



Research Paper

Status of Fe, Cu, Zn and Mn and their relationship with some physical chemical properties in the soils of Sonjo and Lupiro alluvial/flood plains in Kilombero and Ulanga Districts, Morogoro, Tanzania

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ABSTRACT

A study was conducted in Katurukila and Lupiro proposed irrigation schemes in Kilombero and Ulanga Districts during the end of 2014 in order to assess the status of microelements in soils and their relationship with some selected physical chemical properties. Soil samples in three replicates were collected at a depth of 0 – 30 cm from eight different mapping units in a zigzag pattern. Using sub-sampling techniques, samples were mixed thoroughly, sub-sampled, packed, labeled and analyzed for DTPA extractable Fe, Cu, Zn and Mn at SUA laboratory. There was significant ($P \leq 0.05$) variation in the tested microelements within the mapping units and between the study areas. With the exception of Mn which was in excess amounts, Cu, Zn and Fe were sufficient for optimal crop growth. The DTPA extractable Cu, Zn, Fe and Mn ranged from 0.2 – 8.2, 0.4 – 3.1, 35.0 – 258.7 and 3.6 – 121.6 mg kg⁻¹ respectively. There was more ($P \leq 0.05$) concentration of microelements in Katurukila compared with Lupiro. Strong and positive relationships were found between clay, Cu and Fe ($r = 0.72^{***}$, $r = 0.65^*$) but negatively related with silt and sand ($r = -0.64^*$ and -0.88^{***}) respectively. Additionally, Fe was negatively correlated with pH, K/Na, BS and K/TEB ($r = -0.75$, -0.74^{**} , -0.86^{***} , -0.66^*) respectively in Katurukila and with sand ($r = -0.68^{**}$) in Lupiro. It was similarly concluded that Mn increased in the soils as silt, K/Na and K/TEB increased ($r = 0.84^{***}$, 0.73^{***} and 0.69^*) respectively but decreased as Mg/K ratio ($r = -0.58^*$) increased in Katurukila. Likewise, in Lupiro, Mn increased with increased clay ($r = 0.69^{**}$), OC ($r = 0.63^*$) and TN ($r = 0.66^{**}$) but decreased with increase ($r = -0.71^{**}$) in sand and Mg/K ($r = -0.58^*$). Increased Mn accumulation in soils had probably toxic effects on plant growth and development. Overall, these results suggests that in locations where microelements were excessive and therefore toxic to plant growth, measures to reverse the trend should be included in the fertilizer management program in the study areas.

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INTRODUCTION

Micronutrients are mineral elements required by plants and other organisms in small quantities to orchestrate a range of physiological functions (White and Brown, 2010;

Govindaraj et al., 2011; White et al., 2012). They are mostly of high density (usually $> 5.0 \text{ mg m}^{-3}$) and belong largely to the group of “transition elements” of the periodic table.

Microelements such as Fe, Cu, Zn and Mn play a major role in plant growth and development. Zn is a structural component of several enzymes or is required for enzyme activation (Cakmak et al., 1997; Das et al., 2005; Pandey et al., 2006; Fang et al., 2008). Fe is essential for chlorophyll development and function, energy transfer within the plant, a constituent of certain enzymes and proteins, functions in plant respiration, plant metabolism and N₂-fixation. Cu is necessary for carbohydrate and N metabolism, a cofactor in enzymes involved in both respiration and photosynthesis, lignin synthesis needed for cell wall strength and prevention of wilting (O'Halloran and Culotta, 2000; Rosenzweig et al., 2002), promotes seed production and formation, plays an essential role in chlorophyll formation and proper enzyme activity. Manganese (Mn) plays an important role in oxidation and reduction processes, electron transport in photosynthesis, as an activator of more than 35 different enzymes which are involved in oxidation reactions. Mn is also a structural component of the Photosystem II water splitting protein, carboxylation, carbohydrates metabolism, P reactions and citric acid cycle (Uehara et al., 1974; Jackson et al., 1978; Mukhopadhyay and Sharma, 1991; Diedrick, 2010; Millaleo et al., 2010), chlorophyll production, electron storage and delivery to the chlorophyll reaction centers; involved in cell division and plant growth, lipids metabolism, and nitrate reduction enzymes (Ness and Woolhouse, 1980; Mukhopadhyay and Sharma, 1991; Marschner, 1995; Anderson and Pylotis, 1996; Millaleo et al., 2010).

