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ASSESMENT OF SOIL FERTILITY STATUS OF SELECTED RICE GROWING AREAS IN KILOMBERO DISTRICT - MOROGORO, TANZANIA

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ABSTRACT
Soil fertility is an important factor in enhancing crop productivity. The study is aimed at assessing the soil fertility status in selected rice growing areas in Kilombero district and understand fertility variability among soils selected. Composite soil samples were collected in these rice growing areas at 0–20 cm deep and characterized for soil fertility status. This was done by analyzing twenty soil samples from rice growing villages of Kilombero district, whereby 20 soil samples were taken from 20 rice growing villages. The soil analysis included determination of total N, OC, P, soil pH, textural classes, exchangeable bases and micronutrients (ZN, Cu, Mn and Fe). The results showed that the soils surveyed are slightly to moderately acidic (pH 5.2 to 6.2). Results indicated that 80% of the soils were sand, 15% clay and the remaining 5% had loamy textural classes. Organic carbon ranged from very low to medium (0.40-2.53%), total N (0.11-0.32%). Also, results indicated that 50% of soils had P deficiency and 100% had inadequate S levels. In addition, 90% of the soils had inadequate exchangeable K and exchangeable Mg levels ranged from very low to medium (0.10-2.24 cmol(+) kg-1). Soils indicate to had 95% very low Exchangeable Ca with low base saturation. The CEC ranged from low to medium (7.0-21.60 cmol(+) kg-1). Extractable micronutrients such as Fe and Mn were adequate but Zn and Cu were inadequate in 35% and 10% of the soils, respectively. Results indicated that N, P, K, Ca and Zn were generally the limiting nutrients of which S and Na were limiting in all selected soil. Generally, the categorization of nutrient status indicated poor fertility in the studied soils. The results of the study area show deficient levels, however, there were variations in nutrient deficiencies in selected soils.

Keywords: Macronutrients; micronutrients; exchangeable bases; soil fertility; soil fertility categories.

1. INTRODUCTION
Decline in soil fertility due to none use of fertilizers to replenish nutrients taken by crop led to low yields in rice growing areas in Tanzania. Poor soil fertility is the major soil related constraint in rice production. Soil fertility is imperious in enhancing crop productivity including rice

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production. The most limiting nutrients are nitrogen (N), phosphorus (P) and zinc (Zn). However, in some soils, sulphur (S) and potassium (K) deficiencies also occur in Tanzania (Semoka, J.M.R.: personal communication, 2013). The deficiencies of N, P, K and Zn were reported in eastern Same district where rice has been cultivated for over 100 years (Amur and Semu, 2006). Zinc deficiency was reported in Igunga and Nzega districts in Tabora region (Semoka et al., 1996; Msolla, 1991). Sulphur deficiency has been reported in some rice fields in Kilombero valley in Tanzania (Massawe and Amuri, 2013). This trend of nutrient deficiencies in rice cropping systems requires effective sources of fertilizers to supply the respective nutrients. In Tanzania, rice is the second most important cereal crop after maize and the majority of rice farmers depend on it both for food and cash (Boniface, 2012). It is a major source of income, food and employment across the country, and particularly rural areas (Joachim, 2018). Small scale rice farming is characterized by many small holder farmers, cultivating small farms (0.5 to 10 acres), whereby rain fed accounts for 71% and traditional irrigation accounts for 29% of rice grown in Tanzania (RLDC, 2011). These small-scale farmers use no or low inputs. The national average rice yield is as low as 1 t ha-1 (Mghase, 2010), this is due to Rice is grown under three major ecosystems namely: rain-fed lowland (70%), upland ecosystem (20%) and irrigated ecosystem (10%) (Kibanda, 2008). The low paddy production and grain yield obtained by smallholder farmers is due to low soil fertility which is attributed to nutrients mining that induce deficiencies of macro-and micro-nutrients in the soil, among other several constraints. Thus, replenishing deficient nutrients in the soil is necessary if increased rice production is to be realized. Most acid tropical soils are inherently low in P which renders them unproductive. In situations where K, S, and Zn deficiencies occur, the application of P alone at planting/transplanting will not suffice.

2. MATERIAL AND METHODS

2.1 Description of study area

The study was conducted in Kilombero District, a major rice producing valley. Most part of the Kilombero district lies along the Kilombero valley which is part of Rufiji Basin. Kilombero valley extends from east to southwest from below the Udzungwa Mountain. The climate of Kilombero is considered tropical sub humid, with annual rainfall between 1200 to 1400 mm falling between Dec and June. The valley has a bimodal rainfall, short rains fall in November to January and long rains start in March to June (URT, 2008). The annual average temperature in Kilombero ranges between 26°C and 32°C in November.

