

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

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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 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.

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. 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 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 (8.1) and excessive Na⁺ (6.1 cmol (+).kg⁻¹ soil) in 30.9% of the total surveyed area (263.5 ha) in Msagali. Crop production was also slightly constrained by sodicity (ESP = 9.6%) in 73.1% of the total area (130.3 ha) surveyed in Chipogolo and very strongly (ESP = 27.9%) in 55.8% of the total surveyed area in Msagali. The results also showed that total N and Organic Manure (OM) were low, ranging from 0.2 - 1.0 g.kg⁻¹ and 2.3 - 11.7 g.kg⁻¹, respectively. Available P was rated as low to medium and ranged from 1.01 – 5.13 mg P.kg⁻¹ in all sites (i.e. Msagali and Chipogolo). Mg were rated as low (1.0 – 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 – 6.5 cmol (+).kg⁻¹ soil. Results have also showed that 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. 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

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areas.

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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 5,991 ha (2.7%) are potential for irrigation development. of which However, but only 2,891 ha (48.3%) are currently irrigated by water from different sources including 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 [3; 1; 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 presently, there is no research information to quantify and study the influence of soil fertility factors and their effect on crop yields. 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 shown soil fertility decline [7; 4; 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 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 ([14;15] mineral elements. 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 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 [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 survey studies in Tanzania are very

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scarce in the literature [18; 9; 2]. The objective of this study was to assess the soil fertility status in the selected irrigation schemes of Mpwapwa District, Dodoma Region, Tanzania.

2. MATERIAL 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 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 [19]. 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 are between June to October with no rains at all 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

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 by means of these major mineral elements.

2.3 SOIL PHYSICAL-CHEMICAL 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 (NH₄OAc) at pH 7, ethanol and acidified 1MKCl in the first percolate [26]. For soils with pH > 7.5 and high

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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] Page et al., 1982). 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 Chipogolo and 73.1% (i.e. 95.3 ha) of the total surveyed area (130.3 ha) was rated as mildly acidic to as-very-slightly acidic acid-to-slightly-acid and 35 ha (i.e. 26.9%) was rated as neutral (Tables 3 and Table 5). Soil pH 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) [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 - 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 (Table 3, 5) [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 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 [23], these parameters have 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 used-in-this under 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 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 [42; 35; 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

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phenomena, such as drought, flood, and disease; to reduce atmospheric CO₂ levels that contribute to climate change [46; 47; 48; 49].

3.3 TOTAL N

Total nitrogen (TN) status in the study area ranged from 0.2 - 1.0 g.kg⁻¹ in Chipogolo and 0.3 – 0.4 g.kg⁻¹ in Msagali (Table 3) and was rated as very low (Table 5). 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, 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 [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 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) [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 good quality SOM implying a relatively fast mineralisation of N from the organic materials. For example, higher C:N ratios greater than 23 [56] have been shown to favour slow degradation of residues by the associated micro-organisms [57], higher immobilisation effects [56] 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.

3.5 AVAILABLE PHOSPHORUS

In Chipogolo, the data showed that, phosphorus (P) ranged from 2.31 – 5.13 mg P.kg⁻¹ (Table 3) and was rated as low to medium (Table 5). 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 – 2.12 mg P.kg⁻¹ and was rated as low (Tables 3, 5). 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, 5). For example, in alkaline soils, calcium phosphates (Ca₃(PO₄)₂) are less soluble, hence high P retention capacity and consequently low P availability [57].

3.6 EXCHANGEABLE BASES (K, Mg, Ca)

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Results in this study showed that potassium (K) levels in the soil ranged from 0.78 - 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 - 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, 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 [33; 58]. 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 [33; 59].

