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***Research Article***

# 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.

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*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).

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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

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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

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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 x % 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 ($NH_4OAc$) 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

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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

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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, 2006); 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 $CO_2$ levels that contribute to climate change.

### **3.3 Total N**

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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 $N_2$ 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 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

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may lead to reduced crop yields (Uriyo et al., 1979). The observed C:N ratio status in 63.2% the surveyed area in Chipogoro 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 Chipogoro and all the studied sites in Msagali where mineralisation in the soil was lower than immobilisation.

### 3.5 Available phosphorus

Phosphorus (P) is an essential macro-element for plant growth, hence an important soil fertility indicator. In Chipogoro, the data showed that, 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). Based on the current soil fertility recommendation that uses a critical P concentration of > 7 mg $P.kg^{-1}$ to separate P deficient soils (NSS, 1990), 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 ($Ca_3 (PO_4)_2$ are less soluble, hence high P retention capacity and low P availability (Hassett and Banwart, 1992).

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

Results in this study showed that potassium (K) levels in the soil ranged from 0.78 - 7.68 cmol $(+).kg^{-1}$ soil in Chipogoro 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

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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 $Mg^{2+}$ 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 $Mg^{2+}$ in most crops is 2 cmol (+).kg$^{-1}$ (Schwartz and Coralles, 1989). The observed low levels of $Mg^{2+}$ 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 $Mg^{2+}$ 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 (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 $Ca^{2+}$ in the topsoil of the Chipogoro study area ranged from 3.9 - 9.7cmol (+) .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). Marx et al. (1996) 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

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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 $Ca^{2+}$ uptake produce lower crop yields than crops grown with adequate $Ca^{2+}$ (Cox et al., 1976; Hadidi, 1984; Frost and Kretchman, 1989; Smiciklas et al., 1989). 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, 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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The exchangeable Na range from 0.31 - 4.31 cmol (+) $kg^{-1}$ soil corresponding to ESP values ranging from 5.3 – 9.6% in Chipogoro and from 0.43 - 6.1 cmol (+) $kg^{-1}$ soil corresponding to ESP values ranging from 4.2 – 27.9% in Chipogoro (Tables 3, 5). The critical values of ESP above which most crops are affected are established at 15 (Lebron et al., 2002). 26.9% of the total surveyed area in Chipogoro 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 Chipogoro 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 $K^{+}$ (Aslam et al., 1984; Seeman and Sharkey, 1986; Tarczynski et al., 1993; Munns, 1993). The excessive $Na^{+}$ in the soil is likely to cause reduced plant growth and development, thus, decreased crop yields (Aslam et al., 1984; Seeman and Sharkey, 1986; Tarczynski et al., 1993; Munns, 1993; Noble and Rogers, 1993; Gouia et al., 1994; Murguia et al., 1995; Flowers, 1999). Our results suggest that such sodic soils may require appropriate amendments such as 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 (Clark et al., 2007, Makoi and Ndakidemi, 2007) 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 (Makoi and Ndakidemi, 2007).

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### 3.9 Cation ratios

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: 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 (Lombin and Fayemi 1976; NSS, 1990), 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 (NSS, 1990). 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 (NSS, 1990) 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 Chipogoro suggesting that plants would probably respond to the addition of Ca or Mg in such areas (Table 4).

## 4. CONCLUSIONS

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, Tanzania. Our results suggest that soil pH and excessive sodium in the soil

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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.