Generally, shortage in any one of these microelements restricts plant growth and reduces crop yields (Bowen et al., 2010; White et al., 2012; Arunachalam et al., 2013) suggesting that their bioavailability and uptake by plants is essential for crop production (White and Broadley, 2009; White et al., 2012; Makoi et al., 2013). Zn deficiency for example, has been reported in many studies and is one of the widest ranging abiotic stresses in agriculture. FAO recorded Zn deficiency in 50 % of the soil samples collected from 25 countries (Graham, 1991). Studies by Kitundu and Mrema (2006) showed that available or extractable quantities of Zn and Cu were reported as low in almost all soil samples tested ranging from 0.08 to 0.93 mg Zn kg⁻¹ and 0.04 to 0.34 mg Cu kg⁻¹ soil. Depending on the extraction method, available or extractable quantities of Zn were reported as low compared with the quantities in soils (Lindsay and Novell, 1978; Kabata-Pendias and Pendias, 1984). In Mbeya and Morogoro Regions, extractable Zn has been reported to be as low as 0.2 mg kg⁻¹ (Kamasho, 1980; Msanya et al., 2001). However, micronutrient problems are expected to increase in the future because of the increase in cropping intensity, the use of high-yielding varieties and the more extensive use of micronutrient-free high analysis N, P and K fertilizers. A great effort should therefore be made to conduct systematic micronutrient investigation in the areas, particularly in soils of Sonjo and Lupiro proposed irrigation schemes (Sakal et al., 1988; Dhane and Shukla,

1995).

Kilombero and Ulanga are some of the major food and cash crops producing districts in Morogoro, Tanzania supplying most of the cereal grain in the region. Kilombero district for which the Sonjo/Katurukila irrigation scheme is proposed is situated in a vast alluvia/floodplain landscape, between the Kilombero River in the south-east and the Udzungwa - Mountains in the north-west. On the other side of the Kilombero River, in the south-east, the floodplain is part of Ulanga District where Lupiro irrigation scheme is proposed. Sonjo and Lupiro are proposed for irrigation development where crops such as rice (*Oryza sativa* L), maize (*Zea mays* L), sugarcane (*Saccharum officinarum* L) and pineapples (*Ananas comosus* L) will be cultivated. Normally, irrigation development is an expensive undertaking and needs careful planning and soil physical-chemical characterization studies for appropriate soil fertility management.

Management of plant nutrients is largely governed by their status in the soil. Previous studies have indicated that decline in soil fertility including microelements in southern Tanzania is the major form of land degradation (Kamasho, 1980; BACAS, 1996; Mwamfupe, 1998). The drive towards self-sufficiency in food and cash crop production through irrigation development and the adoption of Good Agricultural Practices (GAP) has necessitated the assessment of the nutrient status of soils; particularly the micronutrients which had hitherto been neglected (Mustapha, 2003). In order to meet the envisaged crop yield targets after irrigation development, reliable information on the status of microelements in soils of the proposed study areas is required for future and appropriate soil fertility management. Some studies have also shown that in some parts of Europe and Asia, application of micronutrient fertilizer lead to increased crop yields and quality (Aro et al., 1995; Cakmak et al., 1996; Cakmak, 2002; Nubé and Voortman, 2008). Currently, there is very scanty or no information or literature on the status of soil microelements in the proposed irrigation schemes in Sonjo/Katurukila and Lupiro in Kilombero floodplains. This study was therefore conducted to assess the status of Fe, Cu, Zn and Mn in Sonjo/Katurukila and Lupiro in different geofoms to forecast potential micronutrient problems in order to evaluate fertility status of different soil in Sonjo/Katurukila and Lupiro plains.

MATERIALS AND METHODS

Description of the study area

Sonjo/Katurukila

The proposed Sonjo/Katurukila irrigation project is located 55 km North of Ifakara township along Ifakara - Mikumi road, approximately between latitudes 36°50'E to 37°00'E

and Longitudes 7°45'S and 7°50'S. Topographically, the Sonjo basin is bounded by Udzungwa mountain ranges on the northern side sloping gently southwards drained to Kilombero valley. Geomorphologically, the proposed irrigation scheme falls into one landscape, that is, the alluvia/flood Plain. These are lowland areas east of the Mikumi – Ifakara road whose elevation is slightly below 300 m contour. It is essentially a flat area with moderate to imperfectly drainage condition. Most of clearly drainable sections of rivers flow from NW to SE direction and a few flows southerly. The geology of the area can generally be described as having alluvium deposits probably originating from the high plateau. The climatic condition in the study area is bi-modal with 50% of the total rains falling between March through May and about 41% light rains falling between November through February. The total annual rainfall is 1,461.6 mm. The mean temperature varies from 22.4 to 27.8°C throughout the year. The monthly average of relative humidity (RH) varies from 67.8 (i.e. October) to 78.2% (i.e. April). The potential evaporation is about 1,835 mm per annum and varies widely throughout the year from 116.7 – 195.2 mm per month.