2.2 Reconnaissance survey and soil sampling for general fertility status

A transect walk reconnaissance survey was conducted in the Kilombero valley from NE starting from Mkula to SW of the valley up to Njage. The survey selectively covered the major rice growing areas in villages of the valley, both under traditional irrigation schemes or with potential irrigation and under rain fed condition. Twenty selected major growing areas for rice production in Kilombero District, were Mkula mtunga, Mkula gaza Magombera mtendezi, Magombra kimbyoko, Mang'ula A, Mang'ula B, Njage A,Njage B, Michenga A, Michenga B, Mbasa vijana 1,Mbasa vijana 2, Mbasa kapolo 1, Mbasa kapolo 2, Mbasa kasikana, Mbasa viwanja 70, Signale A, Signale 2 and Kisawasawa A and Kisawasaw 2 villages, were surveyed and soil samples for testing the soil fertility status were collected. Geographical coordinates of villages sites studied were collected using Global Position System (GPS) (Garmin Trex legend HCx, 2007) and are shown in Appendix 1.

2.3 Soil sampling and sample preparation for general fertility status

Twenty composite soil samples were collected at 0-20 cm depth (optimum rooting depth for rice plants) from representative rice growing sites from rice growing villages surveyed. In each site, ten soil sub-samples obtained randomly from a representative 0.5 ha field of a relatively uniform soil. The soil subsamples from each site were then mixed thoroughly to constitute one composite sample. The composite samples were transported to SUA, air- dried ground to pass through a 2-mm sieve for laboratory analysis.

2.4 Soil analysis

The composite soil samples were analyzed for the following important physical and chemical properties of soil: Soil pH was measured in water using a pH meter at the ratio of 1:2.5 soils: water as described by McLean (1982). The CEC of the soil was determined using the ammonium acetate saturation method as described by Chapman (1965). The particle size analysis was determined by the hydrometer method after dispersion with sodium hexametaphosphate as described by Day (1965). Total nitrogen was determined by micro-Kjeldahl digestion-distillation method as described by Bremner and Mulvaney (1982). Available P was extracted by the Bray-1 procedure (Bray and Kurtz, 1945). The organic carbon was determined using Wakley and Black method (Allison, 1965). DTPA extractable micronutrients (Zn, Fe, Mn and Cu) were determined using the procedure by Lindsay and Norvell (1978). Exchangeable bases (Ca2+, Mg2+, Na+, K+) were determined by atomic absorption spectrophotometer (Thomas, 1996). Sulfate-sulfur was determined following a procedure outlined by Moberg (2001).

3. Limiting nutrients in selected rice growing areas

Limiting nutrients for each soil under study were identified after laboratory analysis of soil samples and grouped according to variability and frequencies of their occurrence. Each nutrient parameter was interpreted through rating against published thresholds (e.g., high, medium, low or very low) using the recommended critical values for rating chemical and physical soil parameters. Nutrients with concentrations lower than critical level were considered limiting for crop production. This was done to understand the specific nutrients that are likely to limit rice crop growth and development. Soil fertility categories were established on the basis of limiting nutrients for each village. Villages having the same limiting nutrients were placed in a particular soil fertility category. This was done in order to establish a basis for making specific fertilizer recommendations according to limiting nutrients.

4. Data analysis

The GenStat statistical package was used for analysis of variance (ANOVA) using statistical models as per experimental designs. The treatment means were ranked and separated using Duncan Multiple Range Test at 5 % significance level.

5. RESULTS AND DISCUSSION

5.1 properties in selected rice growing in Kilombero District

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The textural classes of the twenty soil samples tested ranged from coarse textured (sand clay loamy) to moderately fine (loamy) soils (Table 1). According to Landon (1991) medium to heavy textured soils are favourable for rice production because of good water holding capacity and good nutrient supply. Based on these textural classes, 70 % of the soils tested had optimum texture for rice production if other growth factors are not limiting. The villages of Michenga and Mbasa which constitute 30% of the soil samples showed higher percentage sand of >70 (Table 1). The higher percentage sand of > 70% could result in high losses of water and nutrients through leaching. Therefore, recycling of organic materials and compaction of subsoil might be needed to reduce water and nutrients losses.