These results also showed that Mg²⁺ content was low to high in the topsoil of Chipogolo 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 [60]. The observed low levels of Mg²⁺ 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 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 [61; 62; 63; 64]. 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 Chipogolo study area ranged from 3.9 - 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, 5). Likewise in Msagali, 18.4% was rated as medium, 30.9% as high and 50.7% as very high (Tables 3, 5). [65] 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 [66; 67]. It is generally acknowledged that field conditions that limit Ca²⁺ uptake produce lower crop yields than crops grown with adequate Ca²⁺ [68;69;70;71]. 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) [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 - 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, 5). 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

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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 (Na) OR EXCHANGEABLE SODIUM PERCENTAGE (ESP)

The exchangeable sodium (Na^+) range from 0.31 - 4.31 cmol (+) kg^{-1} soil corresponding to ESP values ranging from 5.3 – 9.6% in Chipogolo and from 0.43 - 6.1 cmol (+) kg^{-1} soil corresponding to ESP values ranging from 4.2 – 27.9% in Chipogolo Msagali (Tables 3, 5). 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, 5). 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, 5). 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, 5). 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 [84; 2] 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 ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) as a Ca^{2+} source and/or organic manure, has been reported in northern Tanzania [2].

3.9 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 4). 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 than 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%

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of the total surveyed area in Chipogolo suggesting that plants would probably respond to the addition of Ca or Mg in such areas (Table 4).

4. CONCLUSION

In conclusion, with reference to the established guidelines elsewhere, results from this study provide soil fertility indicators for major soil elements in the selected irrigation schemes in the Mpwapwa District, Dodoma Region, Tanzania. Our results suggest that soil pH and excessive Na^+ in the soil followed by Ca^+ , SOM and CEC 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, Dodoma Region.

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REFERENCES

1. Ngailo JA, Wickama JM, Nyaki AS, Kaswamila AL. Nutrient flow analysis for selected farming systems in the Northern Tanzania: The case of Mbulu, Moshi Rural and Lushoto Districts (pp 49-64). In: Soil and Nutrient management in sub-Saharan Africa in support of the soil fertility initiative. 1999:Pp.376.
2. Makoi JHJR and Ndakidemi PA. Reclamation of sodic soils in northern Tanzania, using locally available organic and inorganic resources. Afr. J. Biotechnol. 2007;16(6):1926 - 1931.
3. Mokwunye AU, de Jager A, Smaling EMA. Restoring and maintaining the productivity of West African soils: Key to sustainable development. Misc. fertilizer stud 14, Int. Dev. Central Africa, Lome, Togo; 1996.
4. Sanchez PA. Soil fertility and hunger in Africa. Sci. 2002;295:2019-2020.
5. Mowo JG, Janssen BH, Oenema O, German LA, Mrema JP, Shemdoe RS. Soil fertility evaluation and management by smallholder farmer communities in northern Tanzania. Agriculture, Ecosyst & Environ. 2006;116 (1-2):47-59.
6. RLDC. Rural Livelihood Development Company, Rice Sector Strategy: Improving rice profitability through increased productivity and better marketing focusing on Tanzania's Central Corridor, November, 2009:Pp 34.
7. Scoones I. Dynamics and Diversity: Soil Fertility and Farming Livelihoods in Africa: Case Studies from Ethiopia, Mali, and Zimbabwe, Earthscan Publications Ltd., London, 2001: pp 244.
8. Hellin J. From soil erosion to soil quality. LEISA Mag. Low External Input Sustain Agric. 2003;19 (4).
9. Ndakidemi PA and Semoka JMR. Soil fertility in Western Usambara Mountains, Northern Tanzania. Pedosphere. 2006;16(2):237-244.
10. Defoer T, Budelman A (Eds.). Managing Soil Fertility in the Tropics. A Resource Guide for Participatory Learning and Action Research. KIT Publishers, Amsterdam; 2000.
11. Lyamchai CJ, Mowo JG, Wickama JM. Managing new working relationships: partnership and networking. In: AHI Regional Conference, Nairobi; 2004.

