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Hybrid maize response to assorted chelated and non chelated foliar applied zinc rates

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Foliar application can be useful for easy and rapid access of nutrients to plants. For this purpose, a field trial was carried out to study maize hybrid response to assorted chelated and non-chelated foliar applied zinc rates. Maize hybrid Monsanto-6525 was sown during the 2nd week of March using seed rate of 25 kg ha^{-1}. The experiment was comprised of Zinc Chelates: Zn Ch: EDTA, Zn Ch: HEDTA and non-chelated $ZnSO_4.7H_2O$ with different application rates: 0, 60, 120 and 180 (g Zn ha^{-1}). Zn fertilizers were sprayed after 15 days of crop emergence with a knap sack hand sprayer. All growth and yield related attributes such as 100-grain weight (31.97 g), number of grains per cob (717.3), grain weight per cob (206 g), biological yield (18.67 t ha^{-1}), grain yield (8.52 t ha^{-1}), protein contents (11.07 %) and oil contents (4.9 %) were affected significantly except plant height. Present study shows that application of Zn Ch: EDTA at 180 g Zn ha^{-1} has pronounced effect on growth, yield and quality related attributes than Zn Ch: EDTA at 60 and 180 g Zn ha^{-1}. Similarly Zn Ch: EDTA performed better than $ZnSO_4.7H_2O$ and Zn Ch: HEDTA at 60, 120 and 180 g Zn ha^{-1}.

Key words: hybrid maize, foliar spray, chelated zinc, fertilizer

Introduction

Zinc is indispensable for plants, animals and man but its deficiency still plagues us today. Global studies ran by FAO (Sillanpa, 1982) revealed that 50% of soil samples collected from 25 countries were deficient in Zn. Micronutrients for major grain food crops are needed for two reasons: enhancement of the agronomic productivity of the crop and improvement of nutritional value of staple foods for humans. It has been estimated that roughly

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40 % of people all over the world suffer from micronutrient malnutrition (Welch *et al*., 1997).

A critical small concentration of zinc is needed to perform several key pathways in plants. These pathways have important roles in growth regulation, photosynthesis and sugar formation, fertility and seed production, and defense against disease. These physiological functions will be impaired and the health and productivity of the plants will be adversely affected due to zinc deficiency. Thus resulting in lower yields (or even crop failure) and frequently in poorer quality crop products (Alloway, 2003).

Pakistani soils were firstly found zinc deficient by Yoshida and Tanaka (1969) and later research established the commonness of widespread Zn deficiency (Alam, 2004). Zinc deficiency is the most widespread micronutrient disorder among different crops (Romheld and Marschner, 1991). The deficiency of this micronutrient frequently occurs in maize which is very sensitive to low Zn supply (Loue, 1988; Tariq *et al*., 2002).

Micronutrients are applied to crops through three main methods: soil fertilization, foliar sprays and seed treatment. Foliar applications of micronutrient sprays are more effective for immediate required goals (Wilhelm *et al*., 1988; Savithri *et al*., 1999). In developed countries, fertilizers containing Zn are commonly added to soils where necessary, and it can also be effective to use foliar sprays but the situations are opposite in under developing countries.

Recent research has shown that a small amount of nutrients, particularly Zn, Fe and Mn applied by foliar spraying increases significantly the yield of crops (Sarkar *et al*., 2007; Wissuwa *et al*., 2008). Also, foliar nutrition is an option when nutrient deficiencies cannot be corrected by applications of nutrients to the soil (Crabtree, 1999; Sarkar *et al*., 2007; Cakmak, 2008). On calcareous soils (like Pakistani soil), adsorption and fixation reactions can substantially reduce the efficacy of micronutrients, therefore, foliar application is the most suitable choice for even application throughout the field.

Zinc sulfate ($ZnSO_4$) has conventionally been used as a "reliable" source of Zn fertilizer but other sources of Zn are also available. The availability of Zn in these sources, made from various by products, depends upon certain key factors which are directly related to the manufacturing process, the source of complexing or chelating agents (organic sources), and the original product used as the Zn source. Many claims are made regarding the relative efficiency of organic versus inorganic Zn sources. Producers of organic sources generally claim a 10:1 advantage of organic sources vs. inorganic sources (zinc sulfate) to satisfy the agronomic demand. However, this claim is disputed by researchers as well as other fertilizer producers. Most research has found that there is approximately a 3:1 to 5:1 advantage for ZnEDTA, a “true” organic chelate (Hergert *et al*., 1984 and Mortvedt, 1979).

The aim of this work was to study whether complexes of Zn with chelating agents and non-chelated inorganic sulfate form with different application rates could enhance growth and yield of maize. Confusion exists in the marketplace and unsubstantiated claims are being made regarding the efficacy of various organic and complex Zn fertilizer products. Therefore, it was important to evaluate the effectiveness of Zn fertilizers to correct Zn deficiencies.

Materials and methods

The experiment was conducted at Agronomic Research Area, University of Agriculture, Faisalabad, during spring 2008 under field conditions to evaluate the hybrid maize response to assorted chelated and non-chelated foliar applied zinc rates. The experiment was laid out in Randomized Complete Block Design with three replications having a net plot size of 6 m x 3 m. For physico-chemical analysis, soil samples were taken before sowing of crop from a depth of 30 cm. The soil of experimental site has loamy texture, with pH of 7.83, EC 2.28 dSm^{-1}, sodium adsorption ratio 450 ppm, organic matter 0.51%, available P 4.02 ppm, available K 279 ppm and DTPA extractable Zn (0.02 M) 0.24 mg kg^{-1} of soil.

