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Effects of Different Zinc Application Methods on Agronomic Traits of Durum Wheat in a Semi-Arid Anatolian Environment

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This study was carried out to determine the effects of different zinc doses and application methods on grain yield, yield components and plant zinc concentrations of durum wheat (cv. Diyarbakir 81) in Southeastern Anatolia region between 2000 and 2002 years. The treatments were soil, seed and leaf applications of zinc to wheat. The amounts of 0, 1800, 3600 and 5400 g zinc ton^{-1} $seed^{-1}$ for the seed application, 0.0, 2.3, 4.6 and 6.9 kg zinc ha^{-1} for soil application and 0.0, 110, 330 and 550 g zinc ha^{-1} for the leaf application were used. The results showed that zinc doses significantly affected all the investigated properties. The highest value for all investigated properties, except protein content, was obtained by the highest zinc doses. Compared to the control, grain yield at third and fourth doses increased 15.0 and 17.4 %, over all application methods, respectively. Yield components, *i.e.*, spike length, spikelet number, grain number per spike and thousand grain weight were increased approximately 10 % upon the addition of third and fourth doses. Application methods significantly affected to grain yield, zinc concentration, protein content of grain and plant height. The highest doses of soil, leaf and seed applications increased grain yield up to 26.9, 12.5 and 12.2 %, respectively. The application of 6.9 kg zinc ha^{-1} to soil or 5400 g zinc ton^{-1} $seed^{-1}$ to seed or 550 g zinc ha^{-1} solution to the plants may be more efficient in terms of their economically feasibility and yield increases.

Key Words: Durum wheat, Fertilization, Zinc, Yield, Protein content.

INTRODUCTION

Zinc deficiency is one major micronutrient deficiency in humans, particularly in developing countries, where cereals with very low levels of Zn are the primary stable food for human consumption[1]. High consumption of cereals with low concentrations and bioavailabilities of zinc has been a major reason for the widespread occurrence of zinc deficiency in humans[1,2].

On the other hand, zinc deficiency in plant growth is a worldwide nutritional constraint, particularly in calcareous soils of arid and semi-arid regions[3]. Eyüboglu *et al.*[4] reported that 50 % of the cultivated area in the Southeastern Anatolian region

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was deficient in zinc because of the high level of clay and lime in the soils, low precipitation and high evaporation. There are numerous studies on the effects of rates and application methods of fertilizers containing zinc employed in the compensation of the deficiency on the yield and yield components of the grain crops[5-8]. For instance, Yadav[9] investigated the effects of fertilizers containing N and Zn on the wheat yield. The grain yield of 3.72 t ha^{-1} was obtained with 50 kg $ZnSO_4$ ha^{-1} while the yield was 3.43 t ha^{-1} without zinc application.

Ibrahim and Shalaby[10] applied the fertilizers containing Fe, Mn, Zn and Cu by the method of soil, leaf and seed to wheat. The seed application was found to most effective method over all different fertilizer. The soil, leaf and seed application methods of zinc to wheat increased yield and yield components and seed application was superior to seed and leaf applications[7].

Grain yield of cereal species grown under zinc deficiency conditions was *ca.* 35 % lower than that of the soils had sufficient zinc[11]. Aydin *et al.*[12] reported that grain yield of barley significantly increased with 5 kg zinc ha^{-1} application. Raghbir *et al.*[13] also showed that 5 mg zinc kg^{-1} application to soil in a pot experiment increased grain content of protein and sulphur content of barley. On the other hand, there was no significant effect of the fertilizers containing zinc in irrigated and rainfed conditions of Harran Plain. However, significant differences in response to zinc among barley cultivars were found for grain yield[14]. Taban *et al.*[15] determined that zinc applications increased grain yield and 1000 grain weight. Soil, leaf and seed zinc application methods increased grain yield of bread wheat and durum wheat at 76, 61 and 52 %, respectively[8].

This study was conducted to determine the effects of different application methods and the amount of zinc fertilizers on zinc content of plants, yield and yield components of durum wheat (c.v. Diyarbakir 81), grown in the South-eastern Anatolian region, where zinc deficiency reached to the considerable levels in the soils.

