# Residual and cumulative effect of fertilizer zinc applied in wheat-cotton production system in an irrigated aridisol

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**ABSTRACT**

The objectives of present study were to determine the residual and cumulative effects of zinc (Zn) fertilizer on cotton (*Gossypium hirsutum* L.) and wheat (*Triticum aestivum* L.) in a silt loam Typic Haplocambid soil (< 0.05 mg/kg diethylenetriaminepentaacetic acid (DTPA)-Zn). The study comprised of two years field experiments where first cotton crop received zinc sulphate ($ZnSO_4 \cdot H_2O$) at five rates (0, 5, 7.5, 10, 12.5 kg Zn/ha) in a randomized complete block design with four replications. After harvest, each plot was divided into two sub-plots. To study the residual effect, one sub-plot of all plots did not receive Zn fertilizer for the subsequent crops; however, the other sub-plot received all Zn rates for 2005–06 wheat, 2006 cotton, and 2006–07 wheat. Fresh applied, residual as well as cumulative Zn application significantly ($P \leq 0.05$) increased crops production for both experimental years. Residual effect of 5.0 kg Zn/ha optimized the 2006 cotton yield; however, wheat productivity was optimized with residual effect of 7.5 kg Zn/ha in 2005–06 and of 10.0 kg Zn/ha in 2006–07. Optimum yield of both crops was attained with a lesser fresh-applied and residual Zn rate than cumulative Zn rate. Total Zn uptake by wheat (134.9–289.6 g/ha) was much greater than by cotton (92.3–192.5 g/ha). It is concluded that one application of 7.5 kg Zn/ha proved adequate for optimizing two cycles of the cotton-wheat production system. Two-year repeated use of 5.0–7.5 kg Zn/ha did not depress crop yields.

**Keywords**: calcareous soil; crops production; micronutrient

Zinc (Zn) is an essential micronutrient that determines nutritional quality of grains (Losak et al. 2011), especially, of wheat. The deficiency of Zn is a well-known problem in wheat production areas. According to an estimate based on soil sampling and analysis, ~50% cereal growing areas of the world are Zn deficient (Sillanpaa 1990).

Cotton (*Gossypium hirsutum* L.) – wheat (*Triticum aestivum* L.) is a well-established crop production system (CWPS) of north-western plains of sub-continent. In addition to this, cotton seed is the second most important source of edible oil. This system of crop production is contributing largely to improve the economic condition of a large number of peoples (> 8 million) engaged in farming, processing trade and textile industry (Mayee et al. 2008). According to an estimate, CWPS covers an area of about 82% to 93% of the total cotton area (4.0 mha), but encompasses only 22% to 25% of the total wheat area in this belt. In India, only 18% to 20% of wheat area is covered by cotton-wheat rotation against about 33% in the north-western parts of Pakistan (Mayee et al. 2008).

Fertilizer Zn use is recommended for both crops and alkaline soils (Rashid 2005, Hussain et al. 2012); however, the impact of residual and continuous Zn fertilizer on crop production is inadequately understood in CWPS and elsewhere. In calcareous soils, up to 90% of applied Zn fertilizer is adsorbed on soil colloids and precipitated (Saeed and Fox

1977). Moreover, in addition to calcareousness, high pH of the soils also decreases the availability of Zn in such soils (Donner and Lynn 1989). Field crops are known to take up only 0.3% to 3.5% of the annually applied fertilizer Zn. Consequently, fertilizer Zn accumulates in the soil. Because of its low mobility in the soil, positive effect of applied Zn on subsequent crops in the rotation may last over variable periods (Brennan 2001). Many farmers apply even less fertilizers than that of the general recommended rates as explained above to cotton and wheat crops in CWPS. Fertilizer Zn recommendations for the cropping system as a whole are yet not available. It was, therefore considered necessary to study the fresh, residual and cumulative effects of Zn applied to cotton on the succeeding wheat, so that necessary fertilizer Zn recommendations can be made for this cropping system.

The objectives of present study were, to determine the residual and cumulative effects of Zn fertilizer on cotton (*Gossypium hirsutum* L.) and wheat (*Triticum aestivum* L.) in the cotton-wheat system on a silt loam Typic Haplocambid soil (< 0.05 mg/kg diethylenetriaminepentaacetic acid (DTPA)-Zn).

