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Full Length Research Paper

Selected chemical properties of soil in the traditional irrigation schemes of the Mbulu district, Tanzania

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A survey of chemical soil properties was conducted on six selected irrigation schemes of the Mbulu district, northern Tanzania. The focus of the study was to establish the status of the main mineral elements important for plant growth and crop production. Soil samples were collected from different sites and were analysed for physical chemical characteristics leading to the assessment of the soil fertility status by means of these main elements. The results showed variations in fertility status in the selected sites. Based on guidelines of soil mineral elements contents established elsewhere, the results showed that soil pH and excessive sodium in the soil followed by calcium in all sites; soil organic matter in 73% and cation exchange capacity in 50% of the sites are the major soil fertility constraints to crop production in the area. Crop production was also constrained by nitrogen in 50% and phosphorous in 46% of the sites. The information from our study could be used in designing fertiliser studies to establish nutrient requirements for different crops grown in these areas.

Key words: calcium, cation exchange capacity, crop production, excessive sodium, fertility constraints, management practices, soil organic matter, survey

INTRODUCTION

Many traditional irrigated agricultural systems in the tropics are characterised by negative mineral element balances essential for plant growth and development (Ngailo et al., 1999) due to extensive farming, excessive leaching, soil degradation, plant removal without fertiliser application and low purchasing power to replenish the depleted mineral elements in the system (Mokwunye et al., 1996; Ngailo et al., 1999; Sanchez, 2002). The Mbulu irrigation schemes are among the potential areas in Tanzania which practise both rain-fed and traditionally-managed supplementary irrigation agricultural activities. Among the important crops of national interest that are cultivated in these areas are: garlic, onions, cabbage, bananas, coffee, wheat, maize, sorghum, millet and beans. In Tanzania, the Mbulu district is the source of high quality garlic and onions, some of which are smuggled to neighbouring countries.

Due to complex interactions between several factors such as soil and crop management, farming systems, and soil fertility, production of both food and cash crops have declined, thus, threatening food security in these areas. For example, the current maize grain yields in these irrigation schemes are less than 1 t ha^{-1} (Ngailo et al., 1999). At present 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 cultivation of the land without proper management practises in some areas of Africa showed soil fertility decline (Smaling and Braun, 1996; Smaling et al., 1997; Scoones, 2001; Ndakidemi and Semoka, 2006). Therefore, the decline in crop yields in many areas of the Mbulu district is likely to be related to deterioration of soil fertility.

Soil fertility key indicators have previously been reported by several researchers (Tisdale and Oades, 1982; Paustian et al., 1997; Monreal et al., 1997; Brady and Weil, 2002). They include soil pH, soil organic matter; cation exchange capacity; exchangeable bases, salinity and sodicity status and the amount of extractable N, P, K, Mg and Ca mineral nutrients. These indicators are realistic in predicting plant growth and development,

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a need for regular 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 provides input into the design and planning of crop nutrition packages in the study areas. To date, soil fertility survey studies in Tanzania are very scarce in the literature (Muchena and Kiome, 1995; Ndakidemi and Semoka, 2006). This study was conducted to asses the soil fertility status in the selected irrigation schemes of Harsha, Diyomat, Dongobesh, Tumati, Mangisa and Guwangw in the Mbulu District, Tanzania.

MATERIALS AND METHODS

Location, topography and climate of the study areas

The Irrigation schemes of Harsha, Diyomat, Dongobesh, Tumati, Mangisa and Guwangw are located in the Mbulu District, Manyara region, in the northern part of Tanzania (3°10' and 4°16' S and longitudes 34°47' and 37°56' E). The altitude of the study area ranged from 1000 to 2400 m asl. The rainfall pattern in the Mbulu District is largely characterised by 6 wet months and 6 dry months. The onset of the rains is in November, with monthly totals between 100 and 175 mm from December through May. December is the wettest month in the Mbulu District. The mean monthly temperature in the selected schemes range between 15°C to 20°C. Potential evaporation as computed by Penman equation is 1543 mm yr^{-1}. Evapotranspiration is generally at its maximum in October just before the onset of the rains and is lowest at the end of May, which is the end of rainy season. Annual relative humidity is 65%, ranging between 55% (October) and 75% (December/April). The major soils in the study area can generally be classified as Phaeozems; Nitisols and Planosols URT (2006).