EXPERIMENTAL

The durum wheat cultivar 'Diyarbakir 81' was used as plant material for present experiment. Field experiments were conducted at rainfed conditions at the Experimental and Research Station of Agricultural Faculty of Dicle University, Diyarbakir during the years of 2000-2002 under rain-fed conditions. Precipitation in the first and following year of the experiments were recorded as 537 and 474 mm, respectively. Some characteristics of soils (0-30 cm) in the experimental site were as follows: Soil texture is clayey loam and the other parameters such as $CaCO_3$, pH, organic matter and available P were 7.8 %, 7.7, 1.8 % and 7.5 mg kg^{-1}, respectively. The concentration of DTPA-extractable micronutrient Zn of soil was 0.37 mg kg^{-1}. Seeding rate was 450 seeds m^{-2} and plot sizes were 8 m^2 at sowing and 4.8 m^2 at harvest. The interval between plots was 0.5 m to prevent the interaction of the fertilizer. Plots were sown after the first rain and received 120 kg ha^{-1} N in two applications (60 kg N at sowing and 60 kg N at stem elongation) and 60 kg ha^{-1} P_2O_5 was applied each year.

Zinc application methods were soil, leaf and seed applications. At the soil application, $ZnSO_4 \cdot 7H_2O$ fertilizer were sprayed to plots before planting at the doses of 0, 2.3, 4.6, 6.9 kg Zn ha^{-1} and incorporated into the soil to 10 cm depth by a rototiller. At the leaf application, the four doses 0.0, 110, 330, 550 g zinc ha^{-1} of the solutions prepared from $ZnSO_4 \cdot 7H_2O$ were applied into leaves three times at 15 d intervals starting from the period of stem elongation onward. At the seed application, 100 mL solution of Teprosyn F-2498 which contains the doses of 0, 1800, 3600 and 5400 g zinc ton^{-1} $seed^{-1}$ was sprayed on 1 kg seed and then seeds were mixed thoroughly and air dried with 12 h duration. First, second, third and fourth zinc doses of all application methods were described as Zn_0, Zn_1, Zn_2 and Zn_3 for all investigated traits in present studies.

Ten plants from each plot at the period of the spike formation selected randomly were taken at the height of 10 cm from the ground cutting by a non-rusting steel scissors so as to determine the zinc concentrations of the wheat[16]. The zinc concentrations of the plants were determined[6] by atomic absorption spectrophotometer after ashing samples at 550 °C and dissolving ash in 3.3 % HCl. The plant height, the spike length, the number of the spikelets, the grain number per spike, the grain weight per spike, the thousand grain weight, the grain yield[17] and the protein rate in the grain (Mark Leco FP-528 protein/nitrogen analyzer apparatus) were determined.

Linear or non-linear regression models were tested to find the best zinc dose to give the highest grain yield. Cubic regression curves which better explain the effects of zinc for all application methods were used.

Experimental design was a split plot design with three replications. Differences among means and treatments were compared by the least significant differences (LSD) at $p < 0.05$ and $p < 0.01$ using MSTAT-C software program. Regression analysis was done by using SPSS software program.

RESULTS AND DISCUSSION

The effects of the application doses on all investigated properties were found to be significant (Tables 1-3). For all investigated traits, except protein content, the highest results were obtained by Zn_3 dose, while the highest protein content was obtained by Zn_2 dose. Application of Zn_2 and Zn_3 doses resulted in *ca.* 10 % increment at spike length, spikelet number, grain number per spike and 1000 grain weight. Also grain yields at Zn_2 and Zn_3 over all application methods were 15.0 and 17.4 % higher than that of Zn_0.

The effects of the application methods on plant height, zinc concentration, grain yield and protein content were significantly different (Tables 1 and 3), while spike length, spikelet number, grain number per year, grain weight per spike and 1000 grain weight were not affected by application methods. Soil application significantly increased the grain yield more than seed and foliar application (Table-3). Soil, foliar and seed application methods increased grain yield up to 15.5, 7.9 and 6.7 %, respectively.

TABLE-1
EFFECTS OF FERTILIZERS CONTAINING ZINC ON PLANT HEIGHT, SPIKE LENGTH AND SPIKELET NUMBER PER SPIKE OF DURUM WHEAT