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- 379 12. Oue'draogo E. Soil quality improvement for crop production in semi arid West Africa.
380 PhD Thesis, Wageningen University, Wageningen; 2004.
- 381 13. Saïdou A, Kuyper TW, Kossou DK, Tossou R, Richards P. Sustainable soil fertility
382 management in Benin: learning from farmers. NJAS-Wageningen. J Life Sci.
383 2004;52: 349-369.
- 384 14. Monreal CM, Dinel H, Schnitzer M, Gamble DS, Biederbeck VO. Impact of carbon
385 sequestration on functional indicators of soil quality as influenced by management in
386 sustainable agriculture. P. 435-457. In: Lal R et al. (eds.) Soil processes and the
387 carbon cycle, Lewis Publ., CRC Press, Boca Raton, FL; 1997.
- 388 15. Brady NC, Weil RR. Nature and Properties of Soils. 13th Edition. With permission of
389 Pearson Education, Inc., Upper Saddle River, New Jersey; 2002.
- 390 16. Angers DA, Pesant A, Vigneux J. Early cropping - induced changes in soil
391 aggregation, organic matter and microbial biomass. SSSAJ. 1992;56:115-119.
- 392 17. Riffaldi R, Saviozzi A, Levi-Minzi R, Menchetti F. Chemical characteristics of soil
393 after 40 years of continuous maize cultivation. Agric Ecosyst Environ. 1994;49:239-
394 245.
- 395 18. Muchena FM and Kiome RM The role of soil science in agricultural development in
396 East Africa. Geoderma. 1995;67:141-157.
- 397 19. Köppen, W. Die Klimate der Erde. Walter de Gruyter, Berlin; 1923.
- 398 20. Makoi JHJR. Soil Fertility assessment for irrigation in the selected schemes of Mbulu
399 District. In: United Republic of Tanzania, Ministry of Agriculture and Food Security,
400 Participatory Irrigation Development Programme. ZITS, Moshi, Kilimanjaro; 2003.
- 401 21. Day PR. Particle fraction and particle size analysis. In: Black CA et al. (Eds).
402 Methods of soil analysis. Part 2. American Society of Agronomy, Madison. 1965:Pp.
403 545-567.
- 404 22. Allison E. Organic carbon. In: Black CA et al. (eds). Methods of soil analysis. Part 2.
405 American Society of Agronomy, Madison. 1965:Pp.1367-1378.
- 406 23. Walkley A, Black A. Determination of organic matter. Soil Sci. 1934;37:29-38.
- 407 24. Peech M. Hydrogen ion activity. In: Black CA et al. (Eds). Methods of soil analysis.
408 Part 2. American Society of Agronomy, Madison. 1965:Pp.914-926.
- 409 25. Bremner JM. Total nitrogen. In: Black CA et al. (eds). Methods of soil analysis. Part
410 2. American Society of Agronomy, Madison. 1965: Pp. 1149-1178.
- 411 26. Chapman HD. Cation exchange capacity. In: Black CA et al. (Eds). Methods of soil
412 analysis. Part 2. American Society of Agronomy, Madison. 1965:Pp. 891-901.
- 413 27. Polemio M, Rhoades JD. Determining cation exchange capacity: A new procedure
414 for calcareous and gypsiferous soils. Soil Sci. Soc. Am. J. 1977;41:524-528.
- 415 28. Hesse PR. A Text Book of Soil Chemistry Analysis. John Murray Ltd. London.
416 1971:Pp. 120-309.
- 417 29. Piper CS. Soil and Plant Analysis. University of Adelaide; 1942.
- 418 30. Rodriguez JB, Self JR and Soltanpour NP. Optimal conditions for phosphorous
419 analysis by the ascorbic acid-molybdenum blue method. Soil Sci Soc Am J.
420 1994;58:866-870.
- 421 31. Murphy J, and Riley JP. A modified single solution method for determination of
422 phosphates in natural waters. Anal Chim Acta. 1962;27:31-36.
- 423 32. Page AL, Miller RH, Keeney DR. eds. Methods of Soil Analysis, Part 2: Chemical
424 and Microbiological Properties, 2nd ed.: American Society of Agronomy, Madison,
425 WI. 1982.
- 426 33. NSS. Laboratory procedures for routine soil analysis, 3rd ed. Ministry of Agriculture
427 and Livestock Development, National Soil Service (NSS), ARI, Mlingano;1990
- 428 34. Schmidt EL. Nitrification in Soil. In: Stevenson, F.J. (Ed), Nitrogen in Agricultural
429 Soils. American Society of Agronomy, Madison, WI, 1982:pp. 253-288. ISBN
430 0891180702.

