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Plant physiology

Relative efficiency of two zinc sources for maize (*Zea mays* L.) in two calcareous soils from an arid area of Iran*

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Summary — Effects of 2 Zn sources (ZnEDTA and $ZnSO_4$) and 4 Zn levels on the growth and Zn utilization by maize plants in 2 arid calcareous soils of Iran were investigated in a glasshouse study. Plants supplied with Zn produced more stem and leaf dry weights and contained more Zn than those grown without Zn. Moreover, ZnEDTA was generally more effective than $ZnSO_4$ in increasing Zn concentration and Zn uptake by stems and leaves. Results of this study indicate that the soils exhibited a highly variable capacity with regard to the growth and Zn accumulation. Maize seedlings grown in the Bajgah soil produced more dry matter yields and absorbed more Zn than those grown in the Airport soil. The more enhancing influence of ZnEDTA over $ZnSO_4$ in terms of growht and Zn utilization by maize in arid region calcareous soils might be due to less fixation and greater transport and movement of chelated Zn to plant roots.

zinc – maize – fertilization – calcareous soil – Iran

Résumé — Efficacité relative de deux formes de zinc pour le maïs cultivé dans deux sols calcaires issus de régions arides d'Iran. *On a étudié en serre les effets de 2 formes de zinc ($ZnSO_4$ et ZnEDTA) et de 4 doses d'apport sur la croissance et l'absorption de Zn par du maïs cultivé sur 2 types de sols calcaires issus de régions arides d'Iran. Les plantes bénéficiant d'un apport de Zn ont une production supérieure de racines, de tiges et de feuilles; en outre la teneur en Zn est accrue. ZnEDTA s'avère plus efficace que $ZnSO_4$, aussi bien en matière d'effet sur la croissance que sur l'absorption et l'accumulation de Zn dans les différentes parties de la plante. Les résultats de cette étude montrent par ailleurs que les 2 types de sol expérimentés sont à l'origine d'une réaction très différente du maïs à l'apport du zinc. C'est ainsi que la croissance de la plante et l'absorption du zinc sont plus importantes pour le maïs cultivé sur le sol issu du site Bajgah que sur celui issu de Airport. La supériorité de ZnEDTA sur $ZnSO_4$ pour la croissance et l'utilisation de Zn par le maïs dans les 2 types de sols calcaires expérimentés peut être interprétée comme résultant d'une moindre fixation du métal par le sol et de l'amélioration de son transfert vers le système racinaire.*

zinc – maïs – fertilisation – sol calcaire – Iran

I. INTRODUCTION

Zinc deficiency in agricultural crops is one of the most common micronutrient deficiencies (Lindsay, 1972). Since Zn is essential in plant nutrition, it has to be supplied to crops in some forms for optimum plant growth where Zn deficiency in the soil is expected. In recent years, the use of various Zn fertilizers to correct Zn deficiency has received widespread interest. In general, application of Zn fertilizers to most soils is relatively ineffective, since the element is readily converted to unavailable forms. The magnitude and strenght of Zn fixation is largely governed by soil pH, type of soil minerals, kind and amount of anions in the soil solution and Zn carriers (Sharpless *et al.*, 1969; Stanton and Burger, 1970; Shuman, 1975).

The relative effectiveness of various Zn sources for plant growth has been reviewed by

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several workers (Giordano and Mortvedt, 1972; Lindsay, 1972; Murphy and Walch, 1972). These reviews point out the conflicting data regarding the efficiency of various Zn sources for crop production. Several workers (Wallace and Romney, 1970; Prasad *et al.*, 1976; Ragab, 1981; Dhillon and Dhillon, 1983) have reported that under glasshouse conditions, chelate forms of Zn were found to be more effective than inorganic forms of Zn. Brown & Krantz (1966) noted that maize responded equally well to broadcast soil application of $ZnS0_4$ and ZnEDTA. When banded, ZnEDTA was more effective than $ZnS0_4$. Diddowson and Watts (1977) concluded that soil-applied $ZnS0_4$ and ZnEDTA produced the same maize dry matter in calcareous soils. In contrast, Shukla and Morris (1967) found that $ZnS0_4$ and Zn0 were equally efficient or superior to chelated Zn in increasing the Zn concentration and uptake of maize in a glasshouse study. In several field experiments (Vinande *et al.*, 1968; Boawn, 1973), ZnEDTA was more effective than $ZnS0_4$. However, Ganiron *et al.* (1969) observed no advantage of ZnEDTA over $ZnS0_4$ when applied as band treatment at seedling. Yet, Schnappinger *et al.* (1969) reported higher yield of maize in field studies from the use of inorganic sources of Zn.

