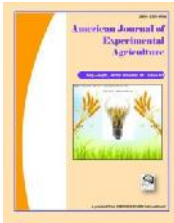

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Selected Soil Chemical Properties and Fertility Assessment in Some Traditional Irrigation Schemes of the Mpwapwa District, Tanzania

H. J. R. Joachim Makoi[1*]

[1]Ministry of Agriculture Food and Cooperatives, Directorate of Irrigation and Technical Services, P.O. Box 9192, Dar as Salaam, Tanzania.

Author's contribution

This whole work carried out by the author HJRJM.

Original Research Article

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ABSTRACT

Aims: To find out the status of the major plant nutrients important for plant growth and development in selected areas in Tanzania.
Place and Duration of Study: The soil physicochemical properties survey was conducted in Msagali and Chipogolo proposed irrigation schemes, Mpwapwa District, Dodoma Region, in Tanzania during the dry season of 2003.
Methodology: Before sampling, the study areas were divided into twenty two (22) pedogeomorphic units or soil types using pedogeomorphic approach. Thirty soil samples were collected from each pedogeomorphic unit at a depth of 0 – 20 cm in a zigzag manner, bulked, homogeneously mixed, and sub-sampled to obtain a representative composite sample. The composite soil samples were sent to Selian Agricultural Research Institute (SARI), Arusha, Tanzania, for analysis of physicochemical characteristics leading to the determination of the soil fertility status by means of these major mineral elements.
Results: The results showed variations in fertility status in the selected sites of each scheme. Based on guidelines of soil mineral elements contents established elsewhere, the soils in Msagali had high pH (8.1) and excessive Na^+ (6.1 cmol (+).kg^{-1} soil) in 30.9% of the total surveyed area (263.5 ha). Crop production in Chipogolo was slightly constrained by sodicity (ESP=9.6%) in 73.1% of the total area (130.3 ha) surveyed and very strongly (ESP =27.9%) in 55.8% of the total surveyed area in Msagali. Total N and Organic Matter (OM) were low, ranging from 0.2 to 1.0g.kg^{-1} and 2.3 to 11.7g.kg^{-1} respectively. Available P was rated as low to medium and ranged from 1.01 to 5.13 mg P.kg^{-1} in all sites (i.e.

**Corresponding author: Email: makoi.joachim230@gmail.com;*

Msagali and Chipogolo). Mg were rated as low (1.0 to 3.2 cmol (+).kg^{-1} soil.) in 26.9% of the area surveyed in Chipogolo and low in 18.4% of the surveyed area in Msagali ranging from 0.6 to 6.5 cmol (+).kg^{-1} soil. Of the total surveyed area, 63.7% in Chipogolo and 18.4% in Msagali have low Cation Exchange Capacity (CEC) with values <12 cmol.kg^{-1}. C:N ratio in 63.2% the total area surveyed in Chipogolo was of good quality (i.e. C:N between 8–12) suggesting ideal conditions for plant growth compared with 36.8% of the total study area in Chipogolo and all the studied sites in Msagali. The data have indicated Ca: Mg ratios to be less than the suggested guidelines in 36.8% of the total surveyed area in Chipogolo suggesting that plants would probably respond to the addition of Ca or Mg in such areas.

Conclusion: The fertility status and overall information from this study could be used in soil and fertiliser management studies to establish nutrient requirements for different crops grown in these areas.

Keywords: Calcium; cation exchange capacity; crop production; excessive sodicity; fertility constraints; management practices; soil organic matter; survey.

1. INTRODUCTION

In Mpwapwa district, Dodoma Region, Tanzania, farmers have realized that huge profit margins can be achieved through crop diversification including rice (*Oryza sativa* L.) cultivation. The district, one of the five districts in Dodoma Region, is among the potential areas in Tanzania which practise both rainfed and irrigated agriculture. It is estimated that agricultural sector contributes about 48% of the total District Gross Domestic Product (GDP). The district has a total area of 223,000 ha potential for agriculture of which more than 5,991ha (2.7%) are potential for irrigation development. However, only 2,891 ha (48.3%) are currently irrigated by water from different sources such as rainwater harvesting, rivers and storage dams. Some of the important crops cultivated in these areas include: Bambara groundnut (*Vigna subterranea* (L.) Verdc.), cassava (*Manihot esculenta*), cowpea (*Vigna unguiculata* L.), groundnuts (*Arachis hypogea* L.), maize (*Zea mays* L.), pearl millet (*Pennisetum glaucum*), onions (*Allium cepa* L.), sorghum (*Sorghum bicolor* L), sunflowers (*Helianthus annuus*), sweet potatoes (*Ipomoea batatas*) and rice (*Oryza sativa* L.). Due to increasing consumption of rice in the region, majority of farmers are now engaged in intensified irrigated rice cultivation in order to address the food crisis within and outside the region. Just as in other tropical areas, the selected areas for rice cultivation in Mpwapwa district are challenged by negative mineral elements balances, essential for plant growth and development [1,2]. These challenges include excessive leaching, soil degradation, non-replenishment of the removed plant nutrients and low purchasing power to replenish the depleted mineral elements [1,3,4].

