Influence of micronutrients on dry matter yield and interaction with other nutrients in annual crops[1]

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Abstract – The objective of this work was to determine the influence of Zn, Mn and Cu on shoot dry matter yield and uptake of macro and micronutrients in upland rice, common bean and corn. Six greenhouse experiments were conducted using a Dark Red Latosol (Typic Haplusthox). Treatments consisted of application of Zn at 0, 5, 10, 20, 40, 80 and 120 mg kg^{-1}, of Mn at 0, 10, 20, 40, 80, 160, 320 and 640 mg kg^{-1} and of Cu application at 0, 2, 4, 8, 32, 64 and 96 mg kg^{-1}. Zinc increased yield of rice, Mn increased yields of corn and bean and Cu improved yields of rice and bean. Uptake of N, Ca, and Cu in rice was decreased by zinc treatment. In common bean, uptake of N, Mg, and Cu was increased by zinc application, whereas, uptake of P was decreased. Manganese increased uptake of Mg, Zn and Fe and decreased uptake of Ca, in corn. Uptake of K, Zn and Mn was increased and uptake of P and Cu was decreased by Mn application, in bean. Copper had positive and negative interactions in the uptake of macro and micronutrients, depending on crop species and nutrients involved.

Index terms: cerrado soils, nutrient uptake, cereal crops, yields.

Influência de micronutrientes na produção de matéria seca e interação com outros nutrientes em culturas anuais

Resumo – O objetivo deste trabalho foi determinar a influência do Zn, Mn e Cu na produção de matéria seca e na absorção de nutrientes pelo arroz de terras altas, feijoeiro e milho. Foram conduzidos seis experimentos em casa de vegetação, num Latossolo Vermelho-Escuro. Os tratamentos constituíram-se de 0, 5, 10, 20, 40, 80 e 120 mg kg^{-1} de Zn, 0, 10, 20, 40, 80, 160, 320 e 640 mg kg^{-1} de Mn e 0, 2, 4, 8, 32, 64 e 96 mg kg^{-1} de cobre. O Zn aumentou a produção de arroz, o Mn aumentou a produção de milho e feijão, e o Cu aumentou a produção de arroz e feijão. O Zn diminuiu a absorção de N, Ca e Cu pelo arroz. No feijoeiro, o Zn aumentou a absorção de N, Mg e Cu e diminuiu a absorção de fósforo. No milho, o Mn aumentou a absorção de Mg, Zn e Fe e diminuiu a absorção de cálcio. A absorção de K, Zn e Mn aumentou no feijoeiro com a aplicação de Mn, porém, a absorção de P e Cu diminuiu. O Cu mostrou efeitos positivo e negativo na absorção de macro e micronutrientes dependendo das espécies e nutrientes envolvidos.

Termos para indexação: solo de cerrado, absorção de nutriente, cultivo de cereais, rendimento.

Introduction

The importance of micronutrients in crop production is increasing in recent years due to use of high yielding cultivars, intensive cropping systems, and liming of acid soils. Most of the cerrado soils are acidic and liming is an essential practice to improve soil pH and decrease toxicity of Al^{3+} (Fageria & Baligar, 2001; Ernani et al., 2002). Liming significantly increases grain yields of annual crops such as common bean, soybean, and corn grown on Oxisols of cerrado (Barbosa Filho & Silva, 2000; Fageria & Baligar, 2001). However, liming decreases uptake of all micronutrients except Mo (Fageria et al., 1997). Hence, liming may induce micronutrients deficiencies. Fageria (2000) reported Fe deficiency in upland rice when pH of cerrado soil was raised more than 6.0 by liming. This means requirements of crops for micronutrients change, when these soils are limed to produce good yields of legumes like common bean and soybean. Deficiencies of micronutrientes in cerrado soils had been widely reported in annual crops (Galrão, 1984, 1991; Couto et al., 1992; Couto

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& Klamt, 1999; Galrão, 1999; Oliveira Júnior et al., 2000; Fageria et al., 2002).