Lupiro

The proposed Lupiro irrigation project is situated in Ulanga District, Morogoro Region. The area lies at latitude 8°25'S and longitude 36°40'E and at an average altitude of 297 m above mean sea level. Lupiro scheme is located on a flood plain drained by Luli River and its seasonal tributaries which run generally in a south – north direction through the project area where a lot of depositions have been occurring periodically in wet season. The deposits originate from Ndororo Mountains in the south where crystalline limestone rock group dominates and hornblende garnet gneiss is the dominant primary mineral (IFAKARA, QDS 235).

Lupiro area has a bi-modal rainfall distribution, characterized by short and long rain periods. On average, it receives an annual rainfall of about 1,300 mm. The short rainy season occurs during October-December and long season between March and May. The dry spell is predominantly between July and October. The project area is located in a zone of potential evaporation varying between 800 - 1,200 mm yr⁻¹. Average temperature ranges from 22 to 28°C. Winds normally blow from the South-East and North-East directions with annual average of 154 km day⁻¹.

Soil sampling and handling

Fieldwork was carried by selecting transects that went across the previously identified mapping or geomorphic units and soils. Representative composite samples were

collected from a depth of 0 – 30 cm in three replicates from 8 representative soil profiles locations (KA-Pa1, KA-Pa2, KA-Pa3 and KA-Pa4) in Katurukila and (LUP1, LUP2, LUP3 and LUP4) in Lupiro making a total of 24 samples. Each soil sample was a composite of five sub-samples collected in a zigzag pattern within a radius of 20 m from the centre of the soil profile. The collected soil samples were stored in properly labelled polythene bags, taken to the laboratory and used in the analysis of micronutrients. In the laboratory, each sample was separately dried in air, ground using a porcelain pestle and mortar and passed through a 2 mm sieve.

Laboratory analyses

Soil physicochemical properties were analysed following standard procedures outlined by Moberg (2000). Diethylene triamine pentaacetic acid (DTPA) extractable micronutrients Fe, Cu, Zn and Mn were determined using the method by Lindsay and Norvell (1978) and their concentrations in the DTPA extracts were determined by Atomic Absorption Spectrophotometer (AAS). Particle size distribution was determined by the hydrometer method after dispersing in sodium hexametaphosphate solution (Bouyoucos, 1951). The soil pH was determined in 1:1 soil/water suspension using a glass electrode pH meter while organic carbon in the soil was determined by the wet combustion method of Walkley and Black (1934). Cation exchange capacity was estimated using the NH₄OAc saturation (pH 7) method, while the leachate was used to determine the exchangeable bases.

Statistical analysis

Data on soils' physicochemical properties were organised using Microsoft Excel. One-way ANOVA was used to compare mapping units/geomorphic units and individual micronutrients. The analysis was performed using the STATISTICA software of 2015 version (StatSoft Inc., Tulsa, OK, USA). Fisher's least significant difference (LSD) was used to compare microelements means at $P \leq 0.05$ level of significance (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Soil textural classes

The data on the physico-chemical properties of the soils studied are presented in Table 1. Tables 2 and 3 showed significant ($P \leq .05$) variation in soil particle distribution between the mapping units in Katurukila and Lupiro study areas. In Katurukila, KA-Pa3 had the lowest ($P \leq .05$) clay compared with the other mapping units (Table 2).

Table 1. Soil fertility data for Katurukila and Lupiro study areas (0 – 20 cm).