## MATERIAL AND METHODS

A permanent layout field experiment was conducted in irrigated cotton (cv. CIM-473) – wheat (cv. Pak-81) cropping system during 2005 to 2007 at the Research farm of the Bahauddin Zakariya University, Multan, Pakistan (30°12'N, 71°29'E). Briefly, soil at experimental farm was developed in an arid climate, is classified as coarse silty, hyperthermic, Typic Haplocambid (Soil Survey Staff 1998). Prior to applying any fertilizer, the topsoil (0–0.15 m), a silt loam, was non-saline ($EC_e$, 2.1 dS/m) and alkaline ($pH_s$, 8.1), which contained 5.6% $CaCO_3$, 0.78% organic carbon (OC) and 0.45% DTPA-Zn. The detail of methods for soil analyses is already published elsewhere Ahmed et al. (2010).

The first crop (cotton) received $ZnSO_4 \cdot H_2O$ at five rates i.e. 0, 5, 7.5, 10, and 12.5 kg Zn/ha in 124 $m^2$ sized experimental plots in a randomized complete block design with four replications. After harvesting, each plot was divided into two subplots. To study residual effect of Zn rates, one sub-plot of all plots did not receive Zn for the subsequent crops. However, for studying effect of continuous Zn applications, the other sub-plot received the above five Zn rates at the sowing of wheat in 2005, cotton in 2006, and wheat in 2007. Basal fertilization for cotton comprised of 150 kg N, 60 kg P and 50 kg K/ha. Basal fertilization for wheat comprised of 130 kg N/ha, 90 kg P/ha and 60 kg K/ha. In cotton, one-third dose of total N was applied each at crop sowing, flower initiation, and peak flowering; in wheat, 30 kg N/ha was applied at crop sowing and 50 kg N/ha was top-stressed each at tillering and grain initiation growth stages. Fertilizer sources were: urea for N, triple super phosphate for P, potassium sulfate for K. Mean maximum and minimum air temperatures were respectively 35°C and 12°C in 2005; 34°C and 13°C in 2006; and 34°C and 14°C in 2007. Rainfall was 9, 4 and 5 mm for 2005, 2006 and 2007, respectively. The crops were irrigated following standard irrigation practices of the area. Cotton was sown in May, picked during October–November and harvested; wheat was planted in November and hearvested in April of the following year.

Zinc concentration was determined in representative diagnostic leaves of both crops [i.e. the youngest cotton leaf blades without petioles of the fourth leaf from the top on the main stem at flower initiation and wheat flag leaves sampled at ~50% head emergence as well as in all mature plant parts (cotton stalks, leaves, burs, and lint, and wheat grains and straw). The crops were harvested at maturity. Composite soil samples, collected from each experimental plot after harvesting of both crops were analyzed for DTPA extractable Zn (Ryan et al. 2001).

Analysis of variance and the least significant (*LSD*) test were applied using the SPSS 18.0 package (Chicago, USA).

## RESULTS

**Crop yield**. Fresh applied, residual as well as cumulative applied fertilizer Zn significantly ($P \leq 0.05$) increased seed cotton and wheat grain yields (Table 1). The statistical analysis revealed a significant effect of treatments on the yield parameters. However in most of the cases, it was observed that the yield parameters were almost statistically similar at various levels of Zn application (Table 1). The curve estimations were performed using Zn application levels against yield parameters. Three types of regression equations (linear, quadratic, and cubic) were calculated. The highest coefficient of determination was found in