The weather data during the course of experimentation showed that maximum and minimum temperatures were not varied to a greater extent and remained uniform. The average temperature of 28 ^{0}C was recorded during the respective crop period. Rainfall varied to greater extent during the month of May with total rainfall of 75.5mm as shown in Figure.

Treatments were comprised of Zinc Chelates (6% Zn contents): Zn Ch: EDTA, Zn Ch: HEDTA and non-chelated $ZnSO_4.7H_2O$ with different application rates: 0, 60, 120 and 180 (g Zn ha^{-1}). Zn fertilizers were sprayed after 15 days of crop emergence with a knap sack hand sprayer fitted with hollow cone nozzle. Calibration was done before spray to calculate exact amount of water needed to spray Zn fertilizers. Maize hybrid Monsanto-6525 was sown at 12th of March using dibbler to maintain plant to plant distance of 30 cm at one side of the ridge with seed rate of 25 kg ha^{-1}. Thinning was carried out after ten days of crop emergence to secure one plant per hill. Nitrogen, phosphorus and potash were applied at the rate of 250-125-125 kg ha^{-1} as urea, DAP and sulphate of potash, respectively. Whole of the phosphorus and potash and half dose of nitrogen were applied at sowing and remaining half of nitrogen at knee height by top dressing. All other agronomic practices were kept normal and uniform for all the treatments.

Measurement of growth related attributes

Ten plants were selected at random from each plot at harvest to calculate height (cm) of the plants by using meter rod from base of the ground to the final growing point and leaf area per plant (cm^2) was calculated by using leaf area meter. Cob length (cm) and cob diameter (cm) were measured from ten randomly selected cobs from each plot by using a foot scale and vernier caliper, respectively. All these observations were averaged to obtain a single replica value. Number of grain rows of each cob was counted individually from ten cobs selected at random from each plot and average was worked out.

Determination of yield related attributes

Cobs were threshed manually to count average number of grains per cob and grain weight per cob (g). Five handful samples of grains were taken to calculate 100-grain weight (g) from each plot randomly. Biological yield (t ha^{-1}) was recorded from each plot and then calculated on hectare basis. After five days of harvesting, cobs were sun dried for five days more and then threshed mechanically with sheller to calculate grain yield (t ha^{-1}) on hectare basis.

Determination of quality related attributes

Seed samples were taken from each plot randomly, ground and subjected to chemical analysis to determine total nitrogen of grain using Gunning and Hibbard's method of H_2SO_4 digestion and micro Kjeldahl method for distillation (Anon., 1990). Crude protein content (%) was determined by multiplying total nitrogen contents with 6.25 as a factor. Oil content (%) of seed was estimated by the NMR test (Robertson & Morrison, 1979).

Economic analysis

The economic analysis for experimental data was examined according to the methodology described in CIMMYT (1988). For this purpose gross income and total expenditure were calculated to evaluate the net field benefits. Net field benefits were calculated by subtracting the total variable cost from total benefits (income) from each treatment. The cost of input and output for each treatment was converted to Rs. ha^{-1}.

To check the variability of the cost with the net field benefits, marginal analysis was carried out. Marginal net field benefit (MNB) is also termed as marginal rate of return (MRR). MRR was formulated by using the formulae given by CIMMYT, 1998 as percent ratio of marginal net field benefit to marginal cost (MC).

$$MRR = MNB / MC \times 100$$

Statistical analysis

Standard procedures were followed to record the data. Data collected were analyzed statistically using Fisher analysis of variance technique. Difference among the treatments' means was compared using least significant difference test at 5 % probability level (Steel *et al*., 1997).

Results

Plant height is one of the important trait in determining the vigor and potential of any crop. The statistical analysis revealed non-significant differences in height of the plants as a function of applications of zinc salts at various proportions (Table 1). The mean comparison revealed that values were in the range of 132 to 143 cm. The leaf area is in direct relationship with light absorption that in return can improve the growth and yield characteristics. The treatments imparted differential impact on leaf area as indicated in Table 1. The foliar application of zinc improved the leaf area significantly and maximum leaf area (517.3 cm^2) was recorded in Zn Ch.

EDTA at 180 g Zn ha^{-1} followed by Zn Ch: HEDTA at 120 g Zn ha^{-1} and Zn Ch: HEDTA at 180 g Zn ha^{-1} with leaf area of 468.0 cm^2 and 473.0 cm^2, respectively. The least leaf area was recorded in control (263.0 cm^2) where Zn application was not carried out while $ZnSO_4.7H_2O$ at 60 and 120 g Zn ha^{-1} also showed similar results.

