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Exploring the role of zinc fertilization methods for agronomic bio-fortification and its impact on phenology, growth and yield characteristics of maize

Explorando o papel dos métodos de fertilização com zinco para bio-fortificação agronômica e seu impacto na fenologia, crescimento e características de rendimento do milho

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Abstract

Zinc (Zn) is a key mineral nutrient for plant and human growth and its deficiency can reduce the plant growth and development, however; agronomic bio-fortification can cure plant and human Zn deficiency. By using different Zn fertilization approaches, this study investigated the role and its impact on phenology, growth and yield of maize during two growing seasons 2015 and 2016. The treatments comprised of: no Zn application (ZnC_0), basal application of 10 kg $ZnSO_4.7H_2O$ ha^{-1} (ZnB_1), basal application of 15 kg $ZnSO_4.7H_2O$ ha^{-1} (ZnB_2), foliar application of 1% solution of $ZnSO_4.7H_2O$ ha^{-1} (ZnF_3), foliar application of 1.5% solution of $ZnSO_4.7H_2O$ ha^{-1} (ZnF_4) applied to two hybrids of maize (YSM-112 and DK-6525). The maize hybrid DK-6525 showed superiority in term of growth and yield than YSM-112. The ZnF_4 brings early emergence, tasseling and silking that resulted in early crop maturity. However, ZnB_2 improved crop growth rate, grain yield and Zn concentration in maize grain by 44, 11.39 and 33.24%, respectively than ZnC_0 (control). Regression model indicated that each 1 g increment in 1000-grain weight improved the grain yield by 0.01 and 0.16 t ha^{-1} of YSM-112 and DK-6525, respectively. Conclusively, it is concluded that DK-6525 with ZnB_2 is suitable for optimal growth and yield of maize and would also be helpful to optimize the yield and Zn concentration of maize.

Key words: Basal and foliar application. Bio-fortification. Growth and yield. Maize hybrids and zinc fertilization.

Resumo

O zinco (Zn) é um nutriente mineral chave para o crescimento de plantas e humanos, e sua deficiência pode reduzir o crescimento e o desenvolvimento das plantas; bio-fortificação agronômica pode curar a deficiência de Zn humano e vegetal. Utilizando diferentes abordagens de fertilização com Zn, este estudo investigou o papel e seu impacto na fenologia, crescimento e produção de milho durante duas safras 2015 e 2016. Os tratamentos foram compostos por: sem aplicação de Zn (ZnC_0), aplicação

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basal de 10 kg de $ZnSO_4$. $7H_2O$ ha^{-1} (ZnB_1), aplicação basal de 15 kg de $ZnSO_4.7H_2O$ ha^{-1} (ZnB_2), aplicação foliar de solução a 1% de $ZnSO_4.7H_2O$ ha^{-1} (ZnF_3), aplicação foliar de solução a 1,5% de $ZnSO_4.7H_2O$ ha_{-1} (ZnF_4) aplicado a dois híbridos de milho (YSM-112 e DK-6525). O híbrido de milho DK-6525 apresentou superioridade em termos de crescimento e produtividade que o YSM-112. O ZnF_4 traz emergência precoce, pendoamento e silagem que resultaram em maturação precoce da cultura. No entanto, o ZnB_2 melhorou a taxa de crescimento da cultura, a produtividade de grãos e a concentração de Zn no grão de milho em 44, 11,39 e 33,24%, respectivamente, do que ZnC_0 (controle). O modelo de regressão indicou que cada incremento de 1 g no peso de 1000 grãos melhorou o rendimento de grãos em 0,01 e 0,16 t ha^{-1} de YSM-112 e DK-6525, respectivamente. Conclusivamente, conclui-se que o DK-6525 com ZnB2 é adequado para o crescimento e produção ideais de milho e também seria útil para otimizar o rendimento e a concentração de Zn do milho.

Palavras-chave: Aplicação basal e foliar. Bio-fortificação. Crescimento e produção. Híbridos de milho e adubação com zinco.

Introduction

Zinc (Zn) is an important micro-nutrient for development and progress of mankind's (SALGUEIRO et al., 2000; BROWN et al., 2001) animals and crops (BROADLEY et al., 2012). Deficiency of Zn in food has been a world dietary problem in humanoid inhabitants (CAKMAK, 2008; KUTMAN et al., 2012). Current estimations showed that more than 30% population of world is pretentious by Zn shortage (CAKMAK et al., 2010; WELCH, 2002). In plants, Zn is an important micro-nutrient for healthy root structure, enzyme activation, detoxification of free radicals and retaining tolerance to plant stressors (CAKMAK, 2008; PECK; MCDONALD, 2010). Because of its catalytic act in breakdown, Zn is the most critical among the micro-nutrients that take part in plant growth and development (FAGERIA, 2002). Soil which is deficient in Zn reduced the plants growth and development (RASHID; RYAN, 2004).

