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Pedogeomorphological Categorization of Selected Soils in Mbogo - Komtonga Irrigation Scheme, Mvomero District, Morogoro Region, Tanzania

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Authors' contributions

This work was carried out in collaboration between both authors. Author HJRJM intellectualized the study and abridged the paper. Authors HM and JHJRM carried out the field work and author HM wrote the draft paper. Author JHJRM carried out the analysis and prepare the tables. Both authors read and contributed to finalize the manuscript.

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ABSTRACT

Pedogeomorphological categorization of selected soil profiles developed on alluvial deposits in Mbogo - Komtonga traditional irrigation scheme, Mvomero District in Morogoro Region, was carried out during February 2017. Using standard grids, pedogeomorphic approach and standard manuals, detailed soil survey was conducted which enabled delineation of soil mapping units from which the representative profiles were identified, described and sampled. Eighteen samples were collected at a depth of 0–30 cm and from each horizon of the selected soil Master pits and analyzed for physico – chemical characterization. Based on FAO soil survey system of classification, the representative profiles were classified as Eutric Fluvisols and/or Eutric Cambisols. The pedon was deep to moderately deep, well to moderately well drained, with brownish black clay top soils or dull yellowish brown soil colors with sub soils stratified with fS, C, CL and SCL. Top soil pH was strongly to medium acid to medium or slightly acid sub soils. OC showed no decline in soil quality. N was very low to low, P and K levels were medium to low or very low; CEC was high to very high in all the profiles. Ca^{2+} and Mg^{2+} in the top soils were high to very high and very low or low to

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medium in the sub soils. Na^+ was rated as low to medium in the top soils of all profiles and low to very low in the sub soils. Base saturation was > 50% and was rated as high. Topsoil Bd and total porosity were ideal to medium. AWC was medium and water storage capacity (AWSC) was good and sufficient for paddy production and other upland crops. These results suggest that where the soil parameters were low to very low as for N, P and SOM should be included in the overall soil fertility management program. Soil reaction may be regulated during irrigation development by provision of sufficient drainage, discharge and flood control structures and minimum application of lime if required.

Keywords: Irrigation; alluvial plain; geomorphology; master pits; classification; mapping units.

ABBREVIATIONS

CEC :Cation Exchange Capacity;
AWC : Available Water Capacity;
AWSC: Available Water Storage Capacity;
SOM : Soil Organic Matter;
OC : Organic Carbon;
Bd : Bulk Density;
N : Nitrogen;
P : phosphorus;
K : potassium;
Ca : Calcium;
Mg : Magnesium;
fS : Fine Sand;
C : Clay;
CL : Clay Loam;
SCL : Sand Clay Loam;

1. INTRODUCTION

Agriculture sector in Tanzania is by far the largest sector of the economy. It accounts for 24.7 per cent of the GDP, 20 per cent of traditional export earnings, 95 per cent of food requirement, employs 75 per cent of the population and food contributes about 55.9 per cent of the inflation basket [1]. Comparatively, the financial sector is only roughly 10 per cent of the size of the agriculture sector [2]. Although there are specific and main traditional export crops in Tanzania such as cashewnuts (*Anacardium occidentale*), maize (*Zea mays* L) and rice (*Oryza sativa* L) have recently assumed the role of both food and cash crops also exported during the years of surplus. Maize (*Zea mays* L.) is an important staple food for the majority of Tanzanians [3] and about 80 per cent of it is produced by small - scale farmers grown on over 4.9 million ha [4,5]. Between 65 and 80 per cent of all maize is consumed within the producing households and only 20 to 35 per cent enters commercial channels. It has been identified as a key crop to enhance food production, income, poverty alleviation and food security [6]. Maize provides 60 per cent of dietary calories, over 30 per cent house income and more than 50 per cent of utilizable protein [7,8]. Estimates suggest that there might be 150 million Tanzanians by 2050, and so, the National demand for maize will have to grow in the future to meet demand of the growing population in response to growth of national Gross Domestic Product (GDP) at nearly 7 per cent per annum. Some studies have reported that Food security must account for opportunities to increase production against projected changes in demand associated with population growth and changing diets, need to reduce the environmental footprint of agriculture, and limited availability of land suitable for crop production [9,10,11].

Rice (*Oryza sativa* L) is the second most important crop after maize (*Zea mays* L). Tanzania is the second largest producer of rice in Southern Africa after Madagascar, with production level of 818,000 tons [12] or 2.2 million tons currently. The cultivated area is 681,000 ha and this represents 18% of Tanzania's cultivated land. About 71% of the rice grown in Tanzania is produced under rain fed conditions, where irrigated land presents 29% of the total land with most of it in small scale traditional irrigations with the average yield of 1 - 1.5 t ha^{-1} [13]. About half of the production is concentrated in Morogoro, Shinyanga, and Mwanza regions and virtually, 99% of rice is grown by smallholders in Tanzania, although some of them are part of large - scale rice irrigation schemes that were formerly state - managed farms [14]. Despite the importance of maize and rice, its production is challenged with amongst others to low investment, low soil fertility, and unsustainable agricultural practices leading to land depletion.

Land depletion is caused by inappropriate land use and soil management practices, including poor cropping and farming systems, shortening and or elimination of the fallow period, insufficient and inadequate use of farm manures and fertilizers, nutrients mining and soil erosion [15]. Soil deprivation and underutilization of appropriate mineral elements in crop production portends food security in Tanzania, Mvomero District inclusive [16]. The main reasons of land deprivation include depletion of plants mineral elements, deletion of whole crop residues, use of low levels of mineral elements during crop production and inadequate soil conservation practices [17] and longer cultivation [18]. These factors has been the main reason for low soil fertility with resultant impact on crop production and productivity including grain quality, cost of production and the increased risk of soil erosion. Maintaining long - term soil fertility through conventional agriculture has certain limitations [19]. For example, studies on a continental soil nutrient balance in 38 sub - Saharan countries involving 35 crops [20] has reported that soil nutrient balances were negative for N, P, K mineral elements with mean annual losses of 22 kg N, 2.5 kg P and 15 kg K ha^{-1}. This indicates that improving the production and productivity of agriculture in Mbogo Komtonga for example, is greatly dependent on efficient utilization and management of soils [21]. Different soil types exhibit varying characteristics due to differences in micro - morphological, morphological, physical, chemical and mineralogical properties [22]. Variations in soil forming factors and processes operating on different parent materials, under different climatic, topographic, and biological conditions over varying periods would cause these variations [23].

Soil categorization and classification therefore helps to generate required information for land use planning and soil management purposes. Soil surveys are important for soil characterization and classification purposes and aids in the creation of data bases on soil morphology, physical and chemical properties [23,24,25]. This information is important for determining agricultural potential, limitations and possible management options for the soils in a particular area thereby helping in selection of the best agricultural enterprises suitable for that area [26,27]. Irrigation projects can be planned and developed based on information obtained from soil characterization and classification. Area specific soil fertility management strategies, aimed at increasing crop production, can be developed for a particular area using soil survey data instead of using general fertilizer recommendations. Information on soil characterization and classification can be utilized widely by land use planners, agriculture researchers, extension staff, development agents and farmers in order to sustainably increase agriculture production.

