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Original Research Article

Growth and yield responses of rice, wheat and beans to Zn and Cu fertilizers in soils of Mbeya region, Tanzania

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Low crop production in most arable lands is associated with soils highly depleted of nutrients. A study was conducted in selected physiographic units of Mbeya Region Tanzania, to investigate the levels of soil macro- and micronutrients effect on crops (rice, wheat and beans) performance. Soils were analyzed in the laboratory. Screen-house experiments with three levels of Zn (0, 7.5 and 15 mg kg^{-1} soil) and Cu (0, 5 and 10 mg kg^{-1} soil) in combination with N and P treatment in completely randomized design with three replications was conducted. The results showed that all soils were deficient in N, P and Cu, while 46% of soils had low Ca. Zn was low in 46% of the soils while K and Fe was sufficient in all soils. Application of 15 mg kg^{-1} Zn and 5 mg kg^{-1} Cu with N and P fertilizers gave significantly highest grain yield of rice (9.05 g pot^{-1}), beans (5.80 g pot^{-1}) and wheat (5.58 g pot^{-1}). The control gave lowest grain yield in all crops. Zink rate of 15 mg kg^{-1} and Cu rate of 5 mg kg^{-1} was sufficient to increase yields in these soils. Field experiments are recommended to confirm Zn and Cu fertilizer recommendations.

Key words: Beans, micronutrients, rice, nutrient deficiency, wheat, yield responses

INTRODUCTION

Unexpected low yields even after use of the common fertilizers have been observed in many parts of the world (Bargali et al., 2004, 2009 and Mishra et al., 2010; Singh et al., 2007). It is possible that the low yields, despite use of the N, P and K fertilizers, are due to deficiency of one or more micronutrients or other macronutrients (Hanson, 1992). Observation from many studies show that the decline in soil fertility has caused not only decline in yields but can also contribute to low crop quality, leading to severe dietary micronutrient deficiencies to human and livestock populations in many areas (White and Broadley, 2009). Though micronutrients are abundant in the earth's crust (Nubẻ and Voortman, 2006), Bell and Dell (2008) observed that the large part of nutrient elements in the soil is "unavailable" to the plant. The unavailability of micronutrient elements partly explains why micronutrient deficiencies still occur.

Many areas in Tanzania have been cultivated for long periods of time without use of micronutrient or any other fertilizers. There is every possibility that food quality might be declining in those areas due to decline in micronutrient status in soils. Such decline in food quality in terms of nutrient contents will be counter-productive to the human nutritional quality needs for sustained good health. For example, Mbeya region, one of the most productive agricultural areas in Tanzania, exporting food crops to many parts of the country, has been reported to have Cu and Zn deficiencies in soils (Kamasho, 1980). However, no follow-up studies have been undertaken to relate the soil micronutrient levels with the quantity of crops grown therein. Reports from other studies show evidence of decline in soil fertility in this region (Mwakifupe, 1998). Human population pressure and the mountainous physiography of Mbeya region, characterized by steep and unstable slopes, have exacerbated land degradation in most of the cultivated lands due to soil erosion (Mashalla, 1988).

Also, Mbeya region is dominated by volcanic soils. Lisuma et al. (2005) reported evidence of zinc and copper

Table 1. Salient features of the selected agricultural sites of the Mbeya region, Tanzania

District	Village/site	Geographical coordinates	Altitude (m.a.s.l.)	Major crops cultivated
Mbeya rural	Mwanzazi	08° 59′ 57.6″S, 033° 39′41.1″E	2271	Irish potato and maize
	Ifiga	08° 55′ 55.5″S, 033° 34′ 00.5″E	1884	Maize, beans, tomato and garlic
	Mkuyuni	08° 55′ 04.8″S, 033° 41′ 33.4″E	1845	Maize and potato
	Makwenje	08° 50′ 43.9″S, 033° 38′ 37.1″E	1514	Maize, beans, sorghum and groundnuts
Rungwe	Ndembela 1	09° 16′ 02.5″S, 033° 37′ 04.7″E	1389	Banana and tomato
	Ndembela 2	09° 16′ 07.2″S, 033° 36′ 54.4″E	1376	Banana and groundnuts
	Itula	09° 22′ 37.0″S, 033° 30′ 30.6″E	1150	Maize, groundnuts and beans
	Ilima	09° 20′ 46.0″S, 033°43′ 00.6″E	596	Rice
Kyela	Tenende plains	09° 33′ 50.4″S, 033° 53′ 13.9″E	508	Rice

deficiencies in soils derived from volcanic ash in Makete district (Iringa region). Therefore, this could be the contributing factor of low copper levels in Mbeya soils because the volcanic soils of some areas in Mbeya (Rungwe) and Makete have a common origin, the Ngozi volcano eruption. Thus, the objectives of this study were to i) evaluate physico-chemical properties of soils, macro and micronutrient contents in soils for adequate crop production, and ii) determine the response of crops to applied macro- and micro-nutrients in micronutrient-deficient soils of Mbeya Region.