Soil sampling and physical-chemical characterisation

Surface soil samples at a depth of 0 to 20 cm were collected from 22 sites each with similar characteristics chosen on the basis of pedogeomorphic approaches which also ensured high representtation of the study area as reported by Makoi (2003). Thirty composite samples were collected from each site, bulked and mixed. A representative sample of about one kg soil from each site was then filled in a labelled plastic bag and sent to the Selian Agricultural Research Institute Arusha, Tanzania for analysis. These samples were air dried and ground to pass through a 2mm-sieve. Particle size analysis was determined by the Bouyoucos hydrometer method (Day, 1965). Organic carbon was done by Walkley and Black wet acid dichromate digestion method (Allison, 1965); soil organic matter was calculated as 1.72 x %OC (Walkley and Black, 1934) pH was determined by a pH meter using soil to water ratio of 1:2.5 as described by Peech (1965) whereas total nitrogen 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 was followed (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 was done with an atomic absorption spectrophotometer (Hesse, 1971). Cation exchange capacity was done following the method by Chapman (1965). Electrical conductivity (EC) was measured by a conductivity meter from the soil solution directly following the procedure described by Piper (1942). Available phosphorus was determined following the Olsen method of extraction (Olsen et al., 1954). 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 method of 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 total exchangeable bases by the cation exchange capacity multiplied by 100. Exchangeable sodium percentage (ESP %) was obtained by dividing total exchangeable sodium by the cation exchange capacity multiplied by 100. The K:TEB was obtained by dividing potassium by the total exchangeable bases.

RESULTS AND DISCUSSION

Soil reaction

Results from the survey have shown that pH ranged from 7.2 - 8.8 in the top soils (Table 1). Forty five percent of the sites were rated as neutral to mildly alkaline with pH ranging from 7.2 - 7.8 (Table 1, NSS, 1990), suggesting that there is no threat to the availability of mineral elements in most crops (Schmidt, 1982; Sanchez et al., 2003). 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 (Sanchez et al., 2003). However, 55% of the surveyed sites had soil pH ranging from 7.9 - 8.8, rated as moderately to strongly alkaline (Table1; NSS, 1990) and mineral elements deficiency such as P, Ca, Fe, Cu, Zn, Mn and Mo are expected to occur (Page et al., 1990; Foy, 1992). Furthermore, unfavourable plant growth conditions such as severe root damage, shallow rooting, poor root development, susceptibility to drought and poor use of subsoil mineral elements have been reported in such pH range (Kauffman, 1977; Adams, 1984). Collectively, the constraints associated with alkaline conditions may threaten the yield potential of cropping systems in the study area.

Total soil organic matter and organic carbon

Soil organic matter content across sites was low to medium, ranging from 3.3 - 66.0 g kg^{-1} in topsoil (Table 1). Since soil organic matter 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 soil organic matter 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 73% of the 22 sites used in this study, suggesting a decline in soil qua-

Table 1. Physical and chemical characteristics of soils from the selected schemes of Mbulu District, Manyara Region, Tanzania

