Asian Journal of Plant Sciences

ISSN 1682-3974

Asian Journal of Plant Sciences 3 (1): 1-5, 2004
ISSN 1682-3974

Response of Maize to Magnesium and Zinc Application in the Semi Arid Zone of West Africa

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Abstract: Zinc sulphate application significantly influenced maize grain yield in a three-year (1997-1999) trial investigating the effect of magnesium and zinc on maize production in the semi arid zone of West Africa. Three levels of Mg (0, 15 and 25 kg ha^{-1}) as magnesium sulphate ($MgSO_4$) and three levels of Zn (0, 5 and 10 kg ha^{-1}) as zinc sulphate ($ZnSO_4$) were applied to maize. The experimental design was split-plot with two levels of nitrogen (40 and 90 kg N ha^{-1}) as the main plot and Mg and Zn as subplots with six replications. Initial soil analysis indicated medium levels of Mg and low levels of Zn. Maize grain yield as a result of Mg application ranged from 1.3 to 2.8 t ha^{-1} representing 0.6 to 16.5% increase during the 3 years, while grain yield due to zinc application ranged between 0.9 and 3.2 t ha^{-1} representing 84 to 108% increase in the three-year period. Zinc and magnesium interaction was synergetic resulting in grain yield ranging between 0.97 and 2.2 t ha^{-1}, indication 27 to 150% increase over the control in the 3-year period. While $ZnSO_4$ application resulted in significant increase in soil zinc level that of magnesium sulphate did not.

Key words: Magnesium sulphate, maize grain yield, zinc sulphate

INTRODUCTION

Maize (*Zea mays* L.) is one of the most important, high value cereals consumed in many household in West Africa. The crop is widely cultivated in the Semi Arid zone of West Africa (SAWA), which is characterized by erratic rainfall pattern and periodic dry spells. Beside this, the major constraint to maize production is poor soil fertility. Generally, soils in the SAWA are highly weathered and are generally poor in nitrogen and phosphorus[1] with potassium deficiency occurring under intensive cultivation. Due to low vegetative cover, high soil temperatures, annual bush burning and low return of organic input, soil organic matter is low. The soils are predominantly lateritic with low activity clay mineral, frequently low in Mg, deficient in Zn and have low cation exchange capacity[2-4].

Inorganic fertilizer application is therefore a prerequisite for maize cultivation in the zone. However, the inorganic fertilizer available to farmers contains mainly N and P with/without K. Though farmers grow various genetically improved maize varieties with high yield potential, grain yield has been observed to be low, rarely exceeding 1 t ha^{-1} in a farmer's field. The low maize grain yield in spite of the application of NPK compound fertilizer, led to the suspicion of possible deficiencies of other important nutrients.

Zinc deficiency was identified as the most common occurring micronutrient problem and occurs in many parts of the world on a wide range of soil types but semi arid areas with highly weathered soils and sandy-textured tend to be most affected[5,6]. It has been reported that Mg and Zn deficiency can be fairly collected by the soil application of inorganic magnesium and zinc sulphate[4,7]. However, high soil Zn concentration adversely affects crop yield[8,9].

The study was carried out to investigate the response of maize to Mg and Zn application and to determine the appropriate application rate of the two nutrients for increase and sustainable grain yield.

MATERIALS AND METHODS

Trial site description: A three year (1997-1999) trial was conducted at the Savanna Agricultural Research Institute experimental fields at Nyankpala, near Tamale, northern Ghana, located at latitude 9°25' 14'N, longitude 0°58' 42'W and at an altitude 183 m (asl)[10]. The area belongs to the semi-arid tropics with a characteristic seasonality of rainfall as shown by total monthly rainfall from 1997-1999 and the long-term (35 years monthly mean) (Table 1). The soil of the trial site is a typical upland soil, developed from iron stone gravel and ferruginized ironstone brash[11] classified as Haplic Lixisol[12] and locally referred to as Tingoli series.