MATERIALS AND METHODS

Description of the study areas

This study was conducted in Mbeya region, in the Southern Highlands of Tanzania. Three out of eight districts of Mbeya region were selected for this study (Mbeya-Rural, Rungwe and Kyela), chosen on the basis of the topography and climatic conditions of the areas. Mbeya-Rural district is topographically characterized by highlands, mountainous peaks, lowlands of Songwe valley and Usangu plains (Mbeya District Council, 2007). Rungwe district is generally mountainous, rising from an altitude of 770 to 2265 m above sea level. These mountains have great influence on the climate of the district, which makes it experience cold and rain seasons (Rungwe District Council, 2010). Kyela district is relatively flat and lies in the flood plains of Lake Nyasa (Kyela District Council, 2009).

Soil fertility survey

A survey of the study areas was undertaken to identify sites for soil sampling for soil fertility evaluation. A transect walk survey was conducted from Mbeya Rural, Rungwe and Kyela districts to capture variability in altitude, climate and soils. In Mbeya rural four villages namely Mwanzazi, Ifiga and Mkuyuni and Makwenje were selected, representing the upper, middle and lower altitudes of the district. In Rungwe district, the study sites included Ndembela, Itula and Ilima villages, representing the upper, middle and lower altitudes of the district, respectively, while in Kyela district, selected site was Tenende plains. Detailed information's about these sites are presented in Table 1.

Soil sampling and analysis

At each site (Table 1), one composite sample, drawn from 8 to 10 sampling points within a 0.25 ha of representative farm was collected at the depth of 20 cm. The soil samples were air-dried and ground to pass through a 2-mm sieve for laboratory analysis at Sokoine University of Agriculture (SUA), Morogoro. Bulk soil samples from Makwenje, Mkuyuni, Ndembela and Tenende sites with low soil Zn and/or Cu (Table 4) were collected at the depth of 0 to 20 cm for pot experiments.

The soil samples were analysed for particle size distribution, soil pH, total nitrogen, organic carbon, extractable phosphorus, cation exchange capacity (CEC) and exchangeable bases, and extractable micronutrients at SUA Soil Science laboratory. Particle size analysis was determined by the Bouyoucos hydrometer method after soil dispersion in sodium hexametaphosphate as described by NSS (1990). Soil pH was determined in 1:2.5 soil: water and soil: 0.01 M $CaCl_2$ ratio suspensions by the potentiometric method (Mclean, 1986). Total N was determined by the micro-Kjedahl digestion-distillation method based on procedure described by Bremner and Mulvaney (1982). Organic carbon was determined using the Walkey-Black wet oxidation method (Nelson and Sommers, 1982). Extractable P was determined using Bray 1 procedure (Bray and Kurtz, 1945) because all soils had pH < 7. The CEC and exchangeable bases of the soil were determined by the ammonium acetate saturation method as described by Chapman (1965). DTPA-extractable micronutrients in all soil samples were determined using the procedure by Lindsay and Norvel (1978). The exchangeable bases (Ca, Mg) and extractable micronutrients (Cu, Mn, Fe, and Zn) in the filtrates were quantified by atomic absorption spectrophotometer at appropriate wavelengths. Exchangeable Na and K in the filtrate was determined by flame photometer, while

Table 2. Particle size distribution in soils of the selected sites of Mbeya region, Tanzania

District	Village /site	Particle size distribution			
		% Sand	%Silt	% Clay	TC
Mbeya Rural	Mkuyuni	32.2	25.3	42.5	C
	Mwanzazi 1	64.2	11.3	24.5	SCL
	Mwanzazi 2	58.2	13.3	28.5	SCL
	Ifiga	38.2	25.3	36.5	CL
	Makwenje 1	40.2	17.3	42.5	C
	Makwenje 2	36.2	21.3	42.5	C
Rungwe	Ndembela A 1	30.2	15.3	54.5	C
	Ndembela A 2	42.2	17.2	40.5	C
	Ndembela B	28.2	17.3	54.5	C
	Itula	68.2	15.3	16.5	SL
	Ilima	66.2	9.3	24.5	SCL
Kyela	Tenende 1	22.2	35.3	42.5	C
	Tenende 2	26.2	31.2	42.5	C

Where: TC = Textural class; C = Clay; SL = Sandy loam; SCL = Sandy clay loam; CL = Clay loam.

extractable P was quantified calorimetrically using molybdenum blue (Murphy and Riley, 1962) using UV spectrophotometer.

