

Selected soil chemical properties in some traditional irrigation schemes of Mpwapwa District, Dodoma Region, Tanzania.

Abstract

Aim: 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 physical chemical soil properties survey was conducted in Msagali and Chipogolo proposed irrigation schemes, Mpwapwa District, Dodoma Region, in Tanzania during the dry season of 2003.

Methods: Soil samples were collected from different sites in each scheme and were analysed for physical chemical 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 results showed that the soil had high soil pH and excessive Na in 30.9% of the surveyed area in Msagali. Crop production was also slightly constrained by sodicity in 73.1% of the total area surveyed in Msagali and very strongly in 55.8% of the total surveyed area in Chipogolo. The results also showed that total N, OM, available P and Mg were very low in all sites (i.e. Msagali and Chipogolo). Results have also showed that of the total surveyed area, 63.7% in Chipogolo and 18.4% in Msagali have low CEC values. C:N ratio in 63.2% the total area surveyed in Chipogolo was of good quality suggesting ideal conditions for plant growth compared with 36.8% of the total study area in Chipogolo and all the studied sites in Msagali. Our results 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 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, 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 contribute about 48% of the total district gross domestic product (GDP). The district has a total area of 223,000 ha potential for agriculture. Of the total, more than 5,991 ha (2.7%) are potential for irrigation development of which only 2,891 ha (48.3%) are currently irrigated by water from different sources including 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 (Ngailo et al., 1999; Makoi and Ndakidemi, 2008). These challenges include excessive leaching, soil degradation, non-replenishment of the removed plant nutrients and low purchasing power to replenish the depleted mineral elements (Mokwunye et al., 1996; Ngailo et al., 1999; Sanchez, 2002).

Due to complex interactions between soil and crop management, farming systems and soil fertility (Mowo et al., 2006), 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 – 1.5 t.ha⁻¹ (Ngailo et al., 1999; RLDC, 2009). Presently, there is no research information to quantify the influence of soil fertility factors and how they can affect crop yields. However, studies in similar environments of continuous land cultivation without proper management practises in some areas of Africa have showed soil fertility decline (Smalling and Braun, 1996; Smalling et al., 1997; Scoones, 2001; Sanchez, 2002; Hellin, 2003; Ndakidemi and Semoka, 2006). Therefore, the decrease in crop yields and its impact on yields and household food security (Defoer and Budelman, 2000; Lyamchai and Mowo, 2000; Ouédraogo, 2004; Saïdou et al., 2004) in many areas of Mpwapwa district forebodes decline in soil fertility.

Key indicators on soil fertility have previously been reported (Monreal et al., 1997; Brady and Weil, 2002) as soil pH, soil organic carbon (OC) or 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 mineral elements. These indicators are realistic in predicting plant growth and development, hence a need for regular and systematic evaluation to establish their levels in the soil in order to achieve sustainable crop 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 (Angers et al., 1992; Riffaldi et al., 1994)

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, soil fertility survey studies in Tanzania are very scarce in the literature (Muchena and

Kiome, 1995; Ndakidemi and Semoka, 2006; Makoi and Ndakidemi, 2008). This study assesses the soil fertility status in the selected irrigation schemes of Mpwapwa District, Dodoma Region, Tanzania.

2 MATERIALS AND METHODS

2.1 Location, topography and climate of the study areas

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 35°30' E, 100 km South West of Mpwapwa town at an altitude of 100 m a.m.s.l. Msagali is located at 6°15'S and 36°25' 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 (Köppen, 1923). The rainfall pattern in the district is characterised by 2 intermediate months and 10 dry months (see Table 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). The driest months occur between the months of June and October, where there is completely no rain as shown in Table 1. 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 21.8°C - 26.7°C while the mean annual temperature is 24.6°C. 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.m⁻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

Surface soil samples at a depth of 0 - 20 cm were collected from 22 sites each with similar characteristics chosen based on pedo-geomorphic approach to ensure high representation of the study areas (Makoi, 2003). Thirty composite samples were collected from each site, bulked and mixed. A representative sample of about 1 kg soil from each site was then filled in a plastic bag, labelled and sent to the Selian Agricultural Research Institute (SARI) Arusha, Tanzania for analysis. These samples were air dried and ground to pass through a 2 mm-sieve.