A detailed study of the soil characteristics and classification will provide baseline information on the physical, chemical and mineralogical properties of the soil for crop production, land use planning and management. Despite the fact that Mbogo - Komtonga irrigation scheme in Mvomero District is an intensive producer of rice and maize there is no soil pedogeomorphological characterization and classification that have been done on the soils of the area. Soil pedogeomorphological characterization and classification of the Mbogo - Komtonga irrigation scheme are very important in providing the needed basic information on soils of the area. Thus, this study aims to characterize the soils of the area based on their pedogeomorphological characteristics, physico - chemical properties and their classification according to the FAO – Unesco Soil Map of the World system of classification [28]. The results emanating from the study will provide information on the soil fertility trends and will serve to guide activities related to the management of the existing land resources for sustainable agricultural production in Mvomero District Therefore, the objective of this study was to characterize the soils under maize production in Mbogo - Komtonga, Mvomero District, Morogoro Region and to recommend management practices required for sustainable crop production.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The study was carried out in Mbogo - Komtonga traditional irrigation scheme located in Mvomero District, Morogoro Region, Tanzania. It 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 (Fig. 1). Agricultural practices in Mbogo - Komtonga irrigation scheme are both traditional irrigation and rainfed. The main crop grown in this area is rice (*Oryza sativa* L) mainly as food and cash crop. According to the interviewed farmers, hand hoe is the overall dominant tool for land preparation. Failure of crops in these areas is due to prolonged flood during rainy season, nutrient leaching and inadequate irrigation water in the dry season, suggesting irrigation development. Generally, when irrigation water is needed it is not sufficiently available and when sufficiently available, there is no drainage. For rice cultivation, early planting starts in December and harvested in May while late planting starts in January and harvested in June. After the main rainy season, most farmers use residual moisture to grow maize, cassava and horticultural crops. The current average production of paddy ranges between 2.5 – 3.0 t ha^{-1}. Among other factors, low crop yield is attributed to low or no use of agricultural inputs, lack and or poor irrigation

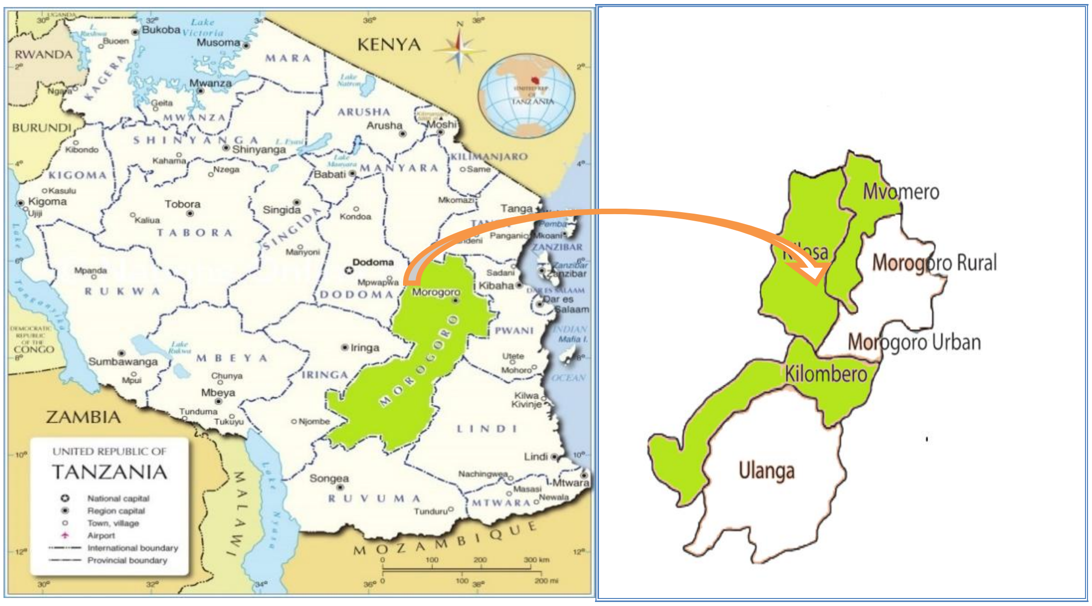
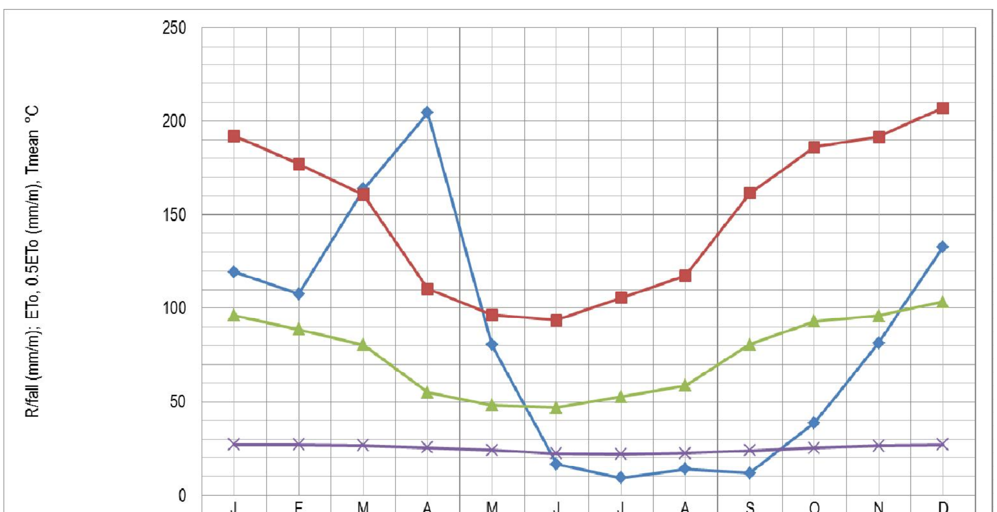


Fig. 1. Location of the study area



	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	11.8	38.6	81.3	132.7
Evap. (Pan) mm m-1	192	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	88.6	80.3	55.1	48.2	46.8	52.7	58.8	80.6	93	95.9	103.4
T mean (°C)	26.9	27	26.6	25.3	24	22.2	21.8	22.4	23.9	25.2	26.3	26.9

Fig. 2. Water balance and the determination of the growing period for Mbogo – Komtonga irrigation schemes

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	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	26.6	25.3	24	22.2	21.8	22.4	23.9	25.2	26.3	26.9
Evap. (Pan) mm m^{-1}	192	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	88.6	80.3	55.1	48.2	46.8	52.7	58.8	80.6	93	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	232.9	172.7	89	85.3	99.4	120.6	150.3	185.5	187.4	238	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