Pot experiments

Glasshouse pot experiments were conducted at the Department of Soil Science, SUA, Morogoro, Tanzania, located at 6° 51′ S and 37° 39′ E. Bulk soil samples from each of the four sites formed an independent experiment. Four kilogram soils from respective four sites were put into pots. The pots were arranged in a randomized complete design with three replications. The treatments were: Control (no fertilizer added); NP-fertilizer (only); NP + 5 mg Cu kg^{-1}; NP + 10 mg Cu kg^{-1}; NP + 7.5 mg Zn kg^{-1}; NP + 15 mg Zn kg^{-1}; NP + 15 mg Zn kg^{-1}+ 5 mg Zn kg^{-1}; NP + 15 mg Zn kg^{-1}+ 10 mg Cu kg^{-1}. The treatments were randomly assigned to each pot in a block. Sources of plant nutrients in these experiments were urea $(CONH_2)_2)$ (46% N), triple super phosphate (TSP) $Ca(H_2PO_4)_2$ (20% P), zinc sulphate $(ZnSO_4.7H_2O)$ and copper sulphate $(CuSO_4.5H_2O)$. Urea and TSP fertilizers were obtained from the market while Zn and Cu were obtained from soil science laboratory (Sokoine University of Agriculture). Four seeds of beans (*Phaseolus vulgaris* L.) were planted on soils from Makwenje and Ndembela sites; three seeds of rice (*Oyza sativa*) (NERICA 4 variety) were planted on the soil from Tenende; and three seeds of wheat (*Triticum aestivam*) were planted on the soil from Mkuyuni. Rates of 240, 200 and 320 mg N per pot and 320, 200 and 160 mg P per pot were applied to beans, wheat and rice, respectively. Different rates of Zn and Cu fertilizers were applied to these soils as shown in the treatments above. With exception of N, which was applied in two splits, at planting time and 20 days after planting, the other fertilizers were applied only at planting time. The soils in the pots were maintained at about field capacity throughout the experimental period, except for rice soils which were flooded 15 days after planting until crop maturity. Two bean plants, and one plant in the case of wheat and rice in each pot, were harvested at flowering and booting stages, respectively, by cutting the stems at 1 cm above the soil surface. The harvested plants were rinsed to remove soil particles and dried at 65°C to constant weight for dry matter determination. The remaining two plants in each pot were allowed to grow to maturity, and thereafter seeds were harvested for grain yield determination.

Statistical analysis

Data on dry matter and grain yields for all crops (rice, wheat and beans) and plant tillers and heights for wheat and rice were collected and subjected to analysis of variance (ANOVA) using MSTAT-C. Mean separation was done using Duncan's New Multiple Range Test at alpha=0.05.

RESULTS

Physico-chemical characteristics and macronutrient content of soils from selected sites in Mbeya region Tanzania

The soils' physical and chemical properties from the study areas are given in Table 2 and Table 3 and 4, respectively. The textural classes of soils from all study sites varied from sandy clay loam (SCL), clay loam (CL) to clay (C) (Table 2). These soils will, therefore, have moderate to high water and nutrient retention capacity, and would be more suitable for production of many crops if other soil factors are not

Table 3. Soil reaction and macronutrient contents of soils of some areas in Mbeya region

District	Site/village	pH					K^+	Ca^{2+}	Mg^{2+}	Na^+	CEC
		H_2O	$CaCl_2$	% O.C.	% N	Extractable P Bray 1(mg kg^{-1})	(cmol+ kg^{-1})				
Mbeya Rural	Mkuyuni	5.09L	4.26	4.38VH	0.15M	6.62VL	1.14H	3.40M	1.06H	0.12L	27.8H
	Mwanzazi 1	5.88M	4.90	4.46VH	0.21M	7.98VL	0.64H	4.29H	0.95H	0.18L	42.6VH
	Mwanzazi 2	5.49L	4.90	2.27M	0.36VH	5.50VL	0.69H	4.24H	0.72H	0.15L	31.8H
	Ifiga	5.51L	4.81	2.45M	0.18M	8.54VL	1.24H	6.47H	0.93H	0.17L	29.4H
	Makwenje 1	4.77L	3.31	1.16L	0.09VL	13.19L	0.54H	1.10L	0.39M	0.12L	22.2M
	Makwenje 2	5.34L	5.14	1.23L	0.11L	7.29VL	0.59H	0.91L	0.40M	0.10L	18.2M
Rungwe	Ndembela A 1	6.19M	4.41	1.70M	0.15M	5.83VL	2.09H	2.13M	1.03H	0.14L	33.4H
	Ndembela A 2	6.28M	4.95	1.51M	0.20M	3.70VL	1.39H	2.06M	0.92H	0.16L	27.0M
	Ndembela B	5.36L	4.80	1.30M	0.13M	3.47VL	1.59H	2.57M	0.79H	0.14L	32.8H
	Itula	5.55L	5.11	4.93VH	0.37VH	7.60VL	0.99H	1.94L	0.48M	0.14L	40.6VH
	Ilima	5.19L	3.76	1.01L	0.09VL	0.90VL	0.28M	1.10L	0.35M	0.25L	16.8M
Kyela	Tenende 1	4.27L	3.89	0.12L	0.23M	5.27VL	0.49H	0.96L	0.25L	0.34L	27.6H
	Tenende 2	5.50L	3.61	0.11L	0.22M	6.73VL	0.62H	0.77L	0.15L	0.32L	25.6H

Note:The ratings of the soil parameters were according to Landon (1991) and Tandon (1995). Where VL = very low, L = low, M = medium, H = high and VH = very high

Table 4. Micronutrient contents in some agricultural soils in Mbeya region, Tanzania