Table 1. Seed cotton and wheat grain yield as affected by fresh applied, residual and cumulative fertilizer Zn

| Zn applied (kg/ha) | Seed cotton yield (t/ha) | | | Wheat grain yield (t/ha) | | | |
|---|---|---|---|---|---|---|---|
| | 2005 fresh applied | 2006 | | 2005–06 | | 2006–07 | |
| | | residual | cumulative | residual | cumulative | residual | cumulative |
| 0 | 2.56[c] | 2.51[b] | 2.53[c] | 3.84[c] | 3.89[c] | 3.80[c] | 3.78[d] |
| 5 | 2.66[b] | 2.66[a] | 2.73[b] | 4.06[b] | 4.12[b] | 3.99[b] | 4.11[c] |
| 7.5 | 2.79[a] | 2.72[a] | 2.88[a] | 4.16[ab] | 4.20[ab] | 4.09[ab] | 4.26[bc] |
| 10 | 2.68[a] | 2.69[a] | 2.79[ab] | 4.22[a] | 4.33[a] | 4.16[a] | 4.42[a] |
| 12.5 | 2.65[a] | 2.68[a] | 2.78[ab] | 4.25[a] | 4.32[a] | 4.17[a] | 4.40[ab] |
| Means | 2.71 | 2.65 | 2.74* | 4.11 | 4.16 | 4.04 | 4.10* |
| *LSD* | 0.15 | 0.10 | 0.12 | 0.14 | 0.19 | 0.17 | 0.15 |

Means followed by the same letter(s) within a column do not differ significantly from each other at $P \leq 0.05$. *significant difference between pairs

the cubic equation. Therefore predicted values of cubic equation were used to predict optimum level of application. The seed cotton yield was optimized with the same dose of fresh applied and residual Zn, i.e. 5 kg Zn/ha. Maximum seed cotton yields were slightly higher with cumulative Zn (i.e. 14%) than with fresh applied and residual Zn.

Wheat grain yield was optimized with a higher dose of Zn than seed cotton yield, i.e. 7.5 kg Zn/ha of residual as well as cumulative Zn during both wheat seasons except for cumulative impact of 10 kg Zn/ha during 2006–07 (Table 1). Maximum increase in wheat grain yield was 17% over control plot (Table 1). The pairwise comparison of yield parameters for different growing season show a significant decrease of seed cotton yield in residual plots of 2006. However in 2006 seed cotton yield in cumulative plots was similar to that in 2005. The wheat grain yield was similar in both residual and cumulative plots in 2005–06 cropping season while in 2006–07 the yield was decreased as compared to cumulative plots.

**Plant and soil zinc status**. Zinc fertilizer application increased Zn concentration in diagnostic leaves of both field crops ($P \leq 0.05$; Table 2). Cumulative Zn resulted in greater increases in leaf Zn concentration than fresh-applied and residual Zn. For instance, maximum increase in cotton leaf Zn concentration was 159% with residual Zn and 219% with cumulative Zn over the respective control Zn concentrations. Similarly, during 2006–07 wheat seasons, residual Zn resulted in 34% lesser leaf Zn concentration than cumulative Zn. Wheat grain Zn concentration was also enhanced with residual as well as cumulative Zn during both crop seasons (Table 2).

Table 2. Zinc concentration (mg/kg) in leaves and grains as affected by residual and cumulative fertilizer Zn

| Zn | Cotton (leaves) | | | Wheat (leaves) | | | | Wheat (grains) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | fresh 2005 | residual | cumulative | residual | | cumulative | | residual | | cumulative | |
| | | 2006 | | 2005–06 | 2006–07 | 2005–06 | 2006–07 | 2005–06 | 2006–07 | 2005–06 | 2006–07 |
| 0 | 19.0[e] | 15.7[d] | 16.1[d] | 18.0[d] | 13.5[d] | 17.5[d] | 14.0[d] | 19.1[d] | 18.0[d] | 18.4[e] | 17.2[d] |
| 5 | 37.0[d] | 29.4[c] | 38.8[c] | 29.0[c] | 20.0[c] | 35.0[c] | 36.5[c] | 23.4[c] | 21.0[c] | 25.9[d] | 28.8[c] |
| 7.5 | 42.5[c] | 33.7[b] | 45.3[b] | 32.0[b] | 26.0[b] | 39.0[b] | 40.2[b] | 29.8[b] | 25.8[b] | 30.1[c] | 33.4[b] |
| 10 | 46.0[b] | 34.6[b] | 49.2[a] | 34.0[a] | 29.0[a] | 41.2[a] | 43.0[a] | 33.4[a] | 28.9[a] | 34.4[b] | 37.0[a] |
| 12.5 | 50.0[a] | 40.6[a] | 51.4[a] | 35.0[a] | 30.0[a] | 43.0[a] | 45.0[a] | 34.8[a] | 30.2[a] | 36.7[a] | 38.4[a] |
| *LSD* | 2.1 | 2.3 | 2.6 | 1.7 | 1.8 | 2.1 | 1.8 | 1.5 | 1.4 | 1.5 | 1.5 |

