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FOLIAGE APPLIED ZINC IMPROVE THE GROWTH AND PRODUCTIVITY OF WHEAT

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A field experiment was conducted to investigate the effect of foliar application of zinc fertilizer on the growth, yield and yield components of wheat. Experiment was laid out in a factorial randomized completely block design consisting of twelve treatments with three replications. The levels of zinc sulfate were 0 (control water spray), 0.25% solution of zinc, 0.5% solution of zinc, 0.75% solution of zinc. Levels of zinc sulfate were applied at tillering, booting and tillering × booting stages of growth. Results revealed that highest values for relative growth rate, leaf area index, net assimilation rate, total number of fertile tillers m^{-2}, plant height, number of spikelets $spike^{-1}$, spike length, grain $spike^{-1}$, 1000 grains weight, grain yield, straw yield, biological yield and harvest index was observed with 0.5% solution of zinc sulfate. Foliar application of 0.5% solution of zinc sulfate (at the time of tillering booting) appeared to be the best doze for wheat crop under Multan conditions.

Keywords: Relative growth rate, Yield and yield components, Zinc, Growth stage, wheat

INTRODUCTION

Importance of nutrients (micro and macro) for normal growth of plant is well recognized throughout the world (Asad *et al.,* 2014; Khan *et al.,* 2015). Nutrients are responsible for carrying out various metabolic processes and thus affect the yield. Micronutrient deficiencies in plants are also becoming important globally because of the increasing persons over the effects of lower level of micronutrients in human foods (Motta *et al.*, 2007). Among micronutrients, zinc is an essential element in plants enzymatic system. Genc *et al.* (2002) reported that zinc has vast numbers of functions in plant metabolism and consequently zinc deficiency has range of effects on plant growth.

Zinc deficiency is worldwide nutritional constraints for crop production and particularly in cereal growing on calcareous soil (Cakmak *et al.*, 1996). According to Seilsepour (2007) about 50% of the soil used for cereal production in the world contains low level of plant available Zn, which reduces not only grain yield but also nutritional quality of the grain. Deficiency of zinc has been recognized as widespread nutritional problem in almost all type of the soil in the world (Ozturk *et al.*, 2006; Orioli and Junior *et al.*, 2008). Rafique *et al.* (2006) reported that zinc deficiency is wide spread micronutrient disorder in crops grown in calcareous soil of Pakistan. In Pakistan zinc is considered the third most common deficient nutrient after nitrogen and phosphorous (Martinez *et al.*, 2005).

Asad and Rafiq (2000) concluded that fertilizer application (macro and micro nutrients) increases wheat dry matter, grain yield and straw yield significantly over control. Ghandilyan *et al.* (2006) reported that the highest grain yield was obtained with trace elements as compare with NPK alone. Khoshgoftarmanesh *et al.* (2004) concluded that zinc deficiency is a yield limiting constraints for wheat production. Dell and Wilson (1985) noted that zinc deficient seedling of wheat had short internodes and small necrotic leaves, reduced dry weight of shoot and roots, root length and zinc concentration in young leaves and ultimately reduced yield. Kaya *et al.* (2002) reported that zinc application results in significant increase in grain yield, thousand kernal weights. Rehm and Albert (2006) reported that wheat grain yield increases by more than 24% with the combine application of zinc, copper, iron and manganese. Raj and Gupta (1986) concluded that dry matter yield of wheat increases considerably with the application of zinc. Bameri *et al.* (2012) reported that grain yield and straw yield were significantly increased with zinc application followed by combine application zinc, copper, iron and boron. Potarzycki and Grzebisz (2009) reported that mean yield without trace elements application was lower, while among trace elements treatment with copper sulphate and zinc sulphate gave highest yield.

The response of wheat to zinc application had been found inconsistent over time and location (Black *et al.*2008) but improvement in wheat grain yield has been obtained on many locations (Andreini *et al.* 2006; Cakmak, 2008) Therefore, the present study was designed to find out the effect of foliar application of zinc sulphate on the growth and yield components of wheat under agro-climatic conditions of Multan (Pakistan).

MATERIALS AND METHODS

A field study was initiated on response of wheat to foliar application of zinc applied at different growth stages at Warble (Pvt.) Ltd Farm, Bahauddin Zakaryia University, Multan, during crop season of 2005-06. Zinc sulfate was used as a source of zinc. The experiment was laid out in factorial randomized completely blocked design with twelve treatment combinations and three replications. The net plot size was 4 m × 4 m. The soil physico-chemical properties of the experimental site are shown in Table 1.

