academicJournals

Vol. 9(11), pp. 963-970, 13 March, 2014
DOI: 10.5897/AJAR2013.7623
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Soil and foliar application of Zinc to maize and wheat grown on a Zambian Alfisol

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Received 9 July, 2013; Accepted 20 February, 2014

The deficiency of zinc (Zn) in human nutrition, commonly found in cereal-based diets accounts for impaired growth (stunting) in children. Since cereals are generally low in this element, bio-fortification may represent an opportunity to increase Zn intake by humans. A study was carried out to evaluate Zn uptake by maize and wheat when they are supplied with increasing rates of foliar or soil applied Zn. Maize and wheat were grown in the field and supplied with 0, 10, 20, 30, or 40 kg Zn ha^{-1} as $ZnSO_4$ applied to the soil, or, 0,1,2,4, or 8 kg Zn ha^{-1} as foliar spray. Zinc application to soil increased maize and wheat yields beyond increments obtained with foliar application, but Zn mass concentration in maize grain was better with foliar applications. Mean maize yield was 1.78 ton ha^{-1} with soil application and 1.14 ton ha^{-1} with foliar application. This was in relation to an average of 52 mg Zn uptake by maize under each of the application methods. Wheat yield was 3.69 ton ha^{-1} under soil application and 2.74 ton ha^{-1} under foliar application. In this case, Zn uptake was higher under soil application (11.31 mg) than under foliar application (7.25 mg). Sesquioxide bound Zn was shown to be best correlated with plant Zn uptake. It was shown that Zn application is beneficial on Zambian soils, and while soil application increases crop yields, foliar application can be more useful to increase Zn mass concentration in maize.

Key words: Foliar spray, maize grain yield, wheat grain yield, zinc fractions, zinc uptake.

INTRODUCTION

Zinc (Zn) deficiency in diet is common among developing nation communities that are highly reliant on cereal-based diets (Jiang et al., 2008; Welch, 1993). This is attributed to inherently infertile soils, soil micronutrient depletion from intensification of cultivation, and general low use of fertilizers, as well as poor mobility of Zn into and within plant. Therefore health challenges such as impaired growth (stunting) in children arise (Hambridge et al., 1986). In order to reverse this trend, application of Zn fertilizer can enhance plant Zn mass concentration. However it is known that numerous factors affect Zn availability leading to reduced or enhanced availability of Zn in the soil.

Zinc deficiency symptoms tend to be slow to appear on crops in arid and semi-arid regions because deficiencies of nitrogen (N), phosphorus (P) and potassium (K) are

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Table 1. Some chemical and physical characteristics of soils used in the greenhouse study.

Soil series	Land use /designation	pH	OM	CEC	Sand	Silt	Clay	Texture
			g kg^{-1}	cmol kg^{-1}		g kg^{-1}		
Nakambala	Cropped	4.8	3.7	28.8	372	256	372	l
	Fallow	5.6	5.1	34.8	392	216	392	l
Makeni	Cropped–11North	7.0	3.9	35.5	332	286	382	l
	Fallow	6.6	8.9	44.8	472	146	382	l
Kashinka	Cropped	7.2	2.6	15.1	532	176	292	Sl
Chilimboyi	Field A	7.2	1.3	14.6	552	136	312	Sl
	Field B	7.1	1.3	13.8	512	136	352	Sl
	Field C	7.5	1.7	10.7	612	96	292	Sl
Chelstone	Field H	4.7	6.7	6.0	632	36	332	Sl
	Fallow	5.3	6.6	4.9	672	36	292	Sl
	Orchard	7.0	6.6	12.6	562	96	342	Sl
Ifisa	Cultivated	7.1	0.5	7.9	612	76	312	Sl
	Fallow	5.4	1.4	7.6	572	56	372	Sl
Chalimbana	Cultivated	6.7	2.6	15.9	652	86	262	Sl
Mushemi	Cultivated	5.7	1.3	6.1	752	36	212	Ls
	Fallow	5.7	1.4	7.1	732	36	232	Ls
Mpongwe	Cultivated	6.5	4.6	34.0	472	196	332	L
	Fallow	4.4	3.2	21.4	552	156	292	Sl
Misamfu Red	Cultivated	4.2	1.6	6.0	756	128	116	Sl
	Fallow	4.7	2.6	7.3	816	68	116	Ls
Mufulira	Cultivated	4.1	1.3	5.3	836	88	76	Ls
	Fallow	4.2	1.6	4.9	736	88	176	Sl