Due to complex interactions between soil and crop management, farming systems and soil fertility [5], production of both food and cash crops have declined, thus, threatening food security in these areas. For example, the current rice and maize grain yields in these irrigation schemes is very low, 1.0 – 1.5 t.ha^{-1} [1,6]. As yet no information is available to quantify and study the influence of soil fertility factors and their effect on crop yields.

However, studies in similar environments of continuous land cultivation without proper management practises in some areas of Africa have shown soil fertility decline [4,7,8,9]. Therefore, the decrease in crop yields and its impact on yields and household food security [10,11,12,13] in many areas of Mpwapwa district forebodes decline in soil fertility.

Key indicators on soil fertility have previously been reported as soil pH, soil organic matter (SOM); cation exchange capacity (CEC); exchangeable bases (EB), salinity (S) and sodicity status (SS) and the amount of extractable N, P, K, Mg, Ca and Na [14,15]. These indicators are realistic in predicting plant growth and development. Hence there is a need for regular and systematic evaluation to establish their levels in the soil so as to achieve sustainable productivity in cropping systems. If unchecked, their limitation may result in complex mineral elements imbalances, consequent poor soil quality, and decline in soil productivity and crop yields [16,17].

Thus, assessment and understanding of the soil fertility status based on the aforementioned attributes will not only provide strategies for soil fertility management and land development, but also will provide input into the design and planning of crop nutrition packages in the study areas. To date, studies on soil fertility status in Tanzania are very scarce in the literature [2,9,18]. The objective of this study was to assess the soil fertility status in the selected irrigation schemes of Mpwapwa District, Dodoma Region and Tanzania.

2. MATERIALS AND METHODS

2.1 Description of Study Area

The irrigation schemes of Chipogolo and Msagali are located in Mpwapwa District, Dodoma Region, in the Central part of Tanzania. Specifically, Chipogolo is located at 6°15'S and 35º30' E, 100 Km South West of Mpwapwa town at an altitude of 100 M a. m. s. l. Msagali is located at 6º15'S and 36º25' E, 16 Km South West of Mpwapwa town at an altitude of 98.5 M a. m. s. l. These schemes are generally on a plain or piedmont landscape. The climate of the two schemes is characterised as hot semi-arid according to Köppen's classification [19]. The rainfall pattern in the district is characterised by 2 intermediate months and 10 dry months Table 1, Fig. 1. The rainfall pattern is unimodal with one rainy season from November through May. Its distribution is unreliable and there is a risk of drought in January and March Table 1, Fig. 1. The driest months are between June to October with no rains at all. The annual rainfall is 642 Mm. month^{-1} while annual evapotranspiration is 2, 147 Mm. month^{-1}. The mean monthly temperature in these schemes is between 21.8ºC - 26.7ºC while the mean annual temperature is 24.6ºC. There is slightly cooler period from May to July marked by the onset of the winds which continues up to October. Sunshine hours range between 7.1 - 9.9 hrs. Potential evaporation at Dodoma station as computed by Penman equation is in the range of 145 Mm. month^{-1} (February) to 254 mm. month^{-1} (October) or 2,147 mm per annum. Relative humidity (RH) is between 61.1% (November) and 78.4% (April). Annual RH is 67.8%. The climatic data representatives for Chipogolo and Msagali schemes are summarized in Table 2.