Zinc application at various doses affected the cob length significantly (Table 1). The application of Zn Ch: HEDTA at 120 g Zn ha^{-1} and Zn Ch: EDTA at 120 g Zn ha^{-1} showed maximum improvement with cob length of 22.15 and 22.17 cm followed by $ZnSO_4.7H_2O$ at 120 g Zn ha^{-1} with cob length of 20.25 cm. Zinc application improved the cob length in all treatments as compared to least cob length recorded in control (16.28 cm). All treatments improved the cob diameter significantly (Table 1) as compared to control, however, highest cob diameter (5.033 cm) was recorded in fields where Zn Ch: EDTA at 180 g Zn ha^{-1} was applied followed by Zn Ch: EDTA at 120 g Zn ha^{-1} with cob diameter of 4.767 cm. The treatments Zn Ch: HEDTA at 120 g Zn ha^{-1} and Zn Ch: HEDTA at 180 g Zn ha^{-1} behaved alike with cob diameters of 4.633 and 4.500 cm and least diameter was recorded in control (3.767 cm) that was at par with $ZnSO_4.7H_2O$ at 60 g Zn ha^{-1} and $ZnSO_4.7H_2O$ at 120 g Zn ha^{-1} with mean cob diameter of 3.767 and 3.833 cm, respectively.

Table 1. Effect of foliar application of zinc salts at various rates on growth related attributes of maize plants

Treatments	Plant height (cm)	Leaf area (cm^2)	Cob length (cm)	Cob diameter (cm)	No. of grain rows per cob
T_0 = Control	132.00	263.0 e	16.28 e	3.767 e	13.33 b
T_1 = $ZnSO_4.7H_2O$ at 60 g Zn ha^{-1}	135.66	272.0 e	18.01 d	3.767 e	13.33 b
T_2 = $ZnSO_4.7H_2O$ at 120 g Zn ha^{-1}	138.66	272.7 e	20.25 b	3.833 e	14.00 b
T_3 = $ZnSO_4.7H_2O$ at 180 g Zn ha^{-1}	136.00	308.0 d	19.71 bc	4.267 d	14.67 ab
T_4 = Zn Ch: EDTA at 60 g Zn ha^{-1}	136.66	334.7 cd	19.49 bc	4.367 d	14.67 ab
T_5 = Zn Ch: EDTA at 120 g Zn ha^{-1}	141.33	370.0 c	22.17 a	4.767 b	14.00 b
T_6 = Zn Ch: EDTA at 180 g Zn ha^{-1}	133.33	517.3 a	19.27 bc	5.033 a	16.67 a
T_7 = Zn Ch: HEDTA at 60 g Zn ha^{-1}	138.00	346.7 c	18.78 cd	4.333 d	14.67 ab
T_8 = Zn Ch: HEDTA at 120 g Zn ha^{-1}	143.00	468.0 b	22.15 a	4.633 bc	16.67 a
T_9 = Zn Ch: HEDTA at 180 g Zn ha^{-1}	136.00	473.0 b	20.04 bc	4.500 cd	15.33 ab
LSD value	---	33.93	1.1532	0.2237	1.891
F-value	0.9714ns	66.066**	20.7300**	34.1614**	3.5244*

Means sharing same letters are statistically similar at $P \leq 5\%$, ** = highly significant at P = 1%, * = significant at P = 5%,
ns = non-significant at P = 5%, LSD = least significant difference

Foliar application of Zn Ch: HEDTA at 120 g Zn ha^{-1} and Zn Ch: EDTA at 180 g Zn ha^{-1} produced maximum number of grains rows per cob i.e. 16.67 grain rows per cob (Table 1). The treatments like $ZnSO_4.7H_2O$ at 180 g Zn ha^{-1}, Zn Ch: EDTA at 60 g Zn ha^{-1}, Zn Ch: HEDTA at 60 g Zn ha^{-1} and Zn Ch: HEDTA at 180 g Zn ha^{-1} followed the ladder with mean values of 14.67, 14.67, 14.67 and 15.33 grain rows per cob. The rest of treatments along with control behaved alike. However, least number of grain rows per cob (13.33) was produced by control and ZnSO4.7H2O at 60 g Zn ha^{-1}.

The application of different zinc salts at their various proportions resulted in marked improvement in 100-grain weight (Table 2). Maximum 100 grain weight of 31.97 g was recorded in groups that received the foliar spray of Zn Ch: EDTA at 120 g Zn ha^{-1} followed by 30.60 g in fields where Zn Ch: HEDTA at 120 g Zn ha^{-1} was applied. Likewise, Zn Ch: HEDTA at 180 g Zn ha^{-1}, $ZnSO_4.7H_2O$ at 180 g Zn ha^{-1} and $ZnSO_4.7H_2O$ at 60 g Zn ha^{-1} showed lower weights of 27.33, 27.70 and 27.73 g but still higher than control (24.88 g).

