American Journal of Plant Sciences, 2014, 5, 2646-2654
Published Online August 2014 in SciRes. http://www.scirp.org/journal/ajps
http://dx.doi.org/10.4236/ajps.2014.518279

Influence of Zinc Nutrition on Growth and Yield Behaviour of Maize (*Zea mays* L.) Hybrids

Azeem Tariq[1], Shakeel A. Anjum[1], Mahmood A. Randhawa[2], Ehsan Ullah[1*], Muhammad Naeem[1], Rafi Qamar[3], Umair Ashraf[1], Mubashar Nadeem[1]

[1]Department of Agronomy, University of Agriculture, Faisalabad, Pakistan
[2]Department of Continuing Education, University of Agriculture, Faisalabad, Pakistan
[3]Department of Agronomy, University College of Agriculture, University of Sargodha, Sargodha, Pakistan
Email: [*]ehsanchahal@gmail.com

Received 24 May 2014; revised 29 June 2014; accepted 1 August 2014

Abstract

A field experiment was conducted during spring 2011 at Agronomic Research Area, University of Agriculture, Faisalabad, Pakistan to evaluate the comparative efficacy of Zn uptake and grain yield in three maize hybrids namely Pioneer-32F 10, Monsanto-6525 and Hycorn-8288 through the application of Zn in the form of $ZnSO_4$. The $ZnSO_4$ treatments comprised; soil application at the time of sowing @ 12 kg·ha^{-1} (Zn_1), foliar application at vegetative stage (9 leaf stage) @ 1% $ZnSO_4$ solution (Zn_2) and foliar application at reproductive stage (anthesis) @ 1% $ZnSO_4$ solution (Zn_3) and one treatment was kept as a control, where zinc was not applied (Zn_0). The experimental results showed substantial difference in all physiological and yield parameters except plant height and stem diameter. Statistically maximum grain yield (8.76 t·ha^{-1}) was obtained with foliar spray of $ZnSO_4$ at 9 leaf stage (Zn_2) in case of Monsanto-6525. As regard to quality parameters, Pioneer-32F 10 and Hycorn-8288 accumulated more zinc contents in grains but Monsanto-6525 attained more zinc concentration in straw. Foliar spray of $ZnSO_4$ at 9 leaf stage produced 19.42% more zinc contents in grains as compared to other $ZnSO_4$ treatments. Foliar spray of $ZnSO_4$ at 9 leaf stage in Monsanto-6525 hybrid produced higher grain yield.

Keywords

Grain Yield, Hybrids, Maize (*Zea mays* L.), $ZnSO_4$

[*]Corresponding author.

How to cite this paper: Tariq, A., Anjum, S.A., Randhawa, M.A., Ullah, E., Naeem, M., Qamar, R., Ashraf, U. and Nadeem, M. (2014) Influence of Zinc Nutrition on Growth and Yield Behaviour of Maize (*Zea mays* L.) Hybrids. *American Journal of Plant Sciences*, **5**, 2646-2654. http://dx.doi.org/10.4236/ajps.2014.518279

1. Introduction

Maize (*Zea mays* L.) ranks the third largest cereal crop after wheat and rice on hectare basis in Pakistan. Its grain is a rich source of many important nutrients and used for multipurpose. But yield of maize crop is alarmingly affected due to deficiency of plant nutrients in Pakistan. The application of essential plant nutrients in optimum quantity and right proportion is a key to enhance and sustain crop productivity [1]. Overall crop nutrition plays a vital role in plant development and it is generally comprised of macronutrients and micronutrients with major role of macro ones, but the micronutrients (Zn, B, Co, Mn, Mo, Cu, Ni and Fe), even being required in smaller amounts are of equally vital for plant growth and development [2]. It is due to the fact that micronutrients not only enhance the grain yields but contribute to improvement of the quality in terms of grain nutrients as well [3]. It was further elucidated that micronutrients can increase grain yield up to 50%, as well as increase macronutrients use efficiency [4]. Therefore, we can pursue the role of micronutrients in balanced combinations for getting optimal production. Especially the uses of specific mineral nutrients have become crucial for better plant growth [5] which can be supplemented as a chemical fertilizer in various cropping zones.