2.2 Soil Sampling

Before sampling, the study areas were divided into twenty two (22) pedogeomorphic units or soil types using pedogeomorphic approach [20]. Thirty soil samples were collected from each pedogeomorphic unit at a depth of 0 – 20 cm in a zigzag manner. The collected soil samples were bulked, homogeneously mixed, and sub-sampled to obtain a kg of a representative composite sample, filled in a plastic bag and labelled. The composite soil samples were sent to Selian Agricultural Research Institute (SARI), Arusha, Tanzania, air dried and ground to pass through a 2 mm-sieve after which they were analysed for physical chemical characteristics leading to the determination of the soil fertility status of these major mineral elements. In the laboratory, samples were divided into three sub-samples to make three replicates after which they were analysed separately.

2.3 Soil Physicochemical Characterisation

Particle size analysis was determined by the Bouyoucos hydrometer method [21]. Organic carbon (OC) was done by Walkley and Black wet acid dichromate digestion method [22]. Soil organic Matter (SOM) was calculated as 1.72 x % OC [23] pH (water) was determined by a pH meter using 1:2.5 soil to water ratio as described by [24] whereas total N was done by semi-micro Kjeldahl digestion [25] followed by ammonium distillation and titrimetric determinations.

Exchangeable bases (Ca, Mg, K, Na) and CEC determination depended on soil pH. In soils with pH<7.5, subsequent percolation with 1M ammonium acetate (NH_4OAc) at pH 7, ethanol and acidified 1MKCl in the first percolate [26]. For soils with pH>7.5 and high carbonates contents, the method recommended by [27] was followed. Determination of K and Na was done with flame photometer, Ca and Mg by atomic absorption spectrophotometer [28]. Cation exchange capacity (CEC) was done following the method by [28]. Electrical conductivity (EC) was measured by a conductivity meter from the soil solution directly following the procedure described by [29]. Available P was extracted spectrophotometrically [30] by reacting with ammonium molybdate using ascorbic acid as a reductant in the presence of antimony, as in [31]. The total exchangeable bases (TEB) were obtained as the sum of exchangeable Ca, Mg, K and Na. Percent base saturation (%BS) was obtained by dividing TEB by CEC and then multiplied by 100 [32]. 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. A one-way ANOVA was used to compare soil mineral elements from the different pedogeomorphic units. The analysis was performed using the STATISTICA software of 2013 version (StatSoft Inc., Tulsa, OK, USA). Fisher's least significant difference (LSD) was used to compare the means at *P*=.05 level of significance.

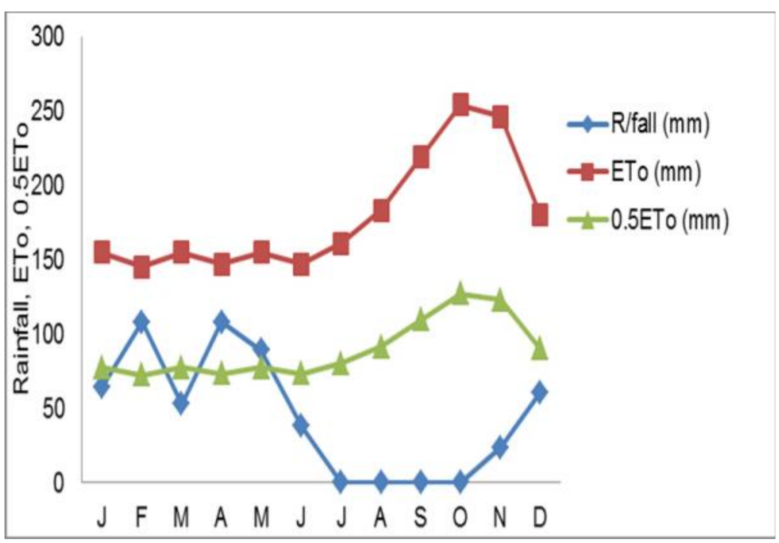

Fig. 1. Water balance and the determination of the growing period for the selected schemes

Table 1. Computations of humidity index (HI) for the selected sites of Mpwapwa District, Dodoma Region, Tanzania

Month	HI	Remarks
January	0.41	Dry
February	0.74	Intermediate
March	0.34	Dry
April	0.61	Intermediate
May	0.25	Dry
June	0	Dry
July	0	Dry
August	0	Dry
September	0	Dry
October	0	Dry
November	0.1	Dry
December	0.34	Dry
Annual	0.30	Dry

Table 2. Climatic data representative to Chipogolo and Msagali irrigation schemes