Table 2. Salient features of the study area

Soil Profile	MU	Village	Scheme	District	Coordinates		Alt. (m)	Parent Material	Landform	Land use	Soil classification	SMR	STR
					North	East							
MB - SP1	MB - Pa1	Mbogo - Komtonga	Irrigation	Mvomero	9316954	344246	364	Alluvial	flat to undulating	Rice cultivation	Eutric Fluvisols (FAO, 1988);	Ustic	Isohyperthermic
MB - SP2	MB - Pa2	Mbogo - Komtonga	Irrigation	Mvomero	9317507	373442	363	Alluvial	flat	Sugarcane production	Eutric Fluvisols	Ustic	Isohyperthermic
MB - SP3	MB - Pa3	Mbogo - Komtonga	Irrigation	Mvomero	9317750	344231	362	Alluvial	flat to undulating	Rice cultivation, ploughed ready for transplanting/ broadcasting	Eutric Fluvisols	Ustic	Isohyperthermic

Table 3. Physical chemical analysis of the collected soil samples

No	Parameter	Analysis method	Reference
1	Bulk density	Core method	Day, 1965
2	Particle density	Particle density was calculated using the mass of the solid particles and the volume they occupy. Mass of the solid particles was obtained by weighing the solid particles and likewise the volume was determined from the mass and density of water displaced by the sample	Soil Survey Staff, 2014
3	Total Porosity	Total soil porosity was calculated by using the bulk and particle density data	
4	Soil moisture retention characteristics	Sand Kaolin Box for low suction values and pressure apparatus for high suction values	Okalebo, et al., 2002; Nelson and Sommers, 1982
5	Particle size analysis	Hydrometer method	Nelson and Sommers, 1982; Bremner and Mulvaney, 1982
6	Textural classes	USDA textural triangle	Thomas, 1996
7	Soil pH	Measured potentiometrically in water and 1 N KCl at a ratio of 1:2.5 weight to volume basis	Nelson and Sommers, 1982; Chapman, 1965.
8	Electrical conductivity (EC)	Measured on a 1:2.5 soil: water suspension using electrical conductivity meter	IUSS Working Group WRB, 2014.
9	Organic carbon	Walkley and Black wet oxidation	Obasi et al., 2015
10	Organic matter	By organic carbon conversion by multiplying with a factor of 1.724	Khan et al., 2012
11	Total N	Micro-Kjeldahl digestion distillation	Kebeney, et. al., 2015
12	Available phosphorus	Bray and Kurtz-1 for low pH soils (pH water < 7) and Olsen for high pH soils (pH water > 7)	Uwingabire, et al., 2016, Uwitonze, et al., 2016.
13	Cation exchange capacity of soil (CEC soil) and exchangeable bases	Determined by saturating soil with neutral 1 M NH_4OAc (ammonium acetate) and the adsorbed NH_4^+ were displaced using 1 M KCl and then determined by Kjeldahl distillation	[USDA-NRCS, 2016].
14	Exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+ and K^+)	Atomic absorption spectrophotometer (AAS)	Lal and Shukla, 2005.
15	total exchangeable bases (TEB)	Calculated arithmetically as the sum of the four exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+ and K^+) for a given soil sample.	

infrastructure and lack of drainage during the rainy season. Rainfall in the study areas is bi-modal with 46.2% of the total rains falling between March through May and about 44.5% light rains falling between November through February. The total average annual rainfall is about 970 mm. Temperature, RH (%), potential evaporation and other climate variables representative of the study areas are presented in Table 1 and Fig 2. The mean temperature varies from 21.8ºC in July to 27.0ºC in February. All pedons have an isohyperthermic soil temperature regime (STR) and udic soil moisture regime. The monthly average relative humidity (RH) varies from 58.8 (i.e. October) to 77.9% (i.e. April). The potential evaporation 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.

2.2 Field Methods

Soil survey was planned by means of gridlines. A GPS device was used to carry out boundary survey, set out grid lines, prepare or reconfirm a base map, as well as recording the coordinates and elevations of all field observations. During the fieldwork, two kinds of observations were made. These were auguring and profile (master) pits observations. Auger observation was taken as an identification of the taxonomic unit for which a particular pedon belong. The standard depth was taken as 120 cm but extended further to 150 cm whenever necessary and possible. A total of one hundred and ten (110) augers were observed at a depth of 120 cm. Core samples were also sampled from 0 – 50 cm and 50 – 100 cm soil depth of each profile. Fourteen (14) core samples were then sampled from 7 profiles. The second observation was full pit or full profile. This was done after the establishment of the important soil sets. A total of three (3) profiles and one (1) minipit were opened and described respectively. These representative profiles were MB-Pa1, MB-Pa2 and MB-Pa3. The approximate volume of a full master pit was 150 cm x 150 cm x 120/150 cm. These observations were concisely described according to the FAO guidelines (1977) for soil description and were carefully entered abreviatively on a pre - prepared data form. Soil classification was done by using the FAO – UNESCO soil map of the world (1988). Overall, 50 disturbed soil samples were collected for physical - chemical characterization. Of the total disturbed samples, 41 were from master pits and 9 were collected as composite soil samples from a soil depth of 0 – 30 cm. Geomorphologically, the proposed irrigation scheme fall into one landscape, that is, the Plain or Floodplain [29]. It is essentially a flat area with moderate to imperfectly drainage condition. Most of clearly drainable sections of rivers flow from NW to SE direction and a few flows southerly. The geology of the area can generally be described as having alluvium deposits probably originating from the high plateau. The high plateau is covered by red brown and in places, light grey earth particularly on the flat ridges. Deep weathering of the gneisses which may have originated during the Neogene’s period is a common feature on the plateau. The lowlands have a thick cover of black cotton soil (mbugas) which in places are replaced by light coloured sandy soils which is partly alluvial. Light grey clays are common in the marshy areas and are probably found in several layers within the soil profile observed in the lowlands suitable for agricultural purposes. Table 2 presents the salient features of the study sites.

2.3 Laboratory Methods

Laboratory methods used in the determination of different physico - chemical characteristics in the study area are summarized in Table 3.

3. RESULTS AND DISCUSSION

3.1 Soil Pedogeomorphological Characteristics and Genesis in Mbogo Komtonga Irrigation Scheme

Salient morphological characteristics of the studied profiles are given in Table 4. All studied soil profiles were deep to moderately deep and water table was estimated at > 180 cm deep. Drainage was observed to be moderately well drained in profiles MB - P1, well drained at MB - P2 and well to moderately well drained at MB - P3. Floods were reported to be common in April - May. All profiles had clay (C) texture in its first horizon or the 0–30 cm soil depth and cracks were observed from the surface to 50 cm soil depth. With the exception of MB - P3 which had no fine sand (fS) texture in the third horizon (i.e. 50–90/120 cm), the rest of the master pits i.e. MB – P1 & P2 had fine sand (fS) texture material on third horizon. However, MB – P3 was more stratified compared with MB – P1 & P2 as C was underlain by sandy loam followed by Sand clay loam followed by gravelly sand material. All top soils of the studied master pits had brownish black colour. Whereas MB – P1 was dominated by brownish black colour in most of its horizons, MB – P2 had more mixed/complex colour and MB – P3 was dominated by dull yellowish brown colour. Consistency in these profiles ranged from hard when dry to soft or loose. For instance, profile MB – P1 & P2 had hard consistency when dry in the first two horizons compared with the only first horizon in profile MB – P2 ascribed to the clay nature of the soil. Generally, the soil structure of the master pits was rated as strong to moderate medium and coarse sub angular blocky. But MB – P3 was dominated by weak medium and coarse sub angular blocky. Infiltration rate was rated as moderate or moderate to high in profile MB – P3. Horizon boundary attributes varied within the pedons, whereby distinctness ranged from abrupt to gradual, but topography was dominantly smooth and wavy. Taken together, morphology and genesis of the studied soils were typical of alluvial soil formation.