District	Site/village	Micronutrients in soil		
		*Fe (mg kg^{-1})	*Cu (mg kg^{-1})	**Zn (mg kg^{-1})
Mbeya Rural	Mkuyuni	25.91H	0.29L	1.41H
	Mwanzazi 1	29.24H	0.29L	2.73 H
	Mwanzazi 2	25.81H	0.29L	3.21H
	Ifiga	38.65H	0.44L	4.17H
	Makwenje 1	41.00H	0.34L	1.25H
	Makwenje 2	29.44H	0.33L	1.08H
Rungwe	Ndembela A 1	20.61H	0.33L	1.09H
	Ndembela A 2	18.65H	0.32L	0.99L
	Ndembela B	15.71H	0.28L	0.87L
	Itula	13.95H	0.43L	0.36L
	Ilima	55.51H	0.32L	0.38L
Kyela	Tenende 1	34.24H	0.29L	0.85L
	Tenende 2	32.19H	0.29L	0.62L

NB.: The ratings of the micronutrient contents i.e. L = low, M =medium and H =high, were according to Landon (1991)** and Motsara and Roy (2008)*

Plate 1. Rice plants in pot experiment (35 days after planting)

limiting. The soil pH (water) ranged from 4.70 to 6.28 (Table 3). The pH of the all soils from Mbeya rural sites are strong (pH 5.0 to 5.5) to moderate acid (pH 5.5 to 6.0) based on categorization by McFarland et al. (2001), except soils from Makwenje. Ndembela (Rungwe) is slightly acid soil (pH 6.1 to 6.5), while soils from Makwenje and Tenende are very strong acid to strong acid (McFarland et al., 2001). Total N was low in the Makwenje (Mbeya rural) and Ilima(Rungwe district). Available P ranged from 3.47 to 8.54 mg P kg^{-1}, and rated low (<15 mg P kg^{-1}) in all sites, (Landon, 1991). Exchangeable K and Mg contents in soils were above the critical range (>0.2 cmol+ kg^{-1} and > 0.30 cmol+ kg^{-1}, respectively) in all study areas, indicating that these soils have adequate levels of K and Mg for crop production, except in Tenende. However, the exchangeable Ca ranged from 0.77 to 6.49 cmol+ kg^{-1}, and low (< 4 cmol + kg^{-1}) (Landon, 1991) in soils from Makwenje, Itula, Ilima and Tenende (Table 3). The very strong to strong acid pH will limit availability of P, Ca and Mg which needs to be adjusted. Low P shows the need for P fertilization for adequate crop production.

Micronutrient content in some soils of selected sites in Mbeya region Tanzania

Extractable Zn ranged from 0.36 to 4.17 mg kg^{-1} while extractable Cu ranged from 0.29 to 0.44 mg kg^{-1} (Table 4). All studied soils from Mbeya-Rural district had extractable Zn above the critical levels >1.0 mg kg^{-1} (Landon, 1991; Motsara and Roy, 2008). Contrary, soils from all study sites of Rungwe and Kyela had Zn levels below the critical values for crop production. About 46% of the soils studied were either deficient in Zn, or are likely to be deficient in this element in the near future if measures to correct Zn deficiency are not adopted. Extractable Cu was low in all sites while extractable Fe levels in the soils from the study sites were very high (>10 mg kg^{-1}) according to Motsara and Roy (2008). Low Zn and Cu in some of the soils studied may limit adequate crop growth and yield without supplementation of these micronutrients.

Growth and yield responses of crops to N, P, and different levels of Zn and Cu fertilizers

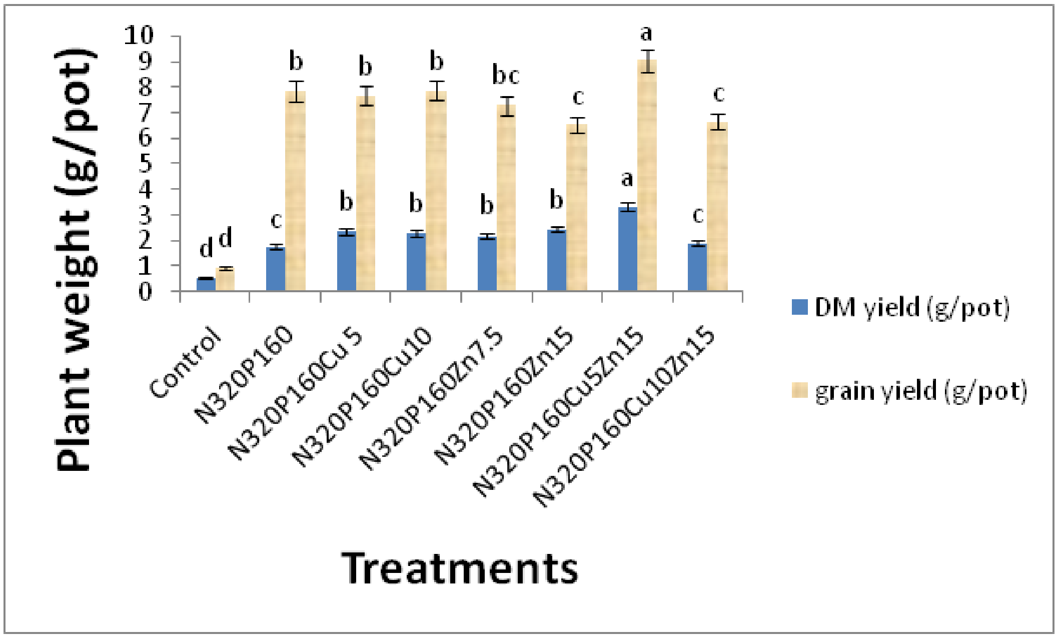
Rice

Rice plants in the absolute control treatment ($N_0P_0Zn_0Cu_0$) were severely stunted (Plate 1) and had low number of tillers and plant height (Figure 1). The rice plants in this control treatment showed nutrient deficiency symptoms, particularly N and P, since the early stage of growth (14 days after planting). The initially green colouration of plants in the control treatment became progressively pale, and became chlorotic with thin stems, and purplish colour in the lower leaves, from two weeks of plant growth to maturity.