Nutrient interaction in crop plants is probably one of the most important factors affecting yields of annual crops. Nutrient interaction can be either positive, negative or neutral (Fageria et al., 1997). It can be measured in terms of crop growth and nutrient concentrations in plant tissue. Soil, plant and climatic factors can influence interaction. In the nutrient interaction studies, all other factors should be at an optimum level, except the variation in level of the nutrient under investigation. Nutrient interaction can occur at the root surface or within the plant. Interactions at the root surface are due to formation of chemical bonds by ions and precipitation or complexes. One example of this type of the interaction is the decrease in the concentration of Fe, Zn, Cu and Mn with liming of acid soils (Fageria, 2000; Fageria et al., 2002). The second type of interaction is between ions whose chemical properties are sufficiently similar and they compete for site of absorption, transport, and function on plant root surface or within plant tissues. Such interactions are more common between nutrients of similar size, charge and geometry of coordination and electronic configuration (Robson & Pitman, 1983).

Interactions vary from nutrient to nutrient, from crop species to species and sometimes among cultivars of the same species. Therefore, this is a very complex issue in mineral nutrition and not well understood in annual crops grown on Oxisols. Information on response of annual crops to micronutrients grown on cerrado soils to micronutrients and influence of micronutrients on uptake of other nutrients is limited.

The objective of this research was to determine the influence of zinc, manganese and copper on shoot dry matter yield and uptake of macro and micronutrients in upland rice, common bean and corn grown on an Oxisol.

Material and Methods

Zinc experiments

Two greenhouse experiments were conducted at the Embrapa-Centro Nacional de Pesquisa de Arroz e Feijão, Santo Antônio de Goiás, GO, Brazil, to study the interaction of zinc with other nutrients in upland rice (*Oryza sativa* L.) and common bean (*Phaseolus vulgaris* L.) grown on a Dark Red Latosol (Typic Haplusthox). Chemical properties of soil used in these experiments were: pH 5.7 in water (1:2.5); P, 0.6 mg kg^{-1}; K, 53 mg kg^{-1}; Ca, 2 cmol$_c$ kg^{-1}; Mg, 0.4 cmol$_c$ kg^{-1}; Al, 0.1 cmol$_c$ kg^{-1}; Cu, 1.7 mg kg^{-1}; Zn, 0.9 mg kg^{-1}; Fe, 112 mg kg^{-1}; Mn, 10 mg kg^{-1} and organic matter 17 g kg^{-1}. Textural analysis was clay, 385 g kg^{-1}; silt, 265 g kg^{-1} and sand, 350 g kg^{-1}. Phosphorus, K and the micronutrients were extracted by the Mehlich 1 extracting solution (0.05 M HCl + 0.0125 M H_2SO_4). The P was determined colorimetrically, K by flame photometry, and micronutrients by atomic absorption spectrophotometry. The Ca, Mg, and Al were extracted with 1 M KCl. The Al was determined by titration with NaOH, and Ca and Mg by titration with EDTA. Organic matter was determined by the Walkley-Black method in which oxidizable matter in a soil sample is oxidized by 1 N $K_2Cr_2O_7$ and H_2SO_4 solution and titration with standard $FeSO_4$ solution. Detailed descriptions of all the soil analysis methods are given in the Soil Analysis Manual (Embrapa, 1997).

Experiments were conducted in plastic pots with 5 kg of soil in each pot. Zinc levels used were 0, 5, 10, 20, 40, 80, and 120 mg kg^{-1} of soil applied as Zn sulfate. Each pot received 400 mg N as ammonium sulfate, 983 mg P as triple superphosphate and 896 mg K as potassium chloride. Experimental design was complete block with three replications and four plants in each pot. Rice plants were harvested 42 days after sowing and common bean plants were harvested 35 days after sowing.