2.3 Soil physical-chemical characterisation

Particle size analysis was determined by the Bouyoucos hydrometer method (Day, 1965). Organic carbon (OC) was done by Walkley and Black wet acid dichromate digestion method (Allison, 1965); SOM was calculated as $1.72 \times \% \text{ OC}$ (Walkley and Black, 1934); pH (water) was determined by a pH meter using 1:2.5 soil to water ratio as described by Peech (1965) whereas total N was done by semi-micro Kjeldahl digestion (Bremner, 1965) 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 (NH₄OAc) at pH 7, ethanol and acidified 1MKCl in the first percolate (Chapman, 1965). For soils with pH > 7.5 and high carbonates contents, the method recommended by Polemio and Rhoades (1977) was followed. Determination of K and Na was done with flame photometer, Ca and Mg by atomic absorption spectrophotometer (Hesse, 1971). Cation exchange capacity (CEC) was done following the

method by Chapman (1965). Electrical conductivity (EC) was measured by a conductivity meter from the soil solution directly following the procedure described by Piper (1942). Available P was extracted spectrophotometrically (Rodriguez et al., 1994) by reacting with ammonium molybdate using ascorbic acid as a reductant in the presence of antimony, as in Murphy and Riley (1962). 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. 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.

3 RESULTS AND DISCUSSION

3.1 Soil reaction

Results from the survey showed that pH of the top soils ranged from 6.1 - 7.1 in Chipogoro and 73.1% (i.e. 95.3 ha) of the total surveyed area (130.3 ha) was rated as very slightly acid to slightly acid and 35 ha (i.e. 26.9%) was rated as neutral (Tables 3 and Table 5). Soil reaction of the top soils in Msagali ranged from 6.9 - 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 5; NSS, 1990). 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 - 7.5 (Schmidt, 1982; Sanchez et al., 2003). However, 30.9% of the surveyed area in Msagali (i.e. MSAG-Pa3) had a soil pH of 8.1 rated as moderately alkaline (Table 3, 5; NSS, 1990) and mineral elements deficiency such as P, Ca, Fe, Cu, Zn, Mn and Mo are likely to occur (Page et al., 1990; Foy, 1992; Makoi and Ndakidemi, 2009). 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 (Kauffman, 1977; Adams, 1984). Collectively, the constraints associated with alkaline conditions may threaten the yield potential particularly in Msagali study area.

3.2 Total soil organic matter and organic carbon

Soil organic matter (SOM) content in the study area ranged from 2.3 - 11.7 g.kg⁻¹ in topsoil (Table 3) and was rated as very low (Table 5). Since SOM content was calculated from soil organic carbon (Walkley and Black, 1934), these parameters has 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 (Loveland and Webb, 2003). Soil organic matter was below the proposed threshold values in all the sites used in this study, suggesting a decline in soil quality (Tables 3, 5). 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 because such materials have been reported 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 (Oades, 1986; Boyle et al., 1989; Le Bissonnais, 1990; Tiessen et al., 1994; Lal et al., 1999; Roscoe et al., 2001; Sanchez et al., 2003; Kockba et al., 2004; Ferreras et al., 2006; Flavel and Murphy, 2007) and soil moisture and nutrient holding capacity (Monreal et al., 1997). 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 CO₂ levels that contribute to climate change.