Table 1. Particle size distribution in selected rice growing areas of Kilombero District

	Particle size distribution and textural classes (%)			
Location/Village name	**Clay**	**Silt**	**Sand**	**Textural Class**
Mkula-Mtunga	27.40	14.20	58.40	*SCL*
Mkula-Gaza	29.40	14.20	56.40	*SCL*
Magombera-Mtendezi	25.40	10.20	64.40	*SCL*
Magombera-Kimbyoko	27.40	10.20	62.40	*SCL*
Mangu’la –A/Mlagayai	23.40	12.20	64.40	SCL
Mangu'la-B (bulk)	23.40	12.20	64.40	*SCL*
Njage A	33.40	26.20	40.40	*CL*
Njage B	33.40	24.20	42.40	*CL*
Michenga A	9.40	10.20	80.40	*SL*
Michenga B	15.40	12.20	72.40	*SL*
Mbasa-Viwanja 70	11.40	10.20	78.40	*SL*
Mbasa-Kapolo 1	23.40	12.20	64.40	*SCL*
Mbasa-Kapolo 2	27.40	20.20	52.40	*SCL*
Mbasa-Kasikana	11.40	12.20	76.40	*SL*
Mbasa Vijana 1	9.40	10.20	80.40	*LS*
Mbasa Vijana 2	11.40	10.20	78.40	*SL*
Kisawawa-A/mikongo	33.40	12.20	54.40	*SCL*
Kisawawa-B	33.40	16.20	50.40	*SCL*
Signale sululu- A	23.40	14.20	62.40	*SCL*
Signale sululu-B	35.40	20.20	44.40	*CL*

Key: SCL = sandy clay loam, SL = sandy loam, LS = loamy sand, CL=clay loamy

5.2 Soil chemical fertility status in selected rice growing areas of Kilombero.

5.2.1 Soil pH

The soil pH ranged from 5.20 to 6.24 (Table 2), which are grouped as low to medium pH according to Landon (1991). This pH range is categorized as slight to medium acidic (Landon, 1991). Van Breeman (1980) reported that the pH range of 4.5 to 6.5 is satisfactory for rice production. Therefore, the results showed that 100% of the selected rice growing villages in Kilombero district is suitable for rice production under flooded conditions

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5.3 Organic carbon

The organic carbon obtained in the soils tested ranged from 0.40% to 2.53% (Table 2). These values are rated as very low to medium, according to Baize (1993), where <0.60 % as very low, 0.6 to 1.25 % as low, 1.26 to 2.50 % as medium, 2.51 to 3.50 % as high and >3.50 % as very high. The results showed that 60 % of soils studied had medium, 25 % had low and 15% had very low OC content. These levels are similar to those obtained in selected soils for rice in Same district (Amuri, 2003). Also, other studies done in some selected paddy growing areas of Morogoro, Tabora, Coast and Mbeya regions showed low C content (Semoka et al., 1996; Msolla, 1991; Shekifu, 1999; Mzee, 2002). The low percentage organic carbon contents translate to low organic matter content in soils. Therefore, to improve and sustain optimum rice production organic soil amendments like manures or crop residues have to be applied.

5.4 Total nitrogen

The percentage total nitrogen in the soils ranged from 0.11 to 0.36 (Table 2). Landon (1991) rated total N in soils as <0.1 as very low, 0.1 to 0.2 as low, 0.2 to 0.5 as medium, and 0.5 to 1.0 as high and >1.0 as very high. The total N of soils tested in this study ranged from low to medium. The results showed that 50% of selected soils in the study area had total N below critical value and 50% had medium total N (Table 2). Amur (2003) also reported total N below the critical value of 0.15 % in some selected paddy production areas in Same district. Mnguu (1997) and Semoka et al. (1996) reported low total nitrogen in selected paddy soils of Morogoro. Low total N might also be due to leaching, long term cultivation with limited use of organic amendments such as manures, and crop residues. This might be as 30% of the soil texture of some studied villages is sand (Table 1), Therefore, to supplement the deficient N, the use of nitrogen fertilizer is necessary in paddy production in these areas.

Table 2. Soil pH, total N, OC, extractable P, S and limiting nutrients of selected rice growing areas in Kilombero district