Description	Unit	J	F	M	A	M	J	J	A	S	O	N	D
Temp. Max	ºC	26.0	25.9	25.6	25.1	23.9	22.1	21.8	21.9	23.8	25.3	26.7	26.5
Rainfall	($mm.month^{-1}$)	64.0	108.0	53.0	89.0	38.0	0.0	0.0	0.0	0.0	0.0	24.0	61.0
ETo	($mm.month^{-1}$)	155.0	145.0	155.0	147.0	155.0	147.0	161.0	183.0	219.0	254.0	246.0	180.0
$0.5ET_o$	($mm.month^{-1}$)	77.5	72.5	77.5	73.5	77.5	73.5	80.5	91.5	109.5	127.0	123.0	90.0
RH	%	72.8	78.0	77.2	78.4	66.8	64.5	64.4	62.8	62.4	58.7	61.1	66.0
SSR	$l.day^{-1}$	511.0	517.0	503.0	481.0	474.0	490.0	488.0	489.0	521.0	527	534.0	517.0
SH	Hrs	7.1	7.2	7.1	6.8	7.8	9.0	9.3	9.6	9.6	9.9	9.6	7.6

Source: Dodoma station except for rainfall data which were taken from Chinyasungwi station, ETo = Potential evapotranspiration, RH = Relative humidity, SSR = Solar Radiation, SH = Sunshine hours

3. RESULTS AND DISCUSSION

3.1 Soil Reaction

Results showed that in Chipogolo, pH of the top soils ranged from 6.1 to 7.1. Of the total surveyed area (130.3 ha); 73.1% (i.e. 95.3 Ha) was rated as mildly acidic to acidic whereas 35 ha (i.e. 26.9%) was rated as neutral Tables 3 and 4. In Msagali, soil pH of the top soils ranged from 6.9 to 8.1 and 37.5% of the total surveyed area (263.5 ha) was rated as very slightly acid, 31.7% as mildly alkaline and 30.9% as moderately alkaline Tables 3 and 4 [33]. Soil pH is an important indicator in assessing soil fertility and its environment. For example, the normal pH range for optimal mineral elements availability for most crops is 6.0 to 7.5 [34,35]. However, 30.9% of the surveyed area in Msagali (i.e. MSAG-Pa3) had a soil pH of 8.1 rated as moderately alkaline Tables 3 and 4 [33] and mineral elements deficiency such as P, Ca, Fe, Cu, Zn, Mn and Mo are likely to occur [36,37,38]. Furthermore, unfavourable plant growth conditions such as severe root damage, shallow rooting, poor root development, susceptibility to drought and poor use of subsoil mineral elements have been reported in such pH range [39,40]. Collectively, the constraints associated with alkaline conditions may threaten the yield potential particularly in Msagali study area.

3.2 Total Soil Organic Matter

Soil organic matter (SOM) content in the study area ranged from 2.3 to 11.7 $g.kg^{-1}$ in topsoil Table 3 and was rated as very low Table 4. Since SOM content was calculated from soil organic carbon [23], these parameters had the same 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 [41]. Soil organic matter was below the proposed threshold values in all the sites under study, suggesting a decline in soil quality Tables 3, 4. It is, therefore, apparent that there is a need to replenish the SOM using resources such as crop residues and manure for maximum crop yields. Understanding the SOM status before any development interventions are undertaken is of vital importance it is known extensively to play a key role in the improvement of soil physical and chemical properties. These properties include structural stability, porosity, mineral elements availability (i.e. N, P and S); cation exchange capacity [35,42,43,44,45] and soil moisture and nutrient holding capacity [14]. SOM has also been reported to have great impact on improving irrigation efficiency for sustainable land productivity; to enhance productivity and environmental quality; to reduce the severity and costs of natural phenomena, such as drought, flood, and disease; to reduce atmospheric CO_2 levels that contribute to climate change [46,47,48,49].

3.3 Total N

Total nitrogen (Total N) status in the study area ranged from 0.2 to 1.0 $G.kg^{-1}$ in Chipogolo and 0.3 to 0.4 $G.kg^{-1}$ in Msagali Table 3 and was rated as very low Table 4. According to [33] guidelines, the proposed value for most crops in Tanzania is 2 g $N.kg^{-1}$ soil. The results show that all the surveyed sites had total N below the threshold value (<2 $G.kg^{-1}$) and was rated as very low Tables 3, 4. The observed low N in these areas may be attributed to, amongst others, low SOM content which is greatly influenced by microbial activity in the soil [50] and high soil pH which could lead to N loss through ammonia volatilisation [51]. In our study, soil samples with relatively higher N levels were obtained from the relatively organic enriched soils. So, any activity envisaged to improve the soil pH, SOM and microbial activities can, consequently, lead to an increase in the %N in the soil. Inadequate amounts of N in the soil are the primary factor that limits plant growth and development in many parts of the world [52,53] suggesting short- and long-term interventions. Practices such as choice of cropping systems involving legumes with N_2 fixation capability, the use of artificial acidified nitrogen fertilisers, animal manure or composts are some of the means by which N input into the soil can be effected.