Treatments		Plant height (cm)			Spike length (cm)			Spikelet number per spike		
		2001	2002	Means	2001	2002	Means	2001	2002	Means
Seed	Zn_0	105.3	114.0	109.7	7.20	8.10	7.65	20.6	21.0	20.8
	Zn_1	106.4	112.6	109.5	7.57	8.47	8.02	21.5	21.6	21.6
	Zn_2	107.2	115.6	111.4	8.03	8.95	8.49	22.1	23.5	22.8
	Zn_3	108.6	119.7	114.1	8.23	8.85	8.54	23.0	23.0	23.0
Soil	Zn_0	104.6	119.8	112.2	7.03	7.98	7.42	20.8	20.7	20.8
	Zn_1	106.3	122.9	114.6	7.53	8.09	7.81	22.8	21.7	22.2
	Zn_2	107.0	124.6	115.8	7.83	8.30	8.07	22.3	22.5	22.4
	Zn_3	107.8	125.3	116.6	8.10	8.54	8.32	21.9	23.3	22.6
Leaf	Zn_0	105.9	116.5	111.2	7.20	7.82	7.51	20.8	21.5	20.6
	Zn_1	107.4	120.4	113.9	7.50	8.24	7.87	22.8	22.1	21.7
	Zn_2	108.7	124.1	116.4	8.10	8.70	8.39	22.3	23.0	22.8
	Zn_3	109.6	126.2	117.9	8.20	8.43	8.31	21.9	23.2	23.4
Interactions (Application × Dose)										
LSD			**N.S**			**N.S**			**N.S**	
Applications means	Seed		111.2 b			8.18			22.04	
	Soil		114.8 a			7.90			22.00	
	Leaf		114.9 a			8.02			22.10	
LSD			**2.523****			**N.S**			**N.S**	
Doses means	Zn_0		110.0 b			7.53 b			20.71 b	
	Zn_1		112.7 ab			7.90 ab			21.82 ab	
	Zn_2		114.5 ab			8.32 a			22.67 a	
	Zn_3		116.2 a			8.39 a			22.99 a	
LSD			**3.949****			**0.537****			**1.576****	

*(p < 0.05), **(p < 0.01), N.S. = Non-significant ; a,b = The differences among the groups with different letters in the same column and line are significant.

Zinc concentration of plants was mostly affected by adding zinc doses. The concentration rose 25 % after each zinc dose increase. Leaf application increased zinc concentration twice higher than seed and soil application. Zinc concentration increased by seed and soil application 1.6 and 6.1 %, respectively, while foliar application increased 106.6 %. Protein content was slightly increased by application methods and seed, soil and foliar application raised protein content of seeds 5.9, 2.5 and 1.2 %, respectively. The effects of zinc application methods and doses on phosphorus concentration of plant were also not significant (data not shown).

There were significant differences in between successive years in durum wheat plant parameters such as plant height, spike length, grain number per spike, grain weight per spike, thousand grain weight, zinc concentration and grain yield. The main reason of the differences in grain yield between two growing seasons can be attributed to heat and drought stress during germination and tillering period and to

TABLE-2
EFFECTS OF FERTILIZERS CONTAINING ZINC ON GRAIN NUMBER PER SPIKE, GRAIN WEIGHT PER SPIKE AND THOUSAND GRAIN WEIGHT

Treatments		Grain number per spike			Grain weight per spike (g)			Thousand grain weight (g)		
		2001	2002	Means	2001	2002	Means	2001	2002	Means
Seed	Zn_0	45.2	48.8	47.0	1.89	2.44	2.17	39.5	48.3	43.9
	Zn_1	47.4	50.9	49.2	1.96	2.57	2.27	43.6	49.3	46.5
	Zn_2	48.6	52.7	50.6	2.22	2.67	2.45	45.1	54.6	49.9
	Zn_3	49.4	53.9	51.6	2.11	2.75	2.43	47.1	51.8	49.4
Soil	Zn_0	42.7	46.7	44.7	1.79	2.33	2.06	41.8	49.9	45.9
	Zn_1	46.5	48.6	47.5	1.93	2.50	2.22	44.6	50.5	47.6
	Zn_2	48.4	51.0	49.7	2.05	2.76	2.40	46.6	53.0	49.8
	Zn_3	46.1	52.3	49.2	1.97	2.79	2.38	45.7	54.0	49.9
Leaf	Zn_0	45.9	47.6	46.7	1.76	2.29	2.03	40.2	49.7	45.0
	Zn_1	46.8	49.3	48.1	1.97	2.48	2.23	42.2	50.6	46.4
	Zn_2	48.8	51.8	50.3	2.08	2.70	2.39	46.7	53.1	49.9
	Zn_3	50.0	52.5	51.3	2.13	2.63	2.40	48.3	51.9	50.1
Interactions (Application × Dose)										
LSD			**N.S**			**N.S**			**N.S**	
Applications means	Seed		49.6			2.33			47.4	
	Soil		47.8			2.27			48.3	
	Leaf		49.1			2.26			47.8	
LSD			**N.S**			**N.S**			**N.S**	
Doses means	Zn_0		46.2 b			2.09 b			44.9 b	
	Zn_1		48.3 ab			2.24 ab			46.8 b	
	Zn_2		50.2 a			2.42 a			49.9 a	
	Zn_3		50.7 a			2.40 a			49.8 a	
LSD			**3.857****			**0.2107****			**2.812****	

*(p < 0.05), **(p < 0.01), N.S. = Non-significant ; a,b = The differences among the groups with different letters in the same column and line are significant.

late heading time (data not shown) in the first year. The plant zinc concentration at the first year was lower than the second year. This difference in zinc concentration may be caused by unexpected rain in the first year after third application of $ZnSO_4 \cdot 7H_2O$ solution to plant.