Among the micronutrients, zinc is an essential nutrient for the standard and healthy growth and development of plants. Generally, zinc affects the synthesis of protein in plants hence is considered to be the most critical micronutrient [6]. Zn is also crucial in taking part in plant development due to its catalytic action in metabolism for all crops especially maize [7] whereas Zn is used by the plant in many of its vital processes such as synthesis of protein, structure and functions of membrane, expression of genes and oxidative stress tolerance [8]. Similarly, application of $ZnSO_4$ significantly increased the maize yield [9]. B and Zn have significant interaction with maize growth and tissue nutrient concentration [10]. Therefore, the deficiency of Zn in soil causes deficiency in crops and altogether this has become a problem all over the world with acute zinc deficiency ranges in arid to semi-arid regions of the world [11]. So, Zinc deficiency is a common phenomenon of crops especially in predominantly high pH soils having low zinc [12]. This trend of Zn deficiency has been detected in new crop varieties as compared to old ones [13]. The genetic differences among crop varieties and species for the uptake of Zn could be promising approach to Zn problem which invites the selection of proper genotypes.

Moreover, the proper method of nutrient application can be another approach for better uptake and utilization of Zn. Amongst different methods, the foliar spray of micronutrients is an efficient one for enhancement of crop productivity [14]. This way of nutrient application is easy and simple in improving plant nutritional condition of maize [15] and wheat [16]. Reasons for effectiveness of foliar spray are simple due to its direct application to the leaves [17]. However, micronutrients can be applied directly into the soil as well. Soil applied Zn is effective in enhancing the grain yield whereas Zn concentration in grain improves via foliar spray of Zn fertilizer. Based on particular studies, soil and foliar applications of zinc enhance the yield of crops [18], whereas increased Zn uptake and accumulation in crop grain have been found with both of the soil and foliar application [19].

Keeping in view of the systematic studies on zinc application methods and different potentials of maize cultivars to take up zinc, a study was planned in order to determine the growth response of maize hybrids under varying levels of zinc application, their comparative uptake and to find out appropriate stage of zinc application.

2. Materials and Methods

The present study was carried out at Agronomic Research Area, University of Agriculture, Faisalabad (184 meters elevation, 31˚N latitude and 73˚ longitudes) during 2011. Soil samples were collected before sowing and after harvest of maize from experimental area in order to have a view of physico-chemical properties of soil with special reference to zinc (**Table 1(a)** & **Table 1(b)**). The experiment was laid out in Randomized Complete Block Design (RCBD) with factorial arrangements having three replications with net plot size of 5.0 m × 2.8 m. The treatments of an experiment included three different methods of Zn application and one control where zinc was not applied (Zn_0) while soil application at sowing @ 12 $kg \cdot ha^{-1}$ (Zn_1), foliar application at vegetative phase (9 leaf stage) @ 1% $ZnSO_4$ solution (Zn_2) and foliar application at reproductive phase (anthesis) @ 1% $ZnSO_4$ solution (Zn_3) and three different hybrid varieties of maize namely Pioneer-32F 10 (H_1), Monsanto-6525 (H_2) and Hycorn-8288 (H_3). Maize hybrids (viz. Pioneer-32F 10, Monsanto-6525 and Hycorn-8288) were sown on 4th February, 2011 as spring crop. Sowing was done with the help of single row hand drill at 70 cm spaced rows using seed rate of 30 $kg \cdot ha^{-1}$. Fertilizers at the rate of 250 $kg \cdot ha^{-1}$ and 125 $kg \cdot ha^{-1}$ N and P_2O_5 were applied. All of phosphorous and half of the nitrogen were applied at the time of sowing in the form of DAP (Diammonium

Table 1. (a) Soil analysis before sowing; (b) Soil analysis after crop harvest.

(a)

Soil properties	Value	Status
pH	8.2	Alkaline
EC ($dS \cdot m^{-1}$)	0.27	Normal
OM (%)	0.73	Low
N (%)	0.0457	Low
P (ppm)	4.5	Very low
K (ppm)	174.5	Sufficient
Zn (ppm)	0.65	Deficient

(b)

Treatments	pH	EC ($dS \cdot m^{-1}$)	OM (%)	N (%)	P (ppm)	K (ppm)	Zn (ppm)
$Zn_0 H_1$	8.1	1.43	0.67	0.044	4.1	176.6	0.56
$Zn_0 H_2$	7.7	1.33	0.68	0.046	4.3	175.8	0.64
$Zn_0 H_3$	8.2	1.48	0.72	0.048	4.8	171.5	0.59
$Zn_1 H_1$	8.0	1.34	0.71	0.042	4.5	165.4	0.67
$Zn_1 H_2$	7.9	1.42	0.68	0.046	4.0	171.8	0.67
$Zn_1 H_3$	8.2	1.51	0.61	0.045	4.3	169.2	0.65
$Zn_2 H_1$	7.9	1.40	0.62	0.043	4.1	168.3	0.61
$Zn_2 H_2$	8.3	1.23	0.66	0.041	5.1	169.4	0.64
$Zn_2 H_3$	7.7	1.51	0.73	0.046	4.6	157.6	0.61
$Zn_3 H_1$	8.1	1.22	0.65	0.045	4.2	167.0	0.58
$Zn_3 H_2$	8.2	1.32	0.68	0.046	4.1	174.5	0.65
$Zn_3 H_3$	7.9	1.38	0.69	0.046	4.7	166.6	0.62