Sample No.	Texture	pH (H ₂ O)	EC (mS.cm ⁻¹)	OC	OM	TN	C/N	Pav (mg.kg ⁻¹)	CEC (cmol (+). kg ⁻¹)	EB				BS (%)	ESP (%)
										Ca	Mg	K	Na		
				(g.kg ⁻¹)				(cmol (+).kg ⁻¹)							
Katurukila															
KA - Pa1	SCL	5.0	0.05	16.9	29.1	0.5	34	12.2	9.0	1.18	0.92	0.05	0.23	26	2.6
KA - Pa2	SCL	4.8	0.09	6.9	11.9	0.5	14	11.9	9.0	1.47	1.00	0.11	0.12	31	1.3
KA - Pa3	C	5.0	0.11	18.5	31.8	1.3	14	6.7	22.0	3.98	3.72	0.11	0.21	37	1.0
KA - Pa4	SCL	5.8	0.02	16.7	28.7	0.9	19	42.5	11.8	2.20	3.58	0.20	0.24	53	2.0
Lupiro															
LUP1	S	6.2	0.03	5.0	8.7	0.4	12	20.2	11.3	0.80	0.70	0.11	0.14	15	1.2
LUP2	S	5.9	0.02	2.8	4.8	0.3	9	33.3	10.7	0.70	0.40	0.05	0.15	13	1.4
LUP3	S	6.1	0.05	11.2	20.4	0.7	17	15.9	11.6	2.20	1.41	0.10	0.14	35	1.2
LUP4	S	5.3	0.03	6.2	10.7	0.4	15	1.3	9.8	0.70	0.28	0.06	0.15	12	1.5

Note: EC = Electrical conductivity; OC = Organic carbon; OM = Organic matter; TN = Total Nitrogen; P = Phosphorus; C/N = Carbon to Nitrogen ratio; EB = Exchangeable bases; CEC = Cation exchange capacity; BS = Base saturation (BS(%) = (TEB/CEC)*100); ESP = Exchangeable sodium percentage; Ca = Calcium; Mg = Magnesium; K = Potassium; Na = Sodium; SCL = Sand Clay loam; CL = Clay loam; SL = Sandy loam; C = Clay.

Table 2. Status of micronutrient concentration in selected mapping units of Katurukila.

MU	Soil textural class (%)			Topsoil DTPA extractable micronutrients (mg.kg ⁻¹)			
	Clay	Silt	Sand	Cu	Zn	Fe	Mn
KA-Pa1	29.1±0.6 ^a	10.6±0.6 ^a	60.2±1.2 ^c	5.8±1.5 ^a	2.9±0.4 ^a	223.7±8.3 ^a	70.6±6.7 ^a
KA-Pa2	29.1±2.9 ^a	7.6±1.2 ^b	63.2±4.0 ^{bc}	8.2±0.8 ^a	2.6±0.4 ^a	236.8±24.7 ^a	32.2±2.8 ^b
KA-Pa3	16.1±1.2 ^b	11.6±1.2 ^a	72.2±2.3 ^a	2.3±0.1 ^b	3.1±0.1 ^a	64.7±1.3 ^b	88.6±1.7 ^a
KA-Pa4	24.1±0.0 ^a	6.6±0.6 ^b	69.2±0.6 ^{ab}	5.3±0.9 ^{ab}	1.6±0.2 ^b	149.5±72.9 ^{ab}	26.2±9.6 ^b
F-statistics							
Rep	15.1 ^{**}	6.8 [*]	5.1 [*]	6.9 [*]	5.2 [*]	4.2 [*]	24.6 ^{***}

*: significant at $P = 0.05$; **: significant at $P = 0.01$; ***: significant at $P = 0.001$. Values followed by dissimilar letters in the same column for each treatment are significantly different from each other at $P = 0.05$ according to Fischer LSD. (LSD: Least significance difference).

Table 3. Status of micronutrient concentration in selected mapping units of Lupiro.

MU	Soil textural class (%)			Topsoil DTPA extractable micronutrients (mg.kg ⁻¹)			
	Clay	Silt	Sand	Cu	Zn	Fe	Mn
LUP1	4.1±0.0 ^c	5.6±2.3 ^a	90.2±2.3 ^a	0.2±0.0 ^b	0.4±0.0 ^b	35.0±14.4 ^b	3.6±1.4 ^b
LUP2	4.1±0.0 ^c	3.6±1.2 ^a	92.2±1.2 ^a	0.2±0.0 ^b	0.6±0.0 ^b	64.7±15.2 ^b	10.1±2.6 ^b
LUP3	14.1±5.8 ^b	4.6±0.6 ^a	81.2±5.2 ^a	0.8±0.3 ^b	1.5±0.5 ^a	108.5±7.6 ^b	162.8±8.3 ^a
LUP4	25.1±0.6 ^a	5.6±1.2 ^a	69.2±1.7 ^b	2.2±0.6 ^a	1.5±0.3 ^a	258.7±81.7 ^a	121.6±58.5 ^a
F-statistics							
Rep	12.4 ^{***}	1.0 ^{ns}	13.0 ^{***}	8.1 ^{**}	5.0 [*]	6.0 [*]	8.1 ^{**}

