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Residual, direct and cumulative effect of zinc application on wheat and rice yield under rice-wheat system

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Abstract

Zinc (Zn) deficiency is prevalent particularly on calcareous soils of arid and semiarid region. A field experiment was conducted to investigate the direct, residual and cumulative effect of zinc on the yield of wheat and rice in permanent layout for two consecutive years, 2004-05 and 2005-06 at Arid Zone Research Institute D.I. Khan. Soil under study was deficient in Zn (0.8 mg kg^{-1}). Effect of Zn on yield, Zn concentrations in leaf and soils were assessed using wheat variety Naseer-2000 and rice variety IRRI-6. Three rates of Zn, ranging from 0 to 10 kg ha^{-1} in soil, were applied as zinc sulphate ($ZnSO_4$. $7H_2O$) along with basal dose fertilization of nitrogen, phosphorus and potassium. Mature leaf and soil samples were collected at panicle initiation stage. The results showed that grain yield of wheat and rice was significantly increased by the direct application of 5 and 10 kg Zn ha^{-1}. Highest grain yield of wheat (5467 kg ha^{-1}) was recorded with the direct application of 10 kg Zn ha^{-1} while 4994 kg ha^{-1} was recorded with the cumulative application of 10 kg Zn ha^{-1} but the yield increase due to residual effect of Zn was statistically lower than the cumulative effect of Zn. Maximum paddy yield was recorded with the cumulative application of Zn followed by residual and direct applied 10 and 5 kg Zn kg ha^{-1}, respectively. Zn concentration in soils ranged from 0.3 to 1.5 mg kg^{-1} in wheat and 0.24 to 2.40 mg kg^{-1} in rice, while in leaves it ranged from 18-48 mg kg^{-1} in wheat and 15-52 mg kg^{-1} in rice. The concentration of Zn in soil and leaves increased due to the treatments in the order; cumulative > residual > direct effect > control (without Zn). The yield attributes like 1000-grain weight, number of spikes, spike length and plant height were increased by the residual, direct and cumulative effect of Zn levels; however, the magnitude of increase was higher in cumulative effect than residual and direct effect of Zn, respectively. Under Zn-deficient soil conditions, yield of wheat can be increased by direct application of Zn, while yield of rice can be maximized by the cumulative use of zinc fertilization.

Key words: *Triticum aestivum* L, *Oryza sativa* L, zinc, grain yield

Introduction

Rice-wheat is the largest cropping system in the world. Approximately 85% of the rice-wheat system is practiced in the indo-gangatic plains of South Asia in Nepal, Bangladesh, India and Pakistan (Timsina and Connor 2001). Rice-wheat is the major prevalent system in Pakistan with an estimated area of 1.6 m ha (Maan and Ashraf, 2001). Despite the prime position of rice-wheat in food security and the economy of the country, the productivity of the system is poor. Rice-wheat is a nutrient exhaustive system and nutrient removal from the soil is much higher than fertilizer input. As a result, wide spread micronutrient deficiencies occurred in rice-wheat system. Zinc (Zn) and boron (B) are increasingly important micronutrient deficiencies particularly on calcareous soils of arid and semi-arid region. Many available reports present that Zn and B deficiencies are most wide spread micronutrients deficiencies all over the world, which cause decline in crop production and quality (Alloway, 2004; Rashid and Ryan 2004; Rafique *et al*., 2008). The soils of rice-wheat area in Pakistan are alkaline calcareous in nature, having low organic matter, nutrient mining with intensive cultivation and imbalanced fertilization which causes nutrient deficiencies including Zn and B (Rafique *et al*., 2006, 2008).

High pH and low levels of organic matter reduce solubility and mobility of Zn in soil and stimulate adsorption of Zn in soil constituents such as clay minerals and metal oxides (Marschner, 1993; Rashid and Ryan, 2004). Zia *et al*. (1996) reported that residual effect of 10 kg Zn ha^{-1} was effective to increase grain yield of rice as compared to 5 kg Zn ha^{-1} in rice-wheat cropping system. Similarly, highest cumulative yield was obtained when 10 kg Zn ha^{-1} was applied to both the crops. Hussain (2004) reported that residual application of 5 kg Zn ha^{-1} increased the paddy yield by 6.1% while cumulative application of Zn increased the paddy yield by 17.0%. Rashid (2005) advocated that soil applied micronutrients leave a beneficial residual effect on succeeding crop (s) grown in the same field. This is because the first crop removes only a small fraction of the applied micronutrient dose.