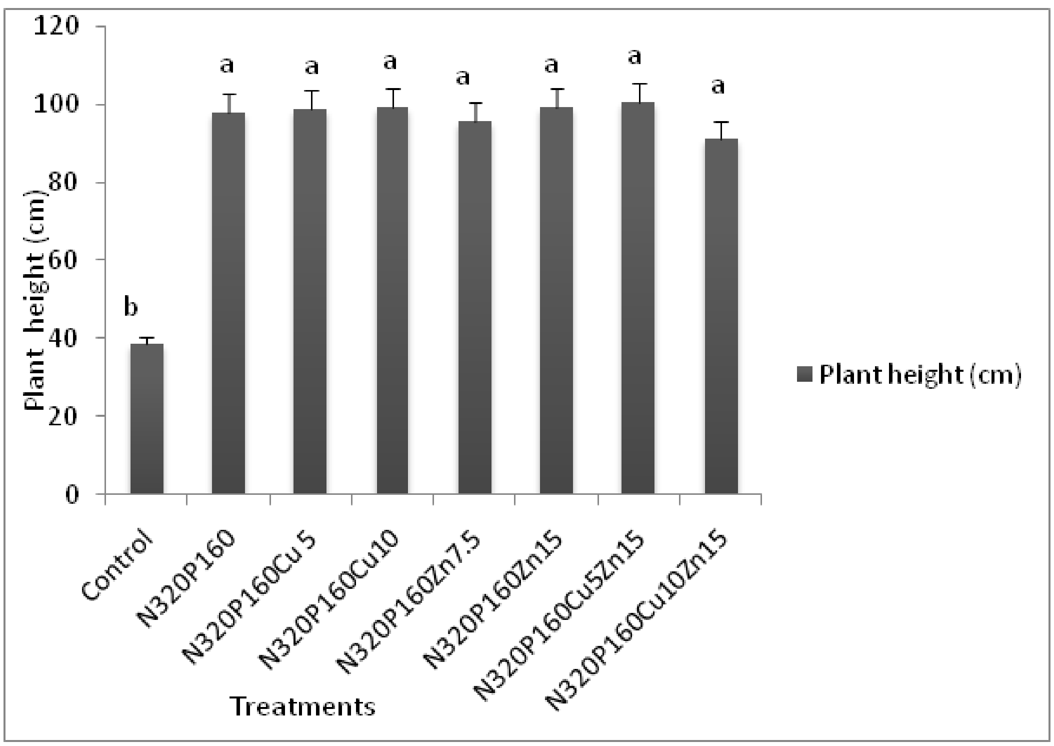
There were no plant tillers in the control treatment (1 tiller). Plant height (38.67 cm), dry matter (0.57 g pot^{-1}) and grain yields (0.93 g pot^{-1}) of the control treatment were the lowest of all the treatments (Figure 1). Application of N and P fertilizers alone led to a significant (P = 0.05) greater number of tillers (2), plant height (97.17 cm) and dry matter (1.8 g pot^{-1}) and grain (7.89 g pot^{-1}) yields over the control. The significant improvement of these growth responses is a proof that these nutrients were limiting in the Tenende soil. The height of rice plants that received levels of Zn and Cu along with N and P were slightly higher than the rice plants that received only N and P, though the difference was not significant (P= 0.05) (Figure 1b). The treatment containing NP in combination with Zn and Cu (NP + Zn_{15} + Cu_5) gave the highest plant height of 100.33 cm, dry matter weight of 3.35 g pot^{-1} and seed weight of 9.05 g pot^{-1}, compared with all other treatments (Figure 1). This may be due to better supply of all deficient nutrients in the right proportions while maintaining nutrient balance for adequate rice plant growth and yields. However, both dry matter and grain yields of rice treated with Zn and Cu in addition to N and P were significantly (P=0.05) higher than those under the N and P treatments alone (Figure 1a).