Manganese experiments

Two greenhouse experiments were conducted to study influence of Mn on uptake of nutrients in corn and common bean plants. The soil used in two experiments was a Dark Red Latosol (Typic Haplusthox). Before application of Mn treatments, the soil used in the two experiments had the following chemical properties: pH, 5.5; Ca, 2 cmol$_c$ kg^{-1}; Mg, 1.3 cmol$_c$ kg^{-1}; Al, 0.2 cmol$_c$ kg^{-1}; P, 9 mg kg^{-1}; K, 44 mg kg^{-1}; Cu, 0.9 mg kg^{-1}; Zn, 4 mg kg^{-1}; Fe, 53 mg kg^{-1}; Mn, 8 mg kg^{-1} and organic matter content of 20 g kg^{-1}. Soil analysis methods was the same as described above in the zinc experiments.

Eight rates of Mn were applied through manganese sulfate for corn, to create different levels of soil manganese. These Mn rates were 0, 10, 20, 40, 80, 160, 320, and 640 mg kg^{-1}. For common bean, Mn levels used were 0, 10, 20, 40, 80, 160, and 320 mg kg^{-1} of soil and were also applied through manganese sulfate. The experiments were conducted in plastic pots with each pot contained 5 kg of soil. Each pot also received 400 mg N through

$(NH_4)_2SO_4$, 787 mg P through triple superphosphate, and 797 mg K through KCl. These basal fertilizer rates were based on an earlier work (Fageria & Baligar, 1997). The experiment design in two experiments was a complete block with three replications. There were four plants per pot in both experiments and soil moisture was maintained approximately at field capacity. Plants were harvested four weeks after sowing in both experiments.

Copper experiments

Two greenhouse experiments were conducted to evaluate interaction of Cu with other nutrients in the upland rice and common bean. The soil used in these two experiments was a Dark Red Latosol (Typic Haplusthox). Before application of Cu treatments, the soil used in two experiments had the following chemical properties: pH, 5.3; Ca, 0.3 $cmol_c$ kg^{-1}; Mg, 0.4 $cmol_c$ kg^{-1}; Al, 0.6 $cmol_c$ kg^{-1}; P, 0.4 mg kg^{-1}; K, 23 mg kg^{-1}; Cu, 1 mg kg^{-1}; Zn, 0.5 mg kg^{-1}; Fe, 65 mg kg^{-1}; Mn, 17 mg kg^{-1}, and organic matter content of 15 g kg^{-1}. Methods used in these experiments for soil analysis were similar to those given in the zinc experiments.

The Cu levels used were 0, 2, 4, 8, 16, 32, 64, and 96 mg kg^{-1} of soil applied as copper sulfate. Before application of Cu treatments and basal fertilization, each pot received 23 g dolomitic lime and were incubated for four weeks. The lime used had CaO 30.8%, MgO 18.4%, $CaCO_3$ 55%, $MgCO_3$ 38.6%, and neutralizing power of $CaCO_3$ 87%. This lime rate was selected on the basis of earlier work in which soil pH of 5.1 was increased to 6.0 with the application of this rate and pH 6.0 was established as an optimum value for the growth of most crop species (Fageria et al., 1997). In the Cu experiments, rice plants were harvested four weeks after sowing, whereas, common bean plants were harvested three weeks after sowing. The experiment design in two experiments was a complete block with three replications.

In Zn, Mn and Cu experiments, after harvesting, the shoots were washed with distilled water several times before drying. Plant material was dried in a forced draft oven at about 70°C to constant weight, and was milled. Ground material was digested with mixtures of nitric and perchloric acids (2:1). In the digested material, P was determined colorimetrically and the other nutrients were analyzed by atomic absorption spectroscopy (Moraes & Rabelo, 1986). For N determination, dried plant material was digested with sulfuric acid and was analyzed by a semimicro-Kjeldahl method (Bremner & Mulvaney, 1982) using a Kjeltec Systems Tecator 1016 digesting and distilling unit.