Deficiency of Zn in the soil does not only reduce plant growth and yield but also causes Zn scarcity in the diet of human being (GAO et al., 2005; BAGCI et al., 2007). Maize is very sensitive to Zn deficiency (TARIQ et al., 2002). Application of Zn in maize improved chlorophyll synthesis, photosynthetic rate and provided resistance to several biotic and abiotic stresses (YOSEFI et al., 2011; ALI et al., 2008). Insufficient Zn supply severely declined the yield of maize under temperate regions (SUBEDI; MA, 2009). To obtain the optimum crop yield appropriate level of Zn must be applied. Zinc fertilizer is widely used to enhance yield and quality of edible parts of crops. Foliar application is one of the primary methods of applying Zn fertilizer. Many researchers reported that foliar application of Zn significantly improved the growth traits of various crops (THALOOTH et al., 2006). Foliar application of Zn resulted in a significant increase in starch content of forage maize at harvest (LEACH; HAMELEERS, 2001). Another major method to apply Zn fertilizer is soil application. It corrected the visible symptoms of Zn scarcity in soil and significantly increased growth of maize (SRIVASTAVA et al., 1999) and grain yield by more than 22% (ORABI et al., 1981). A recent study has shown that a small quantity of Zn through soil application increased meaningfully the outcome of crops (WISSUWA et al., 2008). When micro-nutrient deficiency could not be improved by soil application, foliar nutrition has been shown to yield a good response (CAKMAK, 2008).

In the world, about 50% cereal growing area has low available Zn (GRAHAM; WELCH, 1996; CAKMAK, 2002) and prevalent deficiencies of Zn have also been identified in 50-70% soils of Pakistan (HAMID; AHMAD, 2001). So, there is a dire need to determine the appropriate Zn level and method of application to enhance the maize productivity. Thus, the present study was performed to investigate the influence of basal and foliar application of Zn on phenology, growth and yield of maize hybrids.

Materials and Methods

Experimental site and soil status

The research was carried out at Agronomic Research Area, College of Agriculture, University of Sargodha, Pakistan during two growing seasons 2015 and 2016. Soil samples from experimental area were collected at 0 cm to 30 cm depth before seeding the maize for basic soil property analysis. The characteristics of the collected samples are listed in Table 1. The average soil pH and organic matter ranged between 7.2 to 7.8 and 1.01 to 1.43% at 0 to 30 cm depth, respectively. However, the level of N, P and K was low to medium at experimental site (Table 1).

Table 1. Soil properties of experimental site (Pooled data of two years).

Characteristic	Soil sample depth (cm)			
	0-10	10-20	20-30	Mean
Soil pH	7.20	7.38	7.80	7.46
Organic Matter (%)	1.43	1.25	1.01	1.23
Total Nitrogen (%)	0.072	0.065	0.056	0.064
Olsen's P (mg kg $^{-1}$)	5.40	6.90	9.85	7.38
Extractable K (mg kg^{-1})	173	160	119	150.6
DTPA extractable Zn (mg kg^{-1})	0.81	0.73	0.64	0.72

Experimental design and managements

The experiments was laid out in randomized complete block design (RCBD) with factorial arrangement having four replications that comprised of five treatments: no Zn application (ZnC_0), basal application of 10 kg $ZnSO_4.7H_2O$ ha^{-1} (ZnB_1), basal application of 15 kg $ZnSO_4.7H_2O$ ha^{-1} (ZnB_2), foliar application of 1% solution of $ZnSO_4.7H_2O$ ha^{-1} (ZnF_3), foliar application of 1.5% solution of $ZnSO_4.7H_2O$ ha^{-1} (ZnF_4) applied on two hybrids of maize (YSM-112 and DK-6525). The net plot size was 5 × 3 m maintaining R × R distance of 75 cm and P × P distance of 20 cm. The soil was well-prepared by 2-3 cultivations followed by planking and crop was sown manually on 75 cm apart ridges. Before sowing, seed was treated with Confidor (Imidacloprid) at 5 g kg^{-1} of seed to avoid insect damage to seed and seedling. The 25 kg ha^{-1} seed rate was used. Thinning was done to maintain 20 cm plant to plant distance at early stages of crop development. Fertilizer was applied at 250: 125: 125 kg ha^{-1} N: P: K by using urea, diammonium phosphate and sulfate of potash, respectively. All the P and K and one-third of N were applied just before sowing. The remaining N was added in two splits, with first irrigation and at tasseling. Insecticide namely Imidacloprid was sprayed at the rate 300 g ha^{-1} with the help of knapsack hand sprayer at 2-3 leaf stage to protect the crop against shoot fly. Furadan (carbofuran) was applied at 4-5 leaf stage manually at the rate of 23 kg ha^{-1} to protect the crop against stem borer.