l = loam, ls = loamy sand, sl = sandy loam.

more likely to be expressed by affected plants much sooner than that of Zn (Mapiki and Phiri, 1995). For this reason, whereas application of Zn fertilizer should be an essential component of soil fertility management, it is still seen that compound NPK fertilizers are those normally used. In Zambia, Banda and Singh (1989) proposed a soil available Zn critical level of 0.8 mg kg^{-1} below which it is recommended to apply Zn fertilizer. Local data from various laboratories here show that Zn availability index is low in most of the soils.

Native soil Zn exists in various pools with different rates of solubility, mobility and plant availability (Adriano, 2001). This partitioning of Zn is influenced by soil pH, clay content, organic matter and sesquioxides. Arid and semi-arid region soils that are low or high in pH, low or high in organic matter content, sandy, calcareous, or water-logged are commonly deficient in Zn (Takkar and Walker, 1993). In order to supply Zn to crops grown on these soils, the method of application for effective availability and absorption by plants can be a critical concern. Therefore affordable interventions aimed at raising cereal grain Zn mass concentration could include application of Zn to soil or as foliar sprays. Traditionally, soil application is widespread, however positive response to foliar Zn application has been reported for maize (Grzebisz et al., 2008), sugarcane (Panhwar et al., 2003) and wheat (Erenoglu et al., 2002), among others. In fact, Liew (1988) suggested that foliar micronutrient application could bring about a 6 to 20 times efficiency in crop productivity. On the other hand, Rashid et al. (2000) observed that Zn fertilization to seed-bed was more effective than when broadcasted in the field. The objectives of this study were to investigate which soil Zn pool is most associated to plant Zn uptake, and to determine the response of maize and wheat crops to increasing rates of Zn applied as foliar spray or to soil.

MATERIALS AND METHODS

Greenhouse study

Three kilograms of surface soil sample obtained from cultivated and uncultivated sites at eleven locations around Zambia (Table 1) was placed in polythene pots in the greenhouse. Thereafter six grams of

Table 2. Chemical and physical properties of the UNZA Field Station soil used for the field study.

Field	pH	O.M	N	CEC	Mg	Ca	K	Na	P	Zn	Fe	Cu	Mn	Sand	Silt	Clay	Texture
		%		cmol kg^{-1}					mg kg^{-1}					%			
Maize field	7.2	1.3	0.05	14.6	2.3	5.6	0.7	0.4	7.8	0.5	4.0	0.5	22.4	55.2	13.6	31.2	sl
Wheat field	7.1	1.3	0.06	13.8	2.3	5.3	1.3	0.9	11.4	2.2	4.8	1.1	18.5	51.2	13.6	35.2	sl

sl = sandy loam.

Compound "D" fertilizer (10:20:10) was added to each pot and eight seeds of wheat (*Triticum estivum* L.) var. UNZA WV1 were planted. The pots were watered and arranged in a complete randomized design with three replications, giving sixty-six pots. Two weeks after germination, plants in each pot were thinned down to five. At the end of six weeks, above ground biomass was harvested for dry matter yield, lightly washed in distilled water and allowed to dry in a 70°C oven for 48 h before weighing. Plant dry matter was ground into fine powder and digested in hot H_2SO_4-H_2O_2 solution (Parkinson and Allen, 1975). Plant tissue Zn concentration was determined in the solution using an atomic absorption spectrophotometer. Zinc uptake was calculated as a product of dry matter yield and Zn concentration.