**Reference:**


1. Adams F. Crop response to lime in the Southern United States. In: Adams, F. (Ed.), Soil Acidity and Liming, second ed. Agronomy no. 12, ASA, CSSA, SSSA, WI, pp. 1984: 211-265.
2. Allison E. Organic carbom. In: Black CA et al. (eds). Methods of soil analysis. Part 2. American Society of Agronomy, Madison. 1965:Pp.1367-1378.
3. Anderson GD. Potassium responses of various crops in East Africa. In: Proceedings of the 10th Colloquium of the International Potash Potash Insititute, Abijan, Ivory Coast. International Potash Insititute, Abijan. 1973:Pp. 413-437.
4. Angers DA, Pesant A, Vigneux J. Early cropping - induced changes in soil aggregation, organic matter and microbial biomass. SSSAJ. 1992:56:115-119.
5. Aslam M, Hukffker RC, Rains DW. Early effects of salinity on nitrate assimilation in barley seedlings. Plant Physiol. 1984:76:321-325.
6. Boyle M, Frankenberger WT and Stolzy LH. The influence of organic matter on soil aggregation and water infiltration. J Prod Agric. 1989:2:290-298.
7. Brady NC, Weil RR. Nature and Properties of Soils. 13th Edition. With permission of Pearson Education, Inc., Upper Saddle River, New Jersey; 2002.
8. Bremner JM. Total nitrogen. In: Black CA et al. (eds). Methods of soil analysis. Part 2. American Society of Agronomy, Madison. 1965: Pp. 1149-1178.
9. Chapman HD. Cation exchange capacity. In: Black CA et al. (Eds). Methods of soil analysis. Part 2. American Society of Agronomy, Madison. 1965:Pp. 891-901.

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10. 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.
11. Cox FR, Sullivan GA, Martin CK. Effect of calcium and irrigation treatments on peanut yield, grade and seed quality. Peanut Sci. 1976:3:81-85.
12. Cregan DD, Hirth JR, and Conyers MK. Amelioration of soil acidity by liming and other amendments. In ‘‘Soil Acidity and Plant Growth’’ (A. D. Robson, Ed.), 1989:pp.205-264. Academic Press, Sydney.
13. Day PR. Particle fraction and particle size analysis. In: Black CA et al. (Eds). Methods of soil analysis. Part 2. American Society of Agronomy, Madison. 1965:Pp. 545-567.
14. Defoer T, Budelman A (Eds.). Managing Soil Fertility in the Tropics. A Resource Guide for Participatory Learning and Action Research. KIT Publishers, Amsterdam; 2000
15. Eiland F, Klamer M, Lind AM, Leth M, Baath E. Influence of initial C/N ratio on chemical and microbial composition during long term composing of straw. Microbial Ecol. 2001:41:272-280.
16. Evans HJ and Sorger GJ. Role of mineral elements with emphasis on the univalent cations. Annu Rev Plant Physiol. 1966:17:47-76.
17. Facelli JM, Pickett STA. Plant litter. Its dynamics and effects on plant community structure. Bot Rev. 1991:57:1-32.
18. Ferreras L, Gomez E, Toresani S, Firpo I, Rotondo R. Effect of organic amendments on some physical, chemical and biological properties in a horticultural soil. Bioresource Tech. 2006:97(4):635-640.
19. Flavel TC, Murphy DV. Carbon and Nitrogen mineralization rates after application of organic amendments to the soil. J Environ Quality. 2006:35:183-193.
20. Flowers TJ. Salinisation and horticultural production. Sci Hort. 1999:78: 1-4.
21. Foy CD. Soil chemical factors limiting plant root growth. Adv Soil Sci. 1992:19:97-131.

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22. Frost DJ, Kretchman DW. Calcium deficiency reduces cucumber fruit and seed quality. J Am Soc Hort Sci. 1989:114:552-556.
23. Gillman GP. Influence of organic matter and phosphate content on the point of zero charge of variable charge components in oxidic soils. Aust J Soil Res. 1985:23(4):643-646.
24. Goma HC. Potential for changing traditional soil fertility management systems in the wet miombo woodlands of Zambia: the chitemene and fundikila systems: In: Gichuru MP, Bationo A, Bekunda MA, Goma HC, Mafongoya PL, Mugendi DN, Murwira HK, Nandwa SM, Nyathi P, Swift MJ (eds). 2003. Soil fertility management in Africa: a regional perspective, 2003:pp 187-218.
25. 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 Phyisol. 1994:105:1409-1418.
26. Gourley CJP. Potassium. *In* “Soil Analysis: An Interpretation Manual” (K. I. Peverill, L. A. Sparrow and D. J. Reuter, eds.). CSIRO Publishing, Melbourne; 1999
27. Hadidi NA. The influence of macronutrient deficiency on plant growth and development, fruit yield, seed yield and quality of tomato (*Lycopersicon esculentum* Mill.) and cucumber (*Cucumis sativus* L.). Ph.D. Diss. (Diss. Abstr. AAT 8426398). The Ohio State University, Columbus; 1984
28. Hall JD, Barr R, Al-Abbas AH, and Crane FL. The ultra structure of chloroplasts in mineral deficient maize leaves. Plant Physiol. 1972:50:404-409.
29. Hassett JJ and Banwart WL. Soils and their environment. Prentice Hall, Englewood, New Jersey. 1992:Pp.424.
30. Hellin J. From soil erosion to soil quality. LEISA Mag. Low External Input Sustain Agric. 2003:19 (4).
31. Hesse PR. A Text Book of Soil Chemistry Analysis. John Murray Ltd. London. 1971:Pp. 120-309.