Means followed by the same letter(s) within a column do not differ significantly from each other at $P \leq 0.05$

Table 3. Soil Zn status as affected by residual and cumulative fertilizer Zn

| Zn (kg/ha) | 2005 cotton | DTPA soil Zn (mg/kg) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2005–06 wheat | | 2006 cotton | | 2006–07 wheat | |
| | | residual | cumulative | residual | cumulative | residual | cumulative |
| 0 | 0.48$^{e}$ | 0.39$^{e}$ | 0.40$^{e}$ | 0.32$^{d}$ | 0.31$^{e}$ | 0.25$^{e}$ | 0.26$^{e}$ |
| 5 | 1.21$^{d}$ | 1.0$^{d}$ | 1.57$^{d}$ | 0.79$^{c}$ | 1.89$^{d}$ | 0.40$^{d}$ | 2.11$^{d}$ |
| 7.5 | 1.48$^{c}$ | 1.18$^{c}$ | 1.71$^{c}$ | 0.93$^{b}$ | 1.98$^{c}$ | 0.55$^{c}$ | 2.33$^{c}$ |
| 10 | 1.81$^{b}$ | 1.42$^{b}$ | 1.98$^{b}$ | 1.08$^{a}$ | 2.21$^{b}$ | 0.63$^{b}$ | 2.43$^{b}$ |
| 12.5 | 2.10$^{a}$ | 1.83$^{a}$ | 2.13$^{a}$ | 1.13$^{a}$ | 2.37$^{a}$ | 0.90$^{a}$ | 2.58$^{a}$ |
| *LSD* | 0.05 | 0.07 | 0.13 | 0.06 | 0.08 | 0.03 | 0.09 |

Means followed by the same letter(s) within a column do not differ significantly from each other at $P \leq 0.05$

There was a significant ($P \leq 0.05$) and positive effect of fresh and repeatedly applied Zn fertilizer on soil DTPA extractable Zn level (Table 3). For instance, after the harvest of the first cotton crop, i.e. 2005, application of 0, 5, 7.5, 10 and 12.5 kg Zn/ha resulted in DTPA extractable soil Zn levels of 0.48, 1.21, 1.48, 1.81 and 2.10 mg/kg, respectively. However, in the absence of repeated Zn applications (i.e. in CP) soil Zn levels decreased gradually with successive cropping (Table 3).

Fresh applied, residual as well as cumulative Zn significantly ($P \leq 0.05$) increased Zn uptake by crops (Table 4). Zinc uptake by cotton crop ranged from 116.3 to 182.8 g Zn/ha with fresh applied Zn, from 92.3 to 153.0 g Zn/ha with residual Zn, and 94.0 to 192.5 g Zn/ha with cumulative Zn. Total Zn uptake by wheat crop (i.e. 134.9–289.6 g/ha) was much greater than by cotton (i.e. 92.3–192.5 g/ha) crop. Consequently, Zn uptake associated with near-maximum (95% of maximum) wheat yield (i.e. 197.0–292.8 g/ha) was much greater than for near-maximum seed cotton (i.e. 113.0–172.0 g/ha) yield. The 2006–07 wheat absorbed 16% more Zn compared to 2005–06 wheat.

## DISCUSSION

One application of 7.5 kg Zn/ha proved adequate for optimizing two cycles of cotton and wheat crops in CWPS. Conversely, Sammauria and Yadav (2008) reported increases in yields of wheat and pearl millet with cumulative Zn, but not with residual Zn.