Sampling and measurements

Phenological traits

Days taken to 50% emergence of maize were counted after sowing of crop by daily visit and number of plants germinated was counted in each plot from a selected area until a uniform and constant plant count was achieved and means days taken to 50% emergence were worked out from sowing date. For days taken to 50% tasseling and silking, 3 plants were tagged from every plot at random and noted the date of tasseling. The average number of days taken to 50% tasseling and silking was calculated from date of sowing. The crop was considered to mature when a black layer was formed at the base of each kernel. To record average days taken to maturity three plants in each plot were tagged.

Growth and yield traits

Leaf area index (LAI) was measured by the leaf area meter as the ratio of leaf area to land area suggested by Watson and Dallwitz (1992).

$$\text{LAI} = \text{Leaf area}/\text{Land area}$$

Leaf area duration (LAD) for each sampling date was estimated according to Hunt (1978).

$$\text{LAD} = \frac{(\text{LAI1}+\text{LAI2})\times(\text{T2}-\text{T1})}{2}$$

Where;

LAI_1 and LAI_2 were the leaf area indices at time T_1 and T_2, respectively. Cumulative LAD at final harvest was calculated by adding all LAD values.

Crop growth rate was determined at fortnight intervals by taking five plants at random from each subplot. The sampling was initiated at 30 days after sowing and terminated at the harvest of crop. Soon after each harvest, sample was weighed to determine fresh weight. Each plant sample was chaffed, thoroughly mixed and then sun dried. Afterwards samples were placed in oven at $70\underline{+}\ 5^{o}$C to dry the plant sample to its constant dry weight. Then dry weight per plant was calculated and used to estimate crop growth rate as proposed by BEADLE (1987).

$$CGR = \frac{\text{W2} - \text{W1}}{\text{T2} - \text{T1}}$$

Where

W_2 = Dry weight m^{-2} at second harvest

W_1= Dry weight m^{-2} at first harvest

T_2 = Time corresponding to second harvest

T_1 = Time corresponding to first harvest

Mean CGR was calculated by averaging all CGRs calculated at each destructive harvest.

Data regarding plant height (cm), cob length (cm), cob diameter (cm), 1000-grain weight (g), grain yield (t ha^{-1}) and biological yield (t ha^{-1}) were recoded according to standard procedure. Harvest index (%) was described as ratio of grain yield to biological yield. It was determined by using the following formula.

$$\text{HI (\%)} = \frac{\text{Grain Yield}}{\text{Biological yield}} \times 100$$

Zn concentration in grain

The Zn concentrations was determined by using plasma atomic emission spectroscopy after digesting the grain samples in a closed microwave digestion system in the presence of concentrated HNO_3 and H_2O_2 (with 5:2 v/v, respectively). Sample analysis results were reported as the mean of four replicates. The micronutrient concentrations in edible parts were expressed on a dry weight basis.

Statistical analysis

Data of the both years were pooled because year effect was non-significant. Data collected on phenology, growth and yield were analyzed statistically following Fisher's analysis of variance technique by using Statistix 8.1 software and significant of treatments were tested using least significant difference (LSD) test at 5% probability level (STEEL et al., 1997). Data of grain and biological yield were plotted against 1000-grain weight and plant height, respectively according to non-linear regression model. The regression analysis was performed by using Sigma plot 8.1 (Version 11.0) software.

Results

Phenological traits

The experimental data showed that method of Zn fertilization had significant effects on phonological traits of maize (Table 2 and 3). The application of zinc by using different fertilization method significantly affected the days taken to attain 50% emergence. Both maize hybrids DK-6525 and YSM-112 took similar time to reach 50% emergence. Among all the treatments, basal application of 15 kg Zn ha^{-1} brought an early emergence. In case of time taken to 50% tasseling and silking, the maize hybrid DK-6525 reached to 50% tasseling and silking nearly 2 days earlier than that of YSM-112. As compared to all other Zn fertilization methods, the foliar application of 1.5% Zn solution completed 50% tasseling and silking in significantly shortest time (28.8 and 35.9 days, respectively). However, this treatment remained statistically at par with basal Zn application at 15 kg ha^{-1} and 1% foliar Zn application regarding days taken to 50% silking. The interaction between maize hybrids × Zn fertilization methods was statistically non-significant pertaining to all phenological traits (Table 2). The days taken to tasseling and silking directly influenced the crop maturity. The data contained in table 3 showed that Zn fertilization significantly reduced days taken to crop maturity. The interactive effect of maize hybrids and Zn fertilization methods had significant effect on days taken to maturity. Maize hybrid DK-6525 took significantly the minimum (91 and 93) days to attain maturity with foliar application of 1.5% Zn solution and basal application of 15 Kg ha^{-1} $ZnSO_4$, respectively in comparison to other methods of Zn fertilization.

