26.6 g kg^{-1} to 51.8 g kg^{-1}. This corresponds to 45.7 g kg^{-1} to 89.0 g kg^{-1} SOM in both irrigation schemes. The data showed that % OC in all irrigation schemes was very high in 92.2 % and high in 7.8 % of the surveyed areas. The results show that the top soils of all the surveyed areas in Mvumi and Mbogo - Komtonga irrigation schemes had N in the range of 1.2 to 3.8 mg kg^{-1}, 48.7 % had N below the critical limits whereas 51.3 % were above the same. Available P in both schemes range from 0.68 – 6.53 mg kg^{-1}. Based on the generally accepted threshold P level, all the observed P values in Mvumi and Mbogo - Komtonga respectively were considered to be below the critical range. Cation exchange capacity values in most topsoil in Mvumi and Mbogo - Komtonga irrigation schemes were rated as medium or high to very high. These values range between 27.0 – 54.6 cmol (+) kg^{-1} and were rated as medium in 25.5 %, high in 35.3 % and very high in 39.2 % of the total surveyed areas. Exchangeable Ca in the topsoil of Mvumi and Mbogo - Komtonga irrigation schemes ranged from 3.99 – 31.3 cmol (+) kg-^{1}. These were rated as medium in 0.96 %, high in 34.3 % and very high in 70.2 %. Based on the critical limits, MV – Pa3 in Mvumi is likely to be deficient of Ca^{2+} for most crops as it lies below the proposed critical limits. Exchangeable Mg^{2+} in the irrigation schemes range from 0.28 – 5.07 cmol (+) kg^{-1}, rated as high to very high. These data suggests that all the MUs except for MV – Pa3 in Mvumi and Mbogo - Komtonga have sufficient Mg^{2+} supplies for crop growth. Potassium in Mvumi and Mbogo – Komtonga irrigation schemes, range from 0.61 - 2.97 cmol (+) kg^{-1}. These were rated as medium in 64.3 % to very high in 35.7 % of the total area. The data shows that in Mvumi K is unlikely to respond similar to Mbogo – Komtonga. The results of Na_{exch} indicates that the levels of Na^{+} in the top soils corresponds to 0.15 – 0.47 cmol (+) kg^{-1} soil in both irrigation schemes. These values were rated as low in 16.4 % and medium in 83.6 % and the corresponding ESP range from 0.5 – 2.2 % in Mvumi considered non-sodic. These results suggest that the surveyed areas have no threat to sodicity problems and the major soil fertility constraints were soil reaction (pH), Nitrogen (N), Phosphorus (P) and poor Soil Organic Matter (SOM).*

Keywords— ***Calcium, cation exchange capacity, paddy production, fertility constraints, management practices, soil organic matter, survey.***

I. INTRODUCTION

Agriculture is by far the most important sector of the economy for the farmers in Mvomero and Kilosa districts, as

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it provides employment of about 75 % of the population. However, limited irrigation facilities, limited use of modern farming technology, equipment as well as inputs which improves soil fertility, pose the major limitations to increased crop production and productivity. Soil fertility is imperative in enhancing crop productivity including rice production in Mvumi and Mbogo - Komtonga irrigation schemes that were selected for irrigation development. According to FAO [1], rice (*Oryza sativa* L.) is the second most important food crop in Tanzania after maize in terms of area cultivated and production. It is similarly a major source of employment and income for the rural poor farmers [2]. Annual per capita rice consumption increased from 20.5 kg in 2001 to 25.4 kg in 2011 [3]. At a lower scale, rice yields in Kilosa are 44,246 tons year^{-1} [4]. The smallholder farmers in Mvumi and Mbogo – Komtonga villages, depend on pastoralism as well as rice and maize production (as food and cash crop) for their livelihood. It is therefore important to improve rice production. Although rice is grown in almost all regions of the country, the major producers are Coast, Morogoro, Tabora, Mbeya, Mwanza, Shinyanga, Kilimanjaro and Arusha Regions. The national total annual average rice production was reported to be 1.35 million tons [3]. This national average is however very low and cannot meet the demand of the rapid population increase in the country. The low yields of rice have been attributed to low soil fertility and poor water management [2]. Low soil fertility is a function of soil parent materials [5] and poor mineral elements such as macronutrients management practices used by majority of farmers who tend to apply N fertilizers alone and thereby negatively affecting other nutrients through depletion [6]. Macronutrients play significant role during the entire plant life by performing various beneficial activities in plant metabolism as well as protecting plants from various abiotic and biotic stresses including heavy metals, drought, heat, UV radiations, and from diseases and insect pest attacks [7; 8; 9]. These macronutrients also help to increase the yield, growth, and quality of various crops [9]. Nitrogen is required for plants in the greatest amount [10; 11; 12; 13; 14]; most essential component of all existing cells [10; 11; 14] essential component of all proteins and enzymes and various metabolic processes of energy transformation [15]; an essential constituent of chlorophylls, which is closely associated with photosynthetic process [16] and facilitates plant growth and development [17; 18]. Achieving and maintaining appropriate levels of soil fertility, is of paramount importance if agricultural land is to remain capable of sustaining crop production at an acceptable level. This study therefore assesses soil fertility in the selected irrigation schemes which is essential to help identify strategies with less environmental impact in order to achieve more sustainable agricultural systems through irrigation development.