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To avoid toxicity of micronutrients which results in reduced crop yields, information on the residual effect of micronutrient fertilization after period of application is also desirable. As information on the residual and cumulative effect of Zn application on wheat and rice yield under rice-wheat system under the soil and climatic conditions of D.I. Khan is not available, therefore, the objective of the study was the examination of the residual, direct and cumulative effect of zinc under rice-wheat system on both the crops.

Materials and Methods

A field experiment was started by growing wheat during 2004-05 to study the effect of zinc (Zn) fertilizer (residual and cumulative) on wheat and rice on permanent layout at Arid Zone Research Institute, D. I. Khan. After wheat harvest, rice was planted on the same layout and harvested at maturity. Wheat was again sown after rice harvest during 2005-06 on the same layout to visualize direct, residual and cumulative effect of Zn application. The experiment was laid out in randomized complete block design with seven treatments and three replications. A composite soil sample was taken before commencement of the study to visualize the physico-chemical characteristics of soil. Soil characteristics were pH, 8.0; calcium carbonate ($CaCO_3$) equivalent, 11.0%; organic matter, 0.69%; electrical conductivity (ECe), 0.60 dS m^{-1}; nitrogen, 0.039%; $NaHCO_3$ extractable P, 4.50 (mg kg^{-1}); ammonium acetate extractable K, 90 (mg kg^{-1}); DTPA- extractable Zn, 0.80 (mg kg^{-1}); and textural class was silty clay. The basal dose of NPK at 120-90-60 kg ha^{-1} along with Zn levels were applied in the form of urea, TSP, SOP and zinc sulphate, respectively. All P, K, Zn and half N was applied at sowing in wheat and rice while half remaining N was applied at 2^{nd} irrigation in wheat and panicle initiation to rice crop. Wheat variety Naseer-2000 and rice IRRI-6 was tested. The wheat was planted during last week of November 2005 and harvested in last week of April 2006 while rice was planted during first week of June and harvested during last week of September 2006. All the other cultural practices were followed uniformly throughout the growing season. The soil and leaf samples were collected from individual treatments at spike/panicle initiation stage in both wheat and rice crops, respectively, to determine Zn concentrations in soil and leaf. The plant tissue and soil samples were analyzed at Land Resources, Research Program, NARC, Islamabad. The soil was analyzed for available Zn according to the method given by Lindsay and Norvell (1978). The leaf samples were oven dried (70^{o}C), ground, sieved and analyzed by wet digestion method. The agronomic data, plant height, number of spike/panicle length m^{-2} and spike/panicle length were recorded at maturity, while 1000-garin weight was taken at threshing of wheat and paddy grain. Data were statistically analyzed by using MSTATC software.

Results

Wheat grain yield and yield components

Wheat grain yield was significantly increased by the zinc (Zn) application over control which ranged from 2620 to 5467 kg ha^{-1} (Table 1). The highest grain yield of 5467 kg ha^{-1} was obtained with the direct application of 10 kg Zn ha^{-1} (T_4) followed by cumulative application of 10 kg Zn ha^{-1} (T_7). All the treatments differed significantly from one another. The yield obtained due to residual application of 10 kg Zn ha^{-1} (T_5) was 3474 and 5 kg Zn ha^{-1} (T_3) gave 3170 kg ha^{-1}. These treatments differed significantly from each other. The effect of 10 and 5 kg Zn application on wheat grain yield was in the order of direct effect > cumulative > residual effect. Direct application of 10 and 5 kg Zn ha^{-1} gave an increase of 108.66 and 38.74% while 90.61 and 64.46% increase over control was recorded with the cumulative application of 10 and 5 kg Zn ha^{-1}, respectively. The lowest increases over control were 32.59 and 20.99% with the residual effect of 10 and 5 kg Zn ha^{-1}, respectively. Zn application also significantly increased 1000-grain weight of wheat over control which ranged from 36.84 to 43.36 g. Maximum weight was obtained with the direct application of 10 kg Zn ha^{-1} (T_4) followed by the cumulative (T_7) treatment. All the treatments differed significantly from one another. Similarly, spike length increased significantly with the direct, cumulative and residual effect of 10 and 5 kg Zn ha^{-1} over control, respectively. Maximum spike length (10.20 cm) was observed with the direct application of 10 kg Zn ha^{-1} (T_4) which was statistically at par with the cumulative application of the same level of Zn (T_7). The lowest spike length was recorded in control treatment. The number of spikes m^{-2} was significantly increased with Zn application except T_3, and ranged from 327.7 to 389.3. Maximum number of spikes was recorded with the direct application of 10 kg Zn ha^{-1} (T_4) that was at par with T_6 and T_7. Plant height was also significantly increased with Zn application over control (Table 1). Maximum plant height (96.47 cm) was achieved with the cumulative application of 10 kg Zn ha^{-1} (T_7) that was statistically non significant with the direct application of the same level of Zn (T_4).