3.4 C: N Ratio

The C: N ratio showed no clear relationship with the soil texture in our study. The C: N ratio ranged from 12 to 20 Tables 3, 4 [33]. It is generally accepted that C: N ratios between 8 and 12 are considered to be the most favourable. In this study, 63.2% of the total area (i.e. 130.3 ha) in Chipogolo (CH-Pi2 and CH-Pa1) have favourable SOM indicating a relatively fast mineralisation of N from the organic materials. For example, higher C: N ratios greater than 23 have been shown to favour slow degradation of residues by the associated micro-organisms, higher immobilisation effects and limited N in the soil that may lead to reduced crop yields [54,55,56]. The observed C: N ratio status in 63.2% of the surveyed area in Chipogolo suggests ideal conditions for plant growth, since in such situations mineralisation in the soil is greater than immobilisation, compared with 36.8% of the total study area in Chipogolo and all the studied sites in Msagali where mineralisation in the soil was lower than immobilisation.

3.4 Available Phosphorus

In Chipogolo, the data showed that, phosphorus (P) ranged from 2.31 to 5.13 mg $P.kg^{-1}$ Table 3 and was rated as low to medium Table 4. Of the total study area (130.3 ha), 36.8% was rated as having low P (i.e. 2.31 mg $P.kg^{-1}$) and 63.2% was rated as having moderate P availability (i.e. an average of 4.87 mg $P.kg^{-1}$). In Msagali, the data showed that, P ranged from 1.01 to 2.12 mg $P.kg^{-1}$ and was rated as low Tables 3, 4. Phosphorus is an essential macro-element for plant growth, hence an important soil fertility indicator. Based on the current soil fertility recommendation that uses a critical P concentration of >7 mg $P.kg^{-1}$ to separate P deficient soils [33], P availability was less than critical range. The observed low values of P could partly be attributed to fixation into unavailable forms due to high soil pH especially so in areas such as Msagali Tables 3, 4. For example, in alkaline soils, calcium phosphates $(Ca_3(PO_4)_2$ are less soluble, hence high P retention capacity and consequently low P availability [57].

3.5 Exchangeable Bases (K, Mg, Ca)

Results in this study showed that potassium (K) levels in the soil ranged from 0.78 to 7.68 cmol $(+).kg^{-1}$ soil in Chipogolo and was rated as medium in 26.9% and high or very high in 73.1% of the total area (i.e. 130.3 ha) surveyed. In Msagali, K ranged from 0.33 to 0.55 cmol $(+).kg^{-1}$ soil, and was rated as low in 13.3%, medium in 49.3% and high in 37.4% of the total area (i.e. 263.5 ha) surveyed Tables 3, 4. It is generally accepted that response to K fertilisers is likely when a soil has an exchangeable K value of less than 0.2 cmol (+) $.kg^{-1}$ soil and unlikely when it is above 0.4 cmol $(+).kg^{-1}$ soil [33,58]. Based on the critical concentrations of exchangeable K values of 0.2 to 0.4 cmol $(+).kg^{-1}$ soil, the data suggests that K is not a limiting mineral element to crop productivity in the study area [33,59].

These results also showed that Mg^{2+} content was low to high in the topsoil of Chipogolo area ranging from 1.0 to 3.2 cmol $(+).kg^{-1}$ soil. In this area, Mg content in 26.9% of the total area surveyed was rated as low, 36.8% as medium and 36.3% as high. Mg was rated as low to very high in the topsoil of Msagali area ranging from 0.6 to 6.5 cmol (+).kg^{-1} soil and Mg content in 18.4% of the total area surveyed was rated as low, 13.3% as medium and 68.3% as high or very high Tables 3, 4. The recommended value of Mg^{2+} in most crops is 2 cmol (+).kg^{-1} [60]. The observed low levels of Mg^{2+} in 26.9% of the total area surveyed in Chipogolo and 18.4% of the total area surveyed in Msagali suggest that these areas have insufficient Mg^{2+} supplies for crop growth. Mg is required by a large number of enzymes involved in energy transfer, particularly those utilizing ATP; a constituent of the chlorophyll molecule; is required for the normal structural development of the chloroplast; as well as other organelles such as the mitochondrion [61,62,63,64]. Thus, it is expected that Mg deficiency would have damaging effects on photosynthesis and respiration leading to poor crop yields. As such measures should be undertaken to ameliorate such deficiencies for crop development.