Laboratory analysis

The soil Zn fractionation scheme described by Johnson and Petras (1998) was used to define the various Zn fractions in the soils. However, fresh soil sample was weighed into each solution rather than use the same sample in order to reduce mixing of fractions. Briefly, the following extractions were done for the respective Zn fractions: 20 g soil in 40 ml 0.005 M DTPA for 2 h [exchangeable Zn (Exch-Zn)], one gram soil in 20 ml 1 M CH_3COONH_4/CH_3COOH mixture at pH 5 for 5 h [carbonate bound Zn (Carbo-Zn)], one gram soil in 40 ml 0.1 M $K_2P_2O_7$ for 17 h [organic bound Zn (Org-Zn)], one gram soil in 50 ml acid oxalate at pH 3 (four parts 0.2 M ammonium oxalate and three parts 0.23 M oxalic acid) for 17 h [sesquioxide Zn (Ses-Zn)], one gram soil digested in 25 ml aqua regia (one part HNO_3:three parts HCl) for twenty minutes on a hot plate [Residual Zn (Res-Zn)]. Total Zn (Tot-Zn) was calculated as a sum of all the fractions. Each soil suspension was filtered after shaking or digestion. The concentration of Zn in each extract was determined using the atomic absorption spectrophotometer. All the soils were analyzed in triplicates.

Field study

Between November, 2007 and October, 2008, a field experiment was conducted at the University of Zambia, School of Agricultural Sciences Field Station in Lusaka, located 15.25° S and 28.20° E, and 1260 m asl. The soil here is described as a sandy loam mixed isohyperthermic paleustalf (Msoni, 1985). This area receives 800 to 1000 mm rainfall per annum, primarily from November to April, with mean temperature of 24°C. For initial soil characterization soil samples were collected from 0 to 20 cm depth at ten random sites in the field and the composite soil sample was used for determination of soil physical and chemical properties using standard methods (Van Ranst et al., 1999). The study treatments included two methods of Zn application (foliar and soil application), each at four rates, applied to one crop of maize (*Zea mays* L.) and another crop of wheat (*Triticum estivum* L.) in a randomized complete block design with three replications.

Maize (*var*. MRI 724) was planted on 15th December 2007, and 200 kg ha^{-1} equivalent of Compound "D" fertilizer (10:20:10, NPK) was applied according to standard recommendation, to each of 6 × 2 m^2 plots with 75 cm spacing between the rows. On the same day, five Zn fertilization rates at 0, 10, 20, 30 or 40 kg ha^{-1} Zn were applied to the soil as $ZnSO_4.7H_2O$. At the four-leaf stage, foliar application treatment of $ZnSO_4.7H_2O$ was done uniformly on leaves to supply 0, 1, 2, 4 or 8 kg Zn in 200 L ha^{-1} using a knapsack sprayer. At the six-leaf stage an application of 70 kg N ha^{-1} was made to each of the plots using urea (46% N). A similar process was carried out for the wheat (*var*. UNZA *WV* 1) crop that was planted on 1st May, 2008, except that the 1.2 × 10 m^2 plots in this instance were each supplied with 500 kg ha^{-1} equivalent of Compound "D" fertilizer. A planter was used to drill wheat seeds into rows. At six weeks after planting and at boot stage, respectively, 45 kg N ha^{-1} was drilled in as urea.

Maize was harvested on 30th April, 2008, at the black layer stage from a 1.2 × 6 m^2 area after discarding the two border rows. The grains were air-dried for one week, weighed and corrected for moisture at 12.5%. Similarly, wheat was harvested on 10th October, 2008, from a 0.4 × 10 m^2 area after removing the border rows. Following one week of air-drying, the grains were threshed by hand and weighed. Zinc concentrations in the grains were determined after digesting milled grain sample in H_2SO_4-H_2O_2 solution (Parkinson and Allen, 1975) and measuring on an atomic absorption spectrophotometer. Zinc uptake was calculated as the product of grain weight and Zn concentration.