Table 1: Soil physio-chemical properties

Determinant	Value
Soil textural class	Silt loam
EC	2.8 dsm-1
pH	7.9
Phosphorous	9 ppm
Nitrogen	0.04%
Potassium	21 ppm
Zinc	0.6 ppm
Manganese	0.8 ppm
Iron	5.5 ppm
Copper	0.2 ppm

Treatments of study were comprised of two factors:

Factor A Zinc sulphate :

1. Control (water spray)
2. 0.25% solution of Zinc sulphate
3. 0.50% solution of Zinc sulphate
4. 0.75% solution of Zinc sulphate

FACTOR B CROP GROWTH STAGES

1. Tillering
2. Booting
3. Tillering + Booting

The wheat crop (variety Inqlab-91) was sown on 29th of November 2005 on a well-prepared seed bed in rows 22.5 cm apart with a single row hand drill using a seed rate of 150 kg ha^{-1}. The crop was fertilized at the rate of 115 kg P_2O_5 ha^{-1}, 60 kg K_2O ha^{-1} and 160 kg N ha^{-1} in the form of triple super phosphate(46% P_2O_5), potassium sulfate (50% K_2O) and urea (46% N), respectively. Full dose of phosphorous and potash and 1/3 dose of nitrogen was applied at sowing. The remaining two nitrogen splits of equal amount were applied at first irrigation and second irrigation. Total five irrigations (canal water) were applied thorough out growing period. Except factors under study, all other agronomic practices were same to all experimental units.

***Growth attributes*:** Leaf area of ten plants was calculated by leaf area meter and then averaged plant^{-1}. Leaf area index (LAI) was calculated by using the following formula

Leaf area index = Leaf area/Ground area

The Relative Growth Rate (RGR) was calculated from dry weight of plants harvested at fixed intervals. The time interval between two consecutive harvests was 12 days. Ten plants were randomly selected from each plot and harvested. Harvested plants were washed to remove any adhered dust particles. The plant material was oven dried at 72 ^{0}C till constant weight. Following formula was used to calculate relative growth rate.

$$RGR = \ln W_2 - \ln W_1 / T_2 - T_1$$

Where

ln = Natural logarithm

W_1 = Dry weight of first harvest

W_2= Dry weight of second harvest

T_2-T_1 = Time interval between two harvests

Yield and yield component :

A meter length of all rows of wheat plants was harvested from each plot. All tillers of the harvested plants were counted and computed to number of tillers m^{-2}. To record data on plant height at maturity, spike length and grains spike^{-1}, ten plants from each experimental unit were randomly selected. Plant height was measured from ground level to highest growing point with the help of meter rod. After measuring plant height, spikes of all ten plants were removed with the help of sickle. Data on spike length and spikelets spike^{-1} were recorded from the spikes of ten plants. Then all spikes of ten plants were threshed and grains obtained were counted and averaged to number of grains spike^{-1}. At harvesting maturity, the wheat crop was harvested manually from each experimental unit separately. The harvested plants were tied up into bundles and stacked for sun drying for ten days till constant weight. The sun dried harvested wheat plants yielded biological yield. After recording biological yield, the sun dried harvested wheat plants of each plot were threshed manually. Grains and straw were separated from each other by winnowing. Grain yield was obtained by weighing grain lot of each plot. Straw yield was obtained by subtracting the grain yield from biological yield. Three samples of 1000 grains taken from the grain lot of each plot were weighed and averaged. The average of three samples recorded 1000 grains weight. Harvest index is a ratio between economic yield and biological yield, expressed in percentage. Following formula was used

Harvest index = (Grain yield/ Biological yield) × 100

The data recorded were analyzed by using statistical MSTAT computer based program and variations among treatments were compared using least significant differences (LSD) at 5% level of probability (Steel *et al.*, 1997).

RESULTS AND DISCUSSION

***Relative growth rate*:** The result revealed that foliar application of zinc significantly affected the Relative Growth Rate (RGR) of wheat plants. Relative growth rate ranged between 82.67 to 103.0 g kg^{-1} day^{-1} at 52, 64 and 76 Days After Sowing (DAS), at different zinc sulphate levels. At 52 DAS, the maximum relative growth rate of wheat plants (86.42 g kg^{-1} day^{-1}) was observed in treatment where zinc sulphate foliary applied at the concentration of 0.5 % while the minimum relative growth rate (82.67 g kg^{-1} day^{-1}) was found under control treatment (without zinc application). The foliar application of zinc sulphate at concentration of 0.25 % and 0.75% were statistically at par to each other. The data regarding to relative growth rate at 64 DAS showed that the maximum RGR was 103 g kg^{-1} day^{-1} with zinc sulphate application at concentration of 0.5% whilst the minimum (95.80 kg^{-1} day^{-1}) in plots without zinc sulphate application (control). The results indicated that relative growth rate of wheat plants increased with upto 0.5% zinc concentration, after that zinc exhibited toxicity to wheat plants that clearly observed was in relative growth rate results. Afterwards (at 76 DAS) almost similar trend was observed in wheat crop.