Zinc application increased wheat and cotton leaf Zn concentration (Table 2) from deficient to optimum levels (Reuter et al. 1997, Ahmed et al. 2010). Thus, without Zn fertilization, Zn deficiency was responsible for poor crop growth and low productivity in this Zn deficient Aridisol. Our results are in agreement with those of Potarzycki

Table 4. Zinc uptake (g/ha) by cotton and wheat as affected by fresh applied, residual and cumulative fertilizer Zn

| Zn applied (kg/ha) | Cotton | | | Wheat | | | |
|---|---|---|---|---|---|---|---|
| | 2005 fresh applied | 2006 | | 2005–06 | | 2006–07 | |
| | | residual | cumulative | residual | cumulative | residual | cumulative |
| 0 | 116.3$^{d*}$ | 92.3$^{d}$ | 94.0$^{d}$ | 146.6$^{e}$ | 139.5$^{e}$ | 134.9$^{d}$ | 136.9$^{e}$ |
| 5 | 138.1$^{c}$ | 113.0$^{c}$ | 147.3$^{c}$ | 176.3$^{d}$ | 195.9$^{d}$ | 159.5$^{c}$ | 219.6$^{d}$ |
| 7.5 | 161.8$^{b}$ | 139.0$^{b}$ | 172.0$^{b}$ | 222.9$^{c}$ | 238.2$^{c}$ | 197.0$^{b}$ | 260.2$^{c}$ |
| 10 | 176.0$^{a}$ | 148.0$^{a}$ | 180.8$^{b}$ | 249.3$^{b}$ | 275.2$^{b}$ | 221.1$^{a}$ | 292.8$^{b}$ |
| 12.5 | 182.8$^{a}$ | 153.0$^{a}$ | 192.5$^{a}$ | 261.2$^{a}$ | 289.6$^{a}$ | 229.5$^{a}$ | 305.5$^{a}$ |
| *LSD* | 10.6 | 8.9 | 11.6 | 10.5 | 10.3 | 10.6 | 12.7 |

Means followed by the same letter(s) within a column do not differ significantly from each other at $P \leq 0.05$

and Grzebisz (2009), who reported that higher plant leaf Zn concentration would accumulate towards higher assimilation of photosynthates from source to sink, resulting in higher crop yields.

Data reported herein indicate that soil native DTPA extractable Zn status (i.e. 0.48 mg Zn/kg soil) was inadequate for optimum plant growth (Rafique et al. 2006); freshly applied and cumulative Zn fertilizer raised the level of soil Zn well above the suggested critical level of 1.0 mg/kg (Table 3). As Zn uptake per field crop (i.e. 92.3–305.5 g Zn/ha; Table 4) was a small amount of the fertilizer Zn rate (i.e., 5.0–12.5 kg Zn/ha), the decrease in soil Zn levels over time is attributed primarily to Zn adsorption on soil particles/colloids and precipitation of Zn into compounds of lower solubility (Hussain et al. 2011). Similarly, in residual Zn plots gradual decreases in soil Zn level with crops are attributed predominantly to soil Zn fixation rather than plant Zn uptakes. As Zn availability in calcareous soils is reported to decrease more than in non-calcareous soils (Boawn 1974), crop after crop modest Zn application to Aridisol appears necessary for maintaining adequate soil Zn availability for optimum cotton-wheat productivity.

Only a small amount of the applied fertilizer Zn is removed in harvested parts of wheat and cotton crops (Table 4) as was also reported elsewhere (Rafique et al. 2006, Ahmed et al. 2010). In Indian rice-wheat crop rotation, annual Zn removal from the field is around 0.50 kg Zn/ha (Singh and Abrol 1985).

Conclusively, fertilizer Zn requirement for optimum crop productivity in CWPS was less for cotton (5.0 kg Zn/ha) compared with wheat (7.5 kg Zn/ha) crops. This may be due to deep and extensive root system of cotton crop as compared to wheat that might have helped the plants in taking up nutrients more efficiently (Gulick et al. 1989). Optimum yield of both crops was obtained with lesser rates of fresh applied and residual Zn than that of cumulative Zn. Total Zn uptake by a single crop being quite low (i.e. 134.9–289.6 g/ha by wheat and 92.3–192.5 g/ha by cotton); even a low rate of fertilizer Zn leaves beneficial residual effect for the subsequent crops. Overall, one application of 7.5 kg Zn/ha proved adequate for optimizing two cycles of cotton and wheat crops in CWPS. However, cumulative use of Zn up to 12.5 kg/ha to four crops did not depress crop productivity in this system.

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