Statistical analysis

The data were evaluated statistically by analysis of variance using SAS statistical program (SAS 6.12). The means were compared using Duncan's Multiple Range Test. The relationship between soil Zn and plant variables were evaluated using simple linear regression analysis.

RESULTS AND DISCUSSION

Soil properties

Chemical and physical properties of the soil used in the greenhouse and field studies are presented in Tables 1 and 2, respectively. The soil was largely Alfisols, with some Oxisols and Ultisols, and their pH ($CaCl_2$) values ranged from 4.1 to 7.5. Half of them were acidic while the other half was alkaline (Table 1). Although there was no significant difference (t-test, p=0.05) in mean soil reaction between cultivated and uncultivated soil samples, cultivation generally had the tendency to reduce soil pH. The soil samples were dominated by coarse textured soils ranging between loamy sand to loam. Soil organic matter was highly variable, being very low or very high (<2.5%>) and uncultivated fields were more likely to have

Table 3. Soil Zn fractions of the 11 Zambian soils collected from different locations.

Soil series	Land use /designation	Zn fractions*					
		Exch	Carbo	Org	Ses	Res	Total
		mg kg^{-1}					
Nakambala	Cultivated	1.43	6.80	6.33	74.5	18.96	108.02
	Fallow	0.52	2.68	2.66	44.2	23.30	73.39
Makeni	Cultivated	2.28	20.13	5.71	17.5	22.00	67.67
	Fallow	9.08	16.60	Nd	57.2	13.08	96.03
Kashinka	Cultivated	2.77	4.73	4.38	7.45	14.95	34.28
Chilimboyi	Field A	0.52	28.00	1.84	4.32	9.55	44.23
	Field B	2.15	7.75	6.16	11.9	72.40	100.41
	Field C	3.16	9.40	7.61	11.5	17.9	49.62
Chelstone	Cultivated	T	3.03	1.43	11.1	6.55	22.16
	Fallow	T	2.95	Nd	30.4	5.35	38.75
	Former Orchad	T	8.95	Nd	31.3	13.25	53.54
Ifisa	Cultivated	0.09	1.95	2.38	22.6	5.85	32.92
	Fallow	T	2.28	1.97	49.6	7.60	61.50
Chalimbana	Cultivated	1.00	4.13	5.29	1.55	10.85	22.82
Mushemi	Cultivated	0.44	0.78	0.74	0.55	10.60	13.11
	Fallow	0.73	15.78	10.86	Nd	7.77	35.14
Mpongwe	Cultivated	7.45	12.18	16.06	25.7	28.27	89.71
	Fallow	T	3.00	2.14	4.80	10.59	20.53
Misamfu Red	Cultivated	0.48	8.53	0.72	34.5	7.25	51.52
	Fallow	0.42	1.95	4.73	15.5	11.60	34.20
Mufulira	Cultivated	0.86	2.13	7.72	27.3	5.30	43.37
	Fallow	0.39	1.40	2.68	9.80	6.35	20.62
Mean		1.98	7.51	4.81	22.9	14.97	52.26
SD		5.68	5.83	4.16	20.0	17.20	32.09

*Exch = exchangeable Zn; Carbo = carbonate Zn; Org = organic Zn; Ses = sesquioxide Zn; Res = residual Zn.