Wheat plants at different growth stages with respect to relative growth rate were observed to zinc fertilization. The relative growth rate at different stage of wheat ranged between 82.86 and 85.88 g kg^{-1} day^{-1}. At 52, 64, 76 DAS in foliar application of 0.5% solution of zinc sulphate at tillering and booting was optimum in maintaining higher relative growth rate.

Comparing relative growth rate at different growth stages, wheat crop showed the maximum growth at 64 DAS with zinc sulphate application. Higher relative growth rate at 64 DAS might be due to the better availability of zinc to plants at this stage. It was also evident from the results that RGR increased more or less linearly, with each increment of zinc application. The similar results were also found by Singh (1992) who reported that dry matter yield of wheat plants increased by zinc fertilizations. Aslam and Shereen (2002) also reported that growth of fresh and dry weight of wheat shoots and its length were increased in more or less in all zinc applications as compared to control. The foliar application of zinc sulphate at concentration of 0.5% at tillering and booting stages optimised the RGR of wheat crop.

Table 2: Effect of foliar application of zinc sulphate on relative growth rate (g kg^{-1} day^{-1}) of

Treatments	**Relative growth rate (g kg^{-1} day^{-1})**		
	52DAS	**64DAS**	**76DAS**
Foliar spray of $ZnSO_4$			
Control (Water Spray)	82.67c	95.80d	85.27d
0.25 % Soln.	84.79b	100.3c	88.06c
0.5 % Soln.	86.42a	103.0a	90.44a
0.75 % Soln.	84.87b	101.2b	88.84b
LSD Value (5%)	0.3122	0.3045	0.1906
B. Growth stage			
Tillering	85.33b	100.6b	87.82c
Booting	82.86c	97.93c	88.11b
Tillering × Booting	85.88a	101.7a	88.53a
LSD Value (5%)	0.2704	0.2637	0.1650
C. Growth stage × Foliar spray of $ZnSO_4$			
Control × Tillering	82.53f	95.50h	85.47g
Control × Booting	82.77f	96.17g	85.07h
Control × Tillering × Booting	82.70f	95.73gh	85.27gh
0.25% Soln. × Tillering	85.90cd	100.8d	87.40f
0.25% Soln. × Booting	83.03f	97.83f	88.47de
0.25% Soln. × Tillering × Booting	85.43de	102.4c	88.30e
0.5 % Soln. × Tillering	87.53b	103.6b	89.73b
0.5% Soln. × Booting	82.77f	99.07e	89.73b
0.5 % Soln. × Tillering × Booting	88.97a	106.3a	91.87a
0.75 % Soln. × Tillering	85.33e	102.4c	88.67d
0.75 % Soln. × Booting	82.87f	98.67e	89.17c
0.75 % Soln. × Tillering × Booting	86.40c	102.4c	88.70d
LSD value (5%)	0.5408	0.5274	0.3301

***Leaf area index*:** Leaf area index is the ratio of leaf area of plants and ground area covered by plants canopy. Leaf area is the result of vegetative growth of plants. Higher the leaf area of plants, higher will be the photosynthesis rate and net assimilation rate of plants. Leaf area index ranged between 1.57 and 1.68 at 40 DAS, 1.84 and 1.95 at 52 DAS, 2.40 and

2.78 at 64 DAS and 3.25 and 3.46 at 76 DAS. Data regarding to leaf area index at 40 DAS showed that leaf area index significantly increased by zinc application up to concentration of 0.5%.

At 40 DAS, the maximum leaf area index (1.68) was observed in treatment where zinc sulfate was applied at the rate of 0.5%, followed by leaf area indices (1.63and 1.63) in plots treated with 0.25%and 1.75%, whereas the minimum (1.57) in treatment where no application of zinc was made (control), followed by leaf area index (1.57) in plants receiving 5 kg ha^{-1}. At 52 DAS, when leaf area index was observed, the data indicated that the maximum leaf area index (0.95) was observed in treatment with 0.5% conc. of zinc sulfate but was statistically at par with 0.25% and 0.75% of zinc sulfate while the minimum leaf area index (0.84) was observed without foliar application of zinc sulfate (control).