The exchangeable Ca^{2+} in the topsoil of the Chipogolo study area ranged from 3.9 to 9.7 cmol (+).kg^{-1} soil. The data showed that of the total area, 63.2% was rated as medium and 36.8% as high Tables 3, 4. Likewise in Msagali, 18.4% was rated as medium, 30.9% as high and 50.7% as very high Tables 3, 4. [65] Proposed that in most crops, the recommended threshold level of Ca^{2+} is 5 cmol (+).kg^{-1}. Calcium deficiency occurs frequently in a range of crops when exchangeable Ca concentration is less than 1 cmol (+).kg^{-1} [66,67]. It is generally acknowledged that field conditions that limit Ca^{2+} uptake produce lower crop yields than crops grown with adequate Ca^{2+} [68,69,70,71]. The medium to very high levels of Ca^{2+} in the study areas indicates lower bondage of Ca^{2+} to P at relatively lower soil reactions Tables 3, 4.

3.6 Cation Exchange Capacity

The cation exchange capacity (CEC) status in the soil ranged from 3.73 to 36.6 cmol.kg^{-1} Table 3 and was rated as very low to high Table 4 [33]. Cation exchange capacity refers to the exchange phenomenon of positively charged ions at the surface of the negatively charged colloids. The higher the CEC, the more capable the soil can retain mineral elements. Studies have shown that soils with CEC values of between 6 to 12 cmol.kg^{-1} are poor in exchangeable bases [33]. Of the total surveyed area, 63.7% in Chipogolo and 18.4% in Msagali had CEC values <12 cmol.kg^{-1}. According to [72], soils with low CEC are typically weathered with a low ability to support plant growth with adequate mineral element such as Ca. It is generally accepted that SOM is responsible for 25 - 90% of the total CEC of surface horizons of mineral soils [73,74]. The very low or low to medium CEC found in some areas in this study could be related to low SOM Tables 3, 4. The very low or low CEC values in soils have also been implicated with low yield in most agricultural soils [72]. Any intervention such as applying both manure and the required amount of fertiliser with the aim of improving the CEC of the soil is recommended. By doing so, humus content of the soil will increase and, consequently, improve the CEC that may lead to better retention of mineral elements in the soil.

3.7 Exchangeable Sodium (Na) or Exchangeable Sodium Percentage (ESP)

The exchangeable sodium (Na^{+}) in Chipogolo ranged from 0.31 to 4.31 cmol (+) kg^{-1} soil. This corresponds to ESP values which range from 5.3 to 9.6%. In Msagali Na^{+} values ranged from 0.43 to 6.1 cmol (+) kg^{-1} soil corresponding to ESP values which ranged from 4.2 to 27.9% Tables 3, 4. The critical values of ESP above which most crops are affected are established at 15 [75]. 26.9% of the total surveyed area in Chipogolo had ESP of 5.3

which was below the recommended threshold levels of ESP<6 rated as non-sodic Tables 3, 4. However, 73.1% of the total surveyed area in Chipogolo was rated as slightly sodic. In Msagali, 37.4% of the total surveyed area had 6.1 cmol Na (+) kg^{-1} soil and ESP of 27.9 rated as very high and very strongly sodic respectively. However, 44.2% of the total area was rated as non-sodic and 18.4% as moderately sodic Tables 3, 4. The medium to very high Na or slightly/moderately sodic to very strongly sodic status observed in this study may probably be related to high evaporation, poor management of irrigation water, lack of drainage systems and low Ca^{2+} due to high Na^{+} concentrations in the exchange complex Tables 3, 4. Higher Na^{+} levels in the soil is associated with decline in net photosynthesis; energy losses for salt exclusion mechanisms; greater decrease in mineral elements uptake; poor NO_3^- assimilation required for plant growth; inhibition of vital enzymes and competition with K^{+} [76,77,78,79]. The excessive Na^{+} in the soil is likely to cause reduced plant growth and development, thus, decreased crop yields [80, 81, 82, 83]. Our results suggest that such sodic soils may require appropriate amendments such as farm yard manure (FYM) and or gypsum to reduce the concentration of Na^{+} on the exchange complex, thereafter followed by leaching to replace the soluble Na+ on the soil colloid, through irrigation or rain water [2,84] and use of acidifying fertilisers such as sulphate of ammonia to lower the soil pH. Successful results on the use of locally available soil ameliorants, such as gypsum ($CaSO_4.2H_2O$) as a Ca^{2+} source and/or organic manure, has been reported in northern Tanzania [2].