3.2 Soil Physical Characteristics

3.2.1 Soil texture, silt clay ratio, bulk density (BD) and total porosity (TP)

Table 5 presents data on soil physical properties including texture, silt clay ratio, bulk density and porosity of the studied soils. Soil texture is the most stable physical characteristics of the soil. It influences a number of other soil properties such as structure, consistence, bulk density (Bd), soil moisture regime, permeability, root penetration, infiltration rates, runoff rate, erodibility, workability, root penetration and fertility. In Mbogo – Komtonga soil profiles MB - P1 & P2 had clay top soils overlying clay or sand clay sub soils while profile MB - P3 had clay topsoil overlying sandy loam sub soils. Generally, profile MB – P2 had much heavier texture with the exception of the second horizon when compared with the other two master pits, implying it would behave differently from these two in terms of physical and chemical properties. For example, clayey texture is associated with high water retention capacity and high nutrient supply [30]. Profile MB - P2 would probably offer more favourable conditions for paddy than the other two profiles. Clay content decreased more or less with depth in all pedons providing some indication of non-uniformity in clay eluviation - illuviation. Silt/clay ratio, an indicator of soil susceptibility to erosion was less than the threshold of 0.4 [31], as in profile MB – P1 implying moderate resistance to erosion. Silt/clay ratios in the other two profiles i.e. MB – P2 & P3, showed higher values than the threshold value.

Changes in bulk density for a given soil can alert soil managers to changes in soil quality and ecosystem function. Bulk density reflects the soil's ability to function for structural support, water and solute movement, and soil aeration. It is also used to express soil physical, chemical and biological measurements on a volumetric basis for soil quality assessment and comparisons between management systems. Bulk densities above thresholds indicate impaired function. Generally, in highly productive soils, Bd range from 1.0–1.5 g cm^{-3} (i.e. fine to medium texture) and 1.10 to 1.65 g cm^{-3} (i.e. coarse textured soils) also see Table 6 with potential root restriction occurring at ≥ 1.4 g cm^{-3} for clay and ≥1.6 g cm^{-3} for sandy soils [32]. In Mbogo - Komtonga study area, soil texture in most of the topsoil of the representative profiles was dominated by clay (C) or clay loam (CL) or sand clay loam (SCL). Bulk density (Bd) and total porosity (Pt) are very important factors in the determination of root penetration and proliferation. In some soil profile horizons, soil texture is used to determine the soil Bd that is used to calculate the total porosity. Whereas the Bd of the surface soils in Mbogo - Komtonga range from 1.21 g cm^{-3} -1.24 g cm^{-3}, Bd ranged from 1.21 to 1.68 in profile MB – P1; 1.22 –1.69 in MB–P2 and 1.24–1.49 g cm^{-3} in MB–P3. These correspond to total porosity of 36.5 – 54.4%; 36.3–53.9% and 43.7–53.2% respectively. The data showed that the Bd increased with depth [33,34,35] and was medium in 67% (slightly above adequate but not restrictive) and ideal for plant growth in 33 % of the study area. Similarly, the data indicated that the lower the Bd, the higher the porosity and vice versa (*see* Table 5). High bulk density (Bd) is an indicator of low soil porosity and soil compaction; poor environment for root growth, reduced aeration and undesirable changes in hydrologic function such as reduced water infiltration rates [33,36,37]. The comparatively higher Bd in 67 % of the study areas in Mbogo was probably due to less aggregation, clay (heavy) textural class of the area, fewer roots and compaction caused by the overlaying layers. Similarly, higher Bd can be caused by consistently ploughing or disking to the same depth; allowing equipment traffic especially on wet soil; using a limited crop rotation without variability in root structure or rooting depth; and incorporating, burning, or removing crop residues. In order to reduce the chances of high bulk density and compaction, soil disturbance and production activities when soils are wet should be minimized, field/farm roads for farm equipment should be designed and constructed, sub-soiling to disrupt existing compacted layers, and practices that maintain or increase SOM should be adopted at least once in three years.

3.2.2 Field capacity, permanent wilting point, available water and available water capacity

Field capacity (FC) is the water remaining in soil after it has been thoroughly saturated and allowed to drain freely, usually for one to two days (Table 6). Permanent wilting point (PWP) is the moisture content of soil at which plants wilt and fail to recover when supplied with sufficient soil water. It is an indicator of soil's ability to retain water and make it sufficiently available for plant use. Available water capacity (AWC), usually expressed as a volume fraction, percentage, or depth (cm), is the maximum amount of water held in soil between its field capacity (at pF 2.0) and permanent wilting point (at pF 4.2). In Mbogo – Komtonga, AWC range between 107 mm m^{-1} and 144 mm m^{-1} rated as medium (Table 7). However, water storage capacity (AWSC) was 200 mm m^{-1} (inferred) considered as good and sufficient for paddy production and other upland crops. Lack of AW reduces root and plant growth, and can lead to plant death if sufficient moisture is not provided before PWP. Poor AW is caused by conventional tillage operations; low residue crop rotations, and burning, burying, harvesting, or otherwise removing plant residues; heavy equipment traffic on wet soils, and grazing systems that allow development of livestock loafing areas and livestock trails. In order to improve AWC in soils, farmers should grow high residue crops, cover crops, reduce soil disturbing activities, and manage residue to protect and increase SOM. When feasible, tillage, harvest, and other farming operations requiring heavy equipment can be avoided when the soil is wet so as to minimize compaction. Compacted layers can be ripped to break them and expand the depth of the soil available for root growth.

3.3 Chemical Properties of the Studied Pedons in Mbogo Komtonga, Mvomero District

3.3.1Soil pH

Results of soil pH and other chemical properties of the soils of the studied representative master pits of Mbogo - Komtonga are presented in Table 7. 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 due to the fact that pH affects the form of nutrient ions in soils thus affecting plant availability. 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 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. The pH of top soils of the studied soil profiles in Mbogo - Komtonga irrigation scheme ranged from 5.4 to 6.0. This was rated as strongly acid to medium acid [38]. Similarly, the pH of the sub soils ranged from 5.8 – 6.2 and was rated as medium acid to slightly acid [36,38]. The strong to medium acid observed in the tops soils of these profiles could be ascribed to low amount of bases by leaching during water table fluctuations and water percolation during flooding periods and soil nutrients mining [36,39,40]. The data also showed that pH increased with depth in the studied profiles as likewise reported in [41,42]. The nature of the observed acidity in the top soils of the representative profiles threatens the availability of mineral elements such as P which is readily available in soils with pH centred at 6.5. For example under low pH, P is precipitated due to dissolution of Al and Fe mineral elements leading to its fixation and further soil pH depression [39]. However, most plant mineral elements are available in the pH range of approximately 6.5 – 7.0 [43]. Similarly, soil pH can influence plant growth by its effect on the activity of beneficial micro-organisms [44]. For example, bacteria that decompose SOM are hindered in strong acid soils which in turn prevent OM from breaking down. As a result, OM is accumulated un-decomposed or unbroken, consequently tying up of nutrients such as N making them unavailable to plants. In order to reverse this trend, it is recommended to carryout liming in such soils by using limestone/calcium carbonate ($CaCO_3$) at a rate of 3 - 4 t ha^{-1} to raise the pH from the current status ($5.4 \le pH \le 6.0$) to a pH range of between 6.5 – 7.0 (Hausenbuiller,1978). Other material that can also be used is calcium oxide (CaO) also known as quick lime with Calcium Carbonate Equivalent (CCE) of 179%. Although this material gives quick results, care should be taken as it is difficult to apply for it irritates the eyes. Electrical conductivity (EC) is a measure of relative salt concentration or salinity, and too much salt in the soil can interfere with root function and nutrient uptake [45,46]. EC values of the top soils ranged between 0.23 and 0.32 (dS m^{-1}) and 0.02 – 0.04 (dS m^{-1}) in the sub soils of the studied master pits horizons implying that all the soils were non-saline.