Phosphate) and Urea while remaining half of nitrogen was applied in two splits *i.e*. at five leaf stage and other at tasseling stage. $ZnSO_4$ solution of 1% was prepared from 21% Zinc sulphate salt. Foliar spray of 1% $ZnSO_4$ was applied as per treatment and soil application of $ZnSO_4$ @ 12 $kg \cdot ha^{-1}$ was accomplished at the time of sowing.

Subsequent irrigations were applied, whenever needed to the crop. Thinning was done at 3 - 4 leaf stage in order to maintain plant to plant distance of 20 cm. Crop was kept weed free and insect pest were also controlled with proper application of chemicals. The crop was harvested manually after its maturity on 24^{th} of June 2011.

Data regarding stem diameter, number of leaves per plant, days to 50% tasseling, crop growth rate (CGR), grain yield, Zn concentration in grains and straw were recorded using standard procedures. For this purpose ten plants were randomly selected from each plot and tagged. The field was visited twice a day right from start of tasseling until its completion and the date of start of tasseling were recorded with the help of tags. After completion the tags were removed from the plants and written dates were recorded which were used to calculate the days to 50% tasseling. At harvest, diameter (cm) of ten randomly selected striped stems from the base, middle and top was measured and averaged. Likewise, the leaves were counted randomly from ten plants and then averaged. The cobs were separated from the plants of each plot and put in the paper bags. Then shade dried the cobs in the bags. After drying, the cobs were shelled through a mechanical sheller. The grains from each plot were weighted by using a spring balance in kg. Final data was recorded in tons per hectare after making conversions. Crop Growth Rate (CGR) was calculated as proposed by Hunt (1978) [20] in $g \cdot m^{-2} \cdot day^{-1}$.

$$\text{Crop growth rate} = W_2 - W_1 / t_2 - t_1$$

where

W_1= Total dry matter at the first harvest

W_2 = Total dry matter at the second harvest

t_1 = Date of observation of first dry matter
t_2 = Date of observation of second dry matter
Data collected was analyzed statistically by using Fisher's Analysis of Variance Technique and least significant difference (LSD) test at 5% probability level was applied to compare the treatments' means [21] using the computer statistical program MSTATC.

3. Results and Discussion

3.1. Stem Diameter

The data presented in **Table 2** showed that there was significant difference in stem diameter among all maize hybrids. Maximum stem diameter (1.25 cm) was recorded in Monsanto-6525, followed by Pioneer-32F 10 (1.13 cm) while Hycorn-8288 had minimum stem diameter of 0.99 cm. All treatments of $ZnSO_4$ had no significant effect on stem diameter in maize hybrids. The interaction between maize hybrids and different $ZnSO_4$ treatments was statistically non-significant.

Stem diameter is an important yield contributing trait in maize. It contributes significantly to grain yield of maize because it control both number of grains per cob and grain size. In our study, the results depicted that $ZnSO_4$ application exhibited no significant effect on stem diameter. However, due to genetic variations different maize hybrids showed significant difference regarding stem diameter in maize. Contrarily, foliar application of micronutrients increased the diameter of plant over the control treatment [22]. So, these findings conclude that the entire maize hybrid gave equal stem diameter at all treatments of zinc application.

3.2. Number of Leaves per Plant

Data pertaining to the number of leaves per plant as affected by different treatments of $ZnSO_4$ application in maize hybrids is presented in **Table 3**. The results showed that all maize hybrids produced significantly different number of leaves per plant. Maximum numbers of leaves (13.3) were found in Monsanto-6525, followed by Pioneer-32F 10 which produced 12.7 leaves per plant. Hycorn-8288 produced minimum number of leaves per plant (10.0). There was no significant difference on number of leaves at all $ZnSO_4$ treatments. The interaction between different maize hybrids and $ZnSO_4$ treatments was also found statistically non-significant.