Rice grain yield and yield components

Paddy yield increased significantly by the Zn application over control which ranged from 5190 to 7512 kg ha^{-1} (Table 2). The highest paddy yield was recorded with the cumulative application of 10 kg Zn ha^{-1} (T_7) followed by 7406 and 6702 kg ha^{-1} which was obtained with the direct application of 10 (T_5) and 5 kg Zn ha^{-1} (T_3)

Table 1. Wheat response to zinc application under rice-wheat system (2005-06)

Treatment	Zn kg ha^{-1} to crop				Grain yield (kg ha^{-1})	Increase over control (%)	1000 grain weight (gm)	Spike length (cm)	No. of spikes m^{-2}	Plant height (cm)
	Wheat 2004-05	Rice 2005	Wheat 2005-06	Rice 2006						
1	00	00	00	00	2620 f	---	36.84 e	09.00 d	327.7 e	91.13 d
2	05	00	05	00	3635 d	38.74	39.02 d	09.66 c	363.3 bc	95.00 b
3	00	05	00	05	3170 e	20.99	37.04 e	09.60 c	342.0 de	93.40 c
4	10	00	10	00	5467 a	108.66	43.36 a	10.20 a	389.3 a	96.13 a
5	00	10	00	10	3474 d	32.59	39.13 d	09.73 c	355.7 cd	93.73 c
6	05	05	05	05	4309 c	64.46	40.36 c	09.86 bc	373.3 ab	95.07 b
7	10	10	10	10	4994 b	90.61	42.65 b	10.07 ab	380.0 ab	96.47 a
LSD ≤ 0.05					177.0		00.44	00.30	016.7	01.04

Means followed by same letter do not differ significantly at $p \leq 0.05$

Table 2. Rice response to zinc application under rice-wheat system during 2005-06

Treatment	Zn kg ha^{-1} to crop				Yield (kg ha^{-1})	Increase over control (%)	Plant height (cm)	1000 grain weight (gm)	No. of panicles m^{-2}	Panicle length (cm)	Panicles plant^{-1}
	Wheat 2004-05	Rice 2005	Wheat 2005-06	Rice 2006							
1	00	00	00	00	5190 f	---	107.3 f	24.08 e	316.7 c	15.80 e	15.27 e
2	05	00	05	00	5957 e	14.77	117.3 bc	25.52 bc	346.7 b	19.33 bc	18.87 c
3	00	05	00	05	6702 c	29.13	113.9 d	25.69 bc	353.3 b	18.93 cd	17.73 d
4	10	00	10	00	5930 e	14.25	118.1 b	25.32 c	340.0 b	19.73 b	19.27 c
5	00	10	00	10	7406 b	42.69	111.0 e	25.76 b	375.3 a	18.80 d	17.40 d
6	05	05	05	05	6196 d	19.38	119.7 a	26.51 a	378.7 a	24.47 a	22.20 a
7	10	10	10	10	7512 a	44.73	116.7 c	24.91 d	373.3 a	19.73 b	19.93 b
LSD ≤ 0.05					57.00	---	001.243	00.394	018.14	00.531	00.4904