Site	Texture	pH (H_2O)	EC dSm^{-1}	OC	SOM	N	C/N	Olsen P($mgkg^{-1}$)	CEC (cmol (+) kg^{-1})
				……....g kg^{-1}……….					
Tumati irrigation scheme									
TU-Va1	C	7.6	0.21	22.8	39.2	2.5	9.1	14.80	12.2
TU-Va2	C	7.2	0.14	23.6	40.6	1.8	13.1	48.70	14.5
TU-Va3	C	8.5	0.26	3.5	6.0	2.0	1.8	14.00	10.1
Dongobesh irrigation scheme									
DO-Pi1	C	8.6	0.20	3.3	5.7	2.0	1.7	2.50	8.4
DO-Va1	C	7.6	0.21	23.6	40.6	2.5	9.4	44.40	14.5
DO-Va2	C	8.5	0.15	2.3	4.0	1.3	1.8	2.60	9.4
DO-Va3	C	7.3	0.05	25.3	43.5	2.7	9.4	48.70	13.6
Mangisa irrigation scheme									
MAN-Va1	SiCL	7.9	0.15	3.8	6.5	2.2	1.7	2.90	8.0
MAN-Va2	SiC	7.5	0.13	10.8	18.6	2.5	4.3	59.20	17.4
MAN-Va3	CL	8.0	0.09	2.1	3.6	1.5	1.4	2.50	5.5
Diyomat irrigation scheme									
DIY-Va1	C	8.8	2.09	1.9	3.3	1.9	1.0	2.20	8.2
DIY-Va2	C	7.4	0.12	16.0	27.5	2.0	8.0	60.00	11.3
DIY-H1	L	7.5	0.15	16.0	27.5	2.1	7.6	45.40	13.6
Harsha irrigation scheme									
HAR-Va1	C	8.6	0.17	2.1	3.6	2.0	1.1	2.50	6.50
HAR-Va2	CL/C	8.5	0.18	2.5	4.3	1.9	1.3	2.30	8.25
HAR-H1	C	8.0	0.20	2.9	5.0	2.0	1.5	4.90	12.25
HAR-Pi1	CL	7.9	0.09	3.6	6.2	2.1	1.7	5.00	18.80
HAR-Pi2	CL	8.5	0.11	2.6	4.5	1.9	1.4	2.40	5.15
HAR-Pi3	C	8.5	0.20	2.5	4.3	1.8	1.4	2.00	6.80
Guwangw irrigation scheme									
Gu-Va1	CL	7.2	0.05	38.4	66.0	4.4	8.7	42.30	19.15
Gu-Va2	HC	7.4	0.14	25.7	44.2	4.5	5.7	46.80	17.15
Gu-H2	SiCL	7.5	0.40	14.8	25.5	3.3	4.5	37.70	15.15

TU=Tumati; DO=Dongobesh; MAN=Mangisa; DIY=Diyomat; HAR=Harsha; Gu=Guwangw; Va=Valley; Hi=Hilland; Pi=Piedmont; L=Loam; SiC=Silt clay; SiCL=Silt clay loam; CL=Clay loam; C=Clay; HC=Heavy clay; EC=Electrical conductivity; OC=Organic carbon; TN=Total nitrogen; C/N=Carbon nitrogen ratio; P=Phosphorous; CEC=Cation exchange capacity

lity (Tables 3 and 4). It is, therefore, apparent that there is a need to replenish the organic matter using resources such as crop residues and manure for maximum crop yields. Understanding the soil organic matter 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 (N, P and S), ion-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 holding capacity (Monreal et al., 1997) which also has great impact on improving irrigation efficiency for sustainable land productivity.

Total N

Total nitrogen status in the study area was rated as low to medium with values ranging from 1.0 to 4.5 g kg^{-1} (Table 1). According to NSS (1990) guidelines, the proposed value for most crops in Tanzania is 2 g N kg^{-1} soil. The results show that 32% of the surveyed sites had %N below the threshold value (< 2 g kg^{-1}) and rated as low (Table 3 and 4). The observed low N in these sites may be closely related to amongst others low soil organic matter content which is greatly influenced by microbial activity in the soil (Facelli and Pickett, 1991) and high pH which could lead to N loss through ammonia volatilisation (Rao and Batra, 1983). In our study, soil samples with higher N levels were obtained from the organic enriched soils. So, any activity envisaged to improve the soil pH, soil organic matter 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). Although 68% of the sites had values above or equal to recommended value, and rated as medium (Tables 3 and 4), short and long-term interventions are proposed. 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.