higher values than their cultivated analogs. The soil cation exchange capacities were between 4.9 and 44.8 cmol kg^{-1} (Table 1) with most observed to be low (< 15 cmol kg^{1}), probably due to relatively high sand and low organic matter contents of many of these soils. The mean distribution of Zn among the various soil fractions was in the order: Ses-Zn > Res-Zn > Carbo-Zn > Org-Zn > Exch-Zn (Table 3). Variable observations are reported in literature as discussed subsequently. Plant available Zn levels (Exch–Zn) were low for 14 and marginal for 4 out of the 22 soil samples (Table 3), going by the proposed 0.8 mg kg^{-1} critical level for Zn in Zambian soils (Banda and Singh, 1989). Essentially the soils that were more acidic or more alkaline in reaction were more likely to be deficient in available Zn, probably due to immobilization and reduced solubility of Zn in those soils. This observation is supported by Takkar and Walker (1993) who indicated that Zn deficiency is most common in low- and high pH soils. The other soil fertility parameters (Tables 1 and 2) were low to moderate according to the indices used by the University of Zambia Soil Analysis Laboratory, namely: Organic matter (2.5%); cation exchange capacity (12 cmol kg^{-1}); exchangeable-Ca, Mg and K (0.2 cmol kg^{-1}); extractable-Fe (2.5 mg kg^{-1}); Cu (0.2 mg kg^{-1}); and Mn (1 mg kg^{-1}).

Greenhouse dry matter yield and Zn uptake

Wheat dry matter yield in the greenhouse was not significantly different among the soils, but fallow soils generally produced more (Table 4). A similar pattern was

Table 4. Dry matter yield, Zn concentration and Zn uptake for six-week wheat crop grown in the greenhouse on 11 Zambian soils.

Soil series	Land use/designation	Total dry matter	Zn concentration	Zn uptake
		g pot^{-1}	mg kg^{-1}	mg pot^{-1}
Nakambala	Cultivated	10.00	5.0	5.00
	Fallow	16.33	3.7	6.05
Makeni	Cultivated	13.33	3.4	4.40
	Fallow	15.67	4.7	7.46
Kashinka	Cultivated	8.33	3.8	3.07
Chilimboyi	Field A	10.00	2.7	2.70
	Field B	13.33	4.0	5.41
	Field C	10.00	4.4	4.39
Chelstone	Cultivated	15.00	3.7	5.55
	Fallow	10.00	6.2	6.18
Ifisa	Cultivated	10.00	2.2	2.18
	Fallow	13.33	4.1	5.39
Chalimbana	Cultivated	8.33	4.6	3.43
Mushemi	Cultivated	13.33	3.5	4.83
	Fallow	11.67	5.8	6.79
Mpongwe	Cultivated	11.67	3.6	4.53
	Fallow	13.33	4.0	4.89
Misamfu Red	Cultivated	6.67	4.8	3.51
	Fallow	11.67	3.7	4.16
Mufulira	Cultivated	9.33	4.4	4.05
	Fallow	11.67	2.8	3.23
Mean		11.57	4.05	4.63

observed for Zn uptake and less so for Zn concentrations in plant tissue. To investigate which soil Zn pool was most likely to contribute to plant Zn uptake, the association between soil Zn and plant Zn was determined in a correlation analysis. While the correlation coefficients were generally weak, the sesquioxide bound Zn contributed significantly more to wheat plant Zn uptake than the other Zn pools (Table 5). There was no significant relationship that was observed for the exchangeable, carbonate, organic and residual Zn pools in the soil. Other authors also reported that the sesquioxide bound Zn contributed significantly to Zn uptake by wheat (Singh and Abrol, 1985) and rice (Adhikari et al., 2007; Singh and Abrol, 1985). Contrastingly, Adriano (2001) and Iyengar et al. (1981) observed that sesquioxide bound Zn was less plant available. In terms of the other soil Zn fractions, Behera et al. (2008) observed that most of the Zn from organic pool and the sorbed Zn were taken up by wheat and maize while there was a negative relationship between Zn uptake and sesquioxide bound Zn. Sinha et al. (1977) reported that the organic and clay bound Zn contributed positively and significantly to the Zn taken up by maize and wheat crops. Rico et al. (2009) analyzed 29 soils in Spain and also observed low Zn uptake from organic Zn. The variability in observations by several authors shows that all individual Zn fractions could potentially contribute to the overall Zn uptake of the plant depending on soil physico-chemical properties and the method used for fractionation.