*: significant at $P = .05$; **: significant at $P = .01$; ***: significant at $P = .001$; ns = non-significant. Values followed by dissimilar letters in the same column for each treatment are significantly different from each other at $P = .05$ according to Fischer LSD. (LSD: Least significance difference).

However, KA-Pa3 recorded greater ($P \leq .05$) silt similar to KA-Pa1 and sand compared with the rest of the mapping units. Results showed that the top soil textural class was dominated by sand clay loam (SCL) followed by sandy loam (SL). In Lupiro, LUP4 had the highest ($P \leq .05$) clay compared with the other mapping units (Table 3). However, LUP4 had lowest ($P \leq 0.05$) sand material compared with the rest of the mapping units. No difference was observed in silt distribution amongst the mapping units. Results showed that the top soil textural class was dominated by sand (S) > sandy loam (SL) > sand clay loam (SCL) textures. Generally, there was more ($P \leq 0.05$) Clay and Silt in Katurukila compared with Lupiro study areas. However, there were more sand in Lupiro compared with Sonjo/Katurukila. The observed differences in textural classes in Sonjo/Katurukila compared with Lupiro were ascribed to differences in topography or landscape and the parent material.

Copper (Cu) status

The status of selected microelements in Sonjo/Katurukila and Lupiro study areas are presented in Tables 2, 3 and 4. The data showed that in Katurukila, Cu range from 2.3 to 8.2 mg kg⁻¹ whereas in Lupiro they range from 0.2 to 2.2 mg kg⁻¹. Similarly, results showed that there was significant ($P \leq 0.05$) Cu variation between the mapping units (Table 1) and between the proposed irrigation schemes (Table 3). For example in KA-Pa3, Cu was significantly ($P \leq 0.05$) lower compared with KA-Pa1 and KA-Pa2 but was rated as sufficient. For DTPA-extractable soil Cu, 0.2 mg kg⁻¹ has been considered as the limit below which plants are likely to suffer from Cu deficiency (Viets and Lindsay, 1973; Lindsay and Norvell, 1978; Esu, 1991). These results suggest that the observed Cu in the tested soils were sufficient for optimal crop growth. Some studies have shown that the normal Cu content of agricultural soils is 5 to 50 mg kg⁻¹ and Cu concentrations below 8 mg kg⁻¹ could indicate a deficiency for some crops (McBride, 1994; Kabata-Pendias and Pendias, 2001). However, excess Cu accumulation in soils needs to be monitored as they can be

toxic to plant growth and development. Several studies have shown that in sandy acidic soil, Cu concentrations at >100 mg kg⁻¹ caused phytotoxicity to citrus plants and subsequently decreased their productivity and reduced microbial biomass and diversity in these soils (Alva, 1993; Zhou et al., 2011). In Lupiro however, although results show that there are sufficient Cu in soils, in LUP1 and LUP2 these amounts were just on the borderline, i.e. 0.2 mg kg⁻¹, indicating that there is greater likelihood of dropping below the critical limits. These suggest that management of Cu in soils of Lupiro is necessary compared with Katurukila in order to maintain Cu in soils for plant growth benefits.

Results also show that in Katurukila, there was significant ($P \leq .05$) correlation between percent clay, silt content, pH and Cu in soils (Table 4). Cu was positively correlated with ($r = 0.72^{***}$) clay compared with silt and sand which were negatively ($P \leq 0.05$) correlated with $r = -0.64^*$ and -0.88^{***} respectively just as reported by Perveen et al. (1993) and Chhabra et al. (1996). In Lupiro, Cu was positively correlated with clay content ($r = 0.85^{***}$) but negatively correlated with sand ($r = -0.80^{***}$) at ($P \leq 0.05$). These results suggests that soil properties such as texture and pH has great influence on the Cu released for plant use in the soils of the study areas (Gupt and Aten, 1993; Verma et al., 2005; Vangheluwe et al., 2005; Herselman, 2007; Pati and Mukhopadhyay, 2010; Bassirani et al., 2011).