II. MATERIAL AND METHODS

2.1. Description of Study Area

Morogoro Region is one of the high potential agricultural regions in Tanzania Mainland that is located on the eastern side of the country. The Region lies between latitudes 5º58’ and 10º00’ South of the Equator and between longitudes 35º25’ and 38º30’ East of Greenwich. It is bordered by seven regions. In the north are Tanga and Manyara while in the eastern side are the Coast and Lindi Regions. On the western side there are Dodoma and Iringa Regions while Ruvuma is located in the southern side of the Region. In Morogoro Region expanded rice production project (ERPP) is implemented in three (3) districts which are Kilombero (Njage and Msolwa Ujamaa), Kilosa (Mvumi) and Mvomero (Mbogo - Komtonga and Kigugu) (Fig.1).with a total of five (5) irrigation schemes. Of the five irrigation schemes, Mvumi and Mbogo – Komtonga were selected for the study since no such studies were conducted before.

The centre of Mvumi Village is located at latitude 06º 35' 48.9" South and longitude 37º 13' 31.5" East at an elevation of 413 m above mean sea level [19]. Mvumi irrigation scheme is also located at a distance of approximately 36 km in the North Eastern direction away from Kilosa town. Administratively, Mvumi irrigation scheme is located in Mvumi village, Mvumi ward, Magole Division, Kilosa District in Morogoro region. The proposed irrigation project is reachable from Morogoro City by all-weather roads, passable throughout the year. However, the road to the scheme was not easily passable particularly during the wet season. On the one hand Mvumi village is bordered by Kisangata River to the North; Wami River to the East; Mvumi prison to the south and private farm known as ‘’JITU” to the western side. The scheme has the potential area of about 414 ha, of which 200 ha was under development plan through ERPP project. On the other hand, Mbogo – Komtonga irrigation scheme is bordered by Kichangani village to the North, Nguu Mountains in the West, Diwale/Mbulumi River in Kisala village to the East, and Kigugu village to the South. Administratively, the project area is located at Mbogo - Komtonga village, Sungaji ward, Turiani division, Mvomero District, Morogoro Region.

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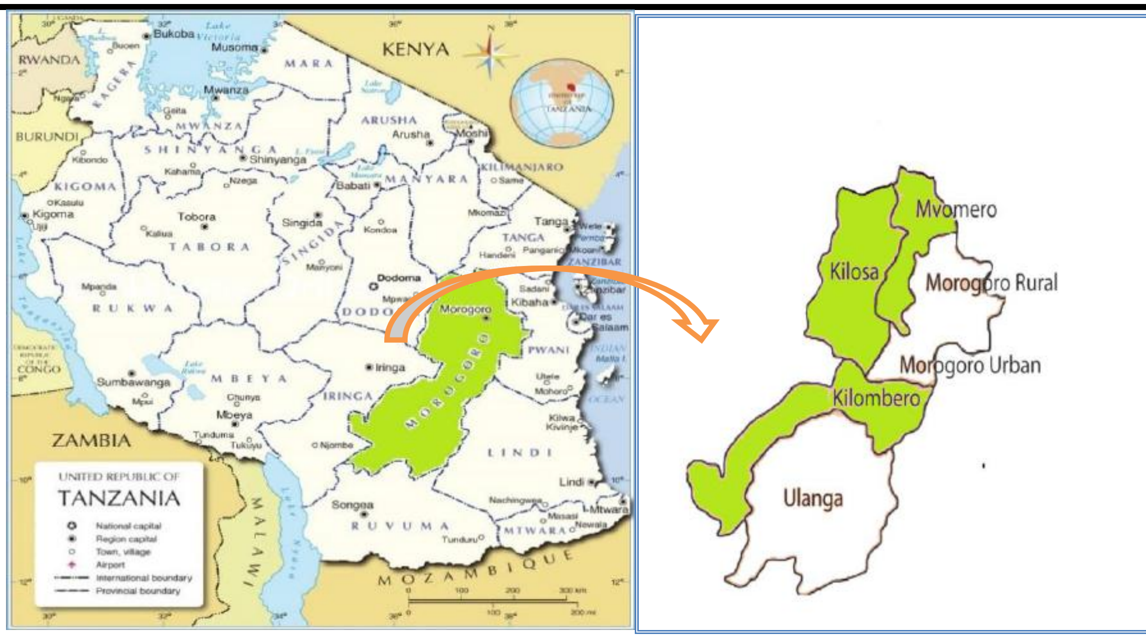

Fig.1: Tanzania Administrative Map (Left) – Districts under ERPP projects in Morogoro Region (Right)

2.2 Climate characteristics of the area

Rainfall in the study areas is bi - modal with 46.2 % of the total rains falling between March and May and about 44.5 % light rains falling between November and February. The total average annual rainfall is about 970 mm. Temperature, RH (%), potential evaporation (ET_o) and other climate variables representative of the study areas are presented in Table 1. The mean temperature varies from 21.8ºC in July to 27.0ºC in February. The monthly average relative humidity (RH) varies from 58.8 (i.e. October) to 77.9 % (i.e. April). The ET_o is about 1,799 mm per annum and varies widely throughout the year from 93.5 to 206.9 mm per month in June and December respectively.

Table.1: Climatic data representative for Mvumi and Mbogo - Komtonga Irrigation schemes.