¹Ministry of Agriculture Food and Cooperatives, Directorate of Irrigation, P.O. Box 9192, Dar es Salaam, Tanzania;
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- 431 35. Sanchez PA, Palm CA, Boul SW. Fertility capability classification: A tool to help
432 assess soil quality in the tropics. *Geoderma*. 2003;114:157-185.
- 433 36. Page AL, Chang AC, Adriano DC. Deficiencies and toxicities of trace elements.
434 *Agricultural Salinity Assessment and Management*, Chapter 7, ASCE Manuals and
435 Reports on Eng. Practice No. 71, ASCE, 1990:pp.138-160.
- 436 37. Foy CD. Soil chemical factors limiting plant root growth. *Adv Soil Sci*. 1992;19:97-
437 131.
- 438 38. Makoi JHJR, Ndakidemi PA. The agronomic potential of vesicular arbuscular
439 mycorrhiza (VAM) in cereals– legume mixtures in Africa. *Afr. J. Microbiol. Res*.
440 2009; 3: 664-675.
- 441 39. Kauffman MD. The effect of soil acidity and lime placement on root growth and yield
442 of winter wheat and alfalfa. Ph.D. Diss. Oregon state Univ., Corvallis. Diss. Abstr.
443 37B, 7, 1977:pp. 3192-3193.
- 444 40. Adams F. Crop response to lime in the Southern United States. In: Adams, F. (Ed.),
445 *Soil Acidity and Liming*, second ed. Agronomy no. 12, ASA, CSSA, SSSA, WI, pp.
446 1984: 211-265.
- 447 41. Loveland P, Webb J. Is there a critical level of organic matter in the agricultural soils
448 of temperate regions: a review. *Soil and Tillage Res*. 2003;70(1):1-18.
- 449 42. Roscoe R, Buurman P, Velthorst EJ, Vasconcellos CA. Soil organic matter dynamics
450 in density and particle size fractions as revealed by the ¹³C/¹²C isotopic ratio in a
451 Cerrado's oxisol. *Geoderma*. 2001;104:185-202.
- 452 43. Kockba M, Ritvo G, Avinimelech Y. The effect municipal solid waste compost (MSW)
453 on the replacement of sodium in sodic soil models. *Soil Sci*. 2004;169:567-572.
- 454 44. Ferreras L, Gomez E, Toresani S, Firpo I, Rotondo R. Effect of organic
455 amendments on some physical, chemical and biological properties in a horticultural
456 soil. *Bioresource Tech*. 2006;97(4):635-640.
- 457 45. Flavel TC, Murphy DV. Carbon and Nitrogen mineralization rates after application of
458 organic amendments to the soil. *J Environ Quality*. 2006;35:183-193.
- 459 46. Doran, J., 1995. Building soil quality. In: *Proceedings of the 1995 Conservation*
460 *Workshop on Opportunities and Challenges in Sustainable Agriculture*. Red Deer,
461 Alta., Canada, Alberta Conservation Tillage Society and Alberta Agriculture
462 Conservation, Development Branch, pp. 151–158.
- 463 47. Drinkwater, L.E., Letourneau, D.K., Workneh, F., van Bruggen, A.H.C., Shennan, C.,
464 1995. Fundamental differences between conventional and organic tomato
465 agroecosystems in California. *Ecol. Appl*. 5, 1098–1112.
- 466 48. Shepherd MA, Harrison R, Webb J. 2006: Managing soil organic matter –
467 implications for soil structure on organic farms, *Soil Use and Management* 18
468 (s1):284 – 292.
- 469 49. Stamatiadis, S., Werner, M., Buchanan, M., 1999. Field assessment of soil quality
470 as affected by compost and fertilizer application in a broccoli field (San Benito
471 County, California). *Appl. Soil Ecol*. 12, 217–225.
- 472 50. Facelli JM, Pickett STA. Plant litter. Its dynamics and effects on plant community
473 structure. *Bot Rev*. 1991;57:1-32.
- 474 51. Rao DLN and Batra L. Ammonia volatilization from applied nitrogen in alkali soils.
475 *Plant Soil*. 1983;70(2): 219-228.
- 476 52. Vermeer JG, Berendse F. The relationship between nutrient availability, shoot
477 biomass and species richness in grassland and wetland communities. *Vegetation*.
478 1983;53:121-126.
- 479 53. Tilman GD. Plant dominance along an experimental nutrient gradient. *Ecol*. 1984;65:
480 1445-1453.
- 481 54. Goma HC. Potential for changing traditional soil fertility management systems in the
482 wet miombo woodlands of Zambia: the chitemene and fundikila systems: In: Gichuru
483 MP, Bationo A, Bekunda MA, Goma HC, Mafongoya PL, Mugendi DN, Murwira HK,