Beans

Use of N, P, Cu, and Zn fertilizers resulted in a significant increase in the bean dry matter and grain yields in both Ndembela and Makwenje soils (Figure 2). The bean plants



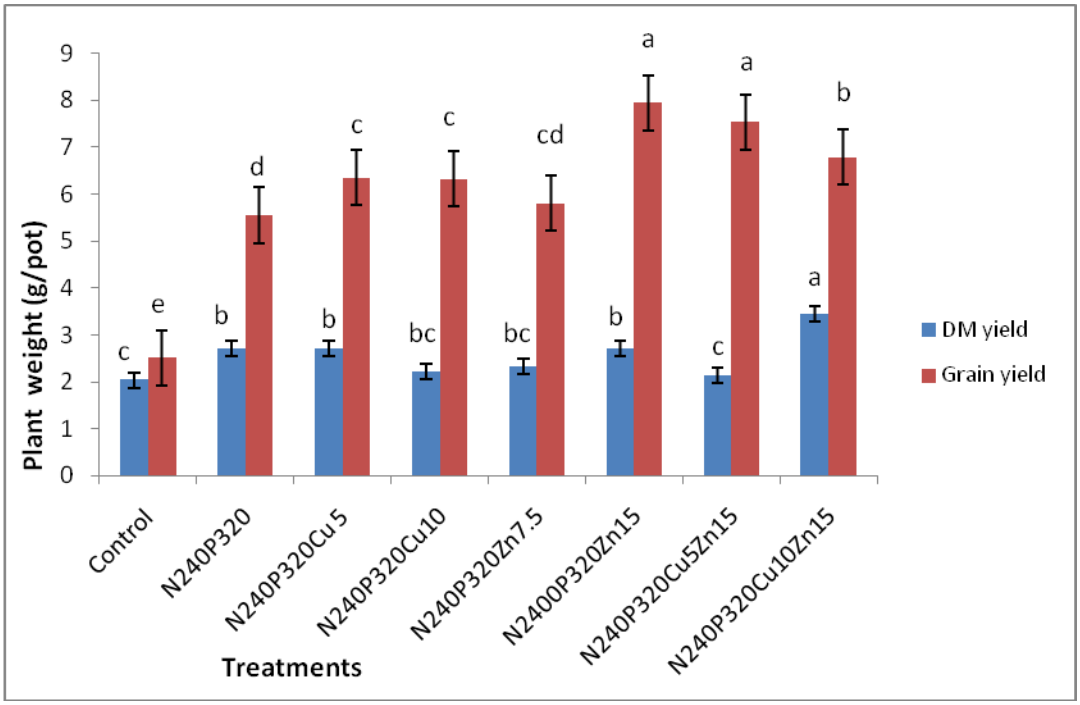
(a)



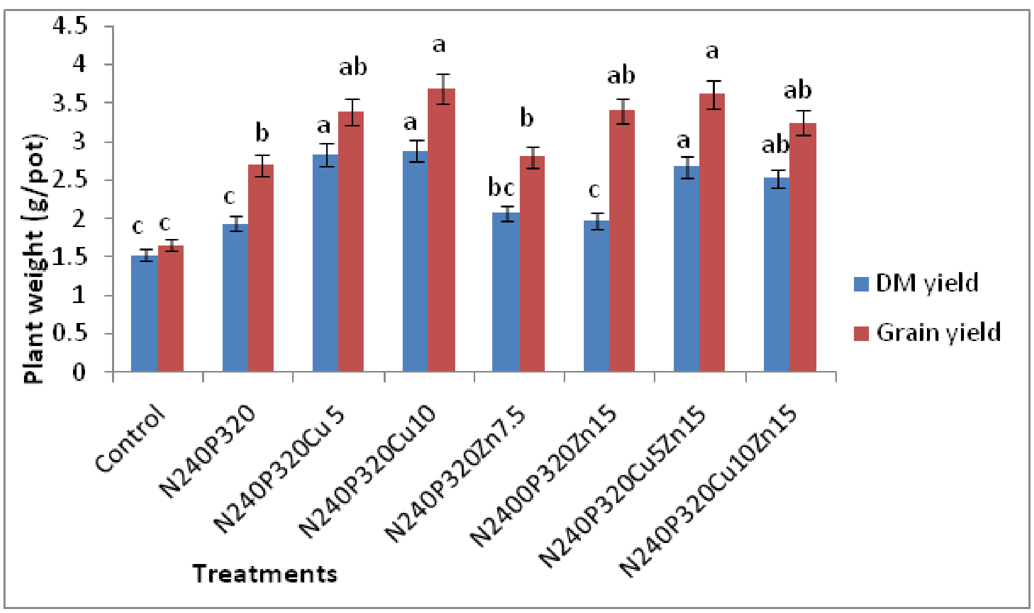
(b)

Figure 1: Effect fertilizers on (a) biomass and grain weight (b) height of rice plants grown in soils from Kyela district. N, P, Cu and Zn imply fertilizer nutrients applied while numbers indicate the rates of each nutrient applied (mg kg^{-1} soil). Bars followed by the same letters represent means which are not significantly different ($P<0.05$) according to Duncan's New Multiple Range Test.

grown in soil from both Ndembela and Makwenje significantly differed (P=0.05) in dry matter yields among fertilizer treatments. The control treatment had the lowest dry matter yields of 2.04 g pot^{-1} and 1.53 g pot^{-1} in both Ndembela and Makwenje soils, respectively (Figure 2). In Ndembela, soil a significant highest dry matter yield of beans was observed in the treatment containing NP+ Cu_{10} + Zn_{15} (Figure 2). Also, use of N and P fertilizers alone was



(a)



(b)