Means followed by same letter do not differ significantly at $p \leq 0.05$

which were significantly different from one another. The paddy yield obtained due to residual application of 10 (T_4) and 5 kg Zn ha^{-1} (T_2) was 5930 and 5957 kg ha^{-1}, respectively, and were statistically at par with each other. The cumulative application of 10 kg Zn ha^{-1} (T_7) gave an increase of 44.73% followed by 42.69% obtained from the direct application of 10 kg Zn ha^{-1} (T_5). The residual application of 5 (T_2) and 10 kg Zn ha^{-1} (T_4) gave an increase of 14.77 and 14.25%, respectively. Plant height of rice significantly increased with the cumulative, direct and residual application of 10 and 5 kg Zn ha^{-1}. Maximum plant height was recorded with the cumulative application of 5 kg Zn ha^{-1} (T_6) while the lowest with the control. Data showed that 1000-grain weight was significantly affected with the cumulative, direct and residual application of 5 and 10 kg Zn ha^{-1} over control. Highest 1000-weight was recorded with the cumulative application of 5 kg Zn ha^{-1} (T_6) followed by the direct application of 10 kg Zn ha^{-1} (T_5) while lowest from the control treatment. The number of panicle m^{-2} was significantly increased with the cumulative, direct and residual effect of Zn application. However, the highest number was recorded in (T_5) followed by (T_4) and (T_7) which were statistically at par with one another. The cumulative, direct and residual application of Zn significantly increased the panicle length over control and ranged from 15.80 to 24.47 cm. The maximum panicle length was achieved with the cumulative application of 5 kg Zn ha^{-1} (T_6) being significantly different from the other treatments. The number of panicles per plant was significantly affected with Zn application. The range of panicle per plant was 15.27 to 22.20. The highest number of panicles per plant was recorded with the cumulative application of 5 kg Zn ha^{-1} (T_6).

Zinc concentration in soil

The application of zinc in wheat significantly affected the concentrations of zinc in soil (Table 3) that ranged from 0.30 to 1.5 mg kg^{-1}. The highest concentration was found with the application of 10 kg Zn ha^{-1} (T_7) to both rice and wheat that differed significantly from all the treatments except T_6. The direct application of 10 (T_4) and 5 kg Zn ha^{-1} (T_2) only to wheat increased the Zn concentration up to 0.92 and 0.68 mg kg^{-1}, respectively, but was at par with T_2,

T_5 and T_6. Similarly, the zinc concentration in soil samples collected from rice crop was also significantly affected with the application of Zn except T_3, T_4 and T_5 and ranged from 0.24 to 2.4 mg kg^{-1} (Table 3). The highest Zn concentration was achieved with the application of 10 kg Zn ha^{-1} (T_7) to wheat and rice which differed significantly from the other treatments followed by 1.6 mg kg^{-1} that was obtained with the application of 5 kg Zn ha^{-1} (T_6) to wheat and rice crop, but was at par with T_5. However, there was an overlapping of various treatments.

Table 3. Effect of zinc on the zinc concentration (mg kg^{-1}) in soil and leaves in rice wheat system

Treatment	Zn kg ha^{-1} to crop				Wheat 2005-06		Rice 2006	
	Wheat 2004-05	Rice 2005	Wheat 2005-06	Rice 2006	Soil	Leaves	Soil	Leaves
1	00	00	00	00	0.30 d	18.0 e	0.24 c	15.0 e
2	05	00	05	00	0.68 c	34.0 cd	0.72 d	32.0 d
3	00	05	00	05	0.57 cd	31.0 d	0.82 cd	36.0 cd
4	10	00	10	00	0.92 bc	38.0 bc	0.97 cd	35.0 cd
5	00	10	00	10	0.84 bc	34.0 cd	1.20 bc	40.0 bc
6	05	05	05	05	1.2 ab	42.0 ab	1.60 b	46.0 ab
7	10	10	10	10	1.5 a	48.0 a	2.40 a	52.0 a
LSD (0.05)					0.368	06.05	0.451	06.023