3.3 Total N

Total nitrogen (TN) status in the study area ranged from 0.2 - 1.0 g.kg⁻¹ in Chipogoro and 0.3 - 0.4 g.kg⁻¹ in Msagali (Table 3) and was rated as very low (Table 5). According to NSS (1990) 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 (Table 3, Table 5). 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 (Facelli and Pickett, 1991) and high soil pH which could lead to N loss through ammonia volatilisation (Rao and Batra, 1983). 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 (Vermeer and Berendse, 1983, Tilman, 1984) suggesting short- and long-term interventions. Practices such as choice of cropping systems involving legumes with N₂ 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 suggesting that the study area has a moderate to good quality SOM (Tables 3, 5; NSS, 1990). 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 Chipogoro (CH-Pi2 and CH-Pa1) have good quality SOM implying a relatively fast mineralisation of N from the organic materials. For example, higher C:N ratios greater than 23 (Goma, 2003) have been shown to favour slow degradation of residues by the associated micro-organisms (Eiland et al., 2001), higher immobilisation effects (Goma, 2003) and limited N in the soil that

217 may lead to reduced crop yields (Uriyo et al., 1979). The observed C:N ratio status in 63.2% the
 218 surveyed area in Chipogoro suggests ideal conditions for plant growth since in such situations
 219 mineralisation in the soil is greater than immobilisation compared with 36.8% of the total study
 220 area in Chipogoro and all the studied sites in Msagali where mineralisation in the soil was lower
 221 than immobilisation.

223 3.5 Available phosphorus

225 Phosphorus (P) is an essential macro-element for plant growth, hence an important soil fertility
 226 indicator. In Chipogoro, the data showed that, P ranged from 2.31 – 5.13 mg P.kg⁻¹ (Table 3) and
 227 was rated as low to medium (Table 5). Of the total study area (130.3 ha), 36.8% was rated as
 228 having low P (i.e. 2.31 mg P.kg⁻¹) and 63.2% was rated as having moderate P availability (i.e. an
 229 average of 4.87 mg P.kg⁻¹). In Msagali, the data showed that, P ranged from 1.01 – 2.12 mg
 230 P.kg⁻¹ and was rated as low (Tables 3, 5). Based on the current soil fertility recommendation that
 231 uses a critical P concentration of > 7 mg P.kg⁻¹ to separate P deficient soils (NSS, 1990), P
 232 availability was less than critical range. The observed low values of P could partly be attributed
 233 to fixation into unavailable forms due to high soil pH especially so in areas such as Msagali
 234 (Tables 3, 5). For example, in alkaline soils, calcium phosphates (Ca₃(PO₄)₂) are less soluble,
 235 hence high P retention capacity and low P availability (Hassett and Banwart, 1992).

237 3.6 Exchangeable bases (K, Mg, and Ca)

239 Results in this study showed that potassium (K) levels in the soil ranged from 0.78 - 7.68 cmol
 240 (+).kg⁻¹ soil in Chipogoro and was rated as medium in 26.9% and high or very high in 73.1% of
 241 the total area (i.e. 130.3 ha) surveyed. In Msagali, K ranged from 0.33 - 0.55 cmol (+).kg⁻¹ soil,
 242 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, 5). 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 (Anderson, 1973; NSS, 1990). Based on the critical concentrations of exchangeable K values of 0.2 - 0.4 cmol (+).kg⁻¹ soil, the data suggests that K is not a limiting mineral element to crop productivity in the study area (NSS, 1990; Gourley, 1999).

These results also showed that Mg²⁺ content was low to high in the topsoil of Chipogoro area ranging from 1.0 – 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 – 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 (Table 3, 5). The recommended value of Mg²⁺ in most crops is 2 cmol (+).kg⁻¹ (Schwartz and Coralles, 1989). The observed low levels of Mg²⁺ in 26.9% of the total area surveyed in Chipogoro and 18.4% of the total area surveyed in Msagali suggest that these areas have insufficient Mg²⁺ 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 (Thomson and Weier, 1962; Marinos, 1963; Evans and Sorger, 1966; Hall et al., 1972). Thus, it is to be 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 Ca²⁺ in the topsoil of the Chipogoro study area ranged from 3.9 - 9.7cmol (+).kg⁻¹soil. The data showed that of the total area, 63.2% was rated as medium and 36.8% as high (Tables 3, 5). Likewise in Msagali, 18.4% was rated as medium, 30.9% as high and 50.7% as very high (Tables 3, 5). Marx et al. (1996) proposed that in most crops, the recommended threshold level of Ca²⁺ 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 (Cregan et al., 1989; McCray and Sumner, 1990). It is generally acknowledged that field conditions that limit Ca²⁺ uptake produce lower crop yields than crops grown with adequate Ca²⁺ (Cox et al., 1976; Hadidi, 1984; Frost and Kretchman, 1989; Smiciklas et al., 1989). The medium to very high levels of Ca²⁺ in the study areas indicates lower bondage of Ca²⁺ to P at relatively lower soil reactions (Tables 3, 5).