Table 2. Days taken to 50% emergence, tasseling and silking as influenced by basal and foliar application of zinc on two maize hybrids (Pooled data of two years).

Treatments	Days taken to 50% emergence			Days taken to 50% tasseling			Days taken to 50% silking		
	Hybrids		Mean	Hybrids		Mean	Hybrids		Mean
	YSM-112	DK-6525		YSM-112	DK-6525		YSM-112	DK-6525	
ZnC_0	6.6^{NS}	6.6	6.6 A	34.3^{NS}	32.6	33.5 A	45.3^{NS}	42.6	44.0 A
ZnB_1	5.6	6.0	5.8 BC	32.3	30.6	31.5 B	40.6	38.3	39.5 B
ZnB_2	5.3	5.3	5.1 C	31.0	29.3	30.1 C	38.6	35.3	37.0 C
ZnF_3	4.6	5.6	6.1 AB	32.3	30.0	31.1 BC	36.6	35.6	36.1 C
ZnF_4	6.0	6.3	5.3 C	29.6	28.0	28.8 D	36.8	35.0	35.9 C
Means of hybrids	5.6	6.0		31.92 a	30.14 b		39.6 a	37.4 b	
LSD (0.05)	NS		0.69	1.10		1.20	2.12		4.16

Values in the column or means of hybrids within the row sharing the same letter did not differ significantly with each other at 5% probability level. **ZnC_0** = no Zn application (control), **ZnB_1** = basal application of 10 kg $ZnSO_4.7H_2O$ ha^{-1}, **ZnB_2** = basal application of 15 kg $ZnSO_4.7H_2O$ ha^{-1}, **ZnF_3** = foliar application of 1% solution of $ZnSO_4.7H_2O$ ha^{-1}, **ZnF_4** = foliar application of 1.5% solution of $ZnSO_4.7H_2O$ ha^{-1}, ^{NS} = Non-significant.

Table 3. Days taken to maturity, leaf area index and leaf area duration as influenced by basal and foliar application of zinc on two maize hybrids (Pooled data of two years).

Treatments	Days taken to maturity			Leaf area index			Leaf area duration ($m^2/d/p$)		
	Hybrids		Mean	Hybrids		Mean	Hybrids		Mean
	YSM-112	DK-6525		YSM-112	DK-6525		YSM-112	DK-6525	
ZnC_0	106.6 a	103.0 b	104.8 A	4.6^{NS}	4.2	4.4 B	39.76 a	38.86 b	39.31 A
ZnB_1	101.6 b	97.6 c	99.6 B	4.4	4.6	4.5 AB	37.60 c	36.86 e	37.23 B
ZnB_2	94.3 de	93.0 ef	93.6 C	5.0	5.1	5.0 A	37.23 d	36.50 g	36.86 C
ZnF_3	94.3 de	93.3 e	93.8 C	4.4	4.5	4.6 B	36.86 e	36.73 ef	36.80 C
ZnF_4	96.3 cd	91.1 f	93.7 C	4.7	4.7	4.7 AB	36.58 fg	36.68 efg	36.63 D
Means of hybrids	98.6 A	95.6 B		4.64	4.65		37.61 A	37.13 B	
LSD (0.05)	3.06		1.65	NS		0.48	0.11		0.12

Values in the column or means of hybrids within the row sharing the same letter did not differ significantly with each other at 5% probability level. **ZnC_0** = no Zn application (control), **ZnB_1** = basal application of 10 kg $ZnSO_4.7H_2O$ ha^{-1}, **ZnB_2** = basal application of 15 kg $ZnSO_4.7H_2O$ ha^{-1}, **ZnF_3** = foliar application of 1% solution of $ZnSO_4.7H_2O$ ha^{-1}, **ZnF_4** = foliar application of 1.5% solution of $ZnSO_4.7H_2O$ ha^{-1}, ^{NS} = Non-significant.