Description	J	F	M	A	M	J	J	A	S	O	N	D
Rainfall (mm m^{-1})	119.4	107.7	163.6	204.4	80.3	16.5	9.3	14.0	11.8	38.6	81.3	132.7
T mean max (ºC)	32.2	32.5	31.9	29.9	28.8	28.1	27.7	28.5	30.2	31.6	32.2	32.3
T mean min (ºC)	21.6	21.5	21.3	20.8	19.1	16.4	15.8	16.4	17.5	18.8	20.3	21.5
T mean (ºC)	26.9	27.0	26.6	25.3	24.0	22.2	21.8	22.4	23.9	25.2	26.3	26.9
Evap. (Pan) mm m^{-1}	192.0	177.1	160.5	110.3	96.3	93.5	105.4	117.5	161.2	186.1	191.7	206.9
0.5ETo (mm m^{-1})	96.0	88.6	80.3	55.1	48.2	46.8	52.7	58.8	80.6	93.0	95.9	103.4
RH mean (%)	65.4	65.2	69.8	77.9	75.7	70.5	68.5	65.8	60.3	58.8	60.3	63.2
SH (hrs.)	7.9	7.7	6.8	5.8	5.9	6.5	6.3	6.6	7.5	8.1	8.2	7.9
WS (km day^{-1})	252.0	232.9	172.7	89.0	85.3	99.4	120.6	150.3	185.5	187.4	238.0	261.6

Source: Mtibwa, Ilonga, Dakawa, Dakawa Rice farm and Morogoro Meteorological weather stations. Total annual rainfall ≈ 970 mm, Total annual Evaporation (Pan) ≈ 1,799 mm

2.3 Soil Sampling

Soil sampling at Mvumi and Mbogo Komtonga irrigation schemes in Kilosa and Mvomero respectively was done after the soils were grouped into similar soil types or pedons following pedogeomorphic approach [20]; [21] whereby a total of seven (7) mapping units were delineated. Of the total (7) mapping units, three (3) were from Mvumi and four (4) from Mbogo - Komtonga irrigation schemes. During the soil survey process, nine (9) disturbed soil samples in four (4) replicates were then collected at a depth of 0 – 30 cm in and around the soil pits representative of the delineated pedogeomorphic units. Soil samples from each soil type were bulked, thoroughly mixed, and sub sampled to obtain a representative composite sample. After the soil samples were

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filled in plastic bags and labelled, they were sent for laboratory analysis at the National Soil Service laboratory, Mlingano (NSS), Tanga, Tanzania. In the laboratory, the samples were air dried and then ground to pass through a 2-mm sieve for determination of physical chemical fertility indicators.

2.4 Soil Physico - Chemical Analysis

Particle size analysis was determined following the procedure in Day [22] and textural classes were determined using the USDA textural class triangle [23]. Organic carbon (OC) was determined by the Walkley and Black wet oxidation method [24] and was converted to organic matter (OM) by multiplying by a factor of 1.724 [25]. Soil pH was measured potentiometrically in water and 1N KCl at a ratio of 1: 2.5 soils: water and KCl [26]. Total nitrogen (N) was determined using micro - Kjeldahl digestion distillation method [27]. Determination of exchangeable bases (EB) and cation exchange capacity (CEC) depended on soil pH. In soils with pH < 7.5, these parameters were extracted by saturating soils with 1M ammonium acetate (NH_4OAc) at pH 7, ethanol and acidified 1MKCl in the first percolate ([28]. The absorbed NH_4^+ displaced by K^+ using 1M KCl was then determined by Kjeldahl distillation method for the estimation of CEC of the soil. For soils with pH > 7.5 and high carbonates contents, the method recommended by Polemio and Rhoades [29] was followed. Determination of K^+ and Na^+ was done with flame photometer, Ca^{2+} and Mg^{2+} by Inductively Coupled Plasma Atomic Absorption Emission Spectrophotometer [30]. Cation exchange capacity (CEC) was done following the method by [30]. Potentiometric method was used to determine electrical conductivity (EC) of soil samples following the procedure described in Piper [31]. The total exchangeable bases (TEB) were calculated arithmetically as a sum of the four exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+ and K^+) for a given soil sample. Available Phosphorus (Pav) was extracted spectrophotometrically [32] by reacting with ammonium molybdate using ascorbic acid as a reductant in the presence of antimony as in [33]. Per cent base saturation (% BS) was obtained by dividing TEB by CEC and then multiplied by 100 [34]. Likewise, exchangeable sodium percentage (ESP) was obtained by dividing total exchangeable sodium by CEC, and then multiplied by 100. The K: TEB was obtained by dividing K by TEB.

2.5 Statistical Analysis

One - Way ANOVA was used to compare soil mineral elements from the different pedogeomorphic units. The analysis was performed using the STATISTICA software of 2016 version (Stat Soft Inc., Tulsa, OK, USA) [35]. The mean values were compared at 5 % level of significance using least significant differences (L.S.D) test.