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- 484 Nandwa SM, Nyathi P, Swift MJ (eds). 2003. Soil fertility management in Africa: a
485 regional perspective, 2003:pp 187-218.
- 486 55. Eiland F, Klammer M, Lind AM, Leth M, Baath E. Influence of initial C/N ratio on
487 chemical and microbial composition during long term composting of straw. Microbial
488 Ecol. 2001;41:272-280.
- 489 56. Uriyo AP, Mongi HO, Chowdhury MS, Sing BR and Semoka JMR. Introductory Soil
490 Science. Tanzania Publishing House, Dar es Salaam. 1979:pp 232.
- 491 57. Hassett JJ and Banwart WL. Soils and their environment. Prentice Hall, Englewood,
492 New Jersey. 1992:Pp.424.
- 493 58. Anderson GD. Potassium responses of various crops in East Africa. In: Proceedings
494 of the 10th Colloquium of the International Potash Institute, Abijan, Ivory
495 Coast. International Potash Institute, Abijan. 1973:Pp. 413-437.
- 496 59. Gourley CJP. Potassium. In "Soil Analysis: An Interpretation Manual" (K. I. Peverill,
497 L. A. Sparrow and D. J. Reuter, eds.). CSIRO Publishing, Melbourne; 1999.
- 498 60. Schwartz HF and Coralles MA. Nutritional disorders in beans. In: Schwartz HF,
499 Coralles MAP (Eds.) Bean production Problems in the tropics. Second edition.
500 International Centre for Tropical Agriculture (CIAT), Cali. 1989:Pp.75-604.
- 501 61. Thomson WW and Weier TE. The fine structure of chloroplasts from mineral-
502 deficient leaves of *Phaseolus vulgaris*. Amer J Bot. 1962;49:1047-1055.
- 503 62. Marinos NG. Studies on submicroscopic aspects of mineral deficiencies. II. Nitrogen,
504 potassium, sulfur, phosphorus and magnesium deficiencies in the shoot apex of
505 barley. Amer J Bot. 1963;50:998-1005.
- 506 63. Evans HJ and Sorger GJ. Role of mineral elements with emphasis on the univalent
507 cations. Annu Rev Plant Physiol. 1966;17:47-76.
- 508 64. Hall JD, Barr R, Al-Abbas AH, and Crane FL. The ultra structure of chloroplasts in
509 mineral deficient maize leaves. Plant Physiol. 1972;50:404-409.
- 510 65. Marx ES, Hart J and Stevens RG. Soil test interpretation guide. Oregon State
511 University Extension Services. Oregon State University, Corvallis. 1996:7pp.
- 512 66. Cregan DD, Hirth JR, and Conyers MK. Amelioration of soil acidity by liming and
513 other amendments. In "Soil Acidity and Plant Growth" (A. D. Robson, Ed.),
514 1989:pp.205-264. Academic Press, Sydney.
- 515 67. McCray JM and Sumner ME. Assessing and modifying Ca and Al levels in acid
516 subsoils. Adv Soil Sci. 1990;14:45-75.
- 517 68. Cox FR, Sullivan GA, Martin CK. Effect of calcium and irrigation treatments on
518 peanut yield, grade and seed quality. Peanut Sci. 1976;3:81-85.
- 519 69. Hadidi NA. The influence of macronutrient deficiency on plant growth and
520 development, fruit yield, seed yield and quality of tomato (*Lycopersicon esculentum*
521 Mill.) and cucumber (*Cucumis sativus* L.). Ph.D. Diss. (Diss. Abstr. AAT 8426398).
522 The Ohio State University, Columbus; 1984.
- 523 70. Frost DJ, Kretchman DW. Calcium deficiency reduces cucumber fruit and seed
524 quality. J Am Soc Hort Sci. 1989;114:552-556.
- 525 71. Smiciklas KD, Mullen RE, Carlson RE, Knapp AD. Drought-induced stress effect on
526 soybean seed calcium and quality. Crop Sci. 1989;29: 1519-1523.
- 527 72. Sanchez PA, Logan TJ. Properties and management of soils in the tropics. John
528 Wiley and Sons, New York. 1992: pp 618.
- 529 73. Van Dijk H. Colloid chemical properties of humic matter. In: McLaren AD, Skujins J
530 (Eds.), Soil Biochemistry, Vol. 2. Marcel Dekker, New York, 1971:pp.16-35.
- 531 74. Oades JM, Gillman GP, Uehara G, Hue NV, van Noordwijk M, Robertson GP, Wada
532 K. Interactions of soil organic matter and variable-charge clays. In: Coleman DC,
533 Oades JM, Uehara G (Eds), Dynamics of Soil Organic Matter in Tropical
534 Ecosystems. University of Hawaii Press, Honolulu, HI, 1989:pp.69-95.
- 535 75. Lebron I, Suarez DL, Yoshida T. Gypsum effect on the aggregate size and geometry
536 of three sodic soils under reclamation. Soil Sci. Soc. Am. J. 2002;66: 92-98.