Many soils in the southern region of Iran are calcareous in nature. Most of the Zn disorders in plants occur in these soils (Navrot and Ravikowitch, 1969). This is believed to be caused by low solubility products of Zn soil complexes and carbonate (Udo *et al.*, 1970). All indications point out that the incidence of Zn disorder will continue as the result of increased use of higher analysis fertilizers, inadequate Zn fertilization and use of high-yielding cultivars. Although some nutritional features of calcareous soils in southern Iran have been investigated, authors are not aware of any information regarding the response of maize to various Zn sources. Therefore, the present study was initiated to evaluate the effects of several rates of soil-applied $ZnS0_4$ and ZnEDTA on the growth and Zn utilization of maize grown in 2 arid region calcareous soils.

MATERIALS AND METHODS

The surface 20-cm layer of an alluvial calcareous soil was collected from 2 locations, Bajgah Agricultural Experiment Station, 15 km north, and Airport, 20 km southeast of Shiraz, Iran. The soils are classified as calcixerollic xerochrept and typic xerofluvent for the 2 locations, respectively. Some physical and chemical properties of the soils are given in Table I.

The air-dried soils were ground to pass a 2-mm sieve and 2000 g of the soil was thoroughly mixed with 5,10 and 20 ZnEDTA ($Na_2ZnEDTA$) or 10,20 and 50 mg Zn as reagent grade $ZnS0_4$. The control was 0 Zn treatment. Nitrogen and P were added to all pots at 150 and 50 mg/kg in the form of $(NH_4)_2S0_4$ and KH_2P0_4, respectively. The experiment layout was 2x2x4 factorial arrangement with 4 replications, carried out in a glasshouse with average day and night temperatures of 34° and 14°C, respectively. Six seeds of a pure line maize cultivar (DC-599) were sown in each pot and seedlings were thinned to 3 after 2 weeks. The pots were irrigated with distilled water to field capacity, as often as necessary during the course of the experiment. The plants were grown during months of May, June and for 60 d and harvested at the 12-leaf stage.

At harvest, tops were cut at the soil surface and separated into leaf and stem. The plant parts were then dried at 70°C in an oven, weighed and ground in a micromill to pass a 40-mesh sieve. One-half-gram plant samples were digested in a mixture of nitric, perchloric and sulfuric acids (5 : 2 : 1). Zinc was determined by a Carl Zeiss Atomic Absorption spectrophotometer and P was analyze colormetrically, using ammonium molybdate-stannous chloride method.

Growth, Zn concentration and Zn uptake data were regressed on Zn rate with respect to the Zn sources and the soil types.

Table I. Physico-chemical characteristics of the soils.

Characteristics	*Bajgah soil*	*Airport soil*
Texture	Loam	Loam
pH	8.20	7.40
EC (mmhos/cm)	0.34	6.90
Calcium carbonate equivalent (%)	40.30	38.75
Organic matter (%)	1.63	1.02
$NaHC0_3$-extractable P(mg/kg)	10.50	5.50
Extractable Zn(mg/kg)		
H_2O	0.36	0.40
HCl,0.1 N	0.20	0.20
DTPA	0.50	0.50

RESULTS AND DISCUSSION

Data for each Zn source-soil combination were analyzed and the second order model:

$$Y = b_0 + b_1 X + b_{11} X^2$$

was fitted, where Y is the dry weight, Zn concentration or Zn uptake, X is Zn rate, b_0 is the intercept and b_1 and b_{11} are computed regression coefficients indicating linear or quadratic effect, respectively. Equations were estimated sequentially, beginning with a linear model. Quadratic term was added only if its inclusion significantly reduced the residual mean squares. The estimated regression equations are

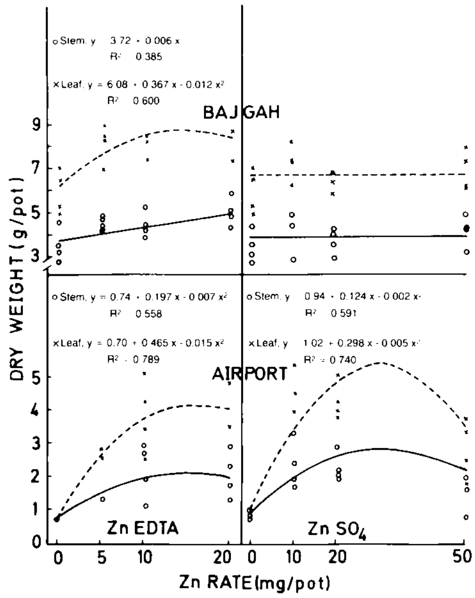

Fig. 1. Stem (0——0) and leaf (X- - -X) dry weights of corn as affected by the rate and form of Zn.