III. RESULTS AND DISCUSSION

3.1 Soil Reaction

The pH of top soils in Mvumi and Mbogo - Komtonga irrigation schemes ranged from 4.4 to 6.3. These were rated as extremely and/or strongly acid to slightly acid [36]. The chemical properties of these soils are summarized in Tables 2 and 3. The data show that pH varied ($P \leq 0.05$) with mapping units in the studied irrigation schemes. In Mvumi irrigation scheme, pH was ($P \leq 0.05$) highest in MV – Pa1 followed by MV – Pa3 and MV – Pa2 which registered the lowest pH levels. Similarly, in Mbogo – Komtonga irrigation scheme, with the exception of MB – Pa3 mapping unit which showed lowest ($P \leq 0.05$) soil reaction, the other mapping units didn't show any ($P \leq 0.05$) variation. The nature of the observed acidity in these soils threatens the availability of mineral elements such as P which is readily available in soils with pH centred at 6.5. Of the total area studied in Mvumi irrigation scheme, 1.7 % is medium acid (MV – Pa3), 44.4 % is slightly acid (MV – Pa1) and 53.9 % is extremely acid (MV – Pa2). Likewise, in the surveyed area in Mbogo – Komtonga Irrigation scheme, 92.2 % is medium acid and 7.8 % is strongly acid. The extremely/strongly acid to medium acid soils (i.e. pH 4.0 - 5.0) such as those observed in some of the surveyed areas can have high concentrations of soluble Al, Fe and Mn which may be toxic to the growth of some plants owing to the sensitivity of many plant roots to Al toxicity [37; 38; 39]. Additionally, if pH is less than five (pH < 5), the availability of some nutrients such as P, Ca, Mg and Mo is very low, a condition that limits plants mineral elements uptake. For example, when pH was 4.4 as in MV – Pa2, P availability was 0.68 mg kg^{-1} but when pH was 6.3 as in MV - Pa1, P availability was 6.53 mg kg^{-1}. However, most plant mineral elements are available in the pH range of approximately 6.5 – 7.0 [40]. Similarly, soil pH can influence plant growth by its effect on the activity of beneficial micro-organisms. For example, bacteria that decompose SOM are hampered in strong acid soils which in turn prevent OM from breaking down [41]. As such, mineral elements required by the plants such as N are tied up and therefore unavailable to plants due to accumulation of un-decomposed or unbroken OM [42; 43]. Soil pH influences the rate of plant nutrient release by weathering, suitability of all materials in the soil, and amount of nutrients ions stored on the cation exchange complex. Before nutrients can be used by plants they must be dissolved in the soil solution. The pH is therefore a good guide for predicting which plant nutrients are deficient. Soils

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tend to become acidic as a result of (1) rainwater leaching away basic ions (Ca, Mg, K and Na); (2) formation of a weak organic acid as a result of CO_2 from decomposing OM and root respiration dissolving in soil water; (3) formation of strong organic and inorganic acids, such as nitric (HNO_3) and sulphuric acid (H_2SO_4), from decaying OM and oxidation of ammonium (NH_3) and sulphur (S) fertilizers. Strongly acid soils are usually the result of the action of these strong organic and inorganic acids.

(See Table 2)

3.2 Total Soil Organic Matter (SOM)

Results of organic carbon (OC) determination from the top soil (0 - 30 cm) samples in Mvumi irrigation scheme ranged from 26.6 g kg^{-1} to 51.8 g kg^{-1} while in Mbogo - Komtonga ranged from 24.7 g kg^{-1} to 49.1 g kg^{-1} (Tables 2 and 3). These tallies with 45.7 g kg^{-1} to 89.0 g kg^{-1} SOM in Mvumi and 42.5 g kg^{-1} to 84.4 g kg^{-1} SOM in Mbogo - Komtonga. The data showed that there was ($P \leq 0.05$) variation between the mapping units in both Mvumi and Mbogo – Komtonga irrigation schemes. For example, % OC and SOM were ($P \leq 0.05$) greatest in MV – Pa2 and MB – Pa4 and ($P \leq 0.05$) lowest in MV – Pa3 and MB – Pa3 respectively. Results also showed that % OC and SOM were very high in 98.3 % and high in 1.7 % of the area surveyed in Mvumi. In Mbogo - Komtonga, % OC and SOM were very high in 84 % and high in 16 % of the studied area. Since SOM content was calculated from SOC [25], these parameters have similar trend and showed systematic trend of decreasing with depth. It is generally accepted that a threshold for SOM in most soils is 34 g kg^{-1} below which decline in soil quality is expected to occur [44]. With the observed data, all values were above the proposed threshold limits, suggesting that no decline in soil quality for both Mvumi and Mbogo - Komtonga irrigation schemes [45]. SOM affects the physico - chemical properties of the soil and its composition and breakdown rate affect: the soil structure and porosity; the water infiltration rate and moisture holding capacity of soils; the diversity and biological activity of soil organisms; and plant nutrient availability. Organic carbon (OC) or SOM in the soil is important because humidified OM molecules may react with mineral colloids and contribute to the stabilization of soil aggregates. Through Fe^{2+} and Al^{3+} oxide, SOM positively affects water retention capacity, adsorption of fulvic and humic compounds and prevents their crystallization, thus, decreasing their fixation power with regards to phosphates at unfavourable pH values. Similarly, SOM provides much of the CEC, and, surface soils contain large quantity of plant nutrients with storehouse considered as slow release of nutrient especially so by N.