Regression analysis showed that relationship between zinc doses and grain yield was significant for application methods. The curves simulated in prediction of grain yield from zinc doses were given in Fig. 1. According to the results of cubic equations, the highest grain yield can be obtained from the doses of 3821 g zinc ton^{-1} $seed^{-1}$ for seed, 12.7 kg zinc ha^{-1} soil and 401 g zinc ha^{-1} for leaf application.

The results of plant height (Table-1) were correlated well with the findings of studies[7,18] showing increases in the plant height from 57.6 to 63.3 cm and from 86 to 95 cm on the zinc application. One of the most common symptoms of the insufficient zinc level is the shortening of the plant height[6].

TABLE-3
EFFECTS OF FERTILIZERS CONTAINING ZINC ON GRAIN YIELD, GRAIN PROTEIN CONTENT AND ZINC CONCENTRATIONS OF THE PLANTS

Treatments		Grain yield (kg ha^{-1})			Grain protein content (%)			Zinc concentrations of the plants (mg kg^{-1})		
		2001	2002	Means	2001	2002	Means	2001	2002	Means
Seed	Zn_0	4028	5140	4584	16.2	15.6	15.2	18.5	19.7	19.1 d
	Zn_1	4534	5437	4985	15.8	15.9	15.5	20.9	20.8	20.9 d
	Zn_2	4936	5333	5135	16.4	16.4	16.0	18.8	22.0	20.4 d
	Zn_3	4653	5640	5147	16.0	16.0	15.7	18.3	22.8	20.5 d
Soil	Zn_0	4140	5350	4745	15.2	14.9	14.7	17.2	20.4	18.8 d
	Zn_1	4303	5990	5147	14.0	14.9	14.9	21.0	21.6	21.3 d
	Zn_2	4896	6237	5566	14.8	15.1	15.3	20.5	23.5	21.9 d
	Zn_3	5026	7023	6025	14.5	15.4	15.5	20.2	24.4	22.3 d
Leaf	Zn_0	4177	5063	4620	13.3	14.3	14.3	21.6	21.8	21.7 d
	Zn_1	4516	5303	4910	13.3	14.8	14.8	25.6	40.6	33.1 c
	Zn_2	4844	5850	5347	13.7	15.9	15.6	30.8	64.2	47.5 b
	Zn_3	4680	5720	5200	13.6	14.9	15.0	34.6	89.0	61.8 a

		Grain yield	Grain protein	Zinc concentrations
Interactions (Application × Dose)				
LSD		**N.S**	**N.S**	**8.044****
Applications means	Seed	4963 b	15.6 a	20.2 b
	Soil	5371 a	15.1 ab	21.1 b
	Leaf	5019 b	14.9 b	41.0 a
LSD		**300.2***	**0.4805***	**5.596****
Doses means	Zn_0	4650 c	14.7 b	19.9 d
	Zn_1	5014 bc	15.1 ab	25.1 c
	Zn_2	5349 ab	15.6 a	29.9 b
	Zn_3	5457 a	15.4 ab	34.8 a
LSD		**416.3****	**0.6992****	**4.644****

*($p < 0.05$), **($p < 0.01$), N.S. = Non-significant ; a,b,c,d = The differences among the groups with different letters in the same column and line are significant.

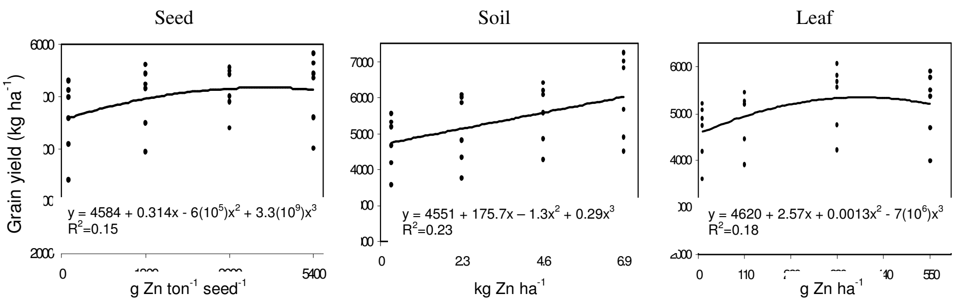

Fig. 1. Regression curve for estimation of grain yield dependent of zinc doses at seed, soil and leaf applications on wheat

Despite the spike length is controlled mainly by the genetic factors, it increased by adding zinc doses. This result was similar with the findings of Sayed *et al.*[19] and Kenbaey and Sade[20]. Also increasing zinc application rates have increased spike length and grain number per spike.