3.3.2 Organic carbon

Organic carbon (OC) or Soil Organic Matter (SOM) in the soil is important because humidified OM molecules may react with mineral colloids and contribute to the stabilization of soil aggregates. While SOM favours water retention capacity and adsorption of fulvic and humic compounds by Fe^{2+} and Al^{3+} oxide, it also prevents their crystallization hence decreasing fixation power with regards to phosphates at unfavourable pH values. 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. Results of organic carbon (OC) determination from the top soil (0 - 30 cm) of the representative master pits in Mbogo - Komtonga ranged from 24.7 g kg^{-1} to 40.0 g kg^{-1} (Table 8). This corresponds to 42.5 g kg^{-1} to 69.3 g kg^{-1} SOM. Organic carbon in most of the profiles showed systematic trend of decreasing with depth. Since SOM content was calculated from SOC [47], these parameters have similar trend. 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 [48]. With the observed data all values were above the proposed threshold limits, suggesting that no decline in soil quality for Mbogo - Komtonga irrigation scheme [49]

3.3.3 Total nitrogen

Inadequate amount of N in the soil is the primary factor that limits plant growth and development in many parts of the world [50,51]. Nitrogen levels in the studied soil Master pits were low to medium with values ranging from 1.5 – 2.0 g kg^{-1} in top soils and 0.4 – 0.6 g kg^{-1} in the sub soils. These values were rated as very low to low [38]. According to NSS [38] guidelines, the proposed threshold value for N in most crops in Tanzania is 2 g kg^{-1} soil. The results show that of the studied Master pits only MB – P1 had N which was at least on the threshold value but MB – P2 & P3 were below the threshold value. The observed low or medium N in the surveyed areas may probably be influenced by microbial activity in the soil and the very low or low soil pH [49,52] [Table 9]. So, any activity envisaged to improve the soil pH, SOM quality as well as microbial activities can, consequently, lead to an increase in N in the soil [49]. The low to very low levels of N in the surveyed areas suggests application of ammoniocal form of N, which resists better to leaching caused by rainfall or irrigation as the case may be in the surveyed areas. As far as humification is concerned, an average C/N ratio of 10 (i.e. 8 - 12) is considered as optimal [36, 46]. The C/N ratio of top soils of the representative master pits ranges from 17 – 21 and was rated as moderate to poor quality SOM. It is generally accepted that C/N ratios between 8 and 12 are considered to be the most favourable, implying a relatively fast mineralisation of N from the organic materials. With the exception of MB-P3 which registered C/N ratio of 17 rated as moderate or medium quality SOM, the rest of the representative Master pits (MB – P1 & P2) had C/N ratio outside the suggested range and were rated as poor quality SOM. However, the C/N ratio observed in the sub soils of all Master pits ranged from 1 – 10 in MB – P1, 2 – 6 in MB – P2 and 5 - 17 in MB – P3 which was rated as medium and good quality SOM. According to [36] and [46], C/N ratio of 10:1 indicates good quality organic material, although they cautioned that C/N ratio might not be a good indicator of soil fertility, and thus encouraged use of individual C and N values instead.

3.3.4 Available phosphorus (Pav)

The data from the top soil of the representative Master pits (MB – P1, P2 & P3) in Mbogo - Komtonga irrigation scheme shows that available P range from 0.87 – 5.47 mg kg^{-1} rated as low (Table 9). Likewise the data in the sub soils range from 0.80 – 3.82 mg kg^{-1} also rated as low. Phosphorus (P) is an essential macro element for plant growth, hence an important soil fertility indicator. In agriculture, management of P is second only to management of N in its importance for the production of healthy and profitable crop yields. An average P level of 7 mg kg^{-1} is considered optimal below which P deficiency symptoms are likely to occur in most crops. Based on the generally accepted threshold P level, all the observed P values in Mbogo - Komtonga are considered to be below the critical range and will definitely need measures to reverse the trend. The generally low P availability manifested in all the mapping units in Mbogo - Komtonga (Table 9) suggests that management of P in these areas is critical for sustainable agricultural development.

3.3.5 Exchangeable bases, cation exchange capacity and per cent base saturation

Results of exchangeable bases, cation exchange capacity and per cent base saturation in the representative Master pits in Mbogo Komtonga are presented in Table 8. Potassium (K) in the top soils ranged from 0.62 cmol (+) kg^{-1} (MB - P3) to 2.97 cmol (+) kg^{-1} (MB - P2) rated as medium to very high. In the sub soils, exchangeable K ranged from 0.03 (MB – P1) – 0.06 cmol (+) kg^{-1} (MB – P3) and were rated as low to very low. 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 [Table 10] [38,53]. The data shows that K is unlikely to respond to Mbogo – Komtonga Irrigation scheme. Exchangeable Ca^{2+} in the topsoil of the representative Master pits ranged from 12.6 cmol (+) kg^{-1} (MB – P3) – 29.64 cmol (+) kg^{-1} (MB – P2) rated as high to very high. In the sub soils, Ca^{2+} ranged from 0.0 (MB – P3) 2.2 (MB – P1) rated as very low to low. [54] 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 compared with field conditions that do not limit Ca^{2+} uptake [55]. Based on the critical limits, and Ca^{2+} levels at the top soils, it is unlikely to have Ca^{2+} deficient of for most crops as it lies below the proposed critical limits. Exchangeable Mg^{2+} in top soils of the representative Master pits in Mbogo - Komtonga range from 4.25 cmol (+) kg^{-1} (MB – P1) – 5.07 cmol (+) kg^{-1} (MB – P2), rated as high to very high. In the sub soils, Mg ranged from 0.38 (MB – P2) – 0.59 (MB – P1) rated as low to medium [38]. The recommended value of Mg^{2+} in most crops is 2 cmol (+) kg^{-1} [56]. These data suggests that based on the top soil data, the studied area have sufficient Mg^{2+} supplies for crop growth even though there is irregular decrease of exchangeable Mg with depth. Topsoil exchangeable Na^{+} and or exchangeable sodium percentage (ESP) the levels as well as the electrical conductivity (EC) in the representative Master pits (MB – P1, P2 & P3) in the study area are presented in Table 10. The results indicates that the levels of Na^{+} in the top soils corresponds to 0.17 (MB – P2) – 0.45 cmol (+) kg^{-1} (MB – P3). These values were rated as low to medium [31]. Exchangeable Na in the sub soils ranged from 0.08 (MB – P2) – 0.38 (MB – P1) rated as very low to low [38]. The values of Na beyond which crop growth and development is impaired is less than 1 cmol (+) kg^{-1} [31].The corresponding ESP range from 0.4 – 1.7% rated as non-sodic. The critical values of ESP above which most crops are affected are established at 15% [57]. These results suggest that the surveyed areas have no threat to sodicity problems [31,46].