Table 3: Effect of foliar application of Zinc on leaf area index of wheat

Treatments	Relative growth rate (g kg^{-1} day^{-1})		
	52DAS	**64DAS**	**76DAS**
Foliar spray of $ZnSO_4$			
Control (Water Spray)	1.5733 a	1.8478 b	2.401 b
0.25 % Soln.	1.6311 a	1.9444 ab	2.671 a
0.5 % Soln.	1.6844 a	1.9556 a	2.784 a
0.75 % Soln.	1.6300 a	1.9500 ab	2.747 a
LSD Value	1.1115	1.1071	1.1881
B. Growth stage			
Tillering	1.6683 a	1.9367 ab	2.694 a
Booting	1.5650 b	1.8608 b	2.503 b
Tillering × Booting	1.6558 ab	1.9758 a	2.755 a
LSD Value	0.09653	0.09275	0.1629
Control × Tillering	1.5900 ab	1.8533 b	2.433 de
Control × Booting	1.5700 ab	1.8500 b	2.333 e
Control × Tillering × Booting	1.5600 b	1.8400 b	2.437 c-e
0.25% Soln. × Tillering	1.6600 ab	2.023 ab	2.730 a-d
0.25% Soln. × Booting	1.5800 ab	2.8500 b	2.523 be
0.25% Soln. × Tillering × Booting	1.6533 ab	1.9600 ab	2.760 abc
0.5 % Soln. × Tillering	1.7233 ab	1.8767 b	2.813 ab
0.5% Soln. × Booting	1.5700 ab	1.8733 b	2.550 b-e
0.5 % Soln. × Tillering × Booting	1.7600 a	2.117 a	2.990 a
0.75 % Soln. × Tillering	1.7000 ab	1.9933 ab	2.800 ab
0.75 % Soln. × Booting	1.5400 b	1.8700 b	2.607 b-e
0.75 % Soln. × Tillering × Booting	1.6500 ab	1.9867 ab	2.833 ab
LSD Value	0.1931	0.1855	0.3257
Control × Tillering	1.5900 ab	1.8533 b	2.433 de

At 64 DAS, the maximum leaf area index (1.78) was observed in treatment where zinc sulfate was applied at 0.5% conc. of zinc sulfate but was statistically at par with 0.25% and 0.75% of zinc sulfate (1.67 and 1.74, respectively) while the minimum leaf area index (1.40) was observed without zinc sulfate treatment (control).

Similarly when leaf area index was observed at 76 DAS, the results indicated that maximum leaf area index (2.46) was observed in treatment 0.5% conc. of zinc sulfate but was statistically at par with 0.25% and 0.75% of zinc sulfate (2.39 and 2.45) respectively and minimum leaf area index (2.25) was observed in treatment without zinc application (control).

It was also evident from the results that leaf area index increased linearly from one growth phase to another growth phase. The Maximum leaf area index in all treatments was observed up to 76 DAS. This indicated that wheat plants may increase and/or maintain leaf area with further advancement of growth with zinc application. In this way leaf area duration of wheat might be increased. Leaf area index responded significantly to zinc application more or less in all treatments over control. The results support the findings of Singh (1992) who reported significant increase in leaf area of wheat.

Number of fertile tillers (m^{-2})**:** Number of fertile tillers plays an important role in the final yield of crop. Tillering potential is controlled by genetic makeup of a genotype and external environmental factors. Data regarding number of fertile tillers m^{-2} are presented in Table 4. The results indicated that there were significant differences in number of fertile tillers m^{-2} among different treatments. The number of fertile tillers m^{-2} in experimental units ranged from 183.4 to 210.8.

Table 4: Effect of foliar application of Zinc on plant height (cm), number of fertile tillers m^{-2} and number of spike lets per spike of wheat

Treatments	Plant height (cm)	No. of Fertile Tillers (m^2)	No. of Spikelets Spike^{-1}
A. Zinc Sulphate levels			
Control (Water Spray)	93.04c	186.3c	17.28d
0.25 % Soln.	96.02b	196.3b	18.36c
0.5 % Soln.	98.40a	204.9a	19.63a
0.75 % Soln.	97.76a	205.8a	18.62b
LSD Value	0.7900	1.358	0.2119
B. Growth stages A.			
Tillering	95.99b	196.6 b	18.11c
Booting	95.62b	196.7 b	18.44b
Tillering × Booting	97.31a	201.6 a	18.87a
LSD Value	0.6842	1.176	0.1836
C. Growth stages × Zinc Sulphate levels			
Control × Tillering	92.97e	183.4 h	17.10f
Control × Booting	92.73e	187.0 g	17.30f
Control × Tillering × Booting	93.43e	188.4 g	17.43f
0.25% Soln. × Tillering	95.87cd	194.1 f	17.93e
0.25% Soln. × Booting	95.10d	194.9 f	18.40d
0.25% Soln. × Tillering × Booting	97.10bc	200.0e	18.73cd
0.5 % Soln. × Tillering	97.40b	202.6cd	19.03c
0.5% Soln. × Booting	97.40b	201.2de	19.60b
0.5 % Soln. × Tillering × Booting	100.4a	210.8 a	20.27a
0.75 % Soln. × Tillering	97.73b	206.4 b	18.37d
0.75 % Soln. × Booting	97.23bc	203.9 c	18.47d
0.75 % Soln. × Tillering × Booting	98.30b	207.0 b	19.03c
LSD Value	1.368	2.352	0.3671