An important feature of plant which contributes towards the grain yield is number of leaves per plant. Non significant effects of $ZnSO_4$ could be attributed to genetic potential of maize hybrids. It was reported that appli-

Table 2. Effect of $ZnSO_4$ application on stem diameter (cm) of maize hybrids.

Treatment	Zn_0	Zn_1	Zn_2	Zn_3	Mean
Pioneer-32F 10	1.12	1.15	1.17	1.06	1.13 B
Monsanto-6525	1.28	1.28	1.15	1.31	1.25 A
Hycorn-8288	0.94	1.06	0.97	0.99	0.99 C
Mean	1.11	1.16	1.10	1.12	
LSD value for	Hybrid = 0.95				

Any two means not sharing a letter in common differ significantly at $p \leq 0.05$.

Table 3. Effect of $ZnSO_4$ application on number of leaves of maize hybrids.

Treatment	Zn_0	Zn_1	Zn_2	Zn_3	Mean
Pioneer-32F 10	12.5	12.7	13.1	12.5	12.7 B
Monsanto-6525	13.3	13.8	12.8	13.2	13.3 A
Hycorn-8288	9.7	10.1	9.9	10.3	10.0 C
Mean	11.8	12.2	11.9	12.0	
LSD value for	Hybrid = 0.42				

Any two means not sharing a letter in common differ significantly at $p \leq 0.05$.

cation of zinc and manganese had positive effects on growth parameters [23]. In contrast to this it was reported that foliar application of zinc significantly increased the growth parameters of mungbean plant [24].

3.3. Number of Days Taken to 50% Tasseling

The data presented in **Table 4** clearly depicts that the interaction between $ZnSO_4$ treatments and maize hybrids for the number of days taken to 50% tasseling was found to be significant. Maximum number of days to tasseling (85.33) was observed with a foliar spray of $ZnSO_4$ at 9 leaf stage (Zn_2) in Pioneer-32F 10 which was statistically at par with same foliar spray in case of Monsanto-6525 (84.00). However, the minimum number of days (80.33) to tasseling was taken by the Hycorn-8288, when foliar application was done at anthesis @ 1% $ZnSO_4$ solution. Moreover, different hybrids also differ significantly in number of days taken to 50% tasseling. However with regard to the zinc treatments, there were no significant differences among the different treatments of $ZnSO_4$ application. The results of our study are quite in line with a study reported that formation of male and female reproductive organs and pollination are disturbed by zinc deficiency, which may be credited to the decrease of Indol Acetic Acid (IAA) synthesis in plant tissues [25].

3.4. Crop Growth Rate (CGR)

Results of this study indicated that the interactive effects of maize hybrids and $ZnSO_4$ application were found significant for mean crop growth rate (CGR) as depicted in **Table 5**. Zn_2H_1 had maximum crop growth rate (26.22) which was statistically at par with Zn_1H_2 (25.01). Minimum MCGR was observed in case of Zn_0H_3. The study further illustrates that Maize hybrids also showed the highly significant effect on mean crop growth rate (MCGR). The data exhibited that Pioneer-32F 10 have 7.4% more crop growth rate than Monsanto-6525 and 40% more than Hycorn-8288. Interestingly, $ZnSO_4$ application was also found to be significant for MCGR in maize hybrids. There was 46% increase in mean crop growth rate from Zn_0 (control) to Zn_2 (foliar application of $ZnSO_4$ at 9^{th} leaf stage). Soil application of $ZnSO_4$ (Zn_1) increased MCGR up to 36% from the control. The results showed that application of $ZnSO_4$ increased the crop growth rate of maize hybrids.

Maximum crop growth rate was recorded up to 85 DAS; this progressive increase in crop growth rate was due to increase in sunshine hours which led to increase the rate of photosynthesis resulted in more CGR. Maize hybrids showed the highly significant effect on mean crop growth rate (MCGR). Result trend of our study revealed that Pioneer-32F 10 had 7.4% more crop growth rate than Monsanto-6525 and 40% more than Hycorn-8288. This increase might be due to more leaf expansion and high rate of photosynthesis in Pioneer plants. Foliar application of $ZnSO_4$ had significant effect on growth rate of plants. It could be possibly due to increase in chlo-

Table 4. Effect of $ZnSO_4$ application on time to 50% tasseling (days) of maize hybrids.