Figure 2: Effect of fertilizers on growth and yield performance of beans grown in (a) Ndembela and (b) Makwenje soils of Mbeya region, Tanzania. N, P, Cu and Zn indicate nutrients applied while numbers after each nutrient indicate the rates of nutrient applied (mg kg^{-1} soil). Bars followed by the same letters represent means which are not significantly different (P<0.05) according to Duncan's New Multiple Range Test.

not sufficient to significantly increase plant biomass accumulation beyond that of the control in Makwenje soil. All treatments with Cu had greater beans dry matter yields than yields under N and P alone or N and P with Zn (Figure 2), showing that Cu is the most limiting micronutrient in these soils. The combination of both Cu and Zn in addition to N and P gave the highest yields of 2.67 g pot^{-1} in Makwenje soil (Figure 2). Highest yields when Cu and Zn were applied in these soils imply that there was a good interaction of these nutrients that resulted in higher response in plant growth. Therefore, it is evident that Cu and Zn are the most limiting nutrients and their use at 10 mg Cu kg^{-1} and 15 mg Zn kg^{-1} is needed to correct the deficiencies in both soils.

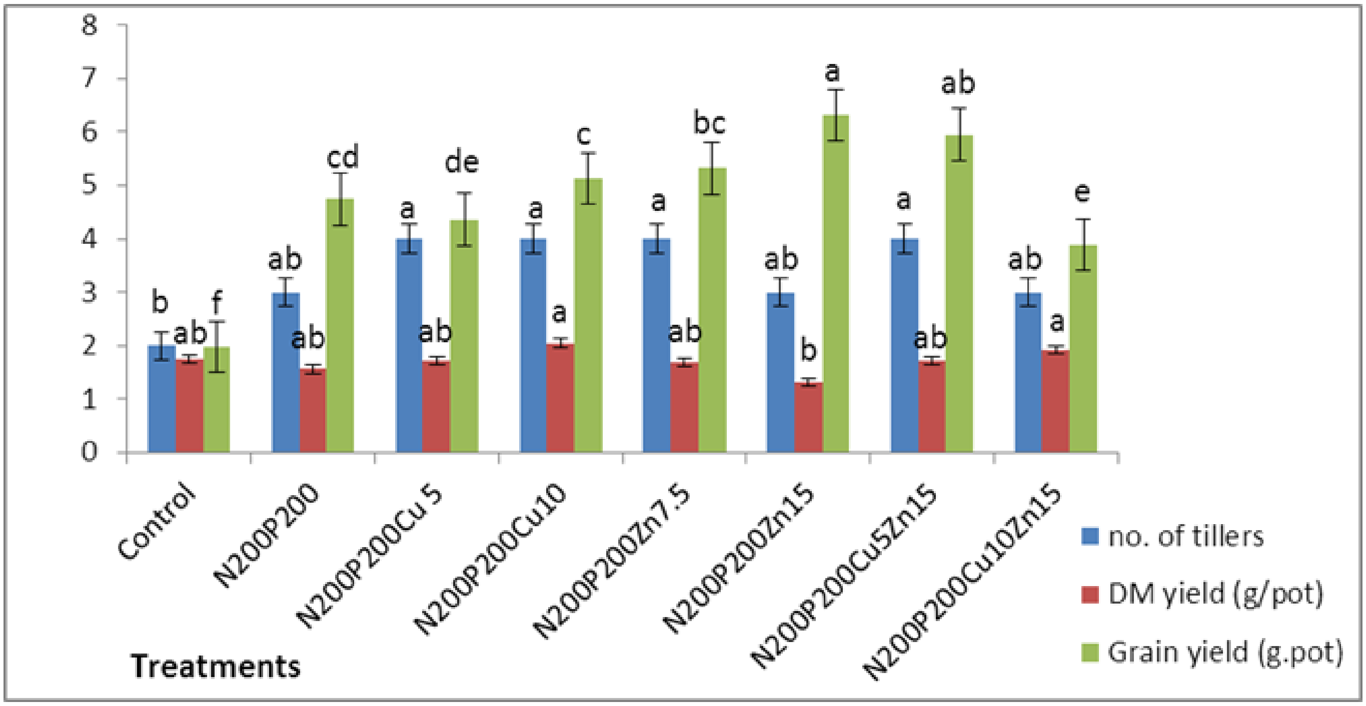


Figure 3: Growth and yield performance of wheat after fertilizer treatments in Mkuyuni soil of Mbeya rural, Tanzania. N, P, Cu and Zn indicate nutrients applied while numbers after each nutrient indicate the rates of each nutrient applied (mg kg^{-1} soil). Bars followed by the same letters represent means which are not significantly different (P<0.05) according to Duncan's New Multiple Range Test

Similarly, differences (*P*=0.05) were observed in the bean grain yields in the fertilizer treatments in both soils (Figure 2). The control pots performed the least in terms of grain yields in both sites (Ndembela and Makwenje soils), despite its biomass weights not being significantly different from some of the bean plants that received fertilizers. The fertilizer treatments resulted in significant differences (*P* = 0.05) in the yields of the seeds produced. In Ndembela soil, the highest grain yields were observed in treatments NP + Zn_{15} and NP + Cu_5 Zn_{15},(Figure 2a) while in Makwenje soil, the highest bean grain yields were observed in the treatments NP + Cu_{10} and NP + Cu_5 Zn_{15} (Figure 2b). Generally, the bean plants in Makwenje soil gave lower grain yields than those beans grown in Ndembela soil, regardless of having used the same bean variety and the same fertilizer treatments in both soils. This is probably due to difference in fertility status of the two soils (Table 3) because Makwenje soil showed Ca deficiency in addition to P, Zn, and Cu deficiencies. Thus, the use of CAN (calcium ammonium nitrate) as source of N and Ca could be better than use of urea.