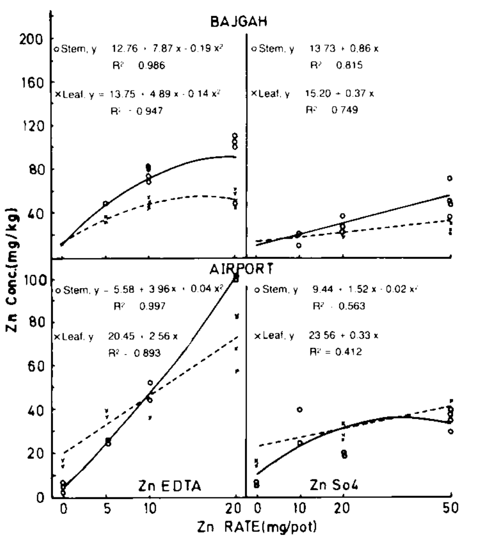

Fig. 2. Zinc concentration of stem (0——0) and leaf (X- - - X) of corn as affected by the rate and form of Zn.

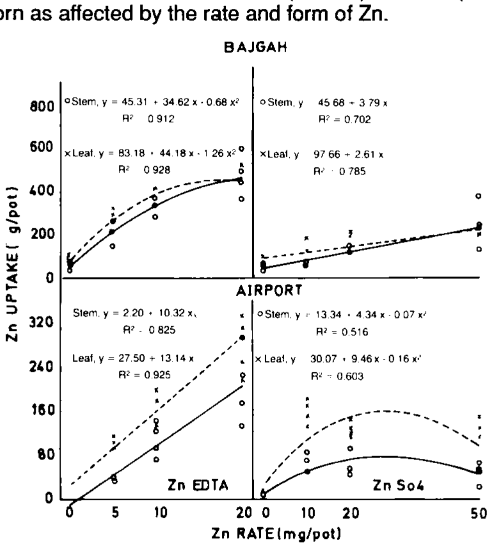

Fig. 3. Zinc uptake by stem (0——0) and leaf (X- - -X) of corn as affected by the rate and form of Zn.

graphically shown in Figures 1, 2 and 3. Also included in Figures 1, 2 and 3 are coefficient of determinations which provide a subjective measure of goodness of fit.

In general, the dry matter yield of maize grown in the Bajgah soil was significantly higher than that grown in the Airport soil (Fig. 1). The lower dry matter production in the Airport soil was probably due to the relatively high soluble salts of this soil (Table I)*. Similar results have been reported for other crop species (Maas *et al.*, 1972; Kashirad *et al.*, 1978).

Zinc addition generally increased stem and leaf dry weights in both soils (Fig. 1). The stimulation of stem and leaf growth exhibited by Zn fertilization is in agreement with previous reports by others (Wallace and Romney, 1970; Ghaly *et al.*, 1979; Prasad and Sinha, 1981; Dhillon and Dhillon, 1983; Singh *et al.*, 1983). Furthermore, for maize grown in the Bajgah soil, the relationship between applied Zn as ZnEDTA and stem dry weight was linear and became curvilinear for leaf dry weight (Fig. 1).

With respect to the Airport soil, there was curvilinear relationship between Zn level and leaf and stem dry weights under ZnEDTA and $ZnS0_4$ nutritional regimes (Fig. 1). Addition of Zn up to 10 mg/pot as ZnEDTA resulted in more leaf dry weight than that of $ZnS0_4$. However, with 20 mg Zn/pot, plant supplied with $ZnS0_4$ produced more leaf growth than those provided with ZnEDTA. In the present study application of Zn to the Airport soil as $ZnS0_4$ generally was more stimulative to stem growth than that of ZnEDTA (Fig. 1). Moreover, stem and leaf dry weights were somewhat suppressed with the highest ZnEDTA and $ZnS0_4$ application rates. This could be possibly due to induced P, Mn, Fe or Cu deficiencies.

The stem and leaf growth stimulation by ZnEDTA was more pronounced in the Airport soil than in the Bajgah soil. For instance, stem and leaf dry weights of maize grown in the Bajgah soil were increased by 36 and 40%, respectively, when Zn level was increased from 0 to 20 mg/pot, while for the Airport soil, those increases were 178 and 486%, respectively. Ravikovitch and Navrot (1976) reported that addition of ZnEDTA increased the tomato (*Lycopersicon esculentum* Mill.) yield by 18 and 58% at the soil salinity levels of 9 and 11 mmhos/cm, respectively.