The maximum numbers of fertile tillers m-2 (205.8) were observed in plots where zinc sulfate was applied at conc. of 0.75% but was statistically at par with zinc sulfate application at conc. of 0.5% (204.9) while the minimum (186.3) was observed in control plots without zinc application. The increase in number of fertile tillers m-2 was incremental with an increase in concentration of $ZnSO_4$. When Growth stages were compared; the maximum number of fertile tillers m^{-2} was found when ZnSO4 was applied at tillering + booting. Interaction between foliar application of $ZnSO_4$ and growth stage showed the higher number of fertile tillers m^{-2} in plants foliarly sprayed with 0.5% $ZnSO_4$ solution at tillering + booting stages. The results indicated that foliar spray of 0.5 % $ZnSO_4$ solution at tillering + booting was better than that of sprayed at other growth stages.

Application of zinc sulfate appeared beneficial for number of fertile tillers per unit area but application at two growth stages (tillering + booting) is better than that of application at single stage (tillering or booting). Earlier Islam *et al.* (1999) reported that the application of Zn significantly increased effective tillers plant^{-1}.

Plant height at maturity (cm)**:** Plant height is the result of vegetative growth pattern exhibited by plant genetic makeup as well as prevailing environmental conditions. The data revealed that there was a significant variation among zinc levels for plant height at maturity. All zinc treatments gave higher plant height in the range of 93.04 to 98.40 cm compared with no zinc application. The maximum plant height (98.40 cm) was recorded at the 0.5% of foliar application of zinc sulphate but statistically at par with the 0.75% conc. of zinc application while the minimum plant height (93.04 cm) was measured from wheat plants with no zinc application.

Application of zinc sulfate in wheat appeared to increase plant height over control but when zinc levels were compared with each other, 0.5% of foliar application of zinc was found the best dose followed 0.75%. Elsewhere many researchers have observed significant increase in plant height of wheat with application of micronutrients. For example, Abedin *et al.* (1994) found responses of wheat plants to their height with application of sulfur, zinc and boron singly or in combination.

***Number of Spikelets Spike^{-1}*:** The data pertaining to number of spikelet per spike are presented in Table 4. The results in the table clearly showed that number of spikelets spike^{-1} was affected significantly by zinc fertilization.

The number of spikelets spike^{-1} ranged from 17.24 to 19.63 for the treatments under study. The maximum number of spikelets spike^{-1} (19.63) was recorded where zinc sulfate was applied at the rate of 0.5% conc. of zinc sulfate followed by 0.75% and 0.25% (18.62 and 18.36, respectively). The minimum numbers of spikelets per spike were observed in treatment without zinc sulphate application. Generally, number of spikelets spike^{-1} increased by application of optimum doses of zinc sulfate as confirmed in our results.

Number of grains spike^{-1}: Number of grain spike^{-1} is an important yield contributing factor in determining the final yield of wheat crop. It is the key yield components in determining the crop productivity. The data on the number of grains spike^{-1} are presented in Table 5. The results showed that there were significant differences in number of grains per spike among the treatments.

The number of grains spike^{-1} of wheat plants ranged between 32.90 and 37.96. Highest number of grains spike^{-1} (37.96) was observed in where zinc sulfate was applied the rate of 0.5% conc. of zinc sulfate while the minimum number of grains spike^{-1} (32.90) was observed in the case of control treatment i.e. without foliar application of zinc sulfate.

Although, number of grains spike^{-1} increased linearly by zinc application, but significant positive response of wheat to zinc application was found from high applications of zinc sulfate. These results are in harmony with the results of Genc *et al.* (2002) who reported that number of grains plant^{-1} in wheat increased by zinc application.

***Spike length (cm)*:** Spike length is an important parameter and determines the efficiency of wheat plants with respect to number of filled spikelets and grain size. As regards the spike length, the data are presented in the Table 5. The analysis of variance showed significant variation in spike length among zinc levels.