3.7 Cation exchange capacity

The cation exchange capacity (CEC) status in the soil ranged from 3.73 - 36.6 cmol (+) kg⁻¹ (Table 3) and was rated as very low to high (Table 5; NSS, 1990). 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 - 12 cmol (+) kg⁻¹ are poor in exchangeable bases (NSS, 1990). Of the total surveyed area, 63.7% in Chipogoro and 18.4% in Msagali had CEC values <12 cmol (+) kg⁻¹. According to Sanchez and Logan (1992), soils with low CEC are typically weathered with a low ability to support plant growth with adequate mineral element such Ca. It is generally accepted that SOM is responsible for 25 - 90% of the total CEC of surface horizons of mineral soils (Van Dijk, 1971 and Oades et al, 1989). The very low or low to medium CEC found in some areas in this study could be related to low SOM (Tables 3, 5). The very low or low CEC values in soils have also been implicated with low yield in most agricultural soils (Sanchez and Logan, 1992). 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.

3.8 Exchangeable sodium or exchangeable sodium percentage (ESP)

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298 The exchangeable Na range from 0.31 - 4.31 cmol (+) kg⁻¹ soil corresponding to ESP values
 299 ranging from 5.3 – 9.6% in Chipogoro and from 0.43 - 6.1 cmol (+) kg⁻¹ soil corresponding to
 300 ESP values ranging from 4.2 – 27.9% in Chipogoro (Tables 3, 5). The critical values of ESP
 301 above which most crops are affected are established at 15 (Lebron et al., 2002). 26.9% of the
 302 total surveyed area in Chipogoro had ESP of 5.3 which was below the recommended threshold
 303 levels of ESP < 6 rated as non-sodic (Tables 3, 5). However, 73.1% of the total surveyed area in
 304 Chipogoro was rated as slightly sodic. In Msagali, 37.4% of the total surveyed area had 6.1 cmol
 305 Na (+) kg⁻¹ soil and ESP of 27.9 rated as very high and very strongly sodic respectively.
 306 However, 44.2% of the total area was rated as non-sodic and 18.4% as moderately sodic
 307 (Tables 3, 5). The medium to very high Na or slightly/moderately sodic to very strongly sodic
 308 status observed in this study may probably be related to high evaporation, poor management of
 309 irrigation water, lack of drainage systems and low Ca²⁺ due to high Na⁺ concentrations in the
 310 exchange complex (Tables 3, 5). Higher Na⁺ levels in the soil is associated with decline in net
 311 photosynthesis; energy losses for salt exclusion mechanisms; greater decrease in mineral
 312 elements uptake; poor NO₃⁻ assimilation required for plant growth; inhibition of vital enzymes
 313 and competition with K⁺ (Aslam et al., 1984; Seeman and Sharkey, 1986; Tarczynski et al.,
 314 1993; Munns, 1993). The excessive Na⁺ in the soil is likely to cause reduced plant growth and
 315 development, thus, decreased crop yields (Aslam et al., 1984; Seeman and Sharkey, 1986;
 316 Tarczynski et al., 1993; Munns, 1993; Noble and Rogers, 1993; Gouia et al., 1994; Murguia et
 317 al., 1995; Flowers, 1999). Our results suggest that such sodic soils may require appropriate
 318 amendments such as FYM and or gypsum to reduce the concentration of Na⁺ on the exchange
 319 complex, thereafter followed by leaching to replace the soluble Na⁺ on the soil colloid, through
 320 irrigation or rain water (Clark et al., 2007, Makoi and Ndakidemi, 2007) and use of acidifying
 321 fertilisers such as sulphate of ammonia to lower the soil pH. Successful results on the use of
 322 locally available soil ameliorants, such as gypsum (CaSO₄.2H₂O) as a Ca²⁺ source and/or
 323 organic manure, has been reported in northern Tanzania (Makoi and Ndakidemi, 2007).