Treatment	Zn_0	Zn_1	Zn_2	Zn_3	Mean
Pioneer-32F 10	84.00 ab	84.00 ab	85.33 a	84.00 ab	**84.33 A**
Monsanto-6525	85.00 a	84.00 ab	84.00 ab	84.00 ab	**84.25 A**
Hycorn-8288	82.67 bc	83.67 ab	81.33 cd	80.33 d	**82.00 B**
Mean	**83.89**	**83.89**	**83.56**	**82.78**	
LSD value for	**Hybrid = 0.91**		**H × Z = 1.83**		

Any two means not sharing a letter in common differ significantly at $p \le 0.05$.

Table 5. Effect of $ZnSO_4$ application on crop growth rate ($g \cdot m^{-2} \cdot d^{-1}$) of maize hybrids.

Treatment	Zn_0	Zn_1	Zn_2	Zn_3	Mean
Pioneer-32F 10	17.70 de	22.21 b	26.22 a	20.44 bc	**21.64 A**
Monsanto-6525	16.24 ef	25.01 a	21.85 b	17.51 de	**20.15 B**
Hycorn-8288	12.05 g	15.48 f	19.18 cd	15.06 f	**15.44 C**
Mean	**15.33 D**	**20.90 B**	**22.42 A**	**17.67 C**	
LSD value for	**Hybrid = 0.89**	**Zinc = 1.03**	**H × Z = 1.79**		

Any two means not sharing a letter in common differ significantly at $p \le 0.05$.

rophyll contents, more leaf area index and relative growth rate of maize hybrids. Similar results have been reported that foliar application of Zn, Fe, Mg and Mn substantially increased growth, yield and yield components of maize and mungbean [24] [26].

3.5. Zn Concentration in Grains

Data related to zinc concentration in grains as presented in **Table 6** revealed that the combined effect of different $ZnSO_4$ treatments and hybrids on grain Zn concentration was found to be statistically significant. Zn_2 treatment *i.e* foliar spray of $ZnSO_4$ at 9 leaf stage gave highest concentration of Zn (51.10 ppm) in grains in case of Pioneer-32F 10. The same zinc treatment produced 33% more grain Zn contents in Pioneer 32F 10 as compared to Monsanto-6525 and Hycorn-8288. Hycorn-8288 perform better under Zn_3 (41.55 ppm) and Zn_1 (40.74 ppm) as compared to Zn_2 (39.25 ppm) and Zn_0 (22.55 ppm) but Monsanto-6525 produced maximum grain Zn contents (38.41 ppm) under Zn_2. Statistically, all maize hybrids showed significant difference in grain Zn concentration. The results also narrated that Zn concentration in grains was significantly increased by the application of $ZnSO_4$.

Foliar application of $ZnSO_4$ significantly increased the grain Zn contents as compared to the soil application and control treatment. Foliar spray of $ZnSO_4$ at 9 leaf stage produce 19.42% more grain Zn contents as compare to other $ZnSO_4$ treatments (Zn_3, Zn_1) and 49.56% more than control treatment. Our findings are in accordance with earlier study which reflected that foliar application of zinc increased the concentration of Zn in grains [27]. Some other researches are also of the same view [28]. Results further demonstrated that foliar application of $ZnSO_4$ at 9 leaf stage produced 33% more grain Zn contents in Pioneer as compared to Monsanto and Hycorn. Foliar and soil application of zinc fertilizers seems to be an effective way of maximizing grain zinc concentration in maize as reported in previous study [19].

3.6. Zn Concentration in Straw

The interactive effects of maize hybrids and $ZnSO_4$ treatments were also found significant for straw zinc contents (**Table 7**). Soil application of Zn (Zn_1) in Monsanto-6525 accumulated maximum straw Zn contents (96.47 ppm) but Pioneer-32F 10 and Hycorn-8288 retained maximum Zn contents (94.84 ppm) and (95.13 ppm) in straw respectively under Zn_2 (foliar spray of $ZnSO_4$ at 9 leaf stage). All hybrids retained minimum Zn contents in straw at Zn_0 (control). Results showed that foliar application of $ZnSO_4$ accumulated 13.33% more Zn contents in straw as compare to soil application. The results revealed that maize hybrids uptake and accumulate more Zn in straw as compare to grains. The study also proposed that the individual effects of $ZnSO_4$ application and maize hybrids were also found significant for straw Zn contents. It was reported that a considerable fraction of

Table 6. Effect of $ZnSO_4$ application on Zn concentration in grains (ppm) of maize hybrids.