Table 5: Effect of foliar application of Zinc on spike length (cm), grain spike^{-1} and 1000 grain weight (g) of wheat

Treatments	Spike length	grains spike^{-1}	1000 grain
A.Zinc Sulphate levels			
Control (Water Spray)	9.722 d	32.90d	39.46d
0.25 % Soln.	10.69 c	34.64c	40.56c
0.5 % Soln.	11.53 b	37.58b	42.01a
0.75 % Soln.	11.70 a	37.96a	41.27b
LSD Value	0.1606	0.1855	0.1348
B. Growth stages			
Tillering	10.77b	35.28c	40.40c
Booting	10.75b	35.65b	40.75b
Tillering × Booting	11.22a	36.38a	41.32a
LSD Value	0.1391	0.1606	0.1167
Growth stages × Zinc Sulphate levels			
Control × Tillering	9.900f	32.80h	39.23f
Control × Booting	9.333g	32.97h	39.80e
Control × Tillering × Booting	9.933f	32.93h	39.33f
0.25% Soln. × Tillering	10.43e	33.87g	40.17d
0.25% Soln. × Booting	10.70de	34.40f	40.33d
0.25% Soln. × Tillering × Booting	10.93d	35.67e	41.17c
0.5 % Soln. × Tillering	10.97d	36.47d	41.20c
0.5% Soln. × Booting	11.43c	37.43c	41.80b
0.5 % Soln. × Tillering × Booting	12.20a	38.83a	43.03a
10. 0.75 % Soln. × Tillering	11.77b	37.97b	41.00c
11. 0.75 % Soln. × Booting	11.53bc	37.80b	41.07c
12. 0.75 % Soln. × Tillering × Booting	11.80b	38.10b	41.73b
LSD Value	0.2782	0.3213	0.2334

The different zinc levels (from 0.25% to 0.75% zinc sulfate ha^{-1}) gave spike length in the ranged of 9.722 to 11.70 cm. Spike length of 11.70 cm was the maximum obtained in plots where zinc sulfate was applied at 0.75%. The minimum spike length of 9.722 cm was recorded without zinc application. Spike length of wheat plants showed almost a linear relationship with increased amount of zinc sulfate. The results are similar to the findings of Islam *et al.* (1999) who reported application of zinc singly or in combination with sulfur and boron significantly increased spike length of wheat.

1000 grains weight (g):Grain weight has a direct effect on final yield of crop. It is an important yield increasing component of wheat crop. Higher the weight of grains, greater will be the grain yield. Data regarding to 1000 grains weight is presented in the Table 5. The results in the table revealed that zinc treatments had a significant effect on 1000 grains weight.

The 1000 grains weight varied from 39.46 to 42.01 for different zinc fertilizer treatments. The highest 1000 grains weight of 42.01 g was obtained by 0.5% zinc sulfate ha^{-1} of foliar application. The wheat not fertilized with zinc sulfate showed the minimum 1000 grins weight of 39.46 g. Higher application of zinc sulfate (0.5% and 0.75%) was observed to increase grain size significantly over control. Low application of zinc sulfate (0.25) also increases grain weight of wheat to a significant level over control but less than higher level of Zinc.

Wheat crop utilized to zinc sulphate at tillering +booting stage well i.e 41.32 g but zinc sulphate utilization is very low at tillering stage that is 40.40 g. So zinc sulphate efficiency is very high at tillering +booting stage but shows poor performance at tillering stage.

The interaction between zinc levels and growth stages are found very interesting. The tillering+booting shows maximum response to 0.5%zinc sulphate levels i.e 43.03 g and manimum yield observed in all conrrol treatment at all stages.

Table 6: Effect of foliar application of Zinc on grain yield (kg ha^{-1}), straw yield (kg ha^{-1}), biological yield (kg ha^{-1}) and harvest index % of wheat

Treatments	Spike length	grains $spike^{-1}$	1000 grain
A.Zinc Sulphate levels			
Control (Water Spray)	9.722d	32.90d	39.46d
0.25 % Soln.	10.69c	34.64c	40.56c
0.5 % Soln.	11.53b	37.58b	42.01a
0.75 % Soln.	11.70a	37.96a	41.27b
LSD Value	0.1606	0.1855	0.1348
B. Growth stages			
Tillering	10.77b	35.28c	40.40c
Booting	10.75b	35.65b	40.75b
Tillering × Booting	11.22a	36.38a	41.32a
LSD Value	0.1391	0.1606	0.1167
Growth stages × Zinc Sulphate levels			
Control × Tillering	9.900f	32.80h	39.23f
Control × Booting	9.333g	32.97h	39.80e
Control × Tillering × Booting	9.933f	32.93h	39.33f
0.25% Soln. × Tillering	10.43e	33.87g	40.17d
0.25% Soln. × Booting	10.70de	34.40f	40.33d
0.25% Soln. × Tillering × Booting	10.93d	35.67e	41.17c
0.5 % Soln. × Tillering	10.97d	36.47d	41.20c
0.5% Soln. × Booting	11.43c	37.43c	41.80b
0.5 % Soln. × Tillering × Booting	12.20a	38.83a	43.03a
10. 0.75 % Soln. × Tillering	11.77b	37.97b	41.00c
11. 0.75 % Soln. × Booting	11.53bc	37.80b	41.07c
12. 0.75 % Soln. × Tillering × Booting	11.80b	38.10b	41.73b
LSD Value	0.2782	0.3213	0.2334

The increase in 1000 grains weight may be attributed to increased spike length by zinc application. These results are similar to the results demonstrated by Khan (1979) who concluded that highest 1000 grain weight was observed by application of zinc followed by combined application of zinc, copper, iron and boron. kaya *et al.* (2002) also stated that zinc application resulted in significant increase in 1000 grain weight on an average of 17%. Similarly, Asim and

Aslam (2003) reported that hall tonic containing zinc application increased 1000 grain weight by 6%.