Wheat

There were no visual nutrient deficiency symptoms observed during the first three weeks in all pots, including the control. However, three weeks after planting, the plants in the control treatment had thinner stems, with fewer tillers (2-3 tillers) than plants in pots where N, P, Zn and Cu fertilizers were applied. This implies that the nutrient deficiency was in the form of hidden-hunger. No significant differences (*P*=0.05) in number of tillers or plant heights were observed when fertilizers were applied to this soil (Figure 3). The NP and the NP with different levels of Zn and Cu treatments showed slightly greater though not significant (*P*= 0.05) wheat plant height and number of tillers than in the control treatment (Figure 3). Similarly, no yield differences (*P*= 0.05) in terms of dry matter were observed between the control and fertilized treatments. Thus, the growth of wheat plants showed no response to fertilization. However, the treatment that received highest level of Cu (with N and P) had significantly higher (*P* = 0.05) dry matter yield (2.05 g pot^{-1}) than the treatment that received NP with Zn15 (1.32 g pot^{-1}). This implies that Cu was the most limiting nutrient in this soil. This is in line with the soil Cu contents (Table 4) where Cu was low but Zn was high in Mkuyuni soil.

On the other hand, grain yields differed significantly (*P* =0.05) among the treatments. The highest grain yield of 6.31 g pot-1 was obtained in the treatment that contained the highest level of Zn in combination with N and P while predictably; the absolute control gave lowest grain yield (1.97g pot-1). The treatment with the highest level of Zn and Cu (NP + Cu_{10} Zn_{15}) decreased the seed yield to 3.98 g pot^{-1} relative to the NP and NP with low Cu and Zn rates and NP with Zn alone treatments. This means that the soil of Mkuyuni had inadequate levels of N, P, Zn and Cu for wheat production. Addition of fertilizers resulted in significant grain yield responses.

DISCUSSION

Most soils of the study areas were deficient in macro and micronutrients. Thus, use of N and P together with micronutrients fertilizers generally improved crop yields significantly. Long term cultivation without nutrients replenishment and/or inherent low nutrients in parent material might be the factors contributing to nutrients deficiency in these soils. Soils with very strong to strong acid pH also pose great reduction in nutrient availability especially P and Ca. These observations imply that there could be a widespread problem of nutrients deficiency in many soils of Mbeya and, possibly, other parts of the country with similar soil properties.

The poor performance of all crops in the control treatments indicates that these soils had inadequate levels of plant nutrients and/or poor availability of plant nutrients. Thus addition of essential plant nutrients in the form of fertilizers for these soils is needed for adequate plant growth. Amendments to adjust pH or appropriate choice of fertilizer type is also necessary for soils with pH < 5.5, such as use of agricultural lime, Minjingu phosphate fertilizers as P source and CAN as N source may give better crop yields. Results obtained in this study are in line with the study conducted in Brazil where Zn and Cu improved dry matter yields in upland rice and bean plants (Fageria, 2002). However, a decrease in dry matter yields was observed at the highest rate of Cu application (Fageria, 2002), as was also observed in wheat in the present study when Cu and Zn were at 10 and 15 mg kg^{-1}, respectively. Similar results were reported in rice plants grown on soils from Pakistan (Cheema et al., 2006), and, in wheat grown in Pakistan (Khan et al., 2006), and Anatolia (Cakmak et al., 1999).

The low levels of nutrients in these soils possibly affected the yield attributes in beans, rice and wheat. It is possible that the wide array of crops grown in the region may be similarly affected by the deficiency of these nutrients. In other words, the quality of the crops grown in these soils may be low with respect to those nutrients. Some soils of the study areas were deficient in both macro and micronutrients, especially N and P, Zn and Cu, and this may be a reflection of the soil fertility status of the entire region. Thus, use of fertilizers to improved crop yields significantly is necessary in these nutrient deficient soils. Application of N and P fertilizer increased grain yield by 80.0%, 18.8% and 17.5% relative to no fertilizer use in rice, beans and wheat, respectively. The use of 5 mg Cu kg^{-1} and 15 mg Zn kg^{-1} in addition to N and P fertilizers further increase the yields by 13%, 31% and 15% relative to the N and P fertilization in rice, beans and wheat, respectively. The pot experiments estimated the rate of 15 mg Zn kg^{-1} in some fertilizer combination to be the optimum for maximizing grain yields of rice, wheat and beans while the rate of 5 mg Cu kg^{-1} seemed to optimize grain yields in all crops.

Therefore, these preliminary results indicate that there is a need to carry out field studies so as to optimize the use of these nutrients for maximum crop yields and improve the quality of the crops.

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