Table 2. Effect of foliar application of zinc salts at various rates on yield and quality related attributes of maize plants

Treatments	**100-grain wt. (g)**	**No. of grains per cob**	**Grain weight per cob (g)**	**Biological yield (t ha^{-1})**	**Grain yield (t ha^{-1})**	**Protein contents (%)**	**Oil contents (%)**
T_0 = Control	24.88 d	460.7 e	144.7 d	13.49 h	6.97 f	9.273 f	4.117 e
T_1 = $ZnSO_4.7H_2O$ at 60 g Zn ha^{-1}	27.33 c	475.3 d	150.0 d	15.52 g	7.36 e	9.290 f	4.190 e
T_2 = $ZnSO_4.7H_2O$ at 120 g Zn ha^{-1}	28.83 bc	467.3 de	169.0 c	17.76 c	7.66 d	9.810 d	4.157 e
T_3 = $ZnSO_4.7H_2O$ at 180 g Zn ha^{-1}	27.70 c	566.7 c	172.3 bc	15.98 f	7.86 cd	9.537 e	4.413 d
T_4 = Zn Ch: EDTA at 60 g Zn ha^{-1}	28.61 bc	570.7 c	171.7 bc	16.25 e	7.69 d	10.27 c	4.310 d
T_5 = Zn Ch: EDTA at 120 g Zn ha^{-1}	31.97 a	620.0 b	206.0 a	18.67 a	7.98 bc	10.70 b	4.767 b
T_6 = Zn Ch: EDTA at 180 g Zn ha^{-1}	28.53 bc	717.3 a	204.3 a	16.57 d	8.52 a	11.07 a	4.900 a
T_7 = Zn Ch: HEDTA at 60 g Zn ha^{-1}	28.84 bc	564.7 c	174.3 bc	16.02 f	7.79 cd	10.61 b	4.387 d
T_8 = Zn Ch: HEDTA at 120 g Zn ha^{-1}	30.60 ab	620.0 b	183.0 b	18.37 b	8.42 a	9.547 e	4.533 c
T_9 = Zn Ch: HEDTA at 180 g Zn ha^{-1}	27.73 c	578.0 c	175.0 bc	16.29 e	8.15 b	9.313 f	4.413 d
LSD value	2.201	12.58	10.90	0.2101	0.2170	0.1715	0.1085
F-value	6.5546**	358.6813**	28.777**	467.6431**	283.1924**	130.6509**	44.8377**

Means sharing same letters are statistically similar at $P \leq 5\%$, ** = highly significant at P = 1%, LSD = least significant difference

Foliar application of zinc salts at various doses significantly affected number of grains per cob (Table 2). Those plots which were treated with Zn

Ch: EDTA at 180 g Zn ha^{-1} produced maximum number of grains per cob i.e. 717.3 grains per cob followed by 620.00 produced by Zn Ch: EDTA at 120 g Zn ha^{-1} and Zn Ch: HEDTA at 120 g Zn ha^{-1} (Table 2). Moreover, treatments like Zn Ch: HEDTA at 180 g Zn ha^{-1}, Zn Ch: EDTA at 60 g Zn ha^{-1}, Zn Ch: HEDTA at 60 g Zn ha^{-1} and $ZnSO_4.7H_2O$ at 180 g Zn ha^{-1} behaved alike with number of grains per cob 578.0, 570.7, 564.7 and 566.7, respectively. The field with out zinc application produced least number of grains per cob (460.7).

Foliar application of zinc salts at various proportions improved the grain weight per cob (Table 2); maximum grain weight per cob of 206.0 and 204.3 g were observed in fields where Zn Ch: EDTA at 120 g Zn ha^{-1} and Zn Ch: HEDTA at 180 g Zn ha^{-1} was applied followed by 183.0 g in Zn Ch: HEDTA at 120 g Zn ha^{-1}. Zinc salts with medium doses of 120 g Zn ha^{-1} were more efficient while minimum grain weight per cob was recorded in control.

Biological yield is an important trait that holds linear correlation with crop yield. Foliar application of zinc salts at various proportions significantly affected the biological yield of maize crop (Table 2). Highest biological yield (18.67 t ha^{-1}) was recorded in the fields where Zn Ch: EDTA at 120 g Zn ha^{-1} was sprayed and followed by 18.37 t ha^{-1}, 17.76 t ha^{-1} and 16.57 t ha^{-1} in Zn Ch: HEDTA at 120 g Zn ha^{-1}, $ZnSO_4.7H_2O$ at 120 g Zn ha^{-1} and Zn Ch: EDTA at 180 g Zn ha^{-1}, respectively. However, minimum biological yield (13.49 t ha^{-1}) was recorded in control where zinc application was not carried out.

Grain yield is one of the most important parameters in terms of economics of the crop and farmers as well. Grain yield was significantly altered as a function of zinc salt application at various doses as indicated from Table 2. It was observed that foliar application of $ZnSO_4.7H_2O$, Zn Ch: EDTA and Zn Ch: HEDTA improved the grain yield significantly; maximum grain yield 8.52 t ha^{-1} and 8.42 t ha^{-1} was recorded in fields where Zn Ch: EDTA at 180 g Zn ha^{-1} and Zn Ch: HEDTA at 120 g Zn ha^{-1} was applied followed by 8.15 t ha^{-1}, 7.98 t ha^{-1} and 7.79 t ha^{-1} in Zn Ch: HEDTA at 180 g Zn ha^{-1}, Zn Ch: EDTA at 120 g Zn ha^{-1} and Zn Ch: HEDTA at 60 g Zn ha^{-1}, respectively in each treated plot. Least grain yield was recorded in control (6.97 t ha^{-1}) where no application of zinc spray was carried out.

