INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
09–074/MFA-AWB/2009/11–4–389–396
http://www.fspublishers.org

Full Length Article

Nutrient Uptake, Growth and Yield of Wheat (*Triticum aestivum*) as Affected by Zinc Application Rates

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ABSTRACT

Soils of Pakistan are generally alkaline and calcareous and usually contain low amounts of available micronutrients. Zinc (Zn) is an essential micronutrient for plant growth and its deficiency is common in cultivated soils of Pakistan. A field experiment was conducted for two years, at Government Adaptive Research Farm Karor Lal Eason, District-Layyah, to study the effect of added zinc on growth and yield parameters, zinc uptake, soil zinc status and also the effect of added zinc in soil. Wheat variety Bhakkar- 2002 was sown during Rabi season, 2005-2006 and 2006-2007 with recommended inputs. The recommended doses of N, P and K were applied @ 150: 100: 60 kg N: P_2O_5: K_2O ha^{-1} in all treatments. Zn was applied @, 4, 8, 12 and 16 kg ha^{-1} as zinc sulphate at the time of sowing in the all treatments except control (recommended NPK). Combined Zn and NPK application significantly improved growth and yield parameters of wheat. Application of Zn increased its total uptake by wheat crop and also resulted in a built-up of Zn in the upper 15 cm layer to be available for next crop. Increasing the dose of Zn showed a little increase in the uptake of Manganese (Mn). The uptake of iron (Fe) increased by applying Zn upto 8 kg ha^{-1}, while