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76. Aslam M, Hukffker RC, Rains DW. Early effects of salinity on nitrate assimilation in barley seedlings. *Plant Physiol.* 1984;76:321-325.
77. Seeman JR, Sharkley TD. Salinity and nitrogen effects on photosynthesis, ribulose-1,5-bisphosphate carboxylase and metabolite pool sizes in *Phaseolus vulgaris* L. *Plant Physiol.* 1986;82:555-560.
78. Tarczynski MC, Jensen RG and Bohnert HJ. Stress protection of transgenic tobacco by production of the osmolyte mannitol. *Sci.* 1993;259: 508-510.
79. Munns R. Physiological processes limiting plant growth in saline soils: some dogmas and hypotheses. *Plant Cell Environ.* 1993;16:15-24.
80. Noble CL and Rogers MJE. Response of temperate forage legumes to water logging and salinity. In: Pessarakli M (ed) handbook of Plant and crops stress. Marcel Dekker. Inc., New York, NY, 1993:pp.473-496.
81. Gouia H, Ghorbal MH, Touraine B. Effect of NaCl on flows of N and mineral ions and on NO₃⁻ reductase rate within whole plants of salt-sensitive bean and salt-tolerant cotton. *Plant Physiol.* 1994;105:1409-1418.
82. Murguia JR, Belles JM and Serrano R. A salt-sensitive 3' (2'), 5'-bisphosphate nucleotidase involved in sulfate activation. *Sci.* 1995;267:232-234.
83. Flowers TJ. Salinisation and horticultural production. *Sci Hort.* 1999;78: 1-4.
84. Clark GJ, Dodgshun N, Sale PWG, Tang C. Changes in chemical and biological properties of a sodic clay subsoil with addition of organic amendments. *Soil Biol. Biochem.* 2007;39(11):2806-2817.
85. Lombin G and Fayemi AA. Magnesium availability in soils from Western Nigeria. *Soil Science.* 1976;122: 91-99.

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

Month	Rainfall (mm/month)	Potential evaporation(mm/month)	HI	Remarks
January	64	155	0.41	Dry
February	108	145	0.74	Intermediate
March	53	155	0.34	Dry
April	108	147	0.61	Intermediate
May	89	155	0.25	Dry
June	38	147	0	Dry
July	0	161	0	Dry
August	0	183	0	Dry
September	0	219	0	Dry
October	0	254	0	Dry
November	24	246	0.1	Dry
December	61	180	0.34	Dry
Annual	642	2,147	0.30	Dry