Location	pH (H_2O)	% OC	% N	P mg/kg^{-1}	S mg/kg^{-1}	Limiting nutrients
Mkula-Mtunga	6.24	2.34 M	0.25 M	7.75 M	1.86 L	S
Mkula-Gaza	5.65	2.48 M	0.32 M	2.98 L	1.64 L	S
Magombera-Mtendezi	5.21	1.58M	0.17 L	0.90 L	4.54 L	N, P, S
Magombera-Kimbyoko	5.35	1.18 L	0.20 L	3.58 L	1.37 L	N, P, S
Mangu'la –A/Mlagayai	5.67	1.72 M	0.31M	14.00 M	1.86 L	S
Mangu'la-B (bulk)	5.67	1.72 M	0.31 M	14.00 M	1.86 L	S
Njage A	5.42	2.46 M	0.28 M	26.21 H	0.66 L	S
Njage B	5.62	2.53 M	0.36 L	8.94 M	1.53 L	N, S
Michenga A	5.27	0.57 VL	0.20 L	5.67 L	1.59 L	N, P, S
Michenga B	5.76	0.84 L	0.15 L	3.27 L	1.31 L	N, P, S
Mbasa-Viwanja 70	5.50	0.40 VL	0.11 L	2.08 L	0.27 L	N, P, S
Mbasa-Kapolo 1	5.28	1.21 L	0.17 L	9.83 M	1.15 L	N, S
Mbasa-Kapolo 2	5.20	1.85 M	0.22 M	6.25 L	1.48 L	P, S
Mbasa-Kasikana	5.81	0.53 VL	0.13 L	1.48 L	0.71 L	N, P, S
Mbasa Vijana 1	5.97	0.77 L	0.11 L	3.58 L	0.22 L	N, P, S
Mbasa Vijana 2	5.81	0.77 L	0.12 L	2.69 L	1.97 L	N, P, S
Kisawawa-A/mikongo	5.74	1.65 M	0.21 M	15.48 M	1.53 L	S
Kisawawa-B	5.75	2.09 M	0.22 M	19.35 M	1.80 L	S
Signale sululu- A	5.80	2.12 M	0.27 M	35.15 H	1.75 L	S
Signale sululu-B	5.90	1.89 M	0.22 M	12.81 M	1.69 L	S

Note: SCL=Sandy clay loam; CL=Clay loam; CL=Clay loam

Key: H=high;M=medium,L=low;VL=Very low

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5.6 Available phosphorus

The available P in the soils tested ranged from 0.90 to 35.15 mg P kg-1 (Table 2). Dobermann and Fairhust (2006) rated available P level in rice growing soils <7 mg P kg-1 as low, 7 to 20 mg P kg-1 as medium and >20 mg P kg-1 as high. Most of these soils (50%) had low available P, while (40%) of the soils tested had medium P and (10%) had high P (Njage A and Signale sululu A vilaages). Other studies done in some selected paddy growing areas of Igunga, Nzega and Same reported low supply of P in paddy areas (Msolla, 1991; Amur, 2003). Also, Mnguu (1997) reported a low P status in some selected paddy growing areas of Morogoro, Coast and Mbeya regions. The soils tested in the study had low P fertility status and hence, P fertilizers application is necessary to correct P deficient soils.

5.7 Sulphur

The extractable Sulphur in the soils ranged from 0.22 to 4.54 mg S kg-1 (Table 2). Dobermann and Fairhust (2006) categorized Sulphur levels of < 9 mg kg-1 soil as low in rice growing soils. Based on this, 100% of the soils tested under this study had low levels of S. Similarly low levels of S have been reported in soils of Kibena tea estates (Kitundu, 2001). Landon (1991) reported that S enhances P uptake by plants while calcium can cause S precipitation and reduces S availability to plants. Also sulphur deficiency reduces N use efficiency by rice (Habtegebrial et al., 2013) and it is likely contributing to low N and P response to rice in Kilombero. Therefore, S containing fertilizers might be needed in these areas with optimum S rate to correct the deficiency.

Table 3: Exchangeable bases of selected rice growing areas of Kilombero District.

Location/village	CEC	Ca	Mg	Na	K	% BS	Limiting nutrients
Mkula-Mtunga	18.60 M	4.28 L	2.24 M	0.45 L	0.14 VL	7.69 L	Ca, Na, K
Mkula-Gaza	19.20 M	3.55 L	1.73 M	0.39 L	0.20 L	6.70 L	Ca, Na, K
Magombera-Mtendezi	11.00 L	1.17 VL	0.59 L	0.33 L	0.04 VL	2.49 L	Ca, Mg, Na, K
Magombera-Kimbyoko	7.00 L	1.07 VL	0.62 L	0.30 L	0.04 VL	2.60 L	Ca, Mg, Na, K
Mangu'la –A/Mlagayai	13.00 L	2.97 L	1.34 M	0.37 L	0.14 VL	5.72 L	Ca, Mg, Na, K
Mangu'la-B (bulk)	13.00 L	2.97 L	1.34 M	0.37 L	0.14 VL	5.72 L	Ca, Na, K
Njage A	19.00 M	3.31 L	1.29 M	0.39 L	0.26 L	6.39 L	Ca, Na, K
Njage B	17.80 M	3.45 L	1.06 M	0.41L	0.16 VL	5.80 L	Ca, Na, K
Michenga A	10.20 L	0.38 VL	0.10 VL	0.31 L	0.07 VL	1.46 L	Ca, Mg, Na, K
Michenga B	8.60 L	1.24 VL	0.37 L	0.39 L	0.15 VL	3.76 L	Ca, Mg, Na, K
Mbasa-Viwanja 70	10.80 L	0.72 VL	0.21 VL	0.30 L	0.18 VL	2.91 L	Ca, Mg, Na, K
Mbasa-Kapolo 1	10.00 L	1.28 VL	0.33 L	0.39 L	0.16 VL	3.55 L	Ca, Mg, Na, K
Mbasa-Kapolo 2	16.40 M	3.24 L	0.98 L	0.40 L	0.15 VL	5.54 L	Ca, Mg, Na, K
Mbasa-Kasikana	10.40 L	1.03 VL	0.20 VL	0.31 L	0.12 VL	2.65 L	Ca, Mg, Na, K
Mbasa Vijana 1	8.40 L	1.03 VL	0.24 VL	0.34 L	0.15 VL	3.35 L	Ca, Mg, Na, K
Mbasa Vijana 2	9.60 L	0.83 VL	0.23 VL	0.33 L	0.09 VL	2.38 L	Ca, Mg, Na, K
Kisawawa-A/mikongo	14.20 L	3.69 L	1.33 M	0.40 L	0.24 L	7.10 L	Ca, Na, K
Kisawawa-B	16.80 M	3.34 L	1.41 M	0.56 L	0.50 M	8.32 L	Ca, Na
Signale sululu- A	21.60 M	7.38 M	1.41 M	0.32 L	0.43 M	12.06 L	Na, K
Signale sululu-B	18.80 M	4.34 L	1.31 M	0.35 L	0.35 L	7.87 L	Ca, Na, K