3.3.6 Cation exchange capacity (CEC)

Cation exchange capacity (CEC) refers to the exchange phenomenon of positively charged ions (cation) at the surface of the negatively charged colloids [58]. It is often used as a characteristic in the determination of the nutrient retention soil 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 [38]. CEC values in the topsoil of the representative Master pits in Mbogo - Komtonga irrigation scheme are as shown in Table 8. Results showed that CEC values ranged between 27.02 cmol (+) kg^{-1} (MB – P3) – 44.8 cmol (+) kg^{-1} (MB – P2) and were rated as high to very high [38]. 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 the required amount of inorganic fertilizer. By adding inorganic fertilizer, one increases the humus content of the soil and consequently resulting into a higher or maintenance of higher CEC hence a better retention of nutrients. The data also showed that percent base saturation (BS) of the representative Master pits varied irregularly and the trend with depth was not clear within the soil profiles. However, the top soils of the representative Master pits recorded relatively higher topsoil values in MB - P1 and MB - P2 than in MB – P3. Based on [46], % BS in all the representative Master pits were rated as high and fertile soils because the BS were greater than 60%.

Table 4. Main pedogeomorphological features of the studied soil profiles in Mbogo Komtonga, Mvomero District, Tanzania

Soil pedons[1]	Horizon	Depth (cm)	Texture	colour		Consistence			Structure	Pores	Roots	Rock fragment	Horizon boundary
				dry	Moist	Dry	moist	wet					
Mbogo													
MB-P1	Ap	0–30	C	brb (10YR 3/2)	brb (10yr 2/2)	h	fr	s & p	str m+c sbk	cm, cf+vf	cf	na	cs
	Bw_1t_1	30–50	C	brb (10YR 3/2)	brb (10yr 2/2)	h	fr	s & p	str m+c sbk	cf+m, mf+vf	vff	na	cs
	Bw_2	50 - 80	fS	na	duybr (10yr 7/3)	fi	fr	s & p	sg	cm		s freq irr qrtz + Fe	cs
	$B_3w_2t_2$	80 –116	C	na	brb (7.5yr 4/2)	na	fr	s & p	mo, m + f sbk		cm, mf+vf	na	cs
	B_4w_3	116 –140	SCL	na	brb (7.5yr 3/2)	na	fr	ns & np	wk, m & f sbk	mf+vf		na	cs
	B_5w_4	140 –180	fS	na	duybr (10yr 7/4)	na	l	ns & np	sg	mf		na	na
MB-P2	Ap	0 – 27/32	C	gbr (7.5YR 4/2)	brb (7.5yr 3/2)	h	fr	s & p	str m+f sbk	cf+vf	vfc, cm, mf+vf	na	cw
	Bw_1	27 – 60/74	SC	br (7.5YR 4/4)	dbr (7.5yr 3/3)	h	fr	ss & sp	mo m &c sbk	vfm+vf	cm, f+vf	na	cw
	Bw_2	60 – 90/120	fS	gybr (10YR7/3)	gybr (10yr 6/4)	l	na	ns & np	wk sg	mf	ff + vf	na	cw
	$Bw_3t_1g_1$	90 –160	C	duyo (10YR 7/4)	g (10yr 4/1)	h	fr	s & p	str m+f sbk	cf+vf	vff	na	cs
	$Bw_4t_2g_2$	160 –180	SC	na	br (10yr 5/2)	na	fr	s & p	wk m+f sbk	fm, cf+mvf	na	na	na
MB-P3	Ap	0 – 28	C	duybr (10YR5/3	brb (10yr3/2)	h	fr	ss & sp	str m+c sbk	mf+vf	cf+mvf	na	cs
	Bw_1	28 – 80	SL	duybr (10YR6/4	duybr (10yr5/4)	s	vfr	ns & np	w m+c sbk	mf+vf	vfc+vff	na	cw
	Bw_2g_1	80 – 126	SCL	na	gybr (10yr 6/4)	na	fr	ns & np	w m+f sbk	fm, mf+vf	vff	na	cs
	Bw_3g_2	178 – 126	SCL	na	duybr (10yr4/3)	na	fr	ns & np	w m+c sbk	cm, mf+vf	vff+vfc	na	cs
	Bw_4	178+	grS	na	duybr (10yr7/3)	na	vfr	ns & np	sg	na	na	na	na

Soil texture: C = clay, SC = sandy clay, SCL= sandy clay loam, SL = sandy loam, fS = fine sand, grS = gravelly sand; Soil colour: brb = brownish black, duybr = dull yellowish brown, g = gray; gbr = grayish brown; gybr = greyish yellowish brown, dbr = dark brown, br = brown; Soil consistence: Dry: s = soft; h = hard; l = loose; na = not applicable. Moist: fr = friable; vfr = very friable; l = loose; Wet: ns = non-sticky; ss = slightly sticky; s = sticky; np = non-plastic; sp = slightly plastic; p = plastic. Structure: Grade: Str = strong; mo = moderate; w = weak; sg = structure less single grained. Size: f = fine; m = medium; c = coarse. Type: sbk = sub angular blocky; Pores: Abundance: f = few; c = common; a =abundant. Size: vf = very fine; f = fine; m = medium; common. Roots: Colour: ybr = yellowish brown; br = brown; dbr = dark brown; gybr = greyish yellowish brown; duyo = dull yellowish orange; duybr = dull yellowish brown; g = grey; brb = brownish black; Type: Fe = iron; Horizon boundary: Distinctness: a = abrupt; c = clear; g = gradual. Topography: s = smooth; w = wavy

Table 5. Some selected physical properties of master pits from Mbogo irrigation scheme