Zinc (Zn) status

Zinc status in Katurukila and Lupiro study areas are presented in Tables 2, 3 and 4. Zinc contents in the soils ranged from 1.6 - 3.1 mg kg⁻¹ in Katurukila and 0.4 - 1.5 mg kg⁻¹ in Lupiro and were rated as moderate. From these results, Zn was ($P \leq 0.05$) different between the mapping units within the study areas and between the proposed irrigation schemes. The data also indicated significantly ($P \leq 0.05$) greater available Zn in Katurukila compared with Lupiro (Table 5). The proposed deficiency level for Zn (DTPA) in most agricultural soils was pegged between 0.4 - 1.0 mg kg⁻¹ (Silanpaa, 1982; Lindsay and Novell, 1978) and values greater than 10 - 20 mg kg⁻¹ were regarded as excess

Table 4. Correlation (r) of microelements to physical and chemical properties in Katurukila and Lupiro proposed irrigation schemes, Morogoro, Tanzania.

S/N	Micronutrients	Clay	Silt	Sand	pH	OC	TN	K/Na	BS	K/TEB	Mg/K
A Katurukila											
1	Cu	0.72**	-0.64*		-0.88***						
2	Fe	0.65*			-0.75**			-0.74**	-0.86***	-0.66*	
3	Mn		0.84***					0.73***		0.69*	-0.58*
B Lupiro											
1	Cu	0.85***		-0.80***							
2	Fe	0.74**		-0.68**							
3	Mn	0.69**		-0.71**		0.63*	0.66**				

*: significant at $P = .05$; **: significant at $P = .01$; ***: significant at $P = .001$. Zn is not shown since it was not significant in both study sites.

Table 5. Comparison of the status of micronutrient concentration in selected mapping units of Katurukila and Lupiro proposed irrigation schemes.

Scheme	Soil textural class (%)			Topsoil DTPA extractable micronutrients (mg.kg ⁻¹)			
	Clay	Silt	Sand	Cu	Zn	Fe	Mn
Katurukila	24.6±1.7 ^a	9.1±0.7 ^a	66.2±1.8 ^b	5.4±0.8 ^a	2.5±0.2 ^a	168.7±26.5 ^a	54.4±8.3 ^a
Lupiro	6.9±1.8 ^b	4.1±0.7 ^b	89.0±1.9 ^a	0.4±0.1 ^b	0.7±0.2 ^b	61.1±10.5 ^b	46.1±20.4 ^a
F-statistics							
Rep	51.1***	25.4***	78.7***	43.8***	39.9***	14.3**	0.1ns

*: significant at $P = .05$; ***: significant at $P = .001$; ns = non-significant. Values followed by dissimilar letters in the same column for each treatment are significantly different from each other at $P = .05$ according to Fischer LSD. (LSD: Least significance difference).

(Silanpaa, 1982). Based on these critical values, available Zn levels in all the MUs in Katurukila and Lupiro were considered as adequate for plant growth and development.

Iron (Fe) status

Tables 2, 3 and 4 show that Fe in Katurukila studied soils ranged from 64.7 to 236.8 mg kg⁻¹ and 35.0 to 258.7 in Lupiro. In Katurukila, these values were (P

$\leq .05$) lowest in KA-Pa3 compared with the soils in the rest of the MU tested which had significantly ($P \leq 0.05$) greater amount of Fe. In Lupiro study area, Fe concentration was ($P \leq 0.05$) greater in LUP4 compared with the rest of the MUs. Comparatively, Katurukila had ($P \leq 0.05$) greater amount of Fe compared with Lupiro. These values are much higher than the critical values of between 0.3 to 10 mg kg⁻¹ reported by Lindsay and Cox (1985) and Mustapha and Singh (2003). The results suggest that it is unlikely that Fe deficiency is experienced

in the study areas as Fe levels were above the proposed critical levels and hence adequate for crops grown in the study areas. Nevertheless, Fe toxicity or deficiency could occur at low and high pH, respectively.

This is true especially when viewed against the report (Chen and Barak, 1982; Sakal et al., 1984; Mengel and Geurtzen, 1986) that Fe deficiency is unlikely in acid soils; as Fe is known to be soluble under relatively acidic and reducing conditions (Chesworth, 1991). The presence of high

concentrations of Fe in soils could lead to its precipitation and accumulations and upon complex chemical reactions, lead to the formation of laterite. This, upon alternate wetting and drying, could irreversibly form hard indurated material called ironstone (petroplinthite) which would restrict rooting depth and drainage, amongst others. These suggest that monitoring of Fe accumulation in the study areas by relevant authorities should be carried out as part of fertilizer management program.