3.3 Total Nitrogen (TN)

Nitrogen (N) is biologically combined with carbon, hydrogen, oxygen and sulphur to create amino acids, the building blocks of proteins. Amino acids are used in forming protoplasm, the site for cell division and thus for plant growth and development. N is also needed for all of the enzymatic reactions in a plant; a major part of the chlorophyll molecule necessary for photosynthesis and a necessary component of several vitamins. Additionally, N improves the quality and quantity of dry matter in leafy vegetables and protein in grain crops. Results from the study areas showed that N levels were low to medium ranging from 1.2 – 2.5 g kg^{-1} in Mvumi similar to Mbogo – Komtonga irrigation schemes with values ranging from 1.5 – 3.8 g kg^{-1} (Table 2). These levels were rated as low in 46.1 % and medium in 53.9 % of the total area surveyed in Mvumi Irrigation scheme. Similarly, TN was rated as low in 52.4 % and medium in 47.6 % in Mbogo – Komtonga irrigation scheme. It was observed that TN in the study area ($P \leq 0.05$) varied between the pedogeomorphic units. In Mvumi Irrigation scheme for instance, the data showed that TN was greatest ($P \leq 0.05$) in MV – Pa2, that is, 2.5 g kg^{-1} and lowest in MV – Pa1, that is 1.2 g kg^{-1} (Table 2). Results also showed that in Mbogo – Komtonga, TN was ($P \leq 0.05$) highest i.e. 3.8 g kg^{-1} in MB – Pa4 and ($P \leq 0.05$) lowest i.e. 1.5 g kg^{-1} in MB – Pa3 (Table 2). According to NSS [36] guidelines, the proposed threshold value for N in most crops in Tanzania is 2 g kg^{-1} soil. The data indicates that of all the surveyed areas in Mvumi and Mbogo – Komtonga irrigation schemes, 46.1 % and 52.4 % had low TN respectively and were below the threshold value (< 2 g kg^{-1}) whereas 53.9 % and 47.6 % in Mvumi and Mbogo – Komtonga respectively had N above the threshold value (Tables 2 and 3). Plants use N primarily for the production and maintenance of leaves in order to maximize carbon fixation. Insufficient N in soils in many parts of the world is the prime factor that limits plant growth and development [46; 47]. The observed low or medium N in the surveyed areas may probably be due to medium or poor quality SOM even though results indicates that SOM values are very high or high. This may greatly be influenced by microbial activity in the soil and the very low or low soil pH [48; 45; Table 3]. Improvement of soil pH, SOM quality as well as microbial activities in the study areas can, subsequently lead to increase in soil N [45]. The low to very low levels of N in the surveyed areas suggests application of N in a form that better resists leaching caused by rainfall or irrigation in the surveyed areas.

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3.4. C/N Ratio

There was significant ($P \leq 0.05$) difference between the studied C:N ratio in mapping units of each of the irrigation schemes (Table 2). The data showed that C: N ratio was ($P \leq 0.05$) higher in MV – Pa1 and ($P \leq 0.05$) lowest in MV – MP1. It was likewise observed that the C: N ration in Mbogo – Komtonga was ($P \leq 0.05$) greatest in MB – Pa2 and ($P \leq 0.05$) lowest in MB – Pa3. However, the C:N ratio results of most of the surveyed areas range from 16 – 29 in Mvumi and 13 – 23 in Mbogo - Komtonga irrigation schemes (Table 2) and were rated as good/medium to poor quality SOM (Table 3). Of the surveyed area 98.3 % and 1.7 % is poor and moderate quality SOM [36] respectively in Mvumi. In Mbogo – Komtonga, 44.6 %, 7.8 % and 47.6 % of the surveyed area showed poor, moderate and good quality SOM respectively. Generally, C/N ratios between 8 and 12 are considered to be the most favourable [36], as N from the organic materials is mineralised relatively faster than otherwise. With the exemption of MV – Pa3 in Mvumi which showed a C/N ratio of 16, that is, medium quality SOM, the rest of the mapping units had C/N ratio outside the suggested range and were rated as poor quality SOM. The C/N ratio observed in BM – Pa3 and BM – Pa4 in Mbogo was rated as medium and good quality SOM respectively, and the remaining areas were rated as poor quality SOM. The observed C/N ratio in MB – Pa4 in Mbogo suggests an ideal condition for plant growth, since in this case mineralization is higher than immobilization in the soil. C/N ratios greater than 23 [49], a situation observed in MV – Pa1 in Mvumi and MB – Pa2 in Mbogo - Komtonga, have been shown to favour slow degradation of residues by the associated micro-organisms [50], higher immobilization effects [49] and limited N in the soil that may lead to reduced crop yields [51].

(See Table 3)

3.5 Available Phosphorus (AP)

Data from the study areas showed that all the top soil samples taken from Mvumi and Mbogo - Komtonga irrigation schemes had ($P \leq 0.05$) low levels of available P (Tables 2 and 3). In Mvumi irrigation scheme, available P was ($P \leq 0.05$) greater in MV – Pa1 and ($P \leq 0.05$) lowest in MV – Pa2. It was similarly revealed that available P in Mbogo – Komtonga was ($P \leq 0.05$) highest in MB – Pa2 and ($P \leq 0.05$) lowest in MB – Pa3. Results indicate that available P in Mvumi range from 0.68 – 6.53 mg kg^{-1} and 0.87 – 5.47 mg kg^{-1} in Mbogo - Komtonga top soils. Phosphorus (P) deficiency is a major abiotic stress that limits crop productivity on 30 – 40 % of the world's arable land [52]. P deficiency symptoms are likely to occur in most crops if an average available P in the soil is below 7 mg kg^{-1} considered as optimal [36]. These results suggests that all the observed P values in Mvumi and Mbogo - Komtonga irrigation schemes respectively are considered to be below the critical range and will definitely need measures to reverse the trend. The generally low P availability revealed in all the mapping units in Mvumi and Mbogo - Komtonga (Tables 2 and 3) also suggests that management of P in these areas is critical for sustainable agricultural development. Phosphorus (P) is an essential macro element for plant growth, hence an important soil fertility indicator. Phosphorus (P) constitutes about 0.2 % of plant's DM and therefore an essential macro element for plant growth [53]. Phosphorus is also required during the process of energy generation and transfer, carbon metabolism, membrane synthesis, enzyme activation, and nitrogen fixation [54] and a constituent of key biomolecules like nucleic acids, phospholipids, and adenosine triphosphate (ATP) [53]. Limited P availability in soils is thus an important nutritional disorder to plant growth and development [55].

3.6 Exchangeable Bases (K, Mg, Ca)

Results of the exchangeable bases (Ca, Mg and K) in the top soils of the surveyed areas are presented in Tables 2 and 3. These results indicate that the levels of exchangeable Ca, Mg and K ($P \leq 0.05$) varied between the mapping units and were generally rated as medium or high to very high.