Growth parameters

The imperative growth controlling attributes of crop plant are leaf area index, leaf area duration and crop growth rate. The Zn fertilization methods had significant effect on leaf area index and leaf area duration (Table 3). There was no difference for leaf area index between the maize hybrids. Compared to all treatments, basal application of 15 kg $ZnSO_4$ ha^{-1} produced the maximum (5.0) leaf area index that did not differ significantly from basal application of 10 kg $ZnSO_4$ and foliar application of 1.5% $ZnSO_4$. The minimum value of leaf area index (4.4) was observed where no Zn was applied. In case of leaf area duration, the interaction of maize hybrids × Zn fertilization methods was significant. Among all interactions, maize hybrid YSM-112 in response to no Zn application attained the maximum leaf area index (39.76 $m^2/d/p$). However, the lowest leaf area duration (36.50 $m^2/d/p$) was observed under basal application of 15 kg Zn ha^{-1} (Table 3). The crop growth rate was significantly affected with basal and foliar application of Zn (Table 4). There was differential response of maize varieties to different Zn fertilization treatments regarding crop growth rate as revealed by significant differences among varieties × Zn fertilization interactions means. Significantly, the highest crop growth rate was shown by both the varieties YSM-112 (16.03 g m^{-2} day^{-1}) and DK-6525 (15.73 g m^{-2} day^{-1}) in response basal application of 15 kg $ZnSO_4$ ha^{-1}. However, maize variety DK-6525 also responded similarly to foliar application of 1.5% solution of $ZnSO_4$ (Table 4).

Table 4. Crop growth rate, plant height and cob length as influenced by basal and foliar application of zinc on two maize hybrids (Pooled data of two years).

Treatments	Crop growth rate (g m^{-2} day^{-1})			Plant height (cm)			Cob length (cm)		
	Hybrids		Mean	Hybrids		Mean	Hybrids		Mean
	YSM-112	DK-6525		YSM-112	DK-6525		YSM-112	DK-6525	
ZnC$_0$	10.66 e	11.26 de	10.96 C	158.6^{NS}	164.6	161.6 C	16.6^{NS}	18.0	17.3 C
ZnB$_1$	13.10 bc	12.56 cd	12.83 B	172.0	171.3	171.6 A	18.3	19.6	19.0 BC
ZnB$_2$	16.03 a	15.73 a	15.88 A	171.6	175.0	173.3 A	21.6	22.6	22.1 A
ZnF$_3$	13.21 bc	13.26 bc	13.24 B	164.3	164.3	164.3 B	19.3	20.6	20.0 B
ZnF$_4$	13.43 bc	14.36 ab	13.90 B	167.5	165.5	163.9 B	21.3	23.4	22.3 A
Means of hybrids	13.28	13.44		166.8	166.1		19.4	20.8	
LSD (0.05)	NS		1.25	NS		1.62	NS		2.29

Values in the column or means of hybrids within the row sharing the same letter did not differ significantly with each other at 5% probability level. **ZnC$_0$** = no Zn application (control), **ZnB$_1$** = basal application of 10 kg $ZnSO_4.7H_2O$ ha^{-1}, **ZnB$_2$** = basal application of 15 kg $ZnSO_4.7H_2O$ ha^{-1}, **ZnF$_3$** = foliar application of 1% solution of $ZnSO_4.7H_2O$ ha^{-1}, **ZnF$_4$** = foliar application of 1.5% solution of $ZnSO_4.7H_2O$ ha^{-1}, ^{NS} = Non-significant.