The influences of added Zn on Zn concentration in stems and leaves of maize

* The dominant salt in the Airport soil is believed to be sodium chloride. Excess sodium chloride has been shown to be detrimental to the growth of many plants including maize.

plants in both soils are shown in Figure 2. Zinc fertilization significantly increased the Zn concentration in various plant parts. In the Bajgah soil Zn concentration in stems and leaves continued to increase with an increase in Zn level as $ZnSO_4$, whereas the relationships became curvilinear for ZnEDTA-treated plants. On the other hand, the concentration of Zn in maize leaves tended to increase linearly with the addition of Zn to the Airport soil as ZnEDTA and/or $ZnSO_4$.

In the regression equation $Y=b_0 + b_1 X\ b_{11} X^2$, b_1 is actually the amount of response obtained per unit of applied Zn.

It therefore may be used as a criterion to compare the effectiveness of different sources and to evaluate their performance in the 2 soils. The larger the $b_1$value, the more effective the source under consideration. The b_{11} does not generally alter the discussion here due to its comparatively small value. Examination of b_1 values given in Figure 2 indicates that ZnEDTA gave a significantly higher Zn concentration than $ZnSO_4$. The more enhancing influence of ZnEDTA in terms of Zn concentration over $ZnSO_4$ has been reported by others (Boawn *et al.*, 1957; Wallace and Romney, 1970; Wallace, 1971; Dhillon and Dhillon, 1983). Ganiron *et al.* (1969) noted that in growth chamber solution culture studies, ZnEDTA produced slightly higher concentration of Zn in maize tissue than did $ZnSO_4$, but only at a concentration of 2.0 μM Zn. At 0.5 μM Zn concentration, there was little if any difference between the 2 forms. The higher Zn concentration due to ZnEDTA application may be attributed to higher mobility and less fixation of Zn from ZnEDTA than from $ZnSO_4$ (Kumar and Singh, 1979). Lahav and Hochberg (1975) found that ZnEDTA was not fixed in soil and was quite mobile. Several workers (Elgawhary *et al.*, 1970; Prasad *et al.*, 1976; Halvorson & Lindsay, 1977; Nand and Verloo, 1983) have reported that Zn chelation increases the transport and movement of Zn to plant roots.

Differences in Zn uptake as a function of Zn addition to both soils are shown in Figure 3. The uptake of Zn generally increased with increasing Zn rates and was mainly due to an increase in either dry matter yield or Zn concentration in various plant parts. Moreover, maize seedlings supplied with ZnEDTA accumulated more Zn in stem and leaf than those provided with $ZnSO_4$. These findings are in agreement with those of Wallace and Romney (1970) and Rhem *et al.* (1980). The results of this experiment indicate that the soils tested exhibit a highly variable capacity to accumulate Zn due to Zn supplement. Maize plants grown in the Bajgah soil contained more Zn than those grown in the Airport soil.

Phosphorus/Zn ratio could be used as an index of the Zn status of the plant. In the present experiment, Zn application decreased P/Zn ratio (Table II). ZnEDTA proved to be more effective in decreasing P/Zn ratios in stem and leaf than $ZnSO_4$. Suppression of P/Zn ratio associated with the Zn application as either source was greater in the Airport soil than in the Bajgah soil.

CONCLUSION

From the foregoing discussion, it is concluded that fertilization with Zn has to be taken into account when considering factors that might

Table II. Effects of rate and source of Zn on P/Zn ratio in maize.

	P/Zn ratio			
	Stem		*Leaf*	
Zn applied (mg/pot)	*Bajgah soil*	*Airport soil*	*Bajgah soil*	*Airport soil*
		ZnEDTA		
0	191	456	149	144
5	54	87	56	47
10	30	43	43	34
20	23	23	34	25
		$ZnSO_4$		
0	191	456	149	144
10	119	66	94	40
20	63	87	69	61
50	35	63	49	44

enhance maize growth in saline soils. Furthermore, ZnEDTA proved to be a more efficient source of Zn for maize in arid region calcareous soils than $ZnSO_4$. Better response of maize to ZnEDTA might be attributed to less fixation and greater transport of Zn to plant roots. A possible alternative procedure is to plant more Zn efficient crop species or cultivars where use of Zn chelates is not economically justified.

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