The results showing the increase of the grain number per spike at the increasing rates of zinc application were in parallel with the findings of those of showing the increase of grain number per spike in wheat from 12.8 to 18.2 at the increased zinc application rates[18] and the increase in the grain number per spike in wheat varieties[7] from 23.8 to 27.4. These increases might result from positive correlations among the spike properties of wheat[21]. Several researchers[15,22-25] also reported that zinc application increased the grain weight of wheat.

Zinc level of wheat at heading time changes[16] between 20 and 70 mg kg^{-1}. Zinc application methods in this study and Zn_1, Zn_2 and Zn_3 doses increased the zinc level up to the optimum level. Leaf zinc application increased zinc concentration twice higher than seed and soil application (Table-3). This might result from the getting lower concentration (by growth) of the zinc level in the tissues of wheat applied by the soil and seed methods[8]. The differences could also be attributed to the differences in the homogenization of zinc spray and uptake (diffusion) of zinc by leaves. The results showed that zinc concentrations of plants increased from 19.9 to 34.9 mg zinc kg^{-1} by increasing doses in all applications. This supports the findings of those showing the increase of zinc concentrations in wheat[6,26] and in different cereals[11].

Zinc content of soil in control plots, 0.37 mg Zn kg^{-1}, produced 4649.7 kg ha^{-1} grain yield, while yield increased up to 5457.0 kg ha^{-1} by the application rate of 6.9 kg Zn ha^{-1}. These increases might result from the positive effect of zinc on the vegetative and generative growth and the efficient use of other nutrients[18,21]. Present findings support and showing that the yield increased at the rate of 17.2 % increasing from 2650 kg ha^{-1} (Zn_0 = soil containing 0.37 mg kg^{-1} Zn) to 3200 kg ha^{-1} by the zinc application rate of 22 kg $ZnSO_4 \cdot 7H_2O$ ha^{-1} in durum wheat[5]. Ozbek and Ozgümüs[7] reported that the highest grain yield in wheat varieties was obtained from soil application method and this was followed by the seed and foliar application methods. Yilmaz *et al.*[8] found 76, 61 and 52 % increase in the soil, foliar and seed application methods, respectively.

The increased protein content of grain as a result of the increased application rates of zinc to wheat might result from the positive effects of consequent protein synthesis of zinc on the amino acid synthesis[18,27]. In this study, the effects of the application rates and methods on protein content were significant and seed and soil applications were more effective than leaf applications. The positive effects of the increased zinc rates to the protein content might result from the increase of synthesis of endogenous plant growth hormone Auxin and of the efficient use of other plant nutrients[18,21,27].

Although all application methods and doses reached to the optimum level of zinc concentrations of the plants, the highest results was obtained from foliar application. The rate of 110 g zinc ha^{-1} of $ZnSO_4 \cdot 7H_2O$ solution was applied three times to the plants and the zinc concentrations of the plants increased to the level of 34.8 ppm. Instead of three times applications, one time application of 550 g zinc ha^{-1} of the solution to the plants on the stem elongation period may be a more economical way with the same result.

The most effective method[28] for correcting zinc deficiency was soil application of zinc. Soil application alone resulted in higher increases in grain yield than from the seed or foliar applications (Table-3). Since the zinc fertilizers have an important residual effect on soils for a relative long time, it may not be necessary to apply zinc every year. For example, soil application of 28 kg zinc ha^{-1} as $ZnSO_4$ was adequate to correct zinc deficiency in plants for 4 to 7 years[3,28]. Therefore, the soil application method may be more effective and more economical than seed or foliar application for correcting zinc deficiency in plants.

Considering the effects of amounts of 6.9 kg zinc ha^{-1}, 5400 g Zn ton^{-1} $seed^{-1}$ and 550 g zinc ha^{-1} of $ZnSO_4 \cdot 7H_2O$ on grain yield, yield components and zinc concentrations of durum wheat for soil, seed and leaf application, respectively. One of these applications might be recommended to obtain appropriate yield and zinc concentrations. Thus zinc-contained fertilizers should be taken into account for the soils where there is insignificant zinc content for an efficient and sustainable agriculture.

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