3.8 Cation Ratios

In Chipogolo, the Ca: Mg ratios ranged from 2 to 3.9; Mg: K ratio: from 0.4 to 2.2 and K: TEB ratio: from 11.6 to 30.9% Table 5. But in Msagali, the Ca: Mg ratios ranged from 2.7 to 13.8; Mg: K ratio: from 1.1 to 14.8 and K:TEB ratio: from 1.2 to 12.3%. According to the established guidelines [33,85], the recommended optimum ratio of Mg: K for most crops is 1 - 4. However, in areas where K was high Mg was low and vice versa suggesting that these mineral elements are antagonistic. These results indicate that almost all sites have optimal K enrichment sufficient to support plant growth. In relation to Ca: Mg, our data suggests less favourable conditions for most crops. The availability of mineral elements for uptake by plants depends not only upon absolute levels but also on relative amounts of individual elements. It has been suggested that the optimal cation ratio for the growth of most crops in the tropical area is assumed to be equal to 12.7:3:1 for Ca: Mg: K respectively [33]. Although the general trend for Ca: Mg: K doesn’t indicate a good ratio in relation to the established standards, the individual nutrient ratios are more important i.e. Ca: Mg; Mg: K and K: TEB. Research has indicated that the Ca: Mg ratio of 3 - 5 in the topsoil [33] is optimal for most crops and the K: TEB ratio of less that 2% is sub-optimal and may limit crop production. Our results have indicated Ca: Mg ratios to be less than the suggested guidelines in only 36.8% of the total surveyed area in Chipogolo suggesting that plants would probably respond to the addition of Ca or Mg in such areas Table 5.

Table 3. Soil fertility status for the selected schemes of Mpwapwa District, Dodoma Region, Tanzania

Sample Name	Texture	pH (H_2O)	EC	OM	TN	C/N	Pav	CEC	Exchangeable Bases				BS	ESP
									Ca	Mg	K	Na		
			(dS.m^{-1})	(g.kg^{-1})			mg.kg^{-1}	cmol.kg^{-1}soil	cmol (+).kg^{-1}soil				(%)	
Chipogolo														
CH-Pi1	CL	6.80a	0.06a	2.90b	0.20b	15.00a	2.31b	9.00b	4.50b	2.20b	0.99b	0.86b	95.00a	9.60a
CH-Pi2	SCL	7.10a	0.10a	2.30b	0.20b	12.00b	4.61a	5.82b	3.90b	1.00c	0.78b	0.31c	100.00a	5.30b
CH-Pa1	C	6.10a	1.67b	11.70a	1.00a	12.00b	5.13a	36.60a	9.70a	3.20a	7.68a	4.31a	95.00a	9.60a
One Way ANOVA *(F-Statistics)*														
Rep		2.5ns	334.8***	205.7***	222.1***	6.9*	59.1***	218.9***	89.8***	80.9***	283.0***	267.4***	0.4ns	31.4***
CV (%)		8.4	14.2	11.3	11.5	8.8	8.4	11.6	9.7	9.9	12.8	12.6	8.4	9.4
Msagali														
MSAG-Pa1	SCL	6.90c	2.42a	4.70c	0.30b	16.00b	1.48b	21.84a	10.40c	3.80b	1.10a	6.10a	98.00a	27.90b
MSAG-Pa2	C	7.40bc	0.56b	5.60b	0.30b	20.00a	1.57b	23.25a	23.50a	1.70c	0.33d	0.97b	100.00a	4.20c
MSAG-Pa3	C	8.10a	0.28c	7.40a	0.40a	19.00a	1.01c	19.88b	19.40b	6.50a	0.44c	0.89b	100.00a	4.50c
MSAG-Pa4	SCL	7.60ab	0.04d	5.90b	0.30b	19.00a	2.12a	3.73c	2.90d	0.60d	0.55b	0.43c	100.00a	11.50a
One Way ANOVA *(F-Statistics)*														
Rep		7.5*	892.9***	68.3***	43.2***	14.1***	132.3***	298.3***	423.0***	1271.0***	372.6***	888.8***	0.2ns	692.9***
CV (%)		4.6	2.6	5.0	4.4	5.0	4.6	4.2	7.5	3.3	2.8	2.6	4.4	2.6