Yield and yield components

There was no difference between maize hybrids for plant height but a significant difference was observed among various Zn fertilizer application treatments. Among all the treatments, premier plant heights (173.2 and 171.6 cm) of maize were measured from plots treated with basal applications of 15 and 10 kg $ZnSO_4$ ha^{-1}, respectively and the minimum plant height (161.6 cm) was observed with no Zn application (Table 4). Comparison of treatment means of maize cob length (Table 4) showed that the maximum cob length (22.3 cm) was observed with foliar application of 1.5% solution of $ZnSO_4$ that did not differ significantly from that measured from plots basally treated with 15 kg ha^{-1} $ZnSO_4$. The maize hybrid DK-6525 produced larger cob diameter than YSM-112 (Table 5). The basal application of 15 kg $ZnSO_4$ ha^{-1} and foliar application of 1 and 1.5% solution of $ZnSO_4$ gave the highest (4.2 cm) maize cob diameter. The data about 1000-grain weight presented in table 5 indicated that maize hybrid DK-6525 was superior over YSM-112 regarding 1000-grain weight. Compared to control, all method of Zn application significantly improved the 1000-grain weight. However, among Zn application methods, basal application of 15 kg Zn ha^{-1} $ZnSO_4$ produced the highest (254.1 g) 1000-grain weight of maize (Table 5). In case of grain yield, Dk-6525 was better than YSM-112. The maize hybrids showed substantial response to various methods of Zn application and the maximum grain yield (4.79 t ha^{-1}) was achieved by the basal application of 15 kg $ZnSO_4$ ha^{-1}. The minimum grain yield was recorded where no Zn was applied. The biological yield of DK-6525 was more than YSM-112 (Table 6). To estimate the relationship between 1000-grain weight and grain yield of maize hybrids, a regression model was used (Figure 1). Model showed that if the 1000-grain weight was increased by 1 g, a corresponding enhancement in grain yield occurred by 0.01 and 0.16 t ha^{-1} in YSM-112 and DK-6525, respectively. All methods of Zn fertilization imparted significant impact on biological yield. Compared to control, all Zn application treatments significantly increased biological yield of maize but basal application of 15 kg $ZnSO_4$ ha^{-1} produced the highest biological yield (10.0 t ha^{-1}) which was followed by foliar application of 1 and 1.5% $ZnSO_4$ solutions. Regression model was fitted to the data of plant height and biological yield (Figure 2). Model indicated linear relationship between these two parameters and it was assessed that by each 1 cm increment in plant height of maize hybrids, biological yield could be improved by 0.03 and 0.007 t ha^{-1} in YSM-112 and DK-6525 hybrids, respectively. Harvest index (%) of DK-6525 was found to be higher as compared to YSM-112. In case of Zn fertilization methods, the highest harvest index (47.96%) was recorded with basal application of 15 kg Zn ha^{-1} (Table 6).

Table 5. Cob diameter, 1000-grains weight and grain yield as influenced by basal and foliar application of zinc on two maize hybrids (Pooled data of two years).

Treatments	Cob diameter (cm)			1000-grain weight (g)			Grain yield (t ha^{-1})		
	Hybrids		Mean	Hybrids		Mean	Hybrids		Mean
	YSM-112	DK-6525		YSM-112	DK-6525		YSM-112	DK-6525	
ZnC$_0$	3.9^{NS}	4.0	3.9 C	213.6^{NS}	236.0	224.8 D	4.26^{NS}	4.33	4.30 D
ZnB$_1$	4.1	4.1	4.1 B	227.3	243.0	235.1 B	4.56	4.65	4.60 C
ZnB$_2$	4.2	4.3	4.2 A	244.6	263.6	254.1 A	4.75	4.84	4.79 A
ZnF$_3$	4.2	4.2	4.2 A	239.0	256.3	247.6 C	4.67	4.72	4.70 B
ZnF$_4$	4.2	4.2	4.2 A	241.9	258.0	235.1 B	4.65	4.74	4.69 B
Means of hybrids	4.1 B	4.2 A		233.3 B	251.4 A		4.58 B	4.66 A	
LSD (0.05)	0.03		0.07	1.28		1.30	0.05		0.03

Values in the column or means of hybrids within the row sharing the same letter did not differ significantly with each other at 5% probability level. **ZnC$_0$** = no Zn application (control), **ZnB$_1$** = basal application of 10 kg $ZnSO_4.7H_2O$ ha^{-1}, **ZnB$_2$** = basal application of 15 kg $ZnSO_4.7H_2O$ ha^{-1}, **ZnF$_3$** = foliar application of 1% solution of $ZnSO_4.7H_2O$ ha^{-1}, **ZnF$_4$** = foliar application of 1.5% solution of $ZnSO_4.7H_2O$ ha^{-1}, ^{NS} = Non-significant.

Table 6. Biological yield, harvest index and Zn concentration in grain as influenced by basal and foliar application of zinc on two maize hybrids (Pooled data of two years).

Treat-ments	Biological yield (t ha^{-1})			Harvest index (%)			Zn concentration in grain (mg kg^{-1})		
	Hybrids		Mean	Hybrids		Mean	Hybrids		Mean
	YSM-112	DK-6525		YSM-112	DK-6525		YSM-112	DK-6525	
ZnC$_0$	9.35^{NS}	9.43	9.39 D	45.56^{NS}	45.98	45.77 D	14.90^{NS}	14.83	14.86 D
ZnB$_1$	9.66	9.74	9.70 C	47.20	47.74	47.47 B	16.93	16.66	16.80 C
ZnB$_2$	9.97	10.02	10.00 A	47.63	48.30	47.96 A	19.93	19.66	19.80 A
ZnF$_3$	9.88	9.93	9.90 B	47.33	47.58	47.45 B	17.20	17.20	17.20 BC
ZnF$_4$	9.87	9.96	9.91 B	47.16	47.59	47.37 C	17.40	18.40	17.90 B
Means of hybrids	9.74 B	9.81 A		46.97 B	47.44 A		17.27	17.35	
LSD (0.05)	0.019		0.022	0.021		0.045	NS		1.09