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Table 1: Total monthly rainfall from 1997-1999 and 35 years monthly average in the Semi Arid Zone of Ghana

	Months											
Years	January	February	March	April	May	June	July	August	September	October	November	December
1997	0.0	0.0	30.5	120.3	147.9	155.8	178.6	181.4	244.8	120.8	0.5	0.0
1998	0.0	0.0	0.0	8.7	117.5	107.5	102.1	140.9	285.1	65.4	17.0	2.4
1999	0.0	34.3	66.3	157.5	144.0	202.8	436.8	398.2	310.0	147.8	0.0	0.0
35 yrs average	1.7	9.3	50.0	82.9	115.3	149.9	153.2	162.7	211.4	81.8	20.1	5.3

Soil and plant laboratory analysis: Composite soil sample was taken to a depth of 200 mm at the start of the trial in 1997 and at maize tasseled stage in 1999 from each plot. The soil samples were air dried, ground and sieved with 2 mm mesh and stored for chemical analysis at Savanna Agricultural Research Institute's Soil Chemistry laboratory. Soil pH was determined in 0.01 M $CaCl_2$ solution in 1: 2.5 soil: solution ratio, soil organic carbon was determined using Walkley-Black method, total nitrogen by Kjeldhal method, available P by Bray 1 procedure, exchangeable potassium and magnesium by ammonium acetate extraction and determined by Atomic Absorption Spectrophotometry (AAS); and acid extractable zinc (Zn) by 0.01 M HCl[13] and determined by AAS. Grain sub samples were taken after harvest and analyzed for Mg and Zn concentration for the estimation of Mg and Zn uptake.

Maize planting and agronomic practices: A full season (120 days) maize variety (*Zea mays* L.) was planted as the test crop at a spacing of 0.80x0.5 m, in the second week of June. After germination, maize seedlings were thinned to two plants per hill giving a plant population of 50,000 plants ha^{-1}. Two levels of nitrogen (40 and 90 kg N ha^{-1}) as ammonium sulphate $(NH_4)_2S0_4$; three levels of magnesium, 0, 15 and 25 kg Mg ha^{-1}, as magnesium sulphate, kieserite, ($MgSO_4$) and three levels of zinc, 0, 5 and 10 kg Zn ha^{-1} as zinc sulphate monohydrate ($ZnSO_4.H_2O$) were applied to the maize. Phosphorus and potassium were applied at 60 and 40 kg ha^{-1} P and K, respectively, as recommended for the semi arid zone of Ghana. Half the quantity of N and the full rate of P, K, Mg and Zn were applied at fourteen days after planting (DAP) as usually done in the zone. The remaining N fertilizer was applied 70 DAP by banding and covered with soil. The first weeding was done 14 DAP immediately before fertilizer application, the second, 42 DAP and the third before the second fertilizer application, 70 DAP. Experimental design was a split plot with N as the main plot and Mg and Zn as subplots with six replications. The same plot area was maintained in all the three years of the study. Maize grain was harvested at physiological maturity and grain weight taken at 15% moisture content.

Statistical analysis: The data collected were subjected to analysis of variance to establish the effect of the zinc, magnesium, nitrogen and their interactions on maize grain yields with the statistical software SPSS for Windows version 10.0. Treatment means were separated where appropriate at $P<0.05$. Also regression analysis was done to establish the relationship between soil zinc concentration at maize tasseled stage and grain yield in 1999.

RESULTS

Some initial soil characteristics at the trial site: The initial soil analysis indicated that the soil is sandy loam, moderately acid with low organic carbon, total nitrogen (N), extractable Zn and cation exchange capacity, while exchangeable magnesium content is considered as medium (Table 2).

Effects of magnesium and zinc fertilizer on maize grain yield: In all the 3 years (1997-1999), maize grain yield was significantly increased by the application of 5 kg Zn ha^{-1}, however, doubling the rate to 10 kg Zn ha^{-1} did not result in corresponding yield increase (Table 3). Percentage increase in maize grain yield due to Zn application over no Zn application from 1997-1999 ranged between 84 to 108%, with the highest percentage increase at 5 kg Zn ha^{-1}. Frey *et al.*[4] reported a grain yield increase of 116.2% as a result of 10 kg Zn ha^{-1} application over no zinc application elsewhere in the zone. In all the three years, 19, 14 and 28% of the variation in grain yield in 1997, 1998 and 1999, respectively, was due to zinc level compared to less than 2% of the variation explained by Mg level. The soil Zn content at maize tasseled stage in 1999 had significant quadratic relationship with the grain yield in that year, with the response equation accounting for 83% of the variation in grain yield (Fig. 1).