C:N ratio

The C:N showed no clear relationship with the soil texture in our study. The C:N ratio ranged from 1.0 to 9.4 even though only one site had a C:N ratio of 13.1 suggesting that the study area has a moderate to good quality soil organic matter (Table 1; NSS, 1990). It is generally accepted that C:N ratios between 8 and 12 (27% of the sites) are considered to be the most favourable, implying a relatively fast mineralisation of nitrogen 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 may lead to reduced crop yields (Uriyo et al., 1979). The observed C:N ratio status in all sites surveyed in this study suggests ideal conditions for plant growth since in such situations mineralisation in the soil is greater than immobilisation.

Available phosphorus

Phosphorous is an essential element for plant growth, hence an important soil fertility indicator. In our study, phosphorus in the soil ranged from 2.0 – 60.0 mg P kg^{-1} (Table 1). Based on current soil fertility recommendation that uses a critical P concentration of 7 mg P kg^{-1} to separate P deficient soils (NSS, 1990), 55% of the surveyed sites had sufficient P levels and 45% would fell in the deficient category. The observed low values of P could partly be attributed to fixation into unavailable forms due to high soil pH (Table 1). For example, in such alkaline soils, calcium phosphates are less soluble, hence high P retention capacity and low P availability (Hassett and Banwart, 1992). Even though most sites had sufficient available P levels, future plans for the deficient sites should include research on mineral P fertiliser or organic manure from various sources in order to moderate P levels in these soils to sustain productivity. In most cases higher P levels in our study were associated with higher levels of organic matter and neutral to mildly alkaline pH (Gillman, 1985).

Exchangeable bases (K, Mg, Ca)

Potassium levels ranged from 0.2 - 7.9 cmol kg^{-1} in the soil (Table 2). It is generally accepted that response to K fertilisers is likely when a soil has an exchangeable K value of < 0.2cmol (+) kg^{-1} soil and unlikely when it is above 0.4 cmol (+) kg^{-1} soil (Table 2; Anderson, 1973; NSS, 1990). Ninety five percent of the surveyed sites were rated as medium or high to very high due to exchangeable K values > 0.4 cmol (+) kg^{-1} soil (Table 2; NSS, 1990). This result generally suggests that K is not a limiting mineral element to crop productivity except in one site.

The exchangeable Ca^{2+} in the topsoil of these schemes ranged from 0.6 - 3.3 cmol (+) kg^{-1}. All sites were rated as very low to low (Tables 2, 3 and 4). Marx et al. (1996) proposed that in most of the crops, the recommended threshold level of Ca^{2+} is 5 cmol (+) kg^{-1}. It is generally acknowledged that field conditions that limit Ca^{2+} uptake produce lower crop yields than crops grown with adequate Ca^{2+} (Cox et al., 1976; Hadidi, 1984; Frost and Kretchman, 1989; Smiciklas et al., 1989). The low to very low levels of Ca^{2+} in all sites indicates higher bondage of Ca^{2+} to P at high soil reactions (Table 2). Research efforts should be directed towards packages that can ameliorate this problem.

These results also showed that Mg^{2+} content was very high in all soils with values ranging from 4.5 - 23.0 cmol (+) kg^{-1} (Table 2). This was the dominant cation in all sites. The recommended value of Mg^{2+} in most crops is 2 cmol (+) kg^{-1} (Schwartz and Coralles, 1989). The high to very high levels of Mg^{2+} in the soils suggest that these schemes have sufficient Mg^{2+} supplies for crop growth.

Cation exchange capacity

The cation exchange capacity (CEC) status in the soil ranged from 6.5 - 19.2 cmol (+) kg^{-1} (Table 1) and was rated as low to medium (Table 3, 4; 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 surveyed sites, 50% have 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 calcium. 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 low to medium CEC found in this study could be related to low soil organic matter of these soils (Table 1). The 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 requi-

Table 2. Chemical characteristics of soils from the selected schemes of Mbulu District, Manyara Region, Tanzania.