Maize grain yield and Zn uptake

The effects of the method of Zn application and Zn rates on maize crop performance are shown in Table 6. Grain yield averaged across the different Zn rates was 56% more and significantly higher when Zn was applied to soil

Table 5. Correlation coefficients for the relationship between zinc fractions in 11 Zambian soils and zinc uptake by wheat grown for six weeks in the green house.

Soil Zn pool	Dry matter yield	Zn concentration	Zn uptake
Exchangeable Zn	0.20	0.07	0.30
Carbonate Zn	0.003	-0.02	0.05
Organic Zinc	-0.15	0.09	-0.004
Sesquioxide Zn	0.15	0.28	0.36*
Residual Zn	0.25	-0.06	0.17
Total Zn	0.23	0.18	0.38*

*Significant at 0.05 level.

Table 6. Yield and Zn uptake of maize and wheat crops supplied with increasing rates of Zn as soil and foliar applications in the field.

Method	Zn Rate	Maize		Wheat	
		Yield	Zn uptake	Yield	Zn Uptake
		$t\ ha^{-1}$	$mg\ plot^{-1}$	$t\ ha^{-1}$	$mg\ plot^{-1}$
Soil	0	1.54^{a}	31.97^{b}	3.49^{a}	8.89^{a}
	10	2.15^{a}	37.97^{b}	4.03^{a}	14.63^{a}
	20	1.69^{a}	41.48^{a}	2.98^{a}	9.83^{a}
	30	2.05^{a}	77.23^{a}	4.26^{a}	12.72^{a}
	40	1.48^{a}	71.34^{a}	3.68^{a}	10.48^{a}
	Mean	1.78	52.00	3.69	11.31
Foliar	0	1.31^{a}	22.74^{c}	2.45^{b}	7.29^{ab}
	1	1.10^{a}	35.29^{c}	2.33^{b}	5.24^{b}
	2	1.05^{a}	42.64^{b}	4.12^{a}	10.11^{a}
	4	1.12^{a}	80.52^{a}	2.59^{b}	8.49^{ab}
	8	1.10^{a}	75.77^{ab}	2.21^{b}	5.13^{b}
	Mean	1.14	51.39	2.74	7.25

[a,b], Means followed by the same letter do not differ significantly at 5% level by DMRT method.

compared to foliar Zn application. Foliar spraying is normally adopted to increase plant nutrient uptake when soil immobilization mechanisms reduces Zn movement in the soil. Additionally it may be a cheaper way to supply nutrients to plants. However in this case it appears that soil application and absorption through the roots was a more effective alternative to increase grain yields. Hossain et al. (2008) also observed that the soil application of Zn resulted in an increase in the grain yields of maize. Similar result though at much lower soil application rate was obtained by Abunyewa and Mercer-Quarshie (2004) in Ghana who reported a 2.18 t ha^{-1} increase in the maize grain yield from supplying 5 kg Zn ha^{-1} to the soil.

Increasing the amount of Zn applied did not affect grain yields statistically nor was there a specific trend among the rates in either the soil or foliar Zn application. However, addition of Zn fertilizer to soil resulted in 4 to 40% more grain yield than control whereas foliar Zn application reduced grain yield by 15 to 20% compared to control. Harris et al. (2007) reported a 25% increase (about 0.7 t ha^{-1}) in grain yield when they applied 2.75 kg Zn ha^{-1} to the soil of a maize field in Pakistan. They observed that increasing the rate to 5.5 kg Zn ha^{-1} produced the same results but with much lower cob weights. In the current study, maize grain yields were not significantly different among different soil Zn fertilization rates and ranged from 1.48 t ha^{-1} at 40 kg Zn ha^{-1} to 2.15 t ha^{-1} at 10 kg Zn ha^{-1}, which was the best rate.