UNDER PEER REVIEW

32. Kauffman MD. The effect of soil acidity and lime placement on root growth and yield of winter wheat and alfalfa. Ph.D. Diss. Oregon state Univ., Corvallis. Diss. Abstr. 37B, 7, 1977:pp. 3192-3193.
33. Kockba M, Ritvo G, Avinimeleck Y. The effect municipal solid waste compost (MSW) on the replacement of sodium in sodic soil models. Soil Sci. 2004:169:567-572.
34. Köppen, W. Dle Klirnate der Erde. Walter de Gruyter, Berlin; 1923
35. Lal R, Mokma D, Lowery B. Relation between soil quality and soil erosion. In: Lal R, Kimble J, Levine E, Stewart BA (Eds), Soil Quality and Soil Erosion. CRC Press, Boca Raton, 1999:pp.237-259.
36. Le Bissonnais Y. Experimental study and modelling of soil surface crusting processes. Catena. Suppl.1990:17:13-28.
37. Lebron I, Suarez DL, Yoshida T. Gypsum effect on the aggregate size and geometry of three sodic soils under reclamation. Soil Sci Soc Am J. 2002:66: 92-98.
38. Lombin G and Fayemi AA. Magnesium availability in soils from Western Nigeria. Soil Science. 1976:122: 91-99
39. Loveland P, Webb J. Is there a critical level of organic matter in the agricultural soils of temperate regions: a review. Soil and Tillage Res. 2003:70(1):1-18.
40. Lyamchai CJ, Mowo JG, Wickama JM. Managing new working relationships: partnership and networking. In: AHI Regional Conference, Nairobi; 2004
41. Makoi JHJR. Soil Fertility assessment for irrigation in the selected schemes of Mbulu District. In: United Republic of Tanzania, Ministry of Agriculture and Food Security, Participatory Irrigation Development Programme. ZITS, Moshi, Kilimanjaro; 2003
42. Makoi JHJR and Ndakidemi PA. Reclamation of sodic soils in Rundugai village, Hai District, Kilimanjaro Region, Tanzania, using locally available organic and inorganic resources. Afr J Biotechnol. 2007:6(16):1926-1931.

UNDER PEER REVIEW

43. Marinos NG. Studies on submicroscopic aspects of mineral deficiencies. II. Nitrogen, potassium, sulfur, phosphorus and magnesium deficiencies in the shoot apex of barley. Amer J Bot. 1963:50:998-1005.

44. Marx ES, Hart J and Stevens RG. Soil test interpretation guide. Oregon State University Extension Services. Oregon State University, Corvallis. 1996:7pp.

45. McCray JM and Sumner ME. Assessing and modifying Ca and Al levels in acid subsoils. Adv Soil Sci. 1990:14:45-75

46. 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

47. Monreal CM, Dinel H, Schnitzer M, Gamble DS, Biederbeck VO. Impact of carbon sequestration on functional indicators of soil quality as influenced by management in sustainable agriculture. P. 435-457. In: Lal R et al. (eds.) Soil processes and the carbon cycle, Lewis Publ., CRC Press, Roca balton, FL; 1997

*48.* 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.