Site					TEB	Ca/Mg	Mg/K	K/TEB	ESP
	Ca	Mg	K	Na					
	…………...cmol (+) kg^{-1}…………….							……..%......	
Tumati irrigation scheme									
TU-Va1	1.65	20.00	1.58	2.23	25.46	0.08	12.66	6.21	18.03
TU-Va2	2.20	7.50	0.59	0.88	11.17	0.29	12.71	5.28	6.21
TU-Va3	2.74	9.50	7.93	1.84	22.01	0.29	1.20	36.03	17.82
Dongobesh irrigation scheme									
DO-Pi1	0.55	16.00	0.77	2.04	19.36	0.03	20.78	3.98	23.81
DO-Va1	1.65	20.00	1.58	2.23	25.46	0.08	12.66	6.21	15.17
DO-Va2	0.55	12.00	1.03	1.61	15.19	0.05	11.65	6.78	17.02
DO-Va3	1.65	7.80	0.74	0.78	10.97	0.21	10.54	6.75	5.88
Mangisa irrigation scheme									
MAN-Va1	2.20	20.00	2.39	1.94	26.53	0.11	8.37	9.01	23.75
MAN-Va2	2.20	7.50	0.59	0.88	11.17	0.29	12.71	5.28	5.17
MAN-Va3	2.20	4.50	1.59	0.60	8.89	0.49	2.83	17.89	10.91
Diyomat irrigation scheme									
DIY-Va1	0.55	23.00	1.56	4.53	29.64	0.02	14.74	5.26	54.88
DIY-Va2	1.10	10.00	0.73	1.28	13.11	0.11	13.70	5.57	11.50
DIY-H1	0.55	5.10	2.49	0.59	8.73	0.11	2.05	28.52	4.41
Harsha irrigation scheme									
HAR-Va1	1.65	19.00	4.41	1.59	26.65	0.09	4.31	16.55	24.62
HAR-Va2	1.65	5.10	0.19	1.58	8.52	0.32	26.84	2.23	19.39
HAR-H1	2.20	9.00	2.59	1.69	15.48	0.24	3.47	16.73	13.88
HAR-Pi1	3.24	9.00	2.56	0.82	15.62	0.36	3.52	16.39	4.26
HAR-Pi2	2.20	7.30	0.63	1.20	11.33	0.30	11.59	5.56	23.30
HAR-Pi3	1.10	22.00	2.38	2.99	28.47	0.05	9.24	8.36	44.12
Guwangw irrigation scheme									
Gu-Va1	2.20	5.50	0.81	0.41	8.92	0.40	6.79	9.08	2.09
Gu-Va2	2.20	8.90	1.53	1.05	13.68	0.25	5.82	11.18	6.41
Gu-H2	2.20	8.80	0.91	1.28	13.19	0.25	9.67	6.90	8.58

TU=Tumati; DO=Dongobesh; MAN=Mangisa; DIY=Diyomat; HAR=Harsha; Gu=Guwangw; Va=Valley; Hi=Hilland; Pi=Piedmont; Ca=Calcium; Mg=Magnesium; K=Potassium; Na=Sodium; TEB=Total exchangeable bases; ESP=Exchangeable sodium percentage

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.

Exchangeable sodium or exchangeable sodium percentage (ESP)

The exchangeable Na range from 0.6 - 4.5 cmol (+) kg^{-1} soil corresponding to ESP values ranging from 2.1 - 54.9% (Tables 1, 2). The critical values of ESP above which most crops are affected are established at 15 (Lebron et al., 2002). Fifty percent of the sites had Na levels below the recommended threshold levels (Table 2, 3, 4). The medium to very high Na or slightly sodic to extremely sodic status observed in these sites 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 (Table 3, 4). Higher Na^+ levels in the soil is associated with decline in net photosynthesis; energy losses for salt exclusion mechanisms; greater decrease in mineral elements uptake; poor NO_3^- assimilation required for plant growth; inhibition of vital enzymes and competition with K^+ (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 or gypsum to reduce

Table 3. Soil fertility status legend for the selected schemes of Mbulu district.