Mean maize Zn uptake values were generally comparable between the two methods of application (Table 6). In the soil applied treatment, Zn uptake increased significantly up to 142 and 123% from the application of 30 and 40 kg Zn ha^{-1}, respectively, compared to the control. Lower application rates, on the other hand, only promoted up to 30% increase in Zn uptake. Under the foliar treatment, Zn uptake was significantly increased by 254 and 233% from the application of 4 and 8 kg Zn ha^{-1}, respectively, compared to the control. The lower rates effected up to 86% increase in uptake. Though the average grain yields were lower with foliar spray treatment compared to soil application, the Zn uptake was similar between these two application methods (Table 6). This could be explained by higher Zn concentrations in the tissue of foliar sprayed crops. There was no visual symptom of leaf-burn observed on the crop. In this study, while foliar Zn application did not enhance maize grain yield, an application rate of 4 kg ha^{-1} was the best for increasing Zn mass concentration while 30 kg ha^{-1} applied to soil was best.

Wheat yield and Zn uptake

Soil application of Zn produced an average wheat grain yield that was 35% more and significantly different from the average grain yield produced by foliar application (Table 6). Contrary to the observation from the current study, Modaihsh (1997) reported that foliar spray of Zn at 1.8 kg ha^{-1} significantly increased grain yield of wheat grown on a calcareous sandy loam soil of Saudi Arabia. Haslett et al. (2000) concluded that foliar application of inorganic or organic Zn fertilizers were efficient in providing the Zn required by wheat for growth. Increasing rates of Zn application to soil did not affect grain yields significantly however Zn application generally resulted in 5 to 15% yield increase compared to the control. Except for a significant increase in yield when 2 kg Zn ha^{-1} was applied, increasing rates of foliar application also did not affect grain yields.

The uptake of Zn by wheat was 56% more with soil application than foliar application (Table 6). The rate of Zn applied did not significantly affect uptake when applied to soil although increases in the range of 11 to 65% over the control were obtained. Foliar Zn application treatments at 2 and 4 kg Zn ha^{-1} increased uptake over the control by 39 and 16%, respectively, while foliar Zn application at 1 and 8 kg Zn ha^{-1} decreased uptake by 30%. Sharma et al. (1988) however observed that both zinc sulphate and zinc oxide increased yield and uptake of Zn by wheat when applied within 45 days of planting.

There was no direct relationship that could be drawn between yield and uptake. This may point to the effect of metabolic mechanisms which regulate uptake, as well as positive assimilation. Nonetheless there appears to be economic benefit to be derived from the increased yields that Zn application brought about in wheat grain. Foliar spray seemed to increase Zn mass concentration however the benefit cannot be conclusive until additional work to partition Zn in the various plant parts is done. Jiang et al. (2008) have shown that there is variability in within-plant allocation and Zn accumulation in rice, which may have implications for availability to and assimilation by human. In this study, the differences in extents of response between maize and wheat crops may be attributed to their different sensitivities to Zn. Clark (1990) classified maize to be most sensitive while wheat is less sensitive to Zn deficiency, therefore their corresponding responses.

Conclusion

The current study demonstrates that application of minimum rates of Zn to soil at 10 kg ha^{-1} to maize and 30 kg ha^{-1} to wheat crops was beneficial. Soil application was more effective in raising yield levels, but foliar application between 2 and 4 kg ha^{-1} increased the Zn mass concentration in plant tissue. Zinc uptake was more from the sesquioxide bound Zn and this may be an indication that there is a positive dynamic equilibrium between this fraction and the more soluble Zn fractions.

Conflict of Interests

The author(s) have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors wish to thank OMNIA Fertilizer Zambia Limited for providing financial support, and Dr. Davies Lungu of the University of Zambia for providing the wheat seed.

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