Key: H= high, M=medium, L= low, VL=very low

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5.8 Cation exchange capacity

The cation exchange capacity (CEC) of the tested soils ranged from 7.0 to 21.60 cmol(+) kg-1(Table 3). Landon, 1991 categorized CEC levels as follows: <5 cmol(+) kg-1 as very low, 5 to 15 cmol(+) kg-1 as low, 15 to 25 cmol(+) kg-1 as medium, 25 to 40 cmol(+) kg-1 as high and >40 cmol(+) kg-1 as very high. The 55% of the tested soils had low CEC. Mzee (2001) reported that nutrient retention capacity is positively correlated with the CEC of the soil and is influenced by soil organic matter, clay content and type of clay minerals of the soil. The CEC is the measure of the potential fertility of the soil and possibly the response to fertilizer application Landon (1991). The results obtained indicate that the 55% had low CEC content, 40% had medium CEC content and 5% had very low CEC content. The studied soil found to had low nutrients retention capacity to nutrients added in form of fertilizer, hence contribute to low soil fertility status.

5.9 Exchangeable bases

5.9.1 Calcium (Ca)

The exchangeable Ca in the soils of the study area ranged from 0.38 to 7.38 cmol (+) kg-1 (Table3). Landon (1991) categorized exchangeable Ca levels as follows: <2.0 cmol (+) kg-1 as very low, 2.0 to 5.0 cmol (+) kg-1 as low, 5.1 to 10.0 cmol (+) kg-1 as medium, 10.1 to 20.0 cmol (+) kg-1 as high and >20.0 cmol (+) kg-1 as very high. Based on this categorization, the status of Ca is low in 95 % of all tested soils except for one site (Signale sululu A) which had medium Ca level. The low status of exchangeable Ca could be due to low pH, low organic matter, low CEC, leaching, long cultivation without nutrients addition, and nature of parent materials where the soils developed (Kitundu, 2001).

5.9.2 Magnesium (Mg)

The exchangeable Mg in the soil tested ranged from 0.10 to 2.24 cmol (+) kg-1 (Table 3). Kitundu (2001) categorized exchangeable Mg levels as follows: <0.3 cmol (+) kg-1 as very low, 0.3 to 1.0 cmol (+) kg-1 as low, 1.1 to 3.0 cmol (+) kg-1 as medium, 3.1 to 6.0 cmol (+) kg-1 as high and >6.0 cmol (+) kg-1 as as very high. According to this categorization, 25% of the soils under this study had very low and 25 % had low exchangeable Mg, while 50 % had medium exchangeable Mg. Therefore, some villages of the soils studied areas need Mg application.

5.9.3 Sodium (Na)

The exchangeable Na in tested soils ranged from 0.30 to 0.56 Cmol (+) kg-1 (Table 3). Ngerageza (1999) categorized exchangeable Na <1 cmol (+) kg-1 as low and >1 cmol (+) kg-1 as high. Thus, all the soils samples under study recorded low in exchangeable Na. Amuri (2003) reported low exchangeable Na in Ndungu irrigation scheme of Same, Kilimanjaro region, Tanzania. The low exchangeable Na would provide good environment for rice growth, because when high percentage of CEC is occupied by Na+, the soil aggregate disperses and lead the soil to be impermeable to water. Therefore, exchangeable Na will not limit rice production in Kilombero district.