Data were analyzed by analysis of variance and appropriate regression models selected on the basis of higher R^2 values were adjusted to evaluate treatment effects. In quantitative treatments such as levels of micronutrients, regression analysis is a more appropriate statistical technique to evaluate treatment effects. Therefore, for discussion purpose, regression analysis was taken into account to evaluate treatment effects.

Results and Discussion

Data related to the influence of Zn application on dry matter yield of upland rice and common bean and uptake of macro and micronutrients are presented in Table 1. Dry matter yield of upland rice was significantly increased with the Zn application, however, yield of common bean had significant negative influence of Zn application. Many workers (Fageria et al., 1997; Fageria et al., 2002) have reported positive influence of Zn on upland rice yield in Brazilian Oxisols. Increasing Zn concentration in the soil significantly improves uptake of Zn in rice as well as common bean plants as expected. Rice plants had much higher concentration of Zn as compared to bean plants. This means Zn requirement for rice is much higher as compared to common bean plants grown on an Oxisol. The differences between crop species and between cultivars within species in Zn uptake and utilization have been widely reported (Cakmak et al., 1998; Baligar & Fageria, 2001). This may be related to a better internal utilization of Zn in bean plants leading to a higher growth rate at low internal Zn concentration as compared to rice plants. These results also indicate that upland rice can tolerate much higher concentration of Zn as compared to bean plants. Fageria et al. (2002) reported critical toxic level much higher in rice plants as compared to common bean plants. Uptake of N and Cu was significantly decreased in rice plants. In common bean, application of Zn significantly improved uptake of N, Mg and copper. However, Zn had significant negative interaction with P uptake. Zinc and P interactions have been reported positive as well as negative (Sumner & Farina, 1986; Wilkinson et al., 2000). Data related to interactions of Zn with other nutrients are scarce and therefore it is not possible to compare results of this study with those reported in the literature.

Response and interactions of manganese with other nutrients were studied in corn and common bean and results are presented in Table 2. Manganese application significantly increased corn as well as common bean dry matter yield. In Oxisols of central Brazil, liming generally induce micronutrient deficiencies and Mn application improved yield of annual crops (Novais et al., 1989). Manganese application significantly increased Mn uptake in corn and common bean plants. However, it was much higher in common bean plants especially at higher Mn levels. This means Mn requirement for common bean is higher as compared to corn.

Manganese application significantly improved uptake of Mg, Zn and Mn in corn. However, uptake of Ca and Fe was significantly decreased with the addition of Mn in the growth medium. Chinnery & Harding (1980) have reported antagonistic effect of Mn on the uptake of Fe and vice-versa. They reported that concentration of Mn in the soybean shoots decreased with increased Fe concentration in the solution, probably an oxidation of Fe by manganese. Leach & Taper (1954) concluded that the optimum Fe/Mn ratios in plants ranged from 1.5 to 3.0 for kidney bean and from 0.5 to 5.0 for tomato. Iron deficiency developed at lower ratios and Mn toxicity at higher ratios. This means, antagonistic interaction between Mn and Fe has some practical implications. For example Fe toxicity is very common in flooded rice due to reduced conditions and Mn toxicity is common in legumes in acid soils when pH is lower than 5.5 (Fageria et al., 1997). Therefore, Fe toxicity in flooded rice can be reduced by Mn application and Mn toxicity in acid soil can be minimized by Fe application. There was no significant effect of Mn on uptake of P, K, and Cu in corn plants. In common bean plants, Mn addition had significant synergistic effect on the uptake of K, Zn and manganese. But Mn had antagonistic effect on uptake of P and Cu in common bean plants.

Table 1. Influence of zinc on dry matter yield and uptake of macronutrients and micronutrients by upland rice and common bean plants.