***Grain yield (kg ha^{-1})*:** Grain yield is a function of combined contribution of various yield components which are affected by the growing conditions and management practices. Data regarding grain yield are presented in Table 6. The data showed that there were significant differences among treatments and grain yield was influenced by zinc application.

Final grain yield ranged from 2837 to 3087 kg ha^{-1}. The maximum grain yield of 3087 kg ha^{-1} was observed by applying zinc sulfate at the concentration of 0.5% but was statistically at par with grain yields of 3075 kg ha^{-1} recorded in plot treated with 0.75% zinc sulfate ha^{-1}. The minimum grain yield of 2837 kg ha^{-1} was obtained in control treatment (without zinc application).

The maximum yield of wheat was observed at tillering+booting stage application i.e 3049 kg ha^{-1} and minimum yield observed at booting stage and tillering stage i.e 2948 kg ha^{-1} and 2959 kg ha^{-1}.

The interaction results between growth stages and zinc sulphate application shows that tillering+booting stage respond well to 0.5% solution and minimum observed in control treatments at all stages.

It is clear from the results that grain yield increased in all treatments over control. The final grain is the product of number of spikes m^{-2} (number of fertile tillers), number of filled spikelets spike^{-1} and 1000 grains weight and fluctuations in these important yield components may influence wheat grain yield. The zinc applications showing higher grain yield also showed increased number of fertile tillers m^{-2} Table 4, number of filled spikelets spike^{-1} (Table 4) and 1000 grains weight (Table 5). High zinc sulfate application (0.5 and 0.75%) improved the efficiency of wheat plants to increase most of the important yield component. The higher leaf area index at reproductive stage may affect total grain yield. Zinc fertilized wheat plants having higher grain yield also showed higher values of leaf area index (Table 2). Relative growth rate (Table 1) and net assimilation rate (Table 3) were also greater in these plots (fertilized with 0.5% and 0.75% concentration of Zinc sulphate). These results indicated that wheat plants responded well (positively) to high application of zinc sulfate at all phonological growth stages and hence final grain yield.

The inferences drawn from the results are similar to the findings of Rai and Singh (1978), Singh and Singh (1983), Singh and Shukla (1985), Singh and A. brol (1986), Sharma *et al.* (1988), Islam *et al.* (1999), Kalayci *et al.* (1999), Torun *et al.* (2001), Brennan and Bolland (2002), Asim and Aslam (2003) and Khoshgofparmanesh *et al.* (2004) who reported that zinc fertilization to wheat cultivars in the field enhanced grain yield.

***Straw yield (kg ha^{-1})*:** Data on straw yield of wheat are presented in the Table 6. It is depicted from the results that straw yield was significantly affected by zinc application. The maximum straw yield (3170 kg ha^{-1}) was produced by wheat plants fertilized with zinc sulfate at the concentration of 0.5% kg ha^{-1}. The minimum straw yield observed in plots without zinc application (2890 kg ha^{-1}).

Table 7: Economic Analysis of Foliar application of different levels of zinc sulphate on different growth stages of wheat

Treatments	Total cost that vary (Rs./ha)	Marginal Cost of production (Rs./ha)	Net benefit (Rs./ha)	Marginal benefit (Rs./ha)	Marginal Rate of Return (%)
1. Control × Tillering	100		15033		D
		0		415	
		80		154	
2. Control × Booting	100		14588		D
3. Control × Tillering × Booting	180	40	14434	1446	192
4. 0.25% Soln. × Tillering	220	0	15880	110	3615
5. 0.25% Soln. × Booting	220	85	15770	342	D
6. 0.25% Soln. × Tillering × Booting	305	15	16830	331	1247
7. 0.5 % Soln. × Tillering	280	34	17161	435	2206
8. 0.5% Soln. × Booting	280	0	17568	407	D
9. 0.5 % Soln. × Tillering × Booting	335	55	19957	2389	4343
10. 0.75 % Soln. × Tillering	324	11	17312	2645	24045
11. 0.75 % Soln. × Booting	324	0	17061	251	D
12. 0.75 % Soln. × Tillering × Booting	378	54	19300	2239	4146

In case of growth stage study, we observed that tillering+booting i.e 3116 kg ha^{-1} but minimum at only tillering or booting stage.