Values in the column or means of hybrids within the row sharing the same letter did not differ significantly with each other at 5% probability level. **ZnC$_0$** = no Zn application (control), **ZnB$_1$** = basal application of 10 kg $ZnSO_4.7H_2O$ ha^{-1}, **ZnB$_2$** = basal application of 15 kg $ZnSO_4.7H_2O$ ha^{-1}, **ZnF$_3$** = foliar application of 1% solution of $ZnSO_4.7H_2O$ ha^{-1}, **ZnF$_4$** = foliar application of 1.5% solution of $ZnSO_4.7H_2O$ ha^{-1}, ^{NS} = Non-significant.

Zinc accumulation in maize grain was also improved by different Zn fertilization treatments (Table 6). The effect of Zn fertilization methods significantly enhanced the Zn concentration in grain but Zn concentration in maize hybrids was statistically similar. Among all the Zn treatments, basal application of 15 kg $ZnSO_4$ ha^{-1} gained the highest Zn accumulation (19.80 mg kg^{-1}) in maize grain. However, the lowest Zn concentration (14.46 mg kg^{-1}) in maize grain was observed where no Zn application was made (Table 6).

Figure 1. Regression analysis of grain yield (t ha^{-1}) of two maize hybrids as influenced by 1000-grain weight (g) under different Zn fertilization methods.

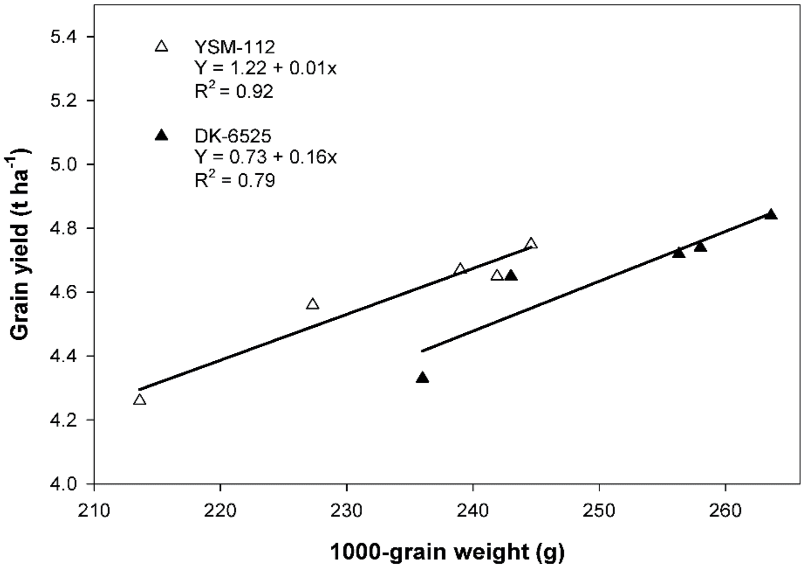
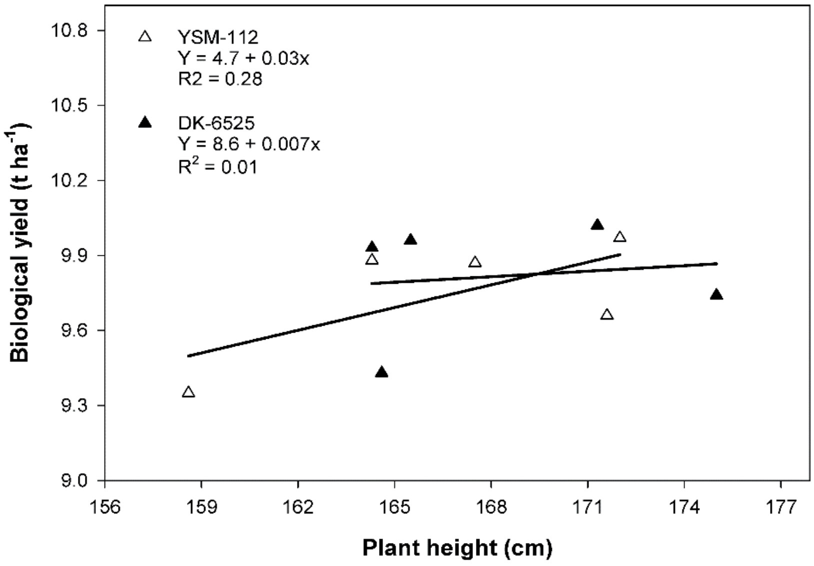


Figure 2. Regression analysis of biological (t ha^{-1}) of two maize hybrids as influenced by plant height (cm) under different Zn fertilization methods.