Zn ($mg\ kg^{-1}$)	Shoot dry wt. (g four $plants^{-1}$)	N	P	K	Ca	Mg	Zn	Cu	Mn	Fe
		($g\ kg^{-1}$)					($mg\ kg^{-1}$)			
					Upland rice					
0	1.73	42.75	2.25	28.50	7.32	4.05	28	13	1,075	115
5	2.05	42.25	2.20	29.00	6.75	3.77	71	14	740	125
10	2.35	40.50	2.20	30.25	6.82	3.80	87	12	663	135
20	2.15	41.50	1.87	30.75	6.95	3.75	125	12	643	113
40	2.13	39.50	2.20	25.50	6.40	3.55	363	12	785	115
80	1.97	37.50	2.27	25.50	6.47	3.77	718	11	593	128
120	1.53	40.25	2.15	25.75	6.32	3.50	863	10	440	103
F test	**	**	ns	*	**	**	**	**	**	ns
CV (%)	10	2	8	10	5	4	18	6	24	18
Regression										
β_0	1.9770	42.7362	2.1607	29.9250	7.0708	3.8849	-4.3774	13.1163	846.6214	120.2178
β_1	0.00988	-0.12598	-0.00048	-0.08676	-0.01602	-0.00591	10.40388	-0.03553	-4.48579	0.17951
β_2	-0.00011	0.00086	0.000006	0.00042	0.00008	0.00003	-0.02510	0.00008	0.01074	-0.00248
R^2	0.6693^{*}	0.8582^{*}	0.11^{ns}	0.6161^{ns}	0.7232^{*}	0.5149^{ns}	0.9864^{**}	0.8012^{*}	0.5495^{ns}	0.3096^{ns}
					Common bean					
0	5.37	41.00	1.80	24.25	19.20	8.22	17	4.75	108	125
5	5.33	40.00	1.82	22.25	19.52	8.20	56	4.50	108	115
10	5.27	40.25	1.45	23.25	20.65	8.37	73	5.00	128	140
20	5.02	41.25	1.32	27.00	19.85	8.40	92	4.75	93	95
40	4.67	40.50	1.10	22.50	21.45	8.45	150	5.50	123	150
80	4.67	40.75	1.05	24.50	18.87	8.02	215	5.00	125	133
120	3.97	38.50	1.02	21.25	18.70	7.72	313	4.25	120	133
F test	ns	ns	**	ns	ns	ns	**	ns	ns	ns
CV (%)	13	7	15	13	9	6	27	21	19	18
Regression										
β_0	5.3385	40.3737	1.7625	23.5014	19.6611	8.2587	35.5717	4.6029	108.3553	119.2847
β_1	-0.01206	0.02868	-0.01990	0.04532	0.03232	0.00599	2.79364	0.02542	0.30915	0.41045
β_2	0.00001	-0.00036	0.00011	-0.00052	-0.00036	-0.00009	-0.00441	-0.00023	-0.00167	-0.00248
R^2	0.9267^{**}	0.7272^{*}	0.9269^{**}	0.2810^{ns}	0.4447^{ns}	0.8822^{*}	0.9864^{**}	0.7387^{*}	0.2001^{ns}	0.1280^{ns}

^{ns}No-significant. * and **Significant at 5% and 1% probability levels, respectively.

Influence of Cu on the dry matter yield of rice and common bean and the effects of Cu on uptake of macro and micronutrients are presented in Table 3. Copper application significantly increased dry matter yield of upland rice and common bean. However, dry matter yields of two species were decreased at the highest Cu concentration. Beneficial effect of Cu on yield of annual crops has been reported by Galrão (1999), grown on an Oxisol of central Brazil. At higher level, Cu toxicity is related to directly or indirectly affects the metabolic processes such as respiration, photosynthesis, CO_2 fixation and gas exchange (Mocquot et al., 1996). Copper in excess interferes with the plant capacity of absorbing or translocating other nutrients, inhibiting root elongation and adversely affecting the permeability of the root cell membrane (Woolhouse & Walker, 1981). Copper in excess also has a destructive effect on the integrity of the chloroplast membrane, leading to a decrease in photosynthetic activity (Mocquot et al., 1996).