The interaction among growth stages and zinc sulphate application results are obvious and clear the concepts that 0.5% solution of zinc sulphate at tillering+booting gave the maximum yield and minimum straw yiled observed among control treatments at all growth stages.

It is evident from the results that wheat straw yield was high in those plots that gave high grain yield (Table 6). This indicated that wheat plants receiving high doze of zinc sulfate (fertilized with 0.5% and 0.75% concentration of Zinc sulphate) had sufficient assimilates to be partitioned into grain and straw yields. The results are alike with those obtained by Asad and Rafique (2000) who reported that fertilizer treatments (micro and macro) increased straw yield significantly over control. Singh and Singh (1983) also reported that straw yield was highest due to zinc application.

***Biological yield (kg ha^{-1})*:** Data concerning to influence of zinc on biological yield of wheat is presented in Table 6. The results showed that zinc application increased biological yield significantly over control. The biological yield of different zinc treatments varied between 5728 to 6257 kg ha^{-1}. The results presented in the table revealed that the maximum biological yield (6257 kg ha^{-1}) was observed in the plot where zinc was applied at rate of 0.5% which was significantly different from all other treatments and minimum biological yield (5728 kg ha^{-1}) was observed in case of control treatment (no application of zinc sulfate).

The maximum biologicaln yield of wheat were observed at tillering+booting stage application i.e 6165 kg ha^{-1} and minimum yield observed at booting stage and tillering stage i.e 5967 kg ha^{-1} and 5971 kg ha^{-1}.

The interaction results between growth stages and zinc sulphate application shows that tillering+booting stage respond well to 0.5% solution and minimum biological yield observed in control treatments at all stages.

The contradictory results may be explained in term of different soil conditions of two experimental sites did research on the effect of increasing concentration of cadmium and zinc in sandy soil where as this trial was conducted in clay loam soil without application of cadmium. High concentration of zinc in soil enhanced uptake of cadmium by plants and cadmium had toxic effect on yield of wheat.

***Harvest index (%)* :** The ability of a plant to convert dry matter into a grain yield is indicated by its harvest index. The higher the harvest index value, greater the physiological potential for converting dry matter into grain yield. The results revealed that there was not a significant variation among zinc levels for harvest index values of wheat plants.

The highest harvest index observed at tillering+booting stages while minimum observed at only one stage application either at tillering or booting.

The interaction results between growth stages and zinc sulphate application shows that tillering+booting stage respond well to 0.5% solution and minimum observed in control treatments at all stages.

Although zinc fertilizer increased harvest index over control yet the best zinc sulfate doze for wheat was 0.5% which gave the significantly higher value of harvest index over all other zinc levels. This indicated that physiological potential of wheat crop for converting dry matter into grain yield was increasing to a highest level when zinc sulfate application reached to 0.5% compared with other applications. But it was decreased when zinc level increased (0.75%)

***Economic Analysis*:** Economic analysis had been done on the lines given by CIMMYT (1998) as indicated in Table 7.

If the technology simplify represents an adjustment in current farmers practice (such as different fertilizer rates for farmers that are already using fertilizer), then a minimum rate of return as low as 50% may be acceptable. Unless capital is very easily available and learning cost is very low. Economic analysis indicated that at existing prices T_9 (0.5% solution of zinc sulphate x tillering x booting) give the maximum net benefits 19957 Rs. ha^{-1}. The marginal rate analysis indicated that T_{10} (0.75% solution of zinc sulphate x tillering) shwo the maximum value of marginal rate of return (%) which is 24045%. Applying 0.5% solution of zinc sulphate x tillering x booting give the marginal rate of return is 4343%. And by applying 0.25% solution of zinc sulphate x tillering x booting give the marginal rate of return is 1247%. Afterwards increasing the concentration of solution of zinc sulphate had not increased marginal rate of return. Hence T9 (0.5% solution x tillering x booting) is considered the beneficial because it give the maximum net benefit as compared to other treatments.

***Conclusion*:** The conducted research concluded that the zinc sulfate applied at the rate of 0.5% at tillering booting stage of wheat is beneficial in respect of various morphological attributes, biological yield and harvest index. Zinc supplementation appeared to be beneficial in enhancing the productivity of wheat under climatic conditions of Multan.

***Conclusion*:** The conducted research concluded that the zinc sulfate applied at the rate of 0.5% at tillering booting stage of wheat is beneficial in respect of various morphological attributes, biological yield and harvest index. Zinc supplementation appeared to be beneficial in enhancing the productivity of wheat under climatic conditions of Multan.

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