49. Muchena FM and Kiome RM The role of soil science in agricultural development in East Africa. Geoderma. 1995:67:141-157.

50. Munns R. Physiological processes limiting plant growth in saline soils: some dogmas and hypotheses. Plant Cell Environ. 1993:16:15-24.

51. Murguia JR, Belles JM and Serrano R. A salt-sensitive 3' (2'), 5'-bisphosphate nucleotidase involved in sulfate activation. Sci. 1995:267:232-234.

52. Murphy J, and Riley JP. A modified single solution method for determination of phosphates in natural waters. Anal Chim Acta. 1962:27:31-36.

53. Ndakidemi PA and Semoka JMR. Soil fertility in Western Usambara Mountains, Northern Tanzania. Pedosphere. 2006:16(2):237-244.

UNDER PEER REVIEW

54. 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.
55. 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.
56. NSS. Laboratory procedures for routine soil analysis, 3rd ed. Ministry of Agriculture and Livestock Development, National Soil Service (NSS), ARI, Mlingano;1990
57. Oades JM. The retention of organic matter in soils. Biogeochem. 1986:5:35-70.
58. Oades JM, Gillman GP, Uehara G, Hue NV, van Noordwijk M, Robertson GP, Wada K. Interactions of soil organic matter and variable-charge clays. In: Coleman DC, Oades JM, Uehara G (Eds), Dynamics of Soil Organic Matter in Tropical Ecosystems. University of Hawaii Press, Honolulu, HI, 1989:pp.69-95.
59. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S. Dep. of Agric. Circ. 1954:939.
60. Oue´draogo E. Soil quality improvement for crop production in semi arid West Africa. PhD Thesis, Wageningen University, Wageningen; 2004
61. Page AL, Chang AC, Adriano DC. Deficiencies and toxicities of trace elements. Agricultural Salinity Assessment and Management, Chapter 7, ASCE Manuals and Reports on Eng. Practice No. 71, ASCE, 1990:pp.138-160.
62. Paustian K, Collins HP, Paul EA. Management controls on soil carbon. p. 15-49. In: E.A. Paul et al. (Eds) Soil organic matter in temperate agroecosystems: Long-term experiments in North America. CRC Press, Boca Raton, FL;1997
63. Peech M. Hydrogen ion activity. In: Black CA et al. (Eds). Methods of soil analysis. Part 2. American Society of Agronomy, Madison. 1965:Pp.914-926.
64. Piper CS. Soil and Plant Analysis. University of Adelaide; 1942

UNDER PEER REVIEW

65. Polemio M, Rhoades JD. Determining cation exchange capacity: A new procedure for calcareous and gypsiferous soils. Soil Sci. Soc. Am. J. 1977:41:524-528.
66. Rao DLN and Batra L. Ammonia volatilization from applied nitrogen in alkali soils. Plant Soil. 1983:70(2): 219-228
67. Riffaldi R, Saviozzi A, Levi-Minzi R, Menchetti F. Chemical characteristics of soil after 40 years of continuous maize cultivation. Agric Ecosyst Environ. 1994:49:239-245.
68. 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.
69. Rodriguez JB, Self JR and Soltanpour NP. Optimal conditions for phosphorous analysis by the ascorbic acid-molybdenum blue method. Soil Sci Soc Am J. 1994:58:866-870.
70. Roscoe R, Buurman P, Velthorst EJ, Vasconcellos CA. Soil organic matter dynamics in density and particle size fractions as revealed by the 13C/12C isotopic ratio in a Cerrado's oxisol. Geoderma. 2001:104:185-202.
71. Saı¨dou A, Kuyper TW, Kossou DK, Tossou R, Richards P. Sustainable soil fertility management in Benin: learning from farmers. NJAS-Wageningen. J Life Sci. 2004:52: 349-369.
72. Sanchez PA. Soil fertility and hunger in Africa. Sci. 2002:295:2019-2020.
73. Sanchez PA, Logan TJ. Properties and management of soils in the tropics. John Wiley and Sons, New York. 1992: pp 618.
74. Sanchez PA, Palm CA, Boul SW. Fertility capability classification: A tool to help assess soil quality in the tropics. Geoderma. 2003:114:157-185.
75. Schmidt EL. Nitrification in Soil. In: Stevenson, F.J. (Ed), Nitrogen in Agricultural Soils. American Society of Agronomy, Madison, WI, 1982:pp. 253-288. ISBN 0891180702.
76. Schwartz HF and Coralles MA. Nutritional disorders in beans. In: Schwartz HF, Coralles MAP (Eds.) Bean production Problems in the tropics. Second edition. International Centre for Tropical Agriculture (CIAT), Cali. 1989:Pp.75-604.