Application of Cu significantly increased Cu concentrations in the shoots of two crop species. However, Cu accumulation was higher in the shoot of upland rice as compared with Cu shoot concentration of common bean. This means common bean was more efficient in dry matter production at low Cu concentration as compared with rice plants. This can also be confirmed on the basis of dry weight production. Copper had significant synergistic effect on the uptake of P, K, and Mn in the upland rice plants. However, concentration of Ca, Mg and Fe were significantly decreased in these plants with the application of copper. Copper did not influence significantly uptake of Zn in rice plants. In bean plants, Cu appli-

Table 2. Influence of manganese on dry matter yield and uptake of macronutrients and micronutrients by corn and common bean plants.

Mn level ($mg\ kg^{-1}$)	Shoot dry wt. ($g\ four\ plants^{-1}$)	P	K	Ca	Mg	Zn	Cu	Mn	Fe
		($g\ kg^{-1}$)				($mg\ kg^{-1}$)			
				Corn					
0	17.93	1.93	23.66	4.36	2.60	24	3.00	87	113
10	20.83	1.63	23.00	4.26	2.40	20	2.00	147	117
20	17.70	1.90	24.33	4.20	2.47	23	3.33	193	123
40	20.00	1.70	22.00	3.93	2.53	21	2.67	363	117
80	20.40	1.73	22.33	4.30	2.70	25	3.00	553	113
160	19.80	1.50	23.33	3.43	2.37	23	2.33	1,067	90
320	20.20	1.50	22.66	3.53	2.53	27	2.66	2,067	93
640	13.77	1.63	25.00	2.93	2.03	32	2.66	3,567	110
F test	**	**	ns	**	**	**	**	**	ns
CV (%)	9	7	11	9	7	6	15	30	16
Regression									
β_0	18.8858	1.8264	23.3422	4.2768	2.5061	22.0657	2.7901	68.5686	120.1196
β_1	0.01523	-0.00201	-0.00635	-0.00362	0.00049	0.01233	-0.00122	6.7715	-0.17238
β_2	-0.00004	0.000003	0.00001	0.000002	-0.000002	0.000005	0.000002	-0.00202	0.00024
R^2	0.8100*	0.6355^{ns}	0.5256^{ns}	0.8545**	0.7099*	0.8326*	0.0366^{ns}	0.9994**	0.7784*
				Common bean					
0	14.47	2.33	32.33	10.77	4.07	36	4.00	70	137
10	14.77	2.17	31.67	10.93	4.17	35	5.33	210	180
20	15.93	2.13	31.33	10.60	3.97	36	4.67	360	207
40	17.23	2.26	32.33	11.10	4.23	36	5.00	520	170
80	15.67	2.23	32.00	11.37	4.33	38	4.00	1,300	120
160	14.30	2.07	38.67	10.36	4.27	42	5.33	1,933	123
320	11.43	1.77	42.00	9.43	4.27	55	6.67	2,367	83
F test	*	ns	**	ns	ns	**	ns	**	ns
CV (%)	11	17	7	7	5	6	26	29	49
Regression									
β_0	15.3295	2.2676	31.1135	10.6923	4.0757	35.3849	4.6440	33.9744	175.2400
β_1	0.00937	-0.00144	0.03743	0.00426	0.00264	0.02027	-0.00122	16.78395	-0.40949
β_2	-0.00007	-	-0.000008	-0.00003	-0.000006	0.00012	0.00002	-0.02968	0.00037
R^2	0.7641*	0.8335*	0.9131**	0.6059^{ns}	0.5499^{ns}	0.9968**	0.6877*	0.9932**	0.6387^{ns}

^{ns}No-significant. * and **Significant at 5% and 1% probability levels, respectively.

Table 3. Influence of copper on dry matter yield and uptake of macronutrients and micronutrients by upland rice and common bean plants.