5.9.4 Potassium (K)

The exchangeable K in the studied soils ranged from 0.04 to 0.50 cmol (+) kg-1 as given in Table 3. Landon (1991) categorized the exchangeable K in soils <0.2 cmol (+) kg-1 as very low, 0.2 to 0.4 cmol (+) kg-1 as low, 0.41 to 1.2 cmol (+) kg-1 as medium, and 1.21 to 2.00 cmol (+)

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kg-1 as high and >2.00 cmol (+) kg-1 as very high. Based on this categorization 70 % of the soils studied had very low exchangeable K, 20 % had low exchangeable K and 10 % had medium exchangeable K content. Mzee (2001) reported low exchangeable K at one site in Lupilo village in Ulanga district. Low exchangeable K might be due to leaching and low CEC, and none re-cycling of crop residues, hence poor K retention capacity of the soils. Therefore, application of potash fertilizers is necessary for optimum rice production.

6. Base saturation

The base saturation (BS) in soils tested ranged from 1.46 to 12.06 % (Table 3). According to Landon (1991), base saturation is the indication of soil fertility status, where BS of <20 % indicates low, 20 to 60% indicates medium, and >60 % indicates high general fertility. Based on this categorization, all the soils in this study had low base saturation hence, are of poor soil fertility. Therefore, there is a need for enhancement of fertilizer use in these areas to replenish the nutrients and general maintenance of fertility status before the situation becomes worse.

7. Micronutrients

7.1 Zinc

The amounts of the DTPA extractable Zn are shown in Table 4. The values range from 0.02 to 2.30 mg Zn kg-1 soil. Most of the soils 65% in the study have Zn levels above the critical level of 1 mg/kg proposed by Landon (1991), with exception of seven villages out of twenty villages studied. Thus, 35% of the soils in this study are deficient in Zn and the situation might become worse in the future if Zn fertilizers will not be applied. Other studies done by Mzee (2001) reported low extractable Zn levels at two sites in Lupilo and Michenga villages in Tanzania. The low levels of Zn in some selected rice growing areas of Igunga and Nzega were also reported by Msolla (1991). The low levels of Zn might be due to free Fe, Al and Mn ions which cause adsorption of Zn to non-exchangeable form of their hydrated oxides surface (Kitundu, 2001). Therefore, application of zinc fertilizers is necessary for optimum rice production.

Table 4. Chemical properties (micronutrients) of the selected rice growing areas in Kilombero district.

Location	Zn	Cu (Mg kg^{-1})	Fe	Mn	Limiting nutrients
Mkula-Mtunga	2.30 H	5.57 H	486.2 H	24.4 H	
Mkula-Gaza	2.11H	5.33 H	149.0 H	15.7 H	
Magombera-Mtendezi	1.68 H	4.67 H	123.9 H	100.4 H	
Magombera-Kimbyoko	2.15 H	4.08 H	98.0 H	71.8 H	
Mangu'la-A/Mlagayai	2.04 H	3.49 H	90.9 H	34.1 H	
Mangu'la- B (bulk)	1.81 H	2.94 H	78.4 H	16.9 H	
Njage A	1.64 H	5.49 H	100.4 H	45.5 H	
Njage B	1.53 H	5.69 H	114.5 H	58.4 H	
Michenga A	BD	0.59 H	31.8 H	10.9 H	Zn
Michenga B	0.62 L	11.76 H	38.8 H	36.1 H	Zn
Mbasa-Viwanja 70	BD	0.16 L	17.3 H	37.3 H	Zn, Cu
Mbasa-Kapolo 1	0.94 H	1.88 H	64.7 H	34.9 H	
Mbasa-Bwawani	1.94 H	3.73 H	102.7 H	81.1 H	
Mbasa-Kasikana	0.02 L	0.20 H	13.7 H	19.2 H	
Mbasa-Kapolo 2	1.79 H	3.45 H	116.1 H	125.1 H	

Mbasa Vijana 1-(exp.site)	0.04 L	0.24 H	13.7 H	46.3 H	Zn
Mbasa Vijana 2-(bulk)	BD	0.12 L	16.5 H	23.92 H	Zn, Cu
Signale-Sululu A	0.87 H	1.76 H	61.9 H	34.5 H	
Signale-Sululu B	1.02 H	2.04 H	118.4 H	61.9 H	
Kisawawa-A/Mikongo	2.30 H	5.57 H	109.8 H	37.6 H	
Kisawawa-B	2.11H	5.33 H	101.6 H	57.3 H	

Key: H= high, L= low,
*BD=below detection

7.2 Copper

The DTPA extractable Cu in tested soils ranged from 0.12 to 5.57 mg Cu kg-1 (Table 4). Dobermann and Fairhust (2006) categorized DTPA extractable Cu levels of 0.2 to 0.3 mg kg-1 soil as adequate in rice growing soils. Most of the tested soils (90 %) had sufficient amounts of available Cu for rice production while 10 % had deficient Cu levels. The soils in villages namely Mbasa vijana 2 and Mbasa viwanja 70 may not supply adequate amounts of copper for plant growth. According to data obtained Cu deficiency does not seem to be extensive in the selected rice growing villages of Kilombero district.