The data concerning protein contents revealed significant results as a function of foliar applied zinc sources indicated by the Table 2. Comparison of mean values revealed significant variations among the treatment means with maximum protein contents of 11.07 % produced by Zn Ch: EDTA at 180 g Zn ha^{-1} followed by 10.70 % and 10.61 % of protein contents recorded in those fields where foliar application of Zn Ch: EDTA at 120 g Zn ha^{-1} and Zn Ch: HEDTA at 60 g Zn ha^{-1} was carried out. However, the fields where treatments of Zn Ch: HEDTA at 120 g Zn ha^{-1} and $ZnSO_4.7H_2O$ at 180 g Zn ha^{-1} was applied behaved alike with protein contents of 9.547 % and 9.537 %, respectively. The least amount of protein contents 9.273 %, 9.290 % and 9.313 % was recorded in control, $ZnSO_4.7H_2O$ at 60 g Zn ha^{-1} and Zn Ch: HEDTA at 180 g Zn ha^{-1} these treatments were statistically at par.

The influence of zinc application was significant regarding oil contents of grains as presented in Table 2. Data regarding the oil contents of maize indicated that Zn Ch: EDTA at 180 g Zn ha^{-1} improved the oil contents most significantly with mean oil contents of 4.90 % followed by 4.77 % recorded in fields where Zn Ch: EDTA at 120 g Zn ha^{-1} was applied. It was observed that $ZnSO_4.7H_2O$ at 180 g Zn ha^{-1}, Zn Ch: EDTA at 60 g Zn ha^{-1}, Zn Ch: HEDTA at 60 g Zn ha^{-1} and Zn Ch: HEDTA at 180 g Zn ha^{-1} behaved alike with mean oil contents of 4.413 %, 4.310 %, 4.387 % and 4.413 %, respectively. However, fields without zinc application gave least oil contents of 4.12 % that was at par with $ZnSO_4.7H_2O$ at 60 g Zn ha^{-1} and $ZnSO_4.7H_2O$ at 120 g Zn ha^{-1} with mean oil contents of 4.19 and 4.16%, respectively.

Economic analysis

The adoptability of a technology or product used is determined by the net monetary gain from it. Foliar applied Zn treatments at various rates gave higher net field benefits over control. The maximum net field benefit of Rs. 101148 ha^{-1} was recorded in Zn Ch: EDTA at 180 g Zn ha^{-1} followed by Zn Ch: HEDTA at 120 g Zn ha^{-1}, Zn Ch: HEDTA at 180 g Zn ha^{-1}, Zn Ch: EDTA at 120 g Zn ha^{-1}, $ZnSO_4.7H_2O$ at 180 g Zn ha^{-1} with net filed benefits of Rs. 100086 ha^{-1}, Rs. 94995 ha^{-1}, Rs. 93030 ha^{-1}, Rs. 90949 ha^{-1}, respectively (Table 3).

Dominance analysis was carried out by arranging the treatments in the order of increasing cost. Those treatments whose cost was higher than the preceding treatment but its net field benefit was lower were termed as "dominated" and denoted by "D". Those treatments which were found dominated were not included in calculation of marginal rate of return. Results obtained through dominance analysis are given in Table 3. The treatments $ZnSO_4.7H_2O$ at 120 g Zn ha^{-1}, $ZnSO_4.7H_2O$ at 180 g Zn ha^{-1} and Zn Ch: HEDTA at 180 g Zn ha^{-1} were found dominated as their net field benefit did not increased with an increase in total cost.

Maximum marginal rate of return 7518 % was recorded in Zn Ch: HEDTA at 120 g Zn ha^{-1} with a net field benefit of Rs. 100086 ha^{-1} as depicted from Table 3.

Sensitivity analysis was carried out because of the change in input and output prices year after year. For this purpose sensitivity analysis was carried out to check the risk due to price variability. This analysis was done with following assumptions.

Constant output prices and input prices increased by 10 %

To check the variability of input prices this type of analysis was carried out for 10 % increase in input prices from the current prices (year 2009). The sensitivity analysis presented in Table 4 represented same results for the marginal rate of return. The maximum marginal rate of return of 6825.21 % was recorded in Zn Ch: HEDTA at 120 g Zn ha^{-1} with net field benefit of Rs. 96412 ha^{-1} even when input prices were increased by 10 %.

Table 3. Dominance and marginal analysis

Treatments*	GI	Dominance analysis		% change	Marginal analysis		
		GE/ TC	NFB		MC	MFB	MRR
	Rs ha^{-1}				Rs ha^{-1}		(%)
T_0 = Control	113262	34293	78969				
T_1 = $ZnSO_4.7H_2O$ at 60 g Zn ha^{-1}	119600	35195	84405	6.88	902	5436	602.61
T_4 = Zn Ch: EDTA at 60 g Zn ha^{-1}	124962	35370	89592	13.45	175	5188	2964.29
T_7 = Zn Ch: HEDTA at 60 g Zn ha^{-1}	126588	35417	91170	15.45	47	1578	3357.45
T_2 = $ZnSO_4.7H_2O$ at 120 g Zn ha^{-1}	124475	35677	88798 D	12.45	---	---	---
T_5 = Zn Ch: EDTA at 120 g Zn ha^{-1}	129675	36027	93648	18.59	610	2478	406.15
T_8 = Zn Ch: HEDTA at 120 g Zn ha^{-1}	136825	36121	100704	27.52	94	7056	7506.38
T_3 = $ZnSO_4.7H_2O$ at 180 g Zn ha^{-1}	127725	36159	91566 D	15.95	---	---	---
T_6 = Zn Ch: EDTA at 180 g Zn ha^{-1}	138450	36684	101766	28.87	563	1062	188.63
T_9 = Zn Ch: HEDTA at 180 g Zn ha^{-1}	132438	36825	95612 D	21.08	---	---	---

GI = gross income, GE/TC = gross expenditure/ total cost, NFB = net field benefit, MC = marginal cost, MFB = marginal net field benefit, MRR = marginal rate of return, D = Dominant
* = treatments are arranged in order of their increasing gross expenditure/ total cost.