Cu ($mg\ kg^{-1}$)	Shoot dry wt. (g four $plants^{-1}$)	P	K	Ca	Mg	Zn	Cu	Mn	Fe
		($g\ kg^{-1}$)				($mg\ kg^{-1}$)			
				Upland rice					
0	1.87	3.03	34.67	4.93	3.67	29	14	260	217
2	1.87	3.17	35.33	4.43	3.60	29	17	327	143
4	1.90	3.10	38.33	4.56	3.60	31	18	310	130
8	2.03	3.27	33.33	4.87	3.63	30	21	293	127
16	2.00	2.77	37.67	4.87	3.63	36	17	303	127
32	1.87	2.93	36.67	4.77	3.60	31	20	327	113
64	2.00	2.93	37.67	4.97	3.73	27	27	340	148
96	0.30	1.63	26.67	6.10	4.43	35	34	163	227
F test	**	**	**	**	**	ns	**	ns	*
CV (%)	8	6	8	7	2	13	15	29	27
Regression									
β_0	1.8025	3.0398	34.7534	4.7570	3.6232	30.8922	16.6087	280.7075	164.6425
β_1	0.02380	0.00856	0.20496	-0.00857	-0.00528	-0.04641	0.10622	3.5814	-2.79529
β_2	-0.00039	-0.00023	-0.00294	0.00022	0.00027	0.00076	0.00078	-0.04890	0.03648
R^2	0.9137^{**}	0.8504^{**}	0.7729^{*}	0.8571^{**}	0.9956^{**}	0.1122^{ns}	0.9221^{**}	0.8158^{*}	0.6892^{*}
				Common bean					
0	5.03	1.87	35.33	18.30	8.20	19	4.33	97	190
2	5.70	1.93	36.67	18.27	8.30	18	5.00	63	203
4	6.63	2.13	34.33	18.43	8.23	17	6.33	67	403
8	6.63	1.90	39.33	18.60	8.23	19	7.67	77	193
16	5.00	1.90	40.00	20.33	8.67	21	6.33	73	163
32	4.60	1.77	27.67	18.53	8.33	20	8.00	80	190
64	4.70	1.73	38.00	17.63	8.40	20	10.33	67	233
96	0.63	1.93	28.33	19.50	8.53	25	15.33	37	280
F test	**	ns	**	ns	ns	ns	**	**	ns
CV (%)	34	7	11	6	4	17	11	20	49
Regression									
β_0	5.7182	1.9896	36.2765	18.7271	8.2708	18.5881	5.5117	75.1137	244.9650
β_1	0.01204	-0.00927	-0.00018	-0.01188	0.00536	0.01400	0.05815	0.27063	-2.50400
β_2	-0.00064	0.00009	-0.00071	0.00016	-0.00003	0.00048	0.00043	-0.00681	0.03074
R^2	0.8374^{*}	0.5059^{ns}	0.2537^{ns}	0.0443^{ns}	0.2967^{ns}	0.7468^{*}	0.9370^{**}	0.6274^{ns}	0.1302^{ns}

^{ns}No-significant. * and **Significant at 5% and 1% probability levels, respectively.

cation significantly increased uptake of Zn and had no significant effect on uptake of P, K, Ca, Mg, Mn and iron. Lexmond & Vorm (1981), Ouzounidou et al. (1995) and Mocquot et al. (1996) reported synergistic, antagonistic or no effect of Cu on the uptake of macro and micronutrients depending on crop species and concentration of copper.

Conclusions

1. Zinc, Mn and Cu requirements in annual crops grown on Oxisols vary among crop species.
2. Upland rice responds to Zn fertilization but for common bean, Zn application does not improve yield and has negative effect.
3. Corn and common bean yields improve with Mn application.
4. Copper fertilization increases dry matter yield of upland rice and common bean.
5. Rice has higher concentration of Cu as compared with common bean for the maximum dry matter yield.
6. Interactions of Zn, Mn, and Cu with macro and micronutrients are either synergistic, antagonistic or have no effects, depending on crop species and nutrients under investigation.

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