Though the application of Mg consistently resulted in increased grain yield in all the three years, the differences observed due to different rate of Mg application were not significant. Percentage increase in maize grain yield due to Mg application over no Mg application from 1997-1999 ranged between 0.6 and 16.5%.

Table 2: Initial soil characteristics of the trial site sampled at 20 mm depth in the semi arid zone of Ghana

Soil	PH (0.01 M $CaCl_2$)	Org. C	Total N	Bray 1 P	Exch. K	Exch.Ca	Exch. Mg	Ext. Zn	CEC	Sand	Silt	Clay
		-------(%)--------		----------(mg kg^{-1})----------					$Cmol_{(+)}kg^{-1}$	--------%--------		
	5.10	1.0	0.06	11.5	37.9	396	56.8	1.64	2.89	74.3	20.6	5.1

Table 3: Effect of Zinc application on maize grain yield in the Semi Arid Zone of Ghana in 1997-1999

	Year		
Zn kg ha^{-1}	1997	1998	1999
	----------t ha^{-1}----------		
0	1.16	1.05	1.07
5	2.41	2.07	2.06
10	2.24	2.04	1.97
$SED_{(2, 94)}$	0.13	0.09	0.11

Table 4: Effect of nitrogen x zinc fertilizer interaction on maize grain yield from 1997-1999 in the semi arid zone of Ghana

	Years					
	1997		1998		1999	
	kg N ha^{-1}					
kg Zn ha^{-1}	40	90	40	90	40	90
	----------t ha^{-1}----------					
0	0.87	1.45	1.10	1.19	1.10	1.04
5	1.79	3.23	2.04	2.09	2.23	1.90
10	1.52	2.96	1.96	2.12	1.94	1.80
$SE_{(2, 94)}$	0.13		0.09		0.11	

Table 5: Effect of magnesium x zinc fertilizer interaction on maize grain yield from 1997-1999 in the semi arid zone of Ghana

	kg Mg ha^{-1}								
	1997			1998			1999		
kg Zn ha^{-1}	0	15	25	0	15	25	0	15	2 5
	----------t ha^{-1}----------								
0	1.01	1.14	1.30	1.56	1.71	1.72	0.97	1.03	1.0
5	2.02	2.52	2.47	2.15	2.03	2.03	1.91	1.93	1.94
10	1.99	2.16	2.54	1.98	1.96	2.15	1.89	1.92	1.56
$SE_{(4, 94)}$	0.16			0.11			0.14		

Table 6: Effect of magnesium x zinc fertilizer interaction on magnesium† and zinc uptake by maize grain in 1999 in the semi arid zone

	kg Mg ha^{-1}		
kg Zn ha^{-1}	0	15	25
	----------Zn uptake g ha^{-1}----------		
0	10.10(2.4)†	8.2(2.1)	9.8(2.4)
5	41.40(4.3)	31.0(3.7)	42.4(3.4)
10	46.00(3.5)	35.0(3.6)	40.2(3.1)
$SE_{(4, 94)}$	4.47(0.41)		

†Magnesium uptake by maize grain (kg ha^{-1}) in parentheses

Table 7: Effect of magnesium and zinc fertilizer application on soil exchangeable magnesium‡ and extractable zinc content in 1999 in the semi arid zone of Ghana

	Kg Mg ha^{-1}		
kg Zn ha^{-1}	0	15	25
	----------mg kg^{-1}----------		
0	1.2(68.5)‡	1.2(71.5)	1.2(73.4)
5	9.7(69.1)	9.0(65.6)	7.8(68.0)
10	16.3(66.5)	15.1(70.0)	14.7(68.4)
$SE_{(4, 94)}$		0.6(4.53)	

‡Soil magnesium content (mg kg^{-1}) in parentheses

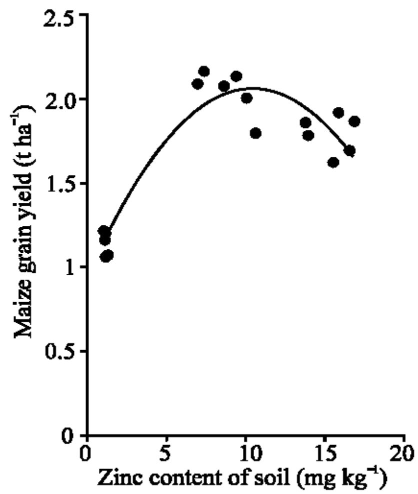

Fig. 1: Influence of extractable soil zinc content on maize grain yield in 1999 in the semi arid zone of Ghana

Frey *et al.*[4] however reported a higher yield increase of 44% as a result of 25 kg Mg ha^{-1} application to maize in northern Ghana.