Constant input prices and output prices decreased by 10 %

This type of analysis was carried out to evaluate the effects of reduction in output prices by 10 % from current prices (year, 2009). The significant results recorded for marginal analysis were the same (Table 4). Maximum marginal rate of return (6755.96 %) was recorded in Zn Ch: HEDTA at 120 g Zn ha^{-1} with net field benefit of Rs. 86404 ha^{-1} even when the output prices decreased by 10 %.

Table 4. Sensitivity analysis

Treatments*	Marginal analysis of constant output prices and input prices increased by 10%					Marginal analysis of constant input prices and output prices decreased by 10%				
	GE/ TC	MC	NFB	MFB	MRR (%)	GE/ TC	MC	NFB	MFB	MRR (%)
	(Rs ha^{-1})					(Rs ha^{-1})				
T_0 = Control	37723	---	75540	---	---	34293	---	67643	---	---
T_1 = $ZnSO_4.7H_2O$ at 60 g Zn ha^{-1}	38715	992	80885	5345	538.73	35195	902	72445	4802	532.34
T_4 = Zn Ch: EDTA at 60 g Zn ha^{-1}	38908	193	86055	5170	2685.71	35370	175	77096	4651	2657.86
T_7 = Zn Ch: HEDTA at 60 g Zn ha^{-1}	38959	52	87628	1573	3043.13	35417	47	78511	1416	3011.70
T_2 = $ZnSO_4.7H_2O$ at 120 g Zn ha^{-1}	D	D	D	D	D	D	D	D	D	D
T_5 = Zn Ch: EDTA at 120 g Zn ha^{-1}	39630	671	90045	2417	360.13	36027	610	80680	2169	355.53
T_8 = Zn Ch: HEDTA at 120 g Zn ha^{-1}	39734	103	97091	7047	6814.89	36121	94	87021	6341	6745.74
T_3 = $ZnSO_4.7H_2O$ at 180 g Zn ha^{-1}	D	D	D	D	D	D	D	D	D	D
T_6 = Zn Ch: EDTA at 180 g Zn ha^{-1}	40353	619	98097	1006	162.39	36684	563	87921	900	159.77
T_9 = Zn Ch: HEDTA at 180 g Zn ha^{-1}	D	D	D	D	D	D	D	D	D	D

GE/TC = gross expenditure/ total cost, MC = marginal cost, NFB = net field benefit, MFB = marginal net field benefit, MRR = marginal rate of return, D = Dominant
* = treatments are arranged in order of their increasing gross expenditure/ total cost

Discussion

Zinc is one of the essential micronutrients required for optimum plant growth. Plants take up zinc in its divalent form. Plant height is one of the most important trait in determining the vigor and potential of any crop. Foliar application of zinc salts affected all growth related attributes significantly except plant height that showed non significant variations among the treatment means. These results are in accordance with Thalooth *et al*. (2006) who reported that application of zinc had not shown any significance for the plant height while it improved all other growth parameters significantly. However, the findings of the present research work are in contradiction to the interventions led by Teixeira *et al*. (2004), Thalooth *et al*. (2006) and Bukvic *et al*. (2003). The investigations led by Thalooth *et al*. (2006) reported similar results for leaf area that support the findings of the present research work. They have recorded maximum leaf area (694.27 cm^2) where Zn application was carried out at 300 ppm as Zn-EDTA.

Zn applications markedly enhance all the yield contributing parameters including cob diameter. These findings are in well support with the work of Jose and Gonzalez (2006). They also reported that yield features of the maize crop were momentously increased with Zn application. The findings of Fecenko and Lozek (1998) were found to be in alike with the present findings and they reported that application of Zn fertilizers at varying levels significantly affected the yield contributing factors of the plants. Similar results were also obtained by Soylu *et al.,* 2005 who also reported significant increase in all yield contributing factors. Rico *et al*. (1996) reported similar results for the yield of maize crop and showed significantly enhanced crop yield with application of different Zn fertilizers at different concentrations. Findings of Ali *et al*. (2008) were in well support with the findings of the present research work. They reported that foliar application of nutrients significantly increased number of spikes m^{-2}, grains per spike, 1000-grain weight, biological yield and grain yield. The results of current study are well supported by the findings of Soleimani (2006) and Ali *et al*. (2008). They reported marked increase in the number of grains with foliar application of nutrients such as zinc. Similar results regarding 1000-grain weight were also reported by Teixeira *et al*. (2004) and Ali *et al*. (2008) while Modaihsh (1997) reported that application of micronutrient combinations either in chelated or non-chelated forms gave greater biological and grain yields than individual applications of the micronutrients. Shukla and Raj *et al*. (1987) reported similar results and found that Zinc treatments have given yield responses of up to 4 tons ha^{-1} in wheat and rice and up to 2 tons ha^{-1} in maize.