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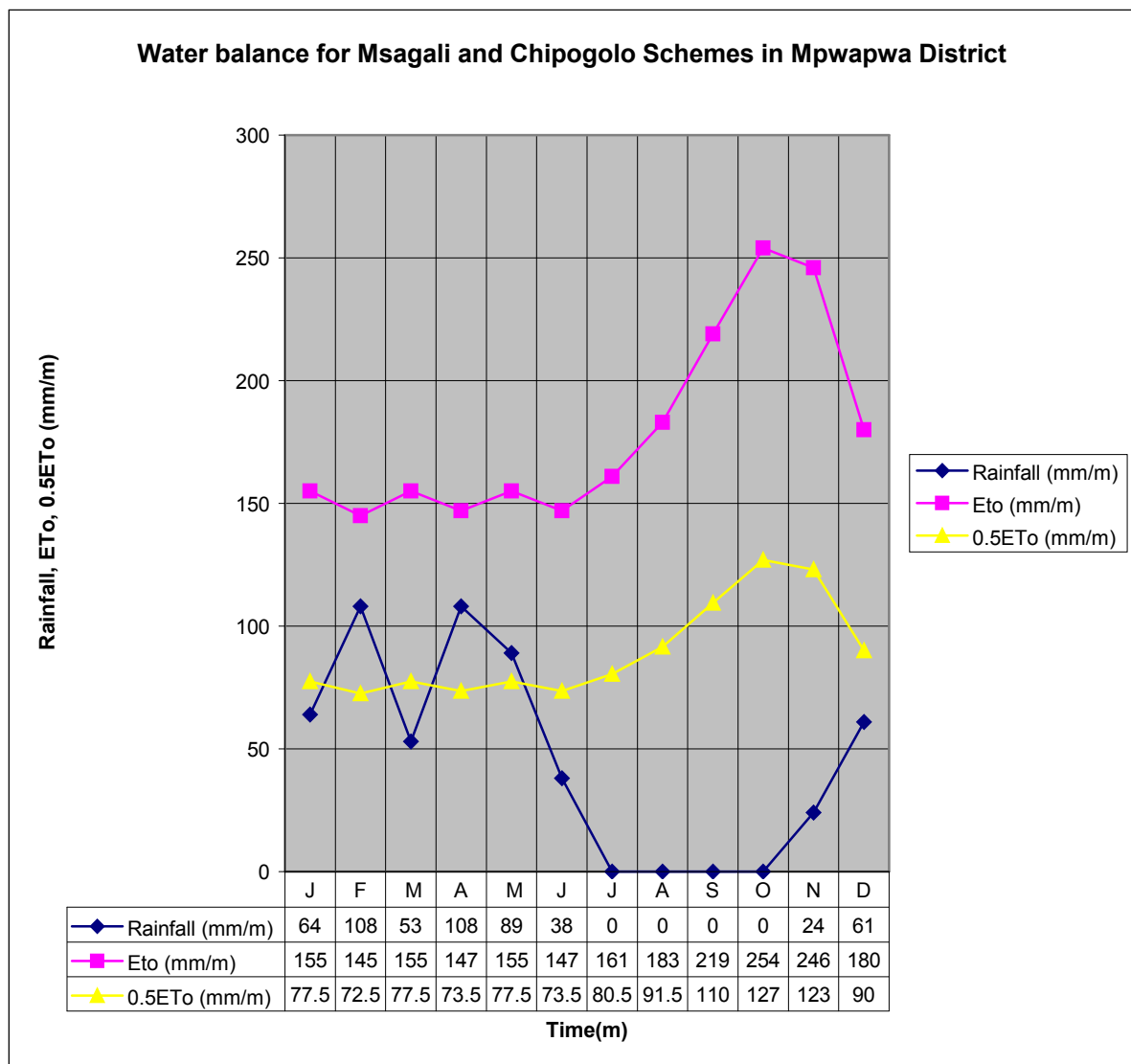


Figure 1: Water balance and the determination of the growing period for the selected schemes.

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684 **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	°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
ET _o	(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

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

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

715 EC = Electrical Conductivity, TN = Total Nitrogen; C/N = Carbon/Nitrogen ration, Pav = Available Phosphorus; K = Potassium; Ca =
716 Calcium; Mg = Magnesium; Na = Sodium, OC = Organic Carbon; CEC = Cation Exchange Capacity; BS = Base Saturation, ESP =
717 Exchangeable Sodium Percentage; SCL = Sand Clay Loam; CL = Clay Loam; C = Clay

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728 **Table 4:** Summary of the results of the nutrient balance in the top soil samples (0 – 50 cm)

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Sample No.	Texture	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

730 K = Potassium; Ca = Calcium; Mg = Magnesium; Na = Sodium, TEB = Total Exchangeable Bases, BS = Base Saturation; SCL = Sand Clay
 731 Loam; CL = Clay Loam; C = Clay

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738 **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

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