Effects of magnesium, Nitrogen and Zinc interaction on maize grain yield: Generally, $ZnSO_4$ application at 5 kg ha^{-1} consistently gave the highest grain yield at each N level in all the 3 years except at 90 kg N ha^{-1} in 1998 (Table 4). Percentage increase in grain yield as a result of Zn and N interaction ranged between 73 and 123% over the yield obtained from application of N alone (Table 4). Whereas in 1997 Zn application resulted in higher grain yield margins at higher N application rate (90 kg N ha^{-1}), in 1998 and 1999 the effect of Zn on grain yield was more pronounced at lower N application rate (40 kg N ha^{-1}). Synergetic interaction between Mg and Zn resulted in percent increases in maize grain yield ranging between 9 and 152% over the control of no Zn and no Mg application (Table 5). Frey *et al.*[4] reported a grain yield increase of 124% over the control when 25 kg Mg ha^{-1} and 10 kg Zn ha^{-1} were applied.

Zinc uptake forms less than 1% of Zn applied in 1999. This however raised grain Zn uptake to 300% over the control (from 8.3 to 39 g ha^{-1}). However, doubling the quantity of Zn applied did not bring corresponding increase in Zn uptake. Less than 15% of Mg applied was taken in the maize grain and this increased grain Mg uptake to 41% compared to the control. Interaction between Mg and Zn application resulted in substantial increase in grain Zn uptake, Mg uptake was however, marginal (Table 6).

Effects of magnesium and zinc fertilizer application on soil magnesium and zinc content: After three years of $ZnSO_4$ application, extractable soil Zn level was observed to range between 1.0 and 16.3 mg kg^{-1} with a mean of 8.5 mg Zn kg^{-1}. The differences observed in soil Mg content as a result of $MgSO_4$ application was not significant. Comparing the initial soil Mg level (Table 2) to the soil Mg level in 1999, the improvement in soil Mg status was not apparent. Soil extractable Zn level increased with increasing $ZnSO_4$ application but decreased with increasing $MgSO_4$ application (Table 7).

DISCUSSION

Improvement in maize crop productivity depends on both genetic and environmental factors. Besides climatic influence, soil fertility plays a key role in crop production. With the availability of improved maize varieties, the low maize yield per unit area in the semi arid zone could be attributed primarily to climatic factors (especially rainfall), soil fertility and farm management practices. Since climatic conditions are beyond control, attention could be focused on improving soil fertility status and good farm management practices for increased productivity per unit area. Mineral fertilizers commonly available to farmers in the semi arid zone of Ghana are either compounded: containing mainly nitrogen (N) and phosphorus (P) `with/without potassium, (K) or straight (single element) fertilizers containing N P or K as the main constituent. Nitrogen and P are commonly deficient in the soils of the zone [1] and these fertilizers are provided primarily to supply these macronutrients for increased crop productivity. However, as has been shown the absence of some essential elements such Mg and Zn in these fertilizers may be partly responsible for the low maize yield in the zone.

With low soil total N level, the response of maize crop to higher N application in 1997 and 1998 was not unexpected. The influence of climate, especially rainfall, cannot be over emphasized in the predominantly rain-fed agricultural system in the SAWA. The excessive wet condition in 1999 especially in July, August and September (Table 1) may have resulted in loss of applied fertilizer especially N to the maize crop as a result of leaching. This may have led to the low response of the maize crop to higher fertilizer N application as reflected in lower grain yield obtained at 90 kg N ha^{-1} in 1999 compared to yield obtained at the same fertilizer level in 1997 and 1998 (Table 5). The occurrence of substantial losses of fertilizer to crops as a result of either high rainfall or dry spells makes fertilizer usage risky and unattractive to many farmers in the zone. Appropriate seed-bed and land preparation methods such as ridging, tied-ridging and use of appropriate fertilizer could improve nutrient use efficiency.