7.3 Manganese

The amount of Mn in soils tested ranged from 10.9 to 125.10 mg Mn kg-1 (Table 4). Based on Kitundu (2001), the critical level for Mn in soils is 1 mg Mn kg-1. Based on this categorization the soils of study areas had high levels of plant available Mn. This might be due to low pH since most of tested soils had pH of < 6.5, this might favour the dissolution of Mn to large extent. The higher level of Mn also obtained in study done by Kitundu (2001) reported 3 mg Mn kg-1 in soils of Lihogosa and Itambo estates. Therefore, Mn is not a limiting nutrient in the soils under study area.

7.4 Iron

The extracted Fe levels in soils under study ranges from 13.7 to 486.2 mg Fe kg-1 and are given in (Table 4). This shows that the soils studied contained plant available Fe above critical level of 4.5 mg kg-1 as established by Tandon (1995). Dobermann and Fairhust (2006) reported that the critical concentration for the occurrence of Fe toxicity is > 300 mg Fe L-1 soil (> 300 mg Fe kg-1).

The soil of Mkula- Mtunga had Fe content of 486 mg Fe kg-1 (Table 4) which may result in Fe toxicity. Amuri (2003) obtained higher levels of Fe above critical level in soils from rice producing areas of Same district. The higher level of Fe could be attributed to low pH in the study area. High available Fe and low pH (<6.5) might affect the availability of phosphate for normal plant growth. According to Landon (1991) soils with high Fe oxides content limits the availability of phosphate.

7. Limiting nutrients in 20 selected rice growing villages in Kilombero district.

Limiting nutrients data and their frequencies of occurrence in twenty selected rice growing villages in Kilombero district are presented on Table 5.

Results indicated that N, P, K, S, Mg, Ca, Cu and Zn were generally the limiting nutrients of which K and S was limiting in all selected villages (Table 6). In general, the results show that

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there are wide variations in soil fertility of the selected rice growing villages and hence there is no possibility of making a blanket fertilizer recommendation for all the villages. This will lead to specific fertilizer and soil fertility management recommendations based on limiting nutrients. The results revealed significant variations in soil properties among the selected rice growing villages. Overall, the categorization of nutrient status indicated poor fertility levels particularly regarding nitrogen, phosphorus, potassium, sulphur, zinc, copper, magnesium, and calcium. Proper inputs of nutrients in form of fertilizers and proper soil management are essential in order to optimize rice production in the Kilombero District. This information provides valuable insights for farmers, agronomists, and policymakers, guiding them toward effective soil fertility management strategies for sustainable rice production in the district.

Table 5. Frequencies of occurrence of each limiting nutrients in selected rice growing areas in Kilombero district.

Frequency of occurrences in limiting nutrient in 20 rice growing villages		
Limiting nutrients	**No. of villages it occurs**	**% of occurance**
N	10	50%
P	9	45%
S	20	100%
Ca	19	95%
Mg	11	55%
Na	19	95%
K	20	100%
Zn	5	25%
Cu	2	10%

Table 6. Soil fertility category and frequencies of their occurrences based on limiting nutrients in selected rice growing villages in Kilombero district.

Soil fertility category	Limiting nutrients	Frequency of occurrence (No.in %)
1	Ca, Na, K, S	6 (30%)
2	Ca, Mg, Na, K, N, P, S	3 (15%)
3	Ca, Mg, Na, K, S	1 (1%)
4	Ca, Na, K, N, S	1 (1%)
5	Ca, Mg, Na, K, Zn, N, P, S	3 (15%)
6	Ca, Mg, Na, K, Zn, Cu, N, P, S	2 (10%)
7	Ca, Mg, Na, K, N, S	1 (5%)
8	Ca, Mg, Na, K, P, S	1 (5%)
9	Ca, Na, S	1 (5%)
10	Na, K, S	1 (5%)

According to soil fertility status, the results of the study under selected rice growing villages showed a wide variation in nutrients deficient levels. This led into different soil fertility categories (Table 6) i.e., ten soil fertility categories discovered based on nutrient variations deficient. This provides clear vision in knowing the status of the soils in terms of nutrients and challenges faced by farmers in implementing proper and sustainable agricultural practices.