3.6.1 Exchangeable Ca

Results of Calcium (Ca) in Mvumi and Mbogo – Komtonga irrigation schemes were ($P \leq 0.05$) different in the studied mapping units. Exchangeable Ca in top soil samples collected from Mvumi irrigation scheme ranged between 3.99 cmol (+) kg^{-1} (MV – MP1) and 13.27 cmol (+) kg^{-1} (MV - Pa2) rated as ($P \leq 0.05$) medium to very high (Tables 2 and 3). In Mbogo - Komtonga irrigation scheme, exchangeable Ca ranged from 12.6 cmol (+) kg^{-1} (MB – Pa3) – 31.3 cmol (+) kg^{-1} (MB – Pa4) rated as ($P \leq 0.05$) high to very high. In Mvumi result show that Ca was very high in 44.4 %, high in 53.9 % and moderate in 1.7 % of the studied areas. Similarly, in Mbogo – Komtonga irrigation scheme, Ca was very high in 92.2 % and medium in 7.8 % of the surveyed areas. Marx et al. [56] proposed that in most of the crops, the recommended threshold level of Ca^{2+} is 5 cmol (+) kg^{-1}. It is generally acknowledged that field conditions that limit Ca^{2+} uptake produce lower crop yields than crops grown with adequate Ca^{2+} [57]. These results indicate that mapping unit MV – Pa3 in Mvumi is likely to be deficient of Ca^{2+} for most crops as it lies below the proposed critical limits. Calcium plays an extremely important role in producing plant tissues and enables plants to grow better; increases the plant tissues'

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resistance and allows for more erect stems, contributes to normal root system development, increases resistance to outside attack, increases the feed value of forage crops (by enriching the plant in calcium)

3.6.2 Exchangeable Mg

Exchangeable Mg^{2+} in Mvumi range from 0.28 cmol (+) kg^{-1} in MV – Pa3 – 4.15 cmol (+) kg^{-1} in MV – Pa2 and was rated as ($P \leq 0.05$) low to high. Mg was high in 98.3 % and low in 1.7 % of the surveyed area in Mvumi irrigation scheme. Exchangeable Mg^{2+} in Mbogo - Komtonga range from 4.25 cmol (+) kg^{-1} in MB – Pa1 to 5.07 cmol (+) kg^{-1} in MB – Pa2, rated as ($P \leq 0.05$) high to very high. The data shows that Mg in 63.6 % of the studied area is high and in 36.4 % of the studied area is very high. Magnesium is a constituent of the chlorophyll molecule, a driving force of photosynthesis; essential for the metabolism and translocation of carbohydrates (sugars); an enzyme activator in the synthesis of nucleic acids (DNA and RNA); regulates uptake of the other essential elements; serves as a carrier of phosphate compounds throughout the plant and enhances the production of oils and fats. The recommended value of Mg^{2+} in most crops is 2 cmol (+) kg^{-1} [58]. These data suggests that all the MUs except for MV – Pa3 in Mvumi and Mbogo - Komtonga have sufficient Mg^{2+} supplies for crop growth.

3.6.3 Exchangeable K

Potassium (K) increases crop yield and improves quality. Likewise, it is required for numerous plant growth processes. K increases root growth and improves drought resistance; activates many enzyme systems; maintains turgor; reduces water loss and wilting; aids in photosynthesis and food formation; reduces respiration; preventing energy losses; enhances translocation of sugars and starch; produces grain rich in starch; increases protein content of plants; builds cellulose and reduces lodging; and helps retard crop diseases. Potassium in Mvumi range from 0.61 cmol (+) kg^{-1} in MV – MP1 to 0.83 cmol (+) kg^{-1} in MV – Pa2 and was rated as ($P \leq 0.05$) medium. In Mbogo - Komtonga, K ranged from 0.62 cmol (+) kg^{-1} in MB – Pa3 to 2.97 cmol (+) kg^{-1} in MB – Pa2 rated as ($P \leq 0.05$) medium to very high. Whereas K was medium in all the studied areas in Mvumi irrigation scheme, in Mbogo – Komtonga irrigation scheme, 5.2 % of the surveyed area had medium K and 94.8 % had very high K. In general terms, a response to K fertilizers is likely when a soil has an exchangeable K value of < 0.2 cmol (+) kg^{-1} soil and unlikely when it is above 0.4 cmol (+) kg^{-1} soil [Tables 2 and 4; 59; 36]. The data shows that in Mvumi irrigation scheme, K if applied, is unlikely to respond. Similar trend was observed in Mbogo – Komtonga irrigation scheme.