The data also showed significant ($P \leq 0.05$) correlation between Fe and pH, Clay, K/Na, BS and K/TEB (Table 5). In Katurukila, Fe was positively correlated with Clay ($r = 0.65^*$) but negatively correlated with pH, K/Na, BS and K/TEB ($r = -0.75, -0.74^{**}, -0.86^{***}, -0.66^*$) respectively (Table 5). Although similar trend for Fe with Clay was observed ($r = 0.74^{**}$) in Lupiro, it was however not so for pH and other soil properties but instead it was only negatively correlated with sand ($r = -0.68^{**}$) just as reported in Chhabra et al. (1996). These results indicate that Fe increased with clay contents but decreased with sand, pH, K/Na, BS and K/TEB.

Manganese (Mn) status

Available Mn in the areas studied in Sonjo/Katurukila ranged from 26.2 to 88.6 mg kg⁻¹ (Table 2) and from 3.6 to 162.8 mg kg⁻¹ in Lupiro (Table 3). These values were rated as high to excess. Within the MUs in Katurukila, available Mn was significantly ($P \leq 0.05$) different with KA-Pa1 and KA-Pa3 having ($P \leq 0.05$) greater Mn compared with KA-Pa2 and KA-Pa4. Similarly, available Mn in LUP3 and LUP4 were ($P \leq 0.05$) greater compared with LUP1 and LUP2. The data also showed significantly ($P < 0.05$) higher available Mn in Katurukila compared with Lupiro. The proposed deficiency level for Mn (DTPA) in the soil varied from 1.0 - 5.0 mg kg⁻¹ with values > 140 - 200 mg kg⁻¹ regarded as excess (Lindsay and Norvell, 1978; Silanpaa, 1982; Esu, 1991). In this study, one LUP mapping unit had excessive Mn (i.e. 162.8 mg kg⁻¹) that could lead to toxicity in crops grown in the study area. The high content of available Mn in the soils of Katurukila and Lupiro may be related to the acidic nature of the soils. It has been reported (Sillanpaa, 1982) that above soil pH of 7.5, the availability of Mn is very low because of the formation of hydroxides and carbonates.

Significant ($P \leq 0.05$) correlation between Mn and silt, pH, K/TEB, K/Na and Mg/K in Katurukila and Clay, Sand, OC, TN in Lupiro are presented in Table 5. In Katurukila, Mn was positively correlated with Silt, K/Na and K/TEB with $r = 0.84^{***}, 0.73^{***}$ and 0.69^* respectively but negatively correlated with Mg/K ($r = -0.58^*$). In Lupiro, Mn was positively correlated with Clay ($r = 0.69^{**}$), Organic Carbon ($r = 0.63^*$) and Total Nitrogen ($r = 0.66^{**}$). However, Mn was negatively correlated ($r = -0.71^{**}$) with Sand. These results indicate that Mn increased with silt contents, K/Na and K/TEB but decreased with sand.

Conclusions

The survey of soils of 4 MUs in Katurukila and 4 MUs in Lupiro proposed irrigation schemes showed important variations in soil microelements. The results suggested that there was significant variation in microelements within the MUs and between the study areas. It was concluded that the observed Cu, Zn and Fe in the tested soils were sufficient for optimal crop growth. However, Mn rated as excessive amounts which may lead to toxicity in crops grown in the study area. The excessive content of available Mn in the soils of the study areas may be related to the acidic nature of the soils. It was also concluded that Cu and Fe were positively correlated with clay and negatively correlated with silt and sand in the study areas. Additionally, Fe was negatively correlated with pH, K/Na, BS and K/TEB in Katurukila, These results indicate that Cu and Fe increased with clay contents but generally decreased with increased sand, pH, K/Na, BS and K/TEB in the study areas. It was similarly concluded that Mn increased in the soils as silt, K/Na and K/TEB increased but decreased as Mg/K ratio increased in Katurukila. Likewise, in Lupiro, Mn increased with increased clay, OC, TN and decreased with increase in sand. Overall, these results suggests that in locations where microelements were found to be excessive and therefore toxic to plant growth, measures to correct the problem should be undertaken.

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