Moreover, Fecenko and Lozek (1998) reported similar results that indicated marked differences among the means of yield contributing factors. The highest maize yield (10.90%) was found where application of 1.5 kg Zn ha^{-1} was carried out. The highest Zn rate (6 kg ha^{-1}) resulted in reduction of yield due to its toxic effect. Sawarkar *et al*. (1999), Kalayci *et al*. (1999), Soomro *et al*., (2000) and Shaheen *et al*. (2007) showed similar findings for grain yield with nutrients application, especially Zn. Several studies have been shown that a small amount of nutrients, particularly Zn and Mn applied by foliar spraying can significantly increase the yield of crops (Crabtree, 1999; Hebbern *et al*., 2005; Mirzapour and Khoshgoftar, 2006; Sarkar *et al*., 2007).

Zinc plays an important role in the production of biomass (Kaya and Higgs, 2002; Cakmak, 2008). Furthermore, zinc may be required for chlorophyll production, pollen function, fertilization and germination (Kaya and Higgs, 2002; Cakmak, 2008). Rastija *et al*. (2002) also reported markedly increased grain yield of all five inbreds investigated with $ZnSO_4.7H_2O$ when applied at the rate of 0.75 % as foliar spray. Fecenko and Lozek (1998) reported that crude protein contents in grain were increased by 0.91 % by the application of 1.5 and 3 kg Zn ha^{-1}. Similar results were also reported by Peck *et al*. (2008). However, findings of the Fang *et al*. (2008) also showed marked differences among the means for protein (maximum of 7 %) and ash contents (maximum of 0.47 %) with fertilizer application.

Application of zinc as foliar spray has markedly increased all the growth, yield and quality related attributes of maize crop. However, application of Zn Ch: EDTA at 180 g Zn ha^{-1} surpassed all other treatments by giving higher values for leaf area, cob diameter, No. of grain rows per cob, No. of grains per cob, grain weight per cob, grain yield, protein and oil contents. Likewise this treatment has proved to give maximum net field benefit of Rs. 101766 ha^{-1} with minimum marginal rate of return of 188.63 %.

References

Alam, S.M. (2004). Influence of zinc and boron application on rice yield and their residual effect on the yield and composition of following wheat. Pakistan Journal of Soil Science 23:6-12.

Ali, S., Khan A.R., Mairaj G., Arif M., Fida M. and Bibi S. (2008). Assessment of different crop nutrient management practices for yield improvement. Australian Journal of Crop Science 2:150-157.

Alloway, B.J. (2003). Zinc in soils and crop nutrition. International Zinc Assocation. online: http://www.zinc crops.org/documents/Zn_in_Soils_and_Crop_Nutrition _2008.pdf.

Anonymous (1990). Official methods of analysis of the association of official analytical chemis. Arlington Virginia, U.S.A.

Bukvic, G., Antunovic M., Popovic, S. and Rastija, M. (2003). Effect of P and Zn fertilization on biomass, yield and its uptake by maize lines (*Zea mays* L.). Plant Soil and Environment 49:505-510.

Cakmak, I. (2008). Enrichment of cereal grains with zinc: Agronomic or genetic biofortification? Plant and Soil 302:1-17.

CIMMYT (1988). From agronomic data to farmer recommendations: An economics training manual. Completely revised edition. Mexico. D.F.

Crabtree, W.L. (1999). Deep placement of Mn fertilizer on a sandy soil increased grain yield and reduced split seed in *Lupinus angustifolius*. Plant and Soil 214:9-14.

Fang, Y., Wang L., Xin Z., Zhao L., An X. and Hu, Q. (2008) Effect of foliar application of zinc, selenium, and iron fertilizers on nutrients concentration and yield of rice grain in China. Journal of Agricultural and Food Chemistry 56:2079-2084.

Fecenko, J. and Lozek O. (1998). Maize grain yield formation in dependence on applied zinc doses and its content in soil. Rostl 44:15-18.

Hebbern, C.A., Pedas P., Schjoerring, J.K., Knudsen, L. and Husted, S. (2005). Genotypic differences in manganese efficiency: field experiments with winter barley (Hordeum vulgare L.). Plant and Soil 272:233-244.

Hergert, G.W., Rehm G.W. and Wiese, R.A. (1984). Field evaluation of zinc sources band applied with ammonium polyphosphate suspensions. Soil Science Society of America Journal 48:1190-1193.

Jose, M. and Gonzalez, D. (2006). Zinc Transformations in Neutral Soil and Zinc Efficiency in Maize Fertilization. Journal of Agricultural and Food Chemistry 54:9488-9495.

Kalayci, M., Torun, B., Eker, S., Aydin, M., Ozturk, L. and Cakmak, I. (1999). Grain yield, zinc efficiency and zinc concentration of wheat cultivars grown in a zinc-deficient calcareous soil in field and greenhouse. Field Crops Research 63:87-98.

Kaya, C. and Higgs, D. (2002). Improvements in physiological and nutritional developments of tomato cultivars grown at high zinc by foliar application of phosphorus and iron. Journal of Plant Nutrition 25:1881-1894.

Loue, A. (1988). Microelements in agriculture. Oxford University Press, Madrid.