Discussion

Most of Pakistani soils are deficient in Zn i.e. the available Zn concentration is less than 1.0 mg kg^{-1} (IMRAN et al., 2016; MAQSOOD et al., 2015). Therefore, this study was performed to determine the effectiveness of various fertilization methods of Zn application on phenology, growth and yield characteristics of maize hybrids. In our study, Zn fertilization significantly enhanced the growth and yield of maize. The increase in phonological traits of maize such as days taken to 50% emergence, tasseling and silking might be due to timely availability and efficient utilization of Zn and other nutrients (WITOLD et al., 2008) that improved the catalytic action in plant and also resulted in early plant maturity. Zinc is most decisive amongst the micro-nutrients that take part in plant growth due to its catalytic action in the metabolism of almost all crops (FAGERIA, 2002). The beneficial effect of Zn fertilization on growth and development of maize and other crops have already been reported (EHSANULLAH et al., 2015; MANZEKE et al., 2014). After germination, Zn increases the seedling growth, root and shoots development of plant and the effects were evident in a Zn deficient soil after six week of growth (WELCH, 1999). The higher values of leaf area index and crop growth rate were obtained by basal application of $ZnSO_4$ at 15 kg ha^{-1} might be due to appropriate level of Zn that activated the plant enzymes which are involved in carbohydrate metabolism, maintenance of the integrity of cellular membranes, protein synthesis, regulation of auxin synthesis and pollen formation (MARSCHNER, 1995). Zinc is also an essential micro-nutrient which is involved in several biochemical pathways and it is regulatory co-factor in proteins and enzymes synthesis (ALLOWAY, 2009). CAKMAK et al. (1989) reported that deficiency of Zn reduced the photosynthates begin to pledge in crop leaves that ultimately affect the leaf area and crop growth rate. Plant height, cob length and cob diameter were increased with basal application of 15 kg Zn ha^{-1} which might be due to appropriate accessibility of Zn to maize plant. According to Ehsanullah et al. (2015), application of Zn stimulates the plant height. AKRAM et al. (2010) stated that both foliar and soil application of Zn enhanced the plant height of maize. The cob length and cob diameter of maize were markedly increased under both basal and foliar application of Zn. This might be due to continuous supply of Zn at the time of its critical phases of the crop growth. These results were in conformity with the findings of Nube and Voortman (2006); Xi-Wen et al. (2011) and Ramachandrappa et al. (2007). In our study, 1000-grain weight and grain yield were significantly influenced by Zn application. The grain yield is an eventual end product of yield contributing components as well as physiological and morphological processes taking place in plants during growth and development. Similar findings were also reported by Tariq et al. (2002) who revealed that soil application at 20 kg Zn ha^{-1} increased the grain yield of maize. Our findings also corroborate the results of Grzebisz et al. (2008) and Ehsanullah et al. (2015) who reported that foliar application of Zn enhanced the grain yield and its component. The increase in biological yield with basal application at 15 kg $ZnSO_4$ ha^{-1} might have been due to enhanced growth on account of protein synthesis or higher activity of carbonic anhydrase (DELL; WILSON, 1985). Zinc is also required for maintaining the integrity of bio-membranes (MARSCHNER, 1995). Similar results are also reported by Khan et al. (2004) and Malavolta (2006) who indicated that basal application of Zn improved the biological yield of crop. The results of our experiment regarding harvest index are contradicted with the findings of Ehsanullah et al. (2015) and Potarzycki and Grzebisz (2009) who stated that foliar application of Zn significantly enhanced the harvest index. In our study, compared to control, a significant increase was found in grain Zn concentration of maize. However, highest Zn concentration in grain was attained by basal application of 15 kg Zn ha^{-1} and is sufficient for desired level of Zn in maize grain.

Rise in Zn concentration in maize grain might also be due to its effective utilization, timely availability and its remobilization from leaves to grain (XUE et al., 2012).

Conclusion

It is concluded from the above study that different hybrids responded differentially to different Zn fertilization methods. But among both hybrids, DK-6525 showed superiority than YSM-112. All methods of Zn fertilization significantly improved the growth and yield of maize. Grain Zn concentration was maximum for human bioavailability with basal application of 15 kg $ZnSO_4$ ha^{-1} and this application of Zn was found to be more efficient in improving maize growth and yield. It is recommended that maize hybrid DK-6525 was used with basal application of 15 kg $ZnSO_4$ ha^{-1} in Zn deficient soils for better growth, productivity and availability of Zn in maize.

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