3.7 Cation Exchange Capacity

Cation exchange capacity (CEC) refers to the exchange phenomenon of positively charged ions (cation) at the surface of the negatively charged colloids [60]. It is often used as a characteristic in the determination of the nutrient retention land quality. The higher the CEC, the more capable the soil is to retain nutrients. High CEC means more nutrients are held on the soil, decreasing their mobility and uptake whereas low CEC means that more nutrients are in the soil solution, making them available to plants but also increasing the likelihood of leaching. Studies have shown that soils with CEC values of between 6 - 12 cmol (+) kg^{-1} soil are poor in exchangeable bases [36]. In this study, CEC levels in Mvumi and Mbogo - Komtonga irrigation schemes top soils were rated as ($P \leq 0.05$) medium or high to very high (Tables 2 and 3). In Mvumi, these values range between 17.9 cmol (+) kg^{-1} (MV – Pa1) – 34.64 cmol (+) kg^{-1} (MV – Pa2), and were rated as ($P \leq 0.05$) medium in 44.4 % of the area to ($P \leq 0.05$) high in 55.6 % of the area surveyed. In Mbogo - Komtonga, these values ranged between 27.02 cmol (+) kg^{-1} (MB – Pa3) – 54.64 cmol (+) kg^{-1} (MB – Pa4) and were rated as ($P \leq 0.05$) high in 7.8 % to ($P \leq 0.05$) very high in 92.2 % of the surveyed areas. The high to very high CEC could be related to the clay mineral and soil organic matter (SOM) or organic carbon (OC) present in these soils. However, it is recommended to apply both manure/compost manure and the required amount of fertilizer. When these inputs added to the soil increases the humus content of the soil, consequently resulting into a higher or maintenance of higher CEC hence a better retention of nutrients.

3.8 Exchangeable Sodium (Na) or Exchangeable Sodium Percentage (ESP) and Electrical Conductivity (EC)

Results of the levels of exchangeable Na, exchangeable sodium percentage (ESP) and electrical conductivity (EC) in Mvumi and Mbogo - Komtonga surveyed areas are presented in Tables 2 and 3. The data show that the levels of Na^{+} in the top soils corresponds to 0.15 – 0.47 cmol (+) kg^{-1} soil in Mvumi and 0.17 – 0.45 cmol (+) kg^{-1} in Mbogo - Komtonga. These values were rated as ($P \leq 0.05$) low in 1.7 % and medium in 98.3 % of the surveyed area in Mvumi. Similar trend was observed in Mbogo – Komtonga where Na was low in 36.4 % and medium in 63.6 % of the total surveyed area. The corresponding ESP range from 0.5 – 2.2 % in Mvumi and 0.4 – 1.7 % in Mbogo - Komtonga. These were ($P \leq 0.05$) rated as non-sodic. The critical values of ESP above which most crops are affected are established at 15 % [61] suggesting that sodicity in the surveyed areas is not a threat to crop production and productivity.

3.9 Cation Ratios

Mineral elements uptake by plants is dependent on absolute levels and relative amounts of individual elements. Results from this study indicate that Ca/Mg and Mg/K ratios reflect imbalances among the individual mineral elements (Table 4). For example, Ca will reduce plant uptake of Mg even if there is enough Mg in the soil whenever the Ca/Mg ratio is high. However, if Ca/Mg ratio is rated as good, but the total amounts of the individual mineral elements are low, then, such mineral elements should be applied. Previous research works in the tropical areas have suggested that the optimal cation ratio for the optimum growth of most crops is assumed to be equal to 76/18/6 for Ca/Mg/K respectively (i.e. 12.7/3/1). Research has likewise indicated that the Ca/Mg ratios of 3 – 5 in the topsoil are considered optimal for most crops. The top soils in the surveyed areas were found to have Ca/Mg ratios ranging from 2.3 – 14.3 in Mvumi and 2.5 – 6.3 in Mbogo – Komtonga irrigation schemes. As for Mg/K ratio, the values ranged from 0.5 – 5.0 in Mvumi and 1.7 – 8.1 in Mbogo - Komtonga irrigation schemes. The optimal range of Mg/K ratio is between 1 – 4 for most crops. The K/TEB ratio range from 4.4 – 12.2 % in Mvumi and 3.3 – 7.8 % in Mbogo - Komtonga. As the K/TEB ratios are greater than 2 % in all the surveyed areas, problems of K – deficiency in the study areas is unlikely.

(See Table 4)

IV. CONCLUSION

In conclusion, the results of the present study provide soil fertility status in Mvumi and Mbogo – Komtonga irrigation schemes. Data also suggest that soil indicators such as pH, TN, P and poor SOM are the overall major soil fertility constraints to crop production in the areas followed by Ca in some mapping units. This information could be incorporated in the soil fertility management programs in Kilosa and Mvomero Districts, thus, contributing significantly in the efficient utilisation of land resources for maximum production and productivity in the study areas.

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Table.2: Soil fertility data for Mvumi and Mbogo Komtonga Irrigation schemes in Kilosa and Mvomero Districts (topsoil samples 0 – 30 cm depth).

MU	Texture	pH	EC	OC	OM	TN	C/N	Pav	CEC	Ca	Mg	K	Na	BS	ESP
		(H_2O)	$dS.m^{-1}$	$g.kg^{-1}$				$mg.kg^{-1}$	(cmol (+).kg^{-1})					(%)	
Mvumi Irrigation Scheme															
MV-Pa1	SCL	6.3a	0.24c	36.6b	63.03b	1.2c	29a	6.53a	17.94c	8.08b	3.47b	0.73b	0.39b	74.00a	2.20a
MV-Pa2	C	4.4c	0.29b	51.8a	89.02a	2.5a	21b	0.68c	34.64a	13.27a	4.15a	0.83a	0.47a	54.00b	1.40b
MV-Pa3	CL	5.9b	0.32a	26.6c	45.71c	1.7b	16c	5.15b	28.34b	3.99c	0.28c	0.61c	0.15c	31.00c	0.50c
One Way ANOVA *(F-Statistics)*															
F Value		240.5***	52.1***	765.9***	764.4***	101.6***	629.1***	3021.9***	688.3***	1891.5***	3273.8***	171.28***	1577.75***	1113.81***	2308.51***
CV (%)		4.8	1.8	12.8	16.8	8.4	9.7	4.7	10.7	6.4	3.9	1.7	1.3	15.3	2.6
Mbogo - Komtonga Irrigation Scheme															
MB-Pa1	C	5.8a	0.32b	38.0c	65.35c	1.8b	21.0b	4.80b	41.02c	22.46c	4.25b	1.15c	0.36c	68.0b	0.9b
MB-Pa2	CL	6.0a	0.24c	40.3b	69.33b	1.8b	23.0a	5.47a	44.84b	29.64b	5.07a	2.97a	0.17d	82.0a	0.4d
MB-Pa3	C	5.4b	0.23c	24.7d	42.50d	1.5c	17.0c	0.87d	27.02d	12.57d	5.02a	0.62d	0.45a	65.0c	1.7a
MB-Pa4	C	5.8a	0.45a	49.1a	84.38a	3.8a	13.0d	4.60c	54.64a	31.34a	4.97a	2.10b	0.42b	69.0b	0.8c
One Way ANOVA *(F-Statistics)*															
F Value		14.4**	746.3***	501.5***	499.96***	1453.4***	413.2***	1728.3***	530.6***	866.8***	48.0***	2169.9***	882.0***	83.6***	1977.8***
CV (%)		4.8	1.2	12.7	16.6	3.2	8.8	4.4	13.3	10.3	4.4	3.0	1.2	16.9	2.2