Means followed by same letter do not differ significantly at $p \leq 0.05$

Zinc concentration in Leaves

The zinc concentration in leaves of wheat sown after rice was significantly affected with the application of zinc except T_2 and T_5. The highest concentration was achieved with the application of 10 kg Zn ha^{-1} (T_7) to both rice and wheat, which was at par with T_6. The direct application of 10 and 5 kg Zn ha^{-1} to wheat increased the concentration up to 38.0 and 34.0 mg kg^{-1}, being at par with each other. The residual application of 10 (T_5) and 5 kg Zn ha^{-1} (T_3) to only preceding rice crop increased the Zn concentrations up to 34.0 and 31.0 mg kg^{-1}, respectively, in wheat leaves that was at par with each other. The zinc concentration in leaves of rice sown after wheat was also significantly affected with the application of zinc and ranged from 15 to 52 mg kg^{-1} (Table 3). The highest concentration was achieved with the application of 10 kg Zn ha^{-1} to wheat and rice followed by 46.0 mg kg^{-1} recorded with the application of 5 kg Zn ha^{-1} (T_6) to wheat and rice being at par with each other. The application of 10 (T_5) and 5.0 kg Zn ha^{-1} (T_3) to only rice crop increased the Zn concentrations in leaves up to 40.0 and 36.0 mg kg^{-1} being at par with each other. The application of 10 and 5.0 kg Zn ha^{-1} to previous crop (wheat) and nil to rice increased the Zn concentrations up to 35.0 and 32.0 mg kg^{-1} that remained at par with each other.

Discussion

The previous year (2004-05) results revealed that paddy grain yield (planted after wheat) gave an increase of 49.6, 45.1 and 43.1 % over control with the cumulative (T7), direct (T5) and residual (T4) application of 10 kg Zn ha^{-1}, respectively. Whereas 39.0, 38.2 and 30.0 % increase over control was achieved with the direct, cumulative and residual effect of 5kg Zn ha^{-1}. These results have already been published (Khan *et al*., 2007). During second year, the wheat crop planted after rice showed that the direct application of 10 kg Zn ha^{-1} (T_4) gave the highest yield as compared to cumulative and residual application of 10 kg ha^{-1} (Table 3). Similarly, cumulative effect of 5 kg Zn ha^{-1} (T_6) gave better results as compared to direct and residual application. These findings are supported by Zia *et al*. (2000) who reported a significant residual Zn application response up to three crops in sequence while the increase in paddy yield of 6.1 and 17 was recorded with the residual and cumulative application of 5 kg Zn ha^{-1} (Hussain, 2004). Nathan *et al*. (2005) also concluded that Zn fertilization increased the yield by 12 to 180%.

The paddy crop planted after wheat gave the highest yield with the cumulative application of 10 kg ha^{-1} (T_7) followed by direct and residual application of the same level, while direct application of 5 kg Zn ha^{-1} (T_3) gave the higher yield as compared to cumulative (T_6) and residual effect (T_2) of the same level, respectively. These results are in line with Zia *et al*. (1996) who concluded that application of 10 kg Zn ha^{-1} to rice produced significantly higher paddy yield as compared to 5 kg Zn ha^{-1}. The residual effect of Zn on wheat grain yield was significant where 10 kg Zn ha^{-1} (T_5) was applied to rice crop as compared to 5 kg Zn ha^{-1}. They further reported that data regarding yield parameters suggested that 10 kg Zn ha^{-1} was the best dose. The increase in paddy yield after wheat was 6.1 and 17% due to residual (T_4) and cumulative application of 10 kg Zn ha^{-1} (T_7). During the present study, data showed that available zinc in soil was significantly higher where cumulative application of 10 kg Zn ha^{-1} was applied as compared to 5 kg Zn ha^{-1} but the zinc concentrations in lower dose were also significantly high as compared to control. These results also affected the grain yield in the same sequence and similar results were also achieved by Zia *et al*. (1996) during his studies in Punjab soil on direct, residual and cumulative effect of zinc in rice-wheat system. Present data showed that cumulative application of 10 and 5 kg Zn ha^{-1} increased the zinc concentrations in leaves in both wheat and rice crop followed by direct and residual application of these levels.

Conclusion

The application of Zn in either way increased the yields of both the crops significantly over control, which indicates response of wheat and rice to Zn. However, direct application of Zn was found significantly better than other fertilizer treatments in case of wheat. While for rice crop the cumulative effect of Zn application was found significantly better than the other treatments.

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