Soils use for the cultivation of maize and other staple cereals in the SAWA are moderately acid to acidic in reaction and have low CEC and Zn content[2,3]. The significant response of maize to $ZnSO_4$ application is as a result of low zinc concentration in the soil. The improved soil Zn availability resulting from Zn application led to increase Zn uptake and efficient utilization of applied fertilizer for increased grain yield. The significant increased in grain yield and the fairly stable yield in spite of the fluctuations in rainfall in the three years of the trial may be due to the capacity of Zn to contribute to the drought tolerance of maize crop as shown in 1998 when dry growing conditions were encountered [14]. Also the important role of Zn in maize pollination could be responsible for the increased grain yield observed in all the three years[15]. It is curious that the consistent relatively lower grain at higher Zn application was not reflected in the observance of toxicity symptoms in the maize crop in any of the three years. Though it must be added that the observed reduction in maize grain yield at 10 kg Zn ha^{-1} application rate was not significant from that of 5 kg Zn ha^{-1}. The cumulative effect of three years of Zn application at 10 kg ha^{-1} resulted in soil Zn concentration ranging between 14 and 16 mg Zn kg^{-1}, which is higher than the tentative Zn toxicity critical value of 12 mg kg^{-1} reported by Keisling *et al.* [9]. The high soil Zn concentration observed at the end of study is attributed to low level of Zn uptake by the maize grain compared to the quantity applied. Considering the low levels of Zn uptake by the maize grain and the higher grain yield obtained when Zn was applied at 5 kg ha^{-1}, it is our opinion that $ZnSO_4$ application at 5 kg Zn ha^{-1} is appropriate for maize production in the zone. Moreover, the cumulative effect of applying Zn at 5 kg ha^{-1} in the three year period of study raised soil Zn concentration above minimum soil critical level of 5 mg Zn kg^{-1} required by crops[6] and below toxicity critical level[9]. The quadratic relationship between soil Zn concentration and maize grain yield confirms the fact that while a certain minimum soil concentration is required for improved grain yield, concentration above a certain critical level would lead to reduced yield. A strong relationship (r^2=83) was observed between the soil zinc concentration at maize tasseled stage and the grain yield in 1999 (Fig. 1). This is probably because high proportion of fertilizer N applied was lost to the maize crop as a result of high mobility of N caused by excessive rainfall in that year. The Zn on the other hand being fairly immobile in the soil could have been more prevalent in the labile pool.

The marginal response of maize to magnesium (Mg) application may be attributed to the level of Mg in the soil, which may have been adequate at that level of maize grain production. This is because higher response to Mg application was observed elsewhere in the zone when soil Mg concentration was than 5 mg kg^{-1} [4]. In spite of the relatively high levels of Mg applied, Mg uptake by the maize grain was quite low ranging between 2 and 4.7 kg ha^{-1}. The low Mg uptake could be due to the low effect of Mg on starch accumulation in the maize crop[16]. The low Mg uptake may account for the lack of substantial change in soil Mg content at the end of the three-year trial. The soil Mg level at the current maize production level on this soil may be adequate. However, intensive and continuous cropping may require Mg application to maintain appropriate soil level for the crop's efficient production. Though Zn deficiency was not conspicuous, the significant increase in maize grain yield observed with the application of Zn at each N level is an indication of hidden hunger of Zn[3,6]. According to Frey *et al.*[4], Hauffe[3] Mg and Zn are latently deficient and are therefore needed to increase and sustain maize production.

With average soil Mg concentration at the start of the study, the repeated application of 25 kg Mg ha^{-1} over three years may be responsible for the lower soil acid extractable Zn as a result of antagonistic relationship of Mg^{2+} and Zn^{2+} at soil exchangeable site[17].

The potential impact of zinc (Zn) on maize grain yield is clearly demonstrated in the zone. Though typical nutrient deficiency symptoms of magnesium (Mg) and Zn were not expressed, the application of the two elements nevertheless significantly increased grain yield. Magnesium and Zn interaction showed synergetic effect on maize grain production in the zone. Considering the increases in grain yield when Mg and Zn were applied in addition to NPK compound fertilizer compared to the yield when NPK was applied alone, we are convince that these two elements (Mg and Zn) must be applied in the semi arid zone. It is hope that the application of Zn and Mg together with NPK will increase and sustain maize production, improve Zn content in the maize grain which is essential for human and animal growth and development and lastly may homogenize the heterogeneous soils of the zone and stabilize maize production.

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