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Therefore, consistent soil testing is needed according to soil fertility categories under study in order to improve soil fertility and rice productivity.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusion

Based on the result of this study, it can be concluded that:

a) Generally, the soil fertility status of the soils under study is poor in terms of nutrients and its availability. Eight out of twenty soil samples i.e., 40% of villages showed major deficiency of both macro and micro nutrients N, P, K, S, Zn, Cu, Ca, Mg and Na. Twelve out of twenty soil samples i.e., 60% of villages had deficient in different nutrients including N, P, K, S, Ca, Mg and Na but showed adequate to high levels of Zn, Cu, Fe and Mn.

b) All soils under study i.e., both villages of rice growing areas showed to had deficiency in S and Na.

c) Low Zn and Cu in some of the soils studied may limit adequate crop growth and yield without supplementation of these micronutrients

d) Based on this study showed a wide variation in nutrients deficiencies hence different soil fertility categories.

8.2 Recommendations

Based on observations and results obtained from the study the following are recommended:

a) Proper soil management practices and frequent soil testing and fertilizer trials are recommended in the context of balanced fertilization rice growing areas in Kilombero based on fertility status categories as stipulated in the study. This will help farmers and policy makers in guiding them through effective soil management strategies for sustainable rice production in Kilombero district.

b) The use of micronutrients fertilizers should be insisted to farmers where there are deficiencies in order to contribute to the long-term soil fertility. Education programs and extension services should be provided to farmers to raise awareness about the importance of soil fertility management and the benefits of adopting sustainable agricultural practices.

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APPENDICES

Appendix 1: Areas of Kilombero district from where the experimental soils were collected

VILLAGE	COORDINATES	DESCRIPTION
Mkula	S 07.79730^0 E 036.91474^0	Over 30 yrs of cultivation. The scheme has total area of about 294 ha but the area cultivated is 100 ha. Inadequate use of fertilizers (mostly urea).Yield is low 8-10 bags/acre. Most areas dominated by sandy clay loam soils, some few places are sandy soil, the dominant crop is rice.
Magombera- scheme	S 07^0.80178 E 036^0.96029	No fertilizer uses. Over 50 years of cultivation. Crop planted: Rice (mainly transplanted). Surface water covered with rust like layer, in such cases crop performance is poor. The soil dominated the area is mainly sandy clay loam with whitish clay soil milky like.
Mang'ula	S 07^0.83868 E 036^0.91877	Crop grown: rice (mainly by direct seeding by broadcasting). Bulk sample taken for pot experiment in screen house. The dominant soil is sandy clay loam. Vertiver grasses dominate the area.
Njage - sheme	S 08^0.24887 E 036^0.17979	Total area is 325 ha. Area cultivated is 225 ha. No fertilizer uses. Rice seedlings; yellowish especially on old leaves. Maize plants; interveinal chlorosis and purple color from stems to leaf margins. Giant nut sedges-is a common weed indicative of rice suitability (Mnguu, C. personal communication, 2011). The soil dominant in area is clay loam. Yield 10 bags / acre.
Michenga A valley	S 08^0.12334 E 036^0.6356	Over 100 years of cultivation. Crop grown: rice (mainly by direct seeding by broadcasting). No fertilizer use. The dominant soil is loamy sand/ sandy loam. The soil is compacted due to grazing and abandoned after yield dropped. The soil is hard when dry. Dust blowing out during cultivation (whitish dust).
Mbasa sheme	S 08^0.09798 E 036^0.71284	Bulk sample was taken; the area showed the signs of nutrients deficiency in phosphorus and nitrogen in rice plants. The crop grown: rice mainly by transplanting). The dominant soil is
Mbasa- Kapolo 1	S 080.09995 E 036^0.71066	Near swampy area. The dominant soil is clay. Crop grown: rice mainly by transplanting.
Mbasa – Viwanja 70	S 08^0.10410 E 036^0.71347	Sandy loam soils- alluvial brought by river during rains. Easy and friable. Crop grown is rice: mainly by transplanting.
Mbasa- Kapolo 2	S 080.09949 E 036^0.71006	Localized heavy clay soils near swampy area. The other area is dominated by sandy clay loam Crop grown: rice mainly by transplanting.
Mbasa- Kasikana	S 08^0.09697 E 036^0.71707	The dominant soil is sandy loam. Crop grown: rice mainly by transplanting.
Mbasa- Kapolo	S 08^0. E 036^0	The dominant soil is sandy clay loam. Easy to work with and friable. Good rice yield is 20-25 bags /acre. Crop grown: rice mainly by transplanting.
Zignale A	S 08^0.00259 E 036^0.83683	Crop grown: Rice rotated with vegetables (tomatoes, egg plants, okra). Area close to traditional irrigation scheme. The soil is clay loam. Relatively good maize crop although yellow stripes observed on maize. Younger maize with P deficiency symptoms