Mirzapour, M.H. and Khoshgoftar, A.H. (2006). Zinc application effects yield and seed oil contents o sunflower grown on saline calcareous soil. Journal of Plant Nutrition 29:1719-1727.

Modaihsh, A.S. (1997). Foliar application of chelated and non-chelated metals for supplying micronutrients to wheat grown on calcareous soil. Experimental Agriculture 33:237-245.

Mortvedt, J.J. (1979). Corn response to zinc sulfate applied alone or with suspensions. Fertilizer Solutions magazine. May.

Peck, A.W., McDonald, G.K. and Graham, R.D. (2008). Zinc nutrition influences the protein composition of flour in bread wheat (*Triticum aestivum* L.). Journal of Cereal Science 47:266-274.

Rastija, M., Bukvic, G. and Josipovic, M. (2002). Response of corn to zinc fertilization. Proc. Union of Scientists-Rousse. Energy efficiency and agricultural engineering. Int. Sci. Conf. Rousse, Bulgaria 1:131-136.

Rico, M.I., Alvarez, J.M. and Mingot, J.I. (1996). Efficiency of zinc ethylenediaminetetraacetate and zinc lignosulfonate soluble and coated fertilizers for maize in calcareous soil. Journal of Agricultural and Food Chemistry 44:3219-3223.

Robertson, J.A. and Morrison, W.H. (1979). Analysis of oil content of sunflower seed by NMR. Journal of the American Oil Chemists' Society 56:961-964.

Romheld, V. and Marschner, H. (1991). Function of micronutrients in plants. In JJ Mortvedt, FR Cox, LM Shuman, RM Welch, eds, Micronutrients in Agriculture, Ed 2. Soil Science Society of America, Madison l:297-328.

Sarkar, D., Mandal, B. and Kundu, M.C. (2007). Increasing use efficiency of boron fertilisers by rescheduling the time and methods of application for crops in India. Plant and Soil 301:77-85.

Savithri, P., Perumal, R. and Nagarajan, R. (1999) Soil and crop management technologies for enhancing rice production under micronutrient constraints. Nutrient Cycling in Agroecosystems 53:83-92.

Sawarkar, S.D., Gupta, D.P., Rathore, G.S. and Tava, S.K. (1999). Response of maize to soil application of zinc on sandy loam soils of Madhiapradesh. Current Res. Uni. Agri. Sci., 28(5):109-110.

Shaheen, R., Samim, M.K. and Mahmud, R. (2007). Effect of zinc on yield and zinc uptake by wheat on some soils of Bangladesh. J. Soil. Nature 1:7-14.

Shukla, V.C. and Raj, H. (1987). Relative response of corn, pearl-millet, sorghum and cowpea to zinc deficiency in soil. Journal of Plant Nutrition 10:2057-2067.

Sillanpa, A.M. (1982). Micronutrients and nutrient status of soils. A global study. FAO Soil Bull. 48, Rome.

Soleimani, R. (2006). The effects of integrated application of micronutrient on wheat in low organic carbon conditions of alkaline soils of western Iran. 18th world congress of soil sci.

Soomro, A.W., Soomro, A.R., Leghari, A.B., Chang, M.S., Soomro, A.H. and Tunio, G.H. (2000). Pakistan Journal of Biological Sciences 3:2008-2009.

Soylu, S., Sade, B., Topal, A., Akgun, N. and Gezgin, S. (2005). Responses of irrigated durum and bread wheat cultivars to boron application in low boron calcareous soil. Turkish Journal of Agriculture and Forestory 29:275-286.

Steel, R.G.D., Torrie, J.H. and Dickey, D.A. (1997) Principles and procedures of statistics. A biometrical approach. 3rd Eds. McGraw-Hill, Book Co. Inc., New York, USA.

Tariq, M., Khan, M.A. and Perveen, S. (2002) Response of maize to applied soil zinc. Asian Journal of Plant Science 1:476-477.

Teixeira, I.T., Borem, A., Araujo, G.A.A. and Fontes, R.L.F. (2004). Manganese and zinc leaf application on common bean grown on a “Cerrado” soil. Sci. Agric. (Piracicaba, Braz.) 61:77-81.

Thalooth, A.T., Tawfik, M.M. and Muhammed, H. (2006). A Comparative study on the effect of foliar application of zinc, potassium and magnesium on growth, yield and some chemical constituents of Mungbean plants grown under water stress conditions. Department of Field Crops Research, National Research Centre, Dokki, Giza, Egypt. World Journal of Agricultural Science 2:37-46.

Welch, R.M., Combs (Jr) G.F. and Duxbury J.M. (1997). Toward a “greener” revolution. Issues in Science and Technology 14:50-58.

Wilhelm, N.S., Graham, R.D. and Rovira, A.D. (1988) Application of different sources of manganese sulphate decreases take-all (Gaeumannomyces graminis var. tritici) of wheat grown in a manganese deficient soil. Australian Journal of Agricultural Research 39:1-10.

Wissuwa, M., Ismail A.M. and Graham R.D. (2008). Rice grain zinc concentrations as affected by genotype native soil-zinc availability, and zinc fertilization. Plant and Soil 306:37-48.

Yoshida, S., Tanaka A. (1969). Zinc deficiency of the rice plant in calcareous soils. Soil Science Journal of Plant Nutrition 15:75-80.

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