324

325 3.9 Cation ratios

326

327 In Chipogoro, the Ca:Mg ratios ranged from 2 to 3.9; Mg:K ratio: from 0.4 to 2.2 and K:TEB ratio:
 328 from 11.6 to 30.9% (Table 4). But in Msagali, the Ca:Mg ratios ranged from 2.7 to 13.8; Mg:K
 329 ratio: from 1.1 to 14.8 and K:TEB ratio: from 1.2 to 12.3%. According to the established
 330 guidelines (Lombin and Fayemi 1976; NSS, 1990), the recommended optimum ratio of Mg:K for
 331 most crops is 1 - 4. However, in areas where K was high Mg was low and vice versa suggesting
 332 that these mineral elements are antagonistic. These results indicate that almost all sites have
 333 optimal K enrichment sufficient to support plant growth. In relation to Ca:Mg, our data suggests
 334 less favourable conditions for most crops. The availability of mineral elements for uptake by
 335 plants depends not only upon absolute levels but also on relative amounts of individual
 336 elements. It has been suggested that the optimal cation ratio for the growth of most crops in the
 337 tropical area is assumed to be equal to 12.7:3:1 for Ca: Mg: K respectively (NSS, 1990).
 338 Although the general trend for Ca: Mg: K doesn't indicate a good ratio in relation to the
 339 established standards, the individual nutrient ratios are more important i.e. Ca: Mg; Mg: K and K:
 340 TEB. Research has indicated that the Ca: Mg ratio of 3 - 5 in the topsoil (NSS, 1990) is optimal
 341 for most crops and the K: TEB ratio of less than 2% is sub-optimal and may limit crop production.
 342 Our results have indicated Ca: Mg ratios to be less than the suggested guidelines in only 36.8%
 343 of the total surveyed area in Chipogoro suggesting that plants would probably respond to the
 344 addition of Ca or Mg in such areas (Table 4).

345

346 4. CONCLUSIONS

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348 In conclusion, with reference to the established guidelines elsewhere, results from this study
 349 provide soil fertility indicators for major soil elements in the selected irrigation schemes in the
 350 Mpwapwa District, Tanzania. Our results suggest that soil pH and excessive sodium in the soil

followed by calcium, soil organic matter and cation exchange capacity are the major soil fertility constraints to crop production in the area. The information from our study could be incorporated in the soil fertility management of Tanzania thus contributing significantly in the utilisation of land resources of the Mpwapwa District.

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Table 1: Computations of humidity index (HI) for the selected sites of Mpwapwa District.

Month	R/fall (mm)	ETo (mm)	HI	Remarks
J	64	155	0.41	Dry
F	108	145	0.74	Intermediate
M	53	155	0.34	Dry
A	108	147	0.61	Intermediate
M	89	155	0.25	Dry
J	38	147	0	Dry
J	0	161	0	Dry
A	0	183	0	Dry
S	0	219	0	Dry
O	0	254	0	Dry
N	24	246	0.1	Dry
D	61	180	0.34	Dry
Annual	642	2,147	0.30	Dry

Drought stress:

(High drought stress)

Annual Rainfall:

Annual potential evaporation:

Rainfall during Dry and intermediate months:

Potential evaporation during Dry and intermediate months:

1,505mm

642 mm

2,147 mm

642 mm

2,147 mm

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

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Description	Unit	J	F	M	A	M	J	J	A	S	O	N	D
Temp. Max	°C	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
0.5ETo	(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

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

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598 **Table 3:** Soil fertility data for the selected sites of Mwapwa District (topsoil samples 0 – 50 cm depth).