Profile No.	Horizons	Horizons Depth	<2	20-50	50-2000	Textural Class	Si/C ratio	Bulk Density	Particle Density	Total Porosity
		(cm)		(μm)					g.cm^{-3}	%
Mbogo										
MB-P1	Ap	0–30	58	24	18	C	0.41	1.209	2.65	54.4
	Bw_1t_1	30–50	66	2	32	C	0.03	1.216	2.65	54.1
	B_2	50 - 80	6	2	92	fS	0.33	1.684	2.65	36.5
	$B_3w_2t_2$	80 –116	72	12	16	C	0.17	1.501	2.65	43.4
	B_4w_3	116 –140	24	2	74	SCL	0.08	1.446	2.65	45.4
	B_5w_4	140 –180	6	2	92	fS	0.33	1.684	2.65	36.5
MB-P2	Ap	0 – 27/32	60	12	28	C	2.33	1.223	2.65	53.8
	Bw_1	27 – 60/74	34	8	58	SC	7.25	1.364	2.65	48.5
	Bw_2	60 – 90/120	6	0	94	fS	0.00	1.688	2.65	36.3
	$Bw_3t_1g_1$	90 –160	62	8	30	C	3.75	1.222	2.65	53.9
	$Bw_4t_2g_2$	160 –180	44	6	50	SC	8.33	1.311	2.65	50.5
MB-P3	Ap	0 – 28	56	12	32	C	2.67	1.241	2.65	53.2
	Bw_1	28 – 80	18	6	76	SL	12.67	1.492	2.65	43.7
	Bw_2g_1	80 – 126	20	6	74	SCL	12.33	1.472	2.65	44.5
	Bw_3g_2	126 – 178	22	8	70	SCL	8.75	1.451	2.65	45.2
	Bw_4	178+				grS			2.65	100.0

C = clay, SC = sandy clay, SCL= sandy clay loam, SL = sandy loam, fS = fine sand, grS = gravelly sand

Table 6. Soil physical characteristics of the selected sites in Mbogo - Komtonga proposed irrigation schemes

Location	MU	B_d	P_d	P_t	Texture	FC	PWP	AW	AWSC
		(g cm^{-3})		(%)				mm.m^{-1}	
Mbogo Komtonga	MB - P1	1.21	2.65	54.4	C	426	285	140	200
	MB - P2	1.22	2.65	53.8	C	381	273	107	200
	MB - P3	1.24	2.65	53.2	C	386	275	111	200

MU = Mapping Unit; B_d = Bulk density; P_d = Particle density; WSC = Water storage capacity; AW = Available water; HC = Hydraulic conductivity; P_t = Total Porosity; SL = Sandy loam; SCL = Sand clay loam; CL = Clay loam; C = Clay

Table 7. Some selected chemical properties of master pits from Mbogo irrigation scheme

Profile No.	Horizons	Horizons Depth (cm)	pH H_2O	pH KCl	EC $dS.m^{-1}$	OC (%)	OM (%)	N (%)	C/N ratio	Av. P $mg.kg^{-1}$
Mbogo										
MB-P1	Ap	0–30	5.8	4.9	0.32	3.80	6.54	0.20	21	4.80
	Bw_1t_1	30–50	6.0	4.6	0.10	1.16	2.00	0.13	9	2.46
	B_2	50 - 80	6.7	5.1	0.02	0.07	0.12	0.05	1	1.06
	$B_3w_2t_2$	80 –116	6.4	4.8	0.10	0.97	1.67	0.10	10	0.88
	B_4w_3	116 –140	6.6	5.1	0.04	0.65	1.12	0.07	9	3.82
	B_5w_4	140 –180	6.8	5.6	0.04	0.09	0.15	0.04	2	0.80
MB-P2	Ap	0 – 27/32	6.0	5.2	0.24	4.03	6.93	0.18	23	5.47
	Bw_1	27 – 60/74	6.2	4.7	0.05	0.55	0.95	0.11	5	0.87
	Bw_2	60 – 90/120	6.6	5.0	0.02	0.07	0.12	0.04	2	1.62
	$Bw_3t_1g_1$	90 –160	6.2	4.3	0.05	0.98	1.69	0.17	6	1.91
	$Bw_4t_2g_2$	160 –180	6.4	4.6	0.05	0.55	0.95	0.09	6	3.70
MB-P3	Ap	0 – 28	5.4	4.3	0.23	2.47	4.25	0.15	17	0.87
	Bw_1	28 – 80	5.8	4.3	0.04	0.36	0.62	0.07	5	2.24
	Bw_2g_1	80 – 126	5.7	4.2	0.04	0.43	0.74	0.07	6	2.54
	Bw_3g_2	126 – 178	5.6	4.1	0.05	1.08	1.86	0.06	17	1.79

pH = soil reaction, EC = Electrical conductivity, OC= Organic carbon, OM = Organic matter, N = Nitrogen, C/N = Carbon Nitrogen ratio, Av.P = Available P

Table 8. Exchangeable cations and related properties the studied soils

Profile No.	Horizons	Horizons Depth (cm)	Exchangeable bases Ca (cmol (+)/kg)	Mg	K	Na	TEB	CECsoil	BS (%)
Mbogo									
MB-P1	Ap	0–30	22.46	4.25	1.15	0.39	28.3	41.0	68
	Bw_1t_1	30–50	20.36	4.57	0.28	0.38	25.6	32.4	77
	B_2	50 - 80	2.99	0.67	0.03	0.14	3.8	10.5	68
	$B_3w_2t_2$	80 –116	18.66	4.53	0.28	0.35	23.8	30.2	77
	B_4w_3	116 –140	8.58	2.06	0.10	0.24	11.0	18.2	71
	B_5w_4	140 –180	2.20	0.59	0.03	0.14	3.0	7.8	82
MB-P2	Ap	0 – 27/32	29.64	5.07	2.97	0.17	37.9	44.8	82
	Bw_1	27 – 60/74	9.58	2.80	0.12	0.26	12.8	18.0	78
	Bw_2	60 – 90/120	1.80	0.38	0.04	0.08	2.3	7.0	84

Profile No.	Horizons	Horizons Depth (cm)	Exchangeable bases					CECsoil	BS (%)
			Ca	Mg	K	Na	TEB		
			(cmol (+)/kg)						
	$Bw_3t_1g_1$	90 –160	14.97	4.61	0.21	0.36	20.2	24.8	79
	$Bw_4t_2g_2$	160 –180	10.18	3.78	0.17	0.33	14.5	20.6	71
MB-P3	Ap	0 – 28	12.57	5.02	0.62	0.45	18.7	27.0	66
	Bw_1	28 – 80	0.00	1.61	0.10	0.14	1.9	6.9	62
	Bw_2g_1	80 – 126	6.59	1.89	0.08	0.09	8.7	16.4	66
	Bw_3g_2	126 – 178	6.19	1.78	0.06	0.18	8.2	16.6	63

Ca = Calcium, Mg = Magnesium, K = Potassium, Na = Sodium, TEB = Total exchangeable bases, CEC = Cation exchange capacity, BS = Base saturation

Table 9. Nutrient ratios of the studied soils

Profile No.	Horizons	Horizons Depth (cm)	Ca/TEB	Ca/Mg	Mg/K	% (K/TEB)
Mbogo						
MB-P1	Ap	0–30	0.80	5.28	3.70	4.07
	Bw_1t_1	30–50	0.80	4.46	16.32	1.09
	B_2	50 - 80	0.78	4.46	22.33	0.78
	$B_3w_2t_2$	80 –116	0.78	4.12	16.18	1.18
	B_4w_3	116 –140	0.78	4.17	20.60	0.91
	B_5w_4	140 –180	0.74	3.73	19.67	1.01
MB-P2	Ap	0 – 27/32	0.78	5.85	1.71	7.85
	Bw_1	27 – 60/74	0.75	3.42	23.33	0.94
	Bw_2	60 – 90/120	0.78	4.74	9.50	1.74
	$Bw_3t_1g_1$	90 –160	0.74	3.25	21.95	1.04
	$Bw_4t_2g_2$	160 –180	0.70	2.69	22.24	1.18
MB-P3	Ap	0 – 28	0.67	2.50	8.10	3.32
	Bw_1	28 – 80	0.00	0.00	16.10	5.41
	Bw_2g_1	80 – 126	0.76	3.49	23.63	0.92
	Bw_3g_2	126 – 178	0.75	3.48	29.67	0.73