: significant at *P*=.01; *: significant at *P*=.001; ns: not significantly different from each other; CV: Coefficient of variation. Values followed by dissimilar letters in the same column for each parameter are significantly different from each other at *P*=.05 according to Fischer Least significance difference (LSD). EC = Electrical Conductivity, TN = Total Nitrogen; C/N = Carbon/Nitrogen ratio, Pav = Available Phosphorus; K = Potassium; Ca = Calcium; Mg = Magnesium; Na = Sodium, OC = Organic Carbon; CEC = Cation Exchange Capacity; BS = Base Saturation, ESP = Exchangeable Sodium Percentage; SCL = Sand Clay Loam; CL = Clay Loam; C = Clay

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Table.3: Soil Fertility Data Interpretation for selected Irrigation schemes in Mvumi and Mbogo Komtonga (0 - 30 cm)

Soil fertility Unit symbol	Land form characteristics	Area (ha)	S (%)	pH (H_2O)	Soil fertility description									
					N	P	K	Ca	Mg	Na	% OC	CEC	ESP	C/N
Mvumi Irrigation scheme														
MV-Pa1	Flat to gently undulating	183.9	<2	SA	L	L	M	VH	H	M	VH	M	NS	PQ
MV-Pa2	Flat to almost flat	223.5	<1	EA	M	L	M	H	H	M	VH	H	NS	PQ
MV-Pa3	Flat	6.9	<2	MA	L	L	M	M	L	L	H	H	NS	MQ
	Total	414.3												
Mbogo – Komtonga Irrigation scheme														
MB-Pa1	Flat to undulating	25.2	<2	MA	L	L	M	VH	H	M	H	VH	NS	PQ
MB-Pa2	Flat	111.4	<2	MA	L	L	VH	VH	VH	L	VH	VH	NS	PQ
MB-Pa3	Flat to undulating	23.4	<2	Str.A	L	L	M	H	H	M	H	H	NS	MQ
MB-Pa4	Flat	145.8	<1	MA	M	L	VH	VH	H	M	VH	VH	NS	GQ
	Total	306.2												

S = Slope, N = Nitrogen, P = Phosphorus, K = Potassium, Ca = Calcium, Mg = Magnesium, %OC = Per cent organic carbon, CEC = Cation exchange capacity, ESP = Exchangeable sodium percentage, C/N = Carbon to Nitrogen ratio: (Based on Mlingano National Soil Service (NSS) Laboratory guide to general soil fertility evaluation); VL = Very low; L = Low; M = Medium; H = High; VH = Very high; NS = Non Sodic; PQ = Poor quality; MQ = Moderate quality; GQ = Good quality

Table.4: Summary of results with emphasis on the nutrient balance in Mvumi and Mbogo Komtonga Irrigation schemes in Kilosa and Mvomero Districts (0 – 30 cm)

Mapping Unit	Texture	Ca/Mg	Mg/K	K/TEB	TEB
Mvumi Irrigation Scheme					
MV-Pa1	SCL	2.30c	4.80b	5.70b	12.70b
MV-Pa2	C	3.20b	5.00a	4.40c	18.70a
MV-Pa3	CL	14.30a	0.50c	12.20a	5.00c
One Way ANOVA *(F-Statistics)*					
F Value		4568.11***	3011.49***	1957.87***	1979.88***
CV (%)		6.7	4.3	6.0	7.7
Mbogo – Komtonga Irrigation scheme					
MB-Pa1	C	5.3c	3.7b	4.1c	28.2b
MB-Pa2	CL	5.8b	1.7d	7.8a	37.8a
MB-Pa3	C	2.5d	8.1a	3.3d	18.7c
MB-Pa4	C	6.3a	2.4c	5.4b	38.8a
One Way ANOVA *(F-Statistics)*					
F Value		805.0***	2813.8***	986.4***	652.5***
CV (%)		4.7	4.7	4.8	11.5

***: significant at *P* =.001; CV: Coefficient of variation. Values followed by dissimilar letters in the same column for each parameter are significantly different from each other at *P* =.05 according to Fischer Least significance difference (LSD). K = Potassium; Ca = Calcium; Mg = Magnesium; Na = Sodium, TEB = Total Exchangeable Bases, BS = Base Saturation; SCL = Sand Clay Loam; SL = Sandy loam; CL = Clay Loam; C = Clay