Sample No.	Textu 	pH (H ₂ O)	EC	OC	TN	C/N	Pav	CEC	Exchangeable Bases				BS	ESP
									Ca	Mg	K	Na		
			(dS.m ⁻¹)	(%)		mg.kg ⁻¹		cmol (+).kg ⁻¹ soil				(%)		
Chipogolo														
CH-Pi1	CL	6.80	0.06	0.29	0.02	15	2.31	9.00	4.50	2.20	0.99	0.86	95	9.60
CH-Pi2	SCL	7.10	0.10	0.23	0.02	12	4.61	5.82	3.90	1.00	0.78	0.31	100	5.30
CH-Pa1	C	6.10	1.67	1.17	0.10	12	5.13	36.6	9.70	3.20	7.68	4.31	95	9.60
Msagali														
MSAG-Pa1	SCL	6.90	2.42	0.47	0.03	16	1.48	21.84	10.40	3.80	1.10	6.10	98	27.90
MSAG-Pa2	C	7.40	0.56	0.56	0.03	20	1.57	23.25	23.50	1.70	0.33	0.97	100	4.20
MSAG-Pa3	C	8.10	0.28	0.74	0.04	19	1.01	19.88	19.40	6.50	0.44	0.89	100	4.50
MSAG-Pa4	SCL	7.60	0.04	0.59	0.03	19	2.12	3.73	2.90	0.60	0.55	0.43	100	11.50

599 EC = Electrical Conductivity, TN = Total Nitrogen; C/N = Carbon/Nitrogen ration, Pav = Available Phosphorus; K = Potassium; Ca =
600 Calcium; Mg = Magnesium; Na = Sodium, OC = Organic Carbon; CEC = Cation Exchange Capacity; BS = Base Saturation, ESP =
601 Exchangeable Sodium Percentage

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611 **Table 4:** Summary of the results of the nutrient balance in the top soil samples (0 – 50 cm)
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Sample No.	Textur 	Exchangeable Bases (cmol (+).kg ⁻¹ soil)				Ca/Mg	Mg/K	K/TEB	TEB	BS
		Ca	Mg	K	Na			(%)	cmol (+).kg ⁻¹ soil	(%)
Chipogoro										
CH-Pi1	CL	4.50	2.20	0.99	0.86	2.00	2.20	11.60	8.60	95
CH-Pi2	SCL	3.90	1.00	0.78	0.31	3.90	1.30	13.00	6.00	100
CH-Pa1	C	9.70	3.20	7.68	4.31	3.00	0.40	30.90	24.90	68
Msagali										
MSAG-Pa1	C	10.40	3.80	1.10	6.10	2.70	3.50	5.10	21.4 0	100
MSAG-Pa2	C	23.50	1.70	0.33	0.97	13.80	5.20	1.20	26.50	100
MSAG-Pa3	SCL	19.40	6.50	0.44	0.89	3.00	14.80	1.60	27.20	98
MSAG-Pi1	SCL	2.90	0.60	0.55	0.43	4.80	1.10	12.30	4.50	100

613 K = Potassium; Ca = Calcium; Mg = Magnesium; Na = Sodium, TEB = Total Exchangeable Bases, BS = Base Saturation

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624 **Table 5:** 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	%OC	CEC	ESP	Ha	%
Chipogoro													
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

625 Classification: According to NSS (1990) guidelines. CH = Chipogolo; MSAG = Msagali; Pa = Plain; Pi = Piedmont; S (%) = Slope percent;
626 TN = Total Nitrogen; P = Phosphorus; K = Potassium; Ca = Calcium; Mg = Magnesium; OC = Organic Carbon; CEC = Cation Exchange
627 Capacity; ESP = Exchangeable Sodium Percentage.