Ca/TEB = Calcium to Total exchangeable bases, Ca/Mg = Calcium to Magnesium ratio, Mg/K = Magnesium to Potassium ratio, K/TEB = Potassium to Total Exchangeable Bases

Table 10. Classification of the studied soil Master Pits in Mbogo Komtonga irrigation scheme, Mvomero District, Tanzania

Profile	Diagnostic horizons	Other diagnostic features	FAO UNESCO soil map of the world classification (1988)		
			Soil unit	**Major soil grouping**	**Soil subunits**
MB - P1	Ochric A, Argic B	Flat to undulating, deep to moderately deep, moderately well drained, brownish black clay over dull yellowish brown fine sand soil over brownish black clay over brownish black sand clay loam over dull yellowish brown fine sand soil. Water table is estimated at >180 cm. Floods reported to be common in April/ May. The soil texture is heavy at the first two horizons but lighter down the profile. Cracks observed on the surface to 50 cm soil depth, medium acid, Ustic moisture regime, stratification, Isohyperthermic STR	Fluvisols	Eutric Fluvisols	Gleyi - Eutric Fluvisol
MB - P2	Ochric A, Cambic B	Almost flat, deep to moderately deep, well drained, greyish brown clay over brown to dark brown sand clay loam over greyish yellow fine sand over dull yellowish orange clay over brown sand clay soil. Water table was estimated at >180 cm. Floods in the area occurs in March/April or November /December. Vertical cracks were observed from the surface to 50 cm soil depth. Animal burrows (crotovinas) were observed in the profile from 0 - 74 cm depth. medium acid, Ustic moisture regime, stratification, Isohyperthermic STR	Fluvisols Cambisols	Eutric Fluvisols Vertic Cambisols	nd
MB - P3	Ochric A	Almost flat, deep to moderately deep, moderately well drained to well drained, dull yellowish brown clay over dull yellowish brown sand clay loam over greyish yellow brown sand clay loam over dull yellowish brown sand clay loam over dull yellowish brown gravel sand soil. Water table was estimated at >150 cm. No previous history of floods in the area was reported. No cracks were observed. Animal burrows were observed from 0 - 126 cm depth, strongly acid, Ustic moisture regime, stratification, Isohyperthermic STR	Fluvisols	Eutric Fluvisols	nd

STR = Soil temperature regime, MB = Mbogo

3.3.7 Nutrient balance

The availability of nutrients for uptake by plants depends not only upon absolute levels but also on relative amounts of individual elements. According to EUROCONSULT [45], a good trend is with Ca^{2+} higher than Mg^{2+}, and Mg^{2+} higher than K^+ (i.e. $Ca^{2+} > Mg^{2+} > K^+$). With the exception of Na^+ that was more or less greater than K^+, the exchangeable cations in the Mbogo – Komtonga irrigation scheme followed that trend: $Ca^{2+} > Mg^{2+} > K^+ < Na^+$ at MB - P1, P2 & P3 (Table 9). A similar observation has been reported elsewhere by Msanya, et al. [59,60,61, 62]. Results from this study showed that the Ca/TEB ratios in the topsoil of the representative Master pits ranged from 0.67 to 0.80 (Table 9). With the exception of MB – P3 Master pit which did not show any decreasing trend with depth, the data showed a generally decreasing trend in MB – P1 & P2. According to Uwitonze, et al. [31] Ca/TEB critical ratios beyond which the uptake of Mg, K and other bases are affected is pegged at more than 0.5 and Ca induced deficiency of Mg and/or K become clear. This result suggests that Ca may alter uptake and induce deficiency of K at all the studied Master pits (i.e. MB – P1, P2 & P3). Ca/Mg ratios ranged from 2.5 to 5.9 in the top soils and generally decreasing with depth in MB – P1 & P2 but not in MB – P3 (Table 9) suggesting that Ca content was greater in top soils compared with the sub soils [31]. Studies has shown that a critical range of between 2 and 4 in Ca/Mg ratio was considered as optimal for plant growth [38] suggesting that only MB – P3 has values within the critical range. With regards to Mg/K ratios the top soils of the representative Master Pits ranged from 1.7 to 8.1 and showed irregular pattern with soil depth. This result suggests that MB – P1 & P2 are within the recommended critical range for optimal nutrient uptake by plants [31]. The percentage K/TEB ratios ranged between 3.3 (MB – P3) to 7.9% (MB – P2) and decreased with soil depth in the Master pit. These top soil values were above 2% (Table 9) and were considered favourable for most tropical crops just as reported in [31]. As the K/TEB ratios are greater than 2% in all the top soils of the studies Master pits, problems of K – deficiency is unlikely [63]. However, sub surface K/TEB ratio was probably lower and K deficiency is likely to happen.

3.3.8 Soil classification

Based on the field and laboratory data, the soils were classified as Eutric Fluvisol and Vertic Cambisol in the FAO soil classification system [28] [Table 10].

4. CONCLUSION AND RECOMMENDATION

In conclusion, the soils in the study area were classified as Eutric Fluvisols and Vertic Cambisols in FAO Soil classification Systems. The soil was deep to moderately deep, well to moderately well drained on flat or almost flat to undulating topography. The soil is stratified, developed under isohyperthermic soil temperature and ustic soil moisture regimes. Typically, the soil was dominantly brownish black in colour and clay texture top soils with gray to dull yellowish brown with overall stratification of fine sand, clay, sand clay and sand clay loam sub soils. Physically, bulk density was slightly above adequate but not restrictive in 67% of the studied profiles and ideal Bd in 33% of the profiles. Chemically, soil reaction shows strongly to medium acid in the top soils but decreasing to medium to slightly acid with depth. Soil organic carbon was in good quality and all values were above the critical limits. N, P and K were very low, low or medium to very low. Ca and Mg were high to very high in the top soils but decreased with depth. CEC was high to very high and the soils were rated as non sodic with low to medium exchangeable Na^+. Ca/Mg ratio showed that 67 % were outside the critical range, Mg/K ratio was within the critical range in 33% of the studied pedons. The top soils indicate that K deficiency is unlikely as K/TEB was greater than two (> 2) which is a generally accepted critical value. Taken together, the observed strongly to medium acid in the top soils in the study area calls for soil reaction management to acceptable levels through liming by using either Calcitic or Dolomitic lime whichever is relevant, available and affordable. Likewise, the low to very low NPK observed in the studied area suggests that such mineral elements should be incorporated in the fertilizer management program during and or after the irrigation development in the area.

DISCLAIMER

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was supported by the National Irrigation Commission through Morogoro Zonal Irrigation Office in Tanzania and the Expanded Rice Production Program (ERPP).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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