: significant at P=.05; *: 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, OM = Organic Matter; CEC = Cation Exchange Capacity; BS = Base Saturation, ESP = Exchangeable Sodium Percentage; SCL = Sand Clay Loam; CL = Clay Loam; C = Clay; CH: Chipogolo; MSAG: Msagali; Pa: Plain; Pi: Piedmont*

Table 4. Soil fertility status for the selected schemes of Mpwapwa district

Soil fertility unit symbol	Texture	S (%)	Soil fertility description									Area	
			pH	TN	P	K	Ca	Mg	OM	CEC	ESP	Ha	%
Chipogolo													
CH-Pi1	CL	3-4	Very slightly acid	Very low	Low	High	High	Medium	Very low	Low	Slightly sodic	48.0	36.8
CH-Pi2	SCL	1-2	Neutral	Very low	Medium	Medium	Medium	Low	Very low	Very low	Non-sodic	35.0	26.9
CH-Pa1	C	< 1	Slightly acid	low	Medium	Very high	Medium	High	Low	High	Slightly sodic	47.3	36.3
Total												**130.3**	**100**
Msagali													
MSAG-Pa1	SCL	< 1	Very slightly acid	Very low	Low	High	Very high	High	Very low	Medium	Very strongly sodic	98.5	37.4
MSAG-Pa2	C	< 1	Mildly alkaline	Very low	Low	Low	Very high	Medium	Very low	Medium	Non-sodic	35.0	13.3
MSAG-Pa3	C	< 1	Moderately alkaline	Very low	Low	Medium	High	Very high	Low	Medium	Non-sodic	81.5	30.9
MSAG-Pa4	SCL	< 4	Mildly alkaline	Very low	Low	Medium	Medium	Low	Very low	Very low	Moderately sodic	48.5	18.4
Total												**263.5**	**100**

Classification: According to NSS (1990) guidelines. CH = Chipogolo; MSAG = Msagali; Pa = Plain; Pi = Piedmont; S (%) = Slope percent; TN = Total Nitrogen; P = Phosphorus; K = Potassium; Ca = Calcium; Mg = Magnesium; OM = Organic Matter; CEC = Cation Exchange Capacity; ESP = Exchangeable Sodium Percentage; SCL = Sand Clay Loam; CL = Clay Loam; C = Clay

Table 5. Summary of the results of the Cation Ratios and Total Exchangeable bases in the top soil samples (0 – 20 cm)

Sample Name	Texture	Ca/Mg	Mg/K	K/TEB (%)	TEB cmol (+).kg^{-1}soil
Chipogolo					
CH-Pi1	CL	2.0c	2.2a	11.6b	8.6b
CH-Pi2	SCL	3.9a	1.3b	13.0b	6.0c
CH-Pa1	C	3.0b	0.4c	30.9a	24.9a
One Way ANOVA *(F-Statistics)*					
Rep		83.79***	282.02***	479.91***	943.86***
CV (%)		6.1	7.1	4.6	4.4
Msagali					
MSAG-Pa1	C	2.7c	3.5c	5.1b	21.4b
MSAG-Pa2	C	13.8a	5.2b	1.2c	26.5a
MSAG-Pa3	SCL	3.0c	14.8a	1.6c	27.2a
MSAG-Pi1	SCL	4.8b	1.1d	12.3a	4.5c
One Way ANOVA *(F-Statistics)*					
Rep		558.0***	2126.0***	493.3***	356.5***
CV (%)		6.3	3.7	7.9	4.9

****: 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; CL = Clay Loam; C = Clay; CH: Chipogolo; MSAG: Msagali; Pa: Plain; Pi: Piedmont*

4. CONCLUSION

In conclusion, these results provide soil fertility status in the selected irrigation schemes. The data also suggest that soil pH and excessive Na^+ in the soil are the major soil fertility constraints to crop production in the area followed by Ca^+, SOM and CEC. This information could be incorporated in the soil fertility management in Tanzania thus contributing significantly in the efficient utilisation of land resources in the study areas.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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