Soil fertility Unit symbol	Land form characteristics	S %	Soil fertility description							
			N	P	K	Ca	Mg	%OC	CEC	ESP
HARSHA IRRIGATION SCHEME										
HAR-Va1	Almost flat	<1	Low	Low	Very high	Very low	Very high	Low	Low	Strongly sodic
HAR-Va2	Almost flat	<1	Low	Low	Low	Very low	High	Low	Low	Strongly sodic
HAR-H1	Gently sloping	<3	Low	Low	Very high	Low	Very high	Low	Medium	Moderately sodic
HAR-Pi1	Slightly sloping	<2	Medium	Low	Very high	Low	Very high	Low	Low	Non sodic
HAR-Pi2	Slightly sloping	<2	Low	Low	Medium	Low	Very high	Low	Low	Strongly sodic
HAR-Pi3	Slightly sloping	<2	Low	Low	Very high	Very low	Very high	Low	Low	Strongly sodic
DIYOMAT IRRIGATION SCHEME										
DIY-Va1	Almost flat	<1	Low	Low	High	Very low	Very high	Low	Low	Extremely sodic
DIY-Va2	Almost flat	<1	Low	High	Medium	Very high	Very high	Medium	Low	Moderately sodic
DIY-H1	Gently sloping	<3	Medium	High	Very high	Very low	High	Medium	Medium	Non sodic
DONGOBESH IRRIGATION SCHEME										
DO-Pi1	Slightly sloping	<2	Low	Low	Medium	Very low	Very high	Very low	Low	Strongly sodic
DO-Va1	Almost flat	<1	Medium	High	High	Very low	Very high	Medium	Medium	Moderately sodic
DO-Va2	Almost flat	<1	Low	Low	Medium	Very low	Very high	Very low	Low	Strongly sodic
DO-Va3	Almost flat	<1	Medium	High	Medium	Very low	Very high	Medium	Medium	**Non sodic**

Classification: According to NSS (1990) guidelines. HAR=Harsha; DIY=Diyomat; DO=Dongobesh; Va=Valley; H=Hilland; Pi=Piedmont; S (%) =Slope percent; N=Total nitrogen; P=Phosphorous; K=Potassium; Ca=Calcium; Mg=Magnesium; OC=Organic carbon; CEC=Cation exchange capacity; ESP=Exchangeable sodium percentage

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) 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).

Cation ratios

The Ca:Mg ratios ranged from 0.02 to 0.49; Mg:K ratio: from 1.2 to 25.5 and K:TEB ratio: from 0.9 to 36% (Table 2). According to the established guidelines, the recommended optimum ratio of Mg:K for most crops is 1 - 4 (Lombin and Fayemi, 1976; NSS, 1990). 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 sugested 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

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

Soil fertility Unit symbol	Land form characteristics	S (%)	Soil fertility description							
			N	P	K	Ca	Mg	%OC	CEC	ESP
UMATI IRRIGATION SCHEME										
TU-Va1	Almost flat	<1	Medium	High	High	Very low	Very high	Medium	Medium	Strongly sodic
TU-Va2	Almost flat	<1	Low	High	Medium	Low	Very high	Medium	Medium	Slightly sodic
TU-Va3	Almost flat	<1	Low	High	Very high	Low	Very high	Very Low	Low	Strongly sodic
MANGISA IRRIGATION SCHEME										
MANG-Va1	Almost flat	<1	Medium	Low	Very high	Low	Very high	Very Low	Low	Strongly sodic
MANG-Va2	Almost flat	<1	Medium	High	Medium	Low	Very high	Low	Medium	Non sodic
MANG-Va3/Hi	Slightly sloping	<2	Low	High	High	Low	High	Very Low	Low	Slightly sodic
GUWANGW IRRIGATION SCHEME										
Gu-Va1	Almost flat	<1	Medium	High	Medium	Low	High	Very high	Medium	Non sodic
Gu-Va2	Almost flat	<1	Medium	High	High	Low	Very high	High	Medium	Slightly sodic
Gu-H2	Gently sloping	<3	Medium	High	Medium	Low	Very high	Medium	Medium	Slightly sodic

Classification: According to NSS (1990) guidelines. S (%) =Slope percent, TU=Tumati; MAN=Mangisa; Gu=Guwangw; Va=Valley; Hi=Hilland

and plants would probably respond to the addition of Ca which was deficient in most sites (Table 2).

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

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