UNDER PEER REVIEW

77. Scoones I. Dynamics and Diversity: Soil Fertility and Farming Livelihoods in Africa: Case Studies from Ethiopia, Mali, and Zimbambwe, Earthscan Publications Ltd., London, 2001: pp 244.
78. 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.
79. Smaling EMA, Braun AR. Soil fertility research in sub-Saharan Africa: New dimensions, new challenges, Commun Soil Sci Plant Anal. 1996:27:365-386.
80. Smaling EMA, Nandwa SM, Janssen BH. Soil fertility in Africa is at stake. In: Buresh RJ, Sanchez PA and Calhoun F (Eds). *Replenishing Soil Fertility in Africa*, Soil Science Society of America, American Society of Agronomy, Soil Science Society of America Special Publication No. 51, Madison, Wisconsin, USA, 1997:pp. 47-61.
81. Smiciklas KD, Mullen RE, Carlson RE, Knapp AD. Drought-induced stress effect on soybean seed calcium and quality. Crop Sci. 1989:29: 1519-1523.
82. Tarczynski MC, Jensen RG and Bohnert HJ. Stress protection of transgenic tobacco by production of the osmolyte mannitol. Sci. 1993:259: 508-510.
83. Thomson WW and Weier TE. The fine structure of chloroplasts from mineral-deficient leaves of Phascoluis vulgaris. Amer J Bot. 1962:49:1047-1055.
84. Tiessen H, Cuevas E and Chacon P. The role of soil organic matter in sustaining soil fertility. Nature.1994:371:783-785.
85. Tilman GD. Plant dominance along an experimental nutrient gradient. Ecol. 1984:65: 1445-1453.
86. Tisdale JM, Oades JM. Organic matter and water-stable aggregates in soils. J. Soil Sci. 1982:33:141-163.
87. Uriyo AP, Mongi HO, Chowdhury MS, Sing BR and Semoka JMR. Introductory Soil Science. Tanzania Publishing House, Dar es Salaam. 1979:pp 232.

UNDER PEER REVIEW

88. URT (United Republic of Tanzania). Ministry of Agriculture and Food Security. Tanzania Soils Maps, Mlingano Agricultural Research Institute, Tanga, Tanzania. Available online: http://www.kilimo.go.tz/Research-Training/Mlingano%20Research/Tanzania%20Soil%20Maps/Soil%20maps.htm; 2006
89. Van Dijk H. Colloid chemical properties of humic matter. In: McLaren AD, Skujins J (Eds.), Soil Biochemistry, Vol. 2. Marcel Dekker, New York, 1971:pp.16-35.
90. Vermeer JG, Berendse F. The relationship between nutrient availability, shoot biomass and species richness in grassland and wetland communities. Vegetation. 1983:53:121-126.
91. Walkley A, Black A. Determination of organic matter. Soil Sci. 1934:37:29-38.

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**Table 1: C**omputations 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: | 1,505mm |
| (High drought stress) | |
| Annual Rainfall: | 642 mm |
| Annual potential evaporation: | 2,147 mm |
| Rainfall during Dry and intermediate months: | 642 mm |
| Potential evaporation during Dry and intermediate months: | 2,147 mm |

**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 | $^{o}C$ | 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 |

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

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

| Sample No. | Texture | pH ($H_2O$) | 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 |

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

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. | 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 |

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

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**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 |

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; OC = Organic Carbon; CEC = Cation Exchange Capacity; ESP = Exchangeable Sodium Percentage.