Treatment	Zn_0	Zn_1	Zn_2	Zn_3	Mean
Pioneer-32F 10	20.64 e	31.28 d	51.10 a	36.00 c	**34.76 AB**
Monsanto-6525	21.78 e	35.81 c	38.41 bc	35.70 c	**32.92 B**
Hycorn-8288	22.55 e	40.74 b	39.25 bc	41.55 b	**36.02 A**
Mean	**21.65 C**	**35.94 B**	**42.92 A**	**37.75 B**	
LSD value for	**Hybrid = 1.85**	**Zinc = 2.14**	**H × Z = 3.71**		

Any two means not sharing a letter in common differ significantly at $p \leq 0.05$.

Table 7. Effect of $ZnSO_4$ application on Zn concentration in straw (ppm) of maize hybrids.

Treatment	Zn_0	Zn_1	Zn_2	Zn_3	Mean
Pioneer-32F 10	27.12 d	74.94 c	94.84 ab	93.53 ab	**72.61 B**
Monsanto-6525	29.74 d	96.47 a	92.10 b	92.71 ab	**77.75 A**
Hycorn-8288	28.12 d	77.81 c	95.13 ab	96.19 a	**74.31 B**
Mean	**28.33 C**	**83.07 B**	**94.02 A**	**94.14 A**	
LSD value for	**Hybrid = 2.00**	**Zinc = 2.31**	**H × Z = 4.00**		

Any two means not sharing a letter in common differ significantly at $p \leq 0.05$.

Table 8. Effect of $ZnSO_4$ application on grain yield ($t \cdot ha^{-1}$) of maize hybrids.

Treatment	Zn_0	Zn_1	Zn_2	Zn_3	Mean
Pioneer-32F 10	4.63 f	6.94 d	7.60 bc	6.02 e	**6.30 B**
Monsanto-6525	6.72 d	7.29 c	8.76 a	7.95 b	**7.68 A**
Hycorn-8288	3.72 g	4.40 f	4.50 f	3.79 g	**4.10 C**
Mean	**5.02 D**	**6.21 B**	**6.96 A**	**5.92 C**	
LSD value for	**Hybrid = 0.17**	**Zinc = 0.20**	**H × Z = 0.35**		

Any two means not sharing a letter in common differ significantly at $p \leq 0.05$.

the phenotypic difference in zinc uptake efficiency is under the genetic control [29]. Differences in Zn use efficiency have been reported in various crops such as wheat [30] and cotton [31]. Foliar application of $ZnSO_4$ accumulated 13.33% more Zn contents in straw as compared to soil application. Contrarily, different wheat genotypes retained more zinc contents in grain as compare to straw [32].

3.7. Grain Yield

Similarly, the interaction between $ZnSO_4$ treatments and hybrids was also found significant for grain yield (**Table 8**) where maximum grain yield (8.76 $t \cdot ha^{-1}$) was obtained with foliar spray of $ZnSO_4$ at 9 leaf stage (Zn_2) in case of Monsanto-6525 and it differed significantly with other hybrids. Furthermore, the study demonstrated that grain yield in different $ZnSO_4$ treatments and maize hybrids individually, were also found significant.

Grain yield is an ultimate end product of many yield contributing components, physiological and morphological processes taking place in plants during growth and development. Maximum grain yield in case of Monsanto-6525 can be attributed to the maximum number of grain rows per cob, number of grains per cob and grain weight per cob. Zinc is an important micronutrient needed by the maize plant and its deficiency especially during the grain filling stage reduces the grain yield and efficiency of plants [33]. The results are also in agreement with the earlier findings that foliar application of $ZnSO_4$ at 5 leaf stage significantly increased the grain yield of maize hybrid [34]. These results are also in consonance with a study which exhibited that foliar application of $ZnSO_4$ is better to increase the grain yield of maize hybrids [16].

4. Conclusion

The study showed that different treatments of $ZnSO_4$ had promotive effects on almost all of the growth, yield and qualitative parameters discussed, except stem diameter and number of leaves per plant. Foliar application of $ZnSO_4$ at 9 leaf stage accumulated 19.4% more Zn contents in maize grains and 12.4% more Zn concentration in straw as compared to soil application and also resulted in higher crop growth rate. On an average, Monsanto-6525 and Pioneer-32F 10 have 80% and 50% more grain yield than Hycorn-8288 hybrid. Maximum marginal rate of return (1145%) was obtained by planting Pioneer-32F 10 with foliar application of 1% $ZnSO_4$ solution at 9 leaf stage.

Acknowledgements

The authors are cordially grateful to Endowment Fund Secretariat, University of Agriculture, Faisalabad, Pakistan for providing financial support. Moreover, the authors are obliged to the in charge of Agro-Biology Laboratory, Department of Agronomy, University of Agriculture, Faisalabad, Pakistan for facilitating in collection and analysis of data.

References

[1] Abunyewa, A.A. and Mercer-Quarshie, H. (2004) Response of Maize to Magnesium and Zinc Application in the Semi Arid Zone of West Africa. *Asian Journal of Plant Sciences*, **3**, 1-5. http://dx.doi.org/10.3923/ajps.2004.1.5

[2] Alloway, B.J. (2004) Zinc in Soils and Crop Nutrition. IZA Publications, International Zinc Association, Brussels, 1-116.

[3] Baloch, Q.B., Chachar, Q.I. and Tareen, M.N. (2008) Effect of Foliar Application of Macro and Micro Nutrients on

Production of Green Chillies (*Capsicum annuum* L.). *Journal of Agricultural Science and Technology*, **4**, 177-184.

[4] Brown, P.H., Cakmak, I. and Zhang, Q. (1993) Form and Function of Zinc in Plants. Kluwar Academic Publishers, Dordecht, 93.

[5] Bybordi, A. and Mamedov, G. (2010) Evaluation of Application Methods Efficiency of Zinc and Iron for Canola (*Brassica napus* L.). *Notulae Scientia Biologicae*, **2**, 94-103.

[6] Cakmak, I., Torun, B., Erenoglu, B. Ozturk, L., Marschner, H., Kalayci, M., Ekiz, H. and Yilmaz, A. (1998) Morphological and Physiological Differences in the Response of Cereals to Zinc Deficiency. *Euphytica*, **100**, 349-357. http://dx.doi.org/10.1023/A:1018318005103

[7] Cakmak, I. (2000) Possible Roles of Zinc in Protecting Plant Cells from Damage by Reactive Oxygen Species. *New Phytologist*, **146**, 85-200. http://dx.doi.org/10.1046/j.1469-8137.2000.00630.x

[8] Cakmak, O., Ozturk, L. and Karanlik, S. (2001) Tolerance of 65 Durum Wheat Genotypes Tozinc Deficiency in a Calcareous Soil. *Journal of Plant Nutrition*, **24**, 1831-1847. http://dx.doi.org/10.1081/PLN-100107315

[9] Chaab, A., Savaghebi, G.R. and Motesharezadeh, B. (2011) Differences in the Zinc Efficiency among and within Maize Cultivars in a Calcareous Soil. *Asian Journal of Agricultural Sciences*, **3**, 26-31.

[10] CIMMYT (1988) From Agronomic Data to Farmer Recommendations: An Economic Training Manual. Completely Revised Edition, Mexico D.F.

[11] Cisse, L. and Amar, B. (2000) The Importance of Phosphatic Fertilizer for Increased Crop Production in Developing Countries. *Proceedings of the AFA* 6*th International Annual Conference*, Cairo, 31 January-2 February 2000, 1-7.

[12] Davies, B.E. (1997) Deficiencies and Toxicities of Trace Elements and Micronutrients in Tropical Soils: Limitations of Knowledge and Future Research Needs. *Environmental Toxicology and Chemistry*, **16**, 75-83. http://dx.doi.org/10.1002/etc.5620160108

[13] Erenoglu, B., Nikolic, M., Römhold, V. and Cakmak, I. (2002) Uptake and Transport of Foliar Applied Zinc (^{65}Zn) in Bread and Durum Wheat Cultivars Differing in Zinc Efficiency. *Plant Soil*, **241**, 251-257. http://dx.doi.org/10.1023/A:1016148925918

[14] George, R. and Schmitt, M. (2002) Zinc for Crop Production. Regents of the University of Minnesota.

[15] Grzebisz, W., Wrońska, M., Diatta, J.B. and Dullin, P. (2008) Effect of Zinc Foliar Application at Early Stages of Maize Growth on Patterns of Nutrients and Dry Matter Accumulation by the Canopy. Part I. Zinc Uptake Patterns and Its Redistribution among Maize Organs. *Journal of Elementology*, **13**, 17-28.

[16] Hoffland, E., Wei, C. and Wissuwa, M. (2006) Organic Anion Exudation by Lowland Rice (*Oryza sativa* L.) at Zinc and Phosphorus Deficiency. *Plant and Soil*, **283**, 155-162. http://dx.doi.org/10.1007/s11104-005-3937-1

[17] Hosseini, S.M., Maftoun, M., Karimian, N., Rounaghi, A. and Emam, Y. (2007) Effect of Zinc and Boron Interaction on Plant Growth and Tissue Nutrient Concentration of Corn. *Journal of Plant Nutrition*, **30**, 773-781. http://dx.doi.org/10.1080/01904160701289974

[18] Hunt, R. (1978) Plant Growth Analysis. Edward Arnold, London, 26-38.

[19] Johnson, S.E., Lauren, J.G., Welch, R.M. and Duxbury, J.M. (2005) A Comparison of the Effects of Micronutrient Seed Priming and Soil Fertilization On the Mineral Nutrition of Chickpea (*Cicer arietinum*), Lentil (*Lens culinaris*), Rice (*Oryza sativa*) and Wheat (*Triticum aestivum*) in Nepal. *Experimental Agriculture*, **41**, 427-448. http://dx.doi.org/10.1017/S0014479705002851

[20] Kassab, O.M. (2005) Soil Moisture Stress and Micronutrients Foliar Application Effects on the Growth and Yield of Mungbean Plants. *Journal of Agricultural Science*, **30**, 247-256.

[21] Khan, H.R., McDonald, G.K. and Rengel, Z. (2004) Zinc Fertilization and Water Stress Affects Plant Water Relations, Stomatal Conductance and Osmotic Adjustment in Chickpea (*Cicer arietinum* L.). *Plant and Soil*, **267**, 271-284. http://dx.doi.org/10.1007/s11104-005-0120-7

[22] Lauer, J. (2006) What Happen within the Corn Plant When Drought Occurs? *Wisconsin Crop Management Conference*, **10**, 225-228.

[23] Malakouti, M.J. (2008) The Effect of Micronutrients in Ensuring Efficient Use of Macronutrients. *Turkish Journal of Agriculture and Forestry*, **32**, 215-220.

[24] Marschner, H. (1995) Mineral Nutrition of Higher Plant. 2nd Edition, Academic Press, New York, 890.

[25] Maqsood, M.A., Rahmatullah, Kanwal, S., Aziz, T. and Ashraf, M. (2009) Evaluation of Zn Distribution among Grain and Straw of Twelve Indigenous Wheat (*Triticum aestivum* L.) Genotypes. *Pakistan Journal of Botany*, **41**, 225-231.

[26] Mortvedt, J.J., Cox, F.R., Shuman, L.M. and Welch, R.M. (1991) Micronutrients in Agriculture. 2nd Edition, Soil Science Society of America, Madison, Soil Science Society of America Book Series No. 4.

[27] Tariq, M., Khan, M.A. and Perveen, S. (2002) Response of Maize to Applied Soil Zinc. *Asian Journal of Plant Sci-*

ences, **1**, 476-477. http://dx.doi.org/10.3923/ajps.2002.476.477

[28] Obata, H., Kawamura, S., Senoo, K. and Tanaka, A. (1999) Changes in the Level of Protein and Activity of Cu/ZnSuperoxide Dismutase in Zinc Deficient Rice Plant, *Oryza sativa* L. *Soil Science and Plant Nutrition*, **45**, 891-896. http://dx.doi.org/10.1080/00380768.1999.10414338

[29] Potarzycki, J. and Grzebisz, W. (2009) Effect of Zinc Foliar Application on Grain Yield of Maize and Its Yielding Components. *Plant Soil and Environment*, **55**, 519-527.

[30] Phonde, D.B., Nerkar, Y.S., Zenda, N.A., Chavan, R.V. and Tiwari, K.N. (2005) Most Profitable Sugarcane Production in Maharashtra. *Better Crops*, **89**, 21-23.

[31] Rashid, A. and Ryan, J. (2004) Micronutrient Constraints to Crop Production in Soils with Mediterranean-Type Characteristics: A Review. *Journal of Plant Nutrition*, **27**, 959-975. http://dx.doi.org/10.1081/PLN-120037530

[32] 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. http://dx.doi.org/10.1023/A:1009753729599

[33] Shukla, U.C. and Raj, H. (1987) Influence of Genotypical Variability on Zinc Response in Cotton (*Gossypium hirsutum* L.). *Plant and Soil*, **104**, 151-154. http://dx.doi.org/10.1007/BF02370638

[34] Steel, R.G.D., Torrie, J.H. and Dicky, D.A. (1997) Principles and Procedures of Statistics, a Biological Approach. 3rd Edition, McGraw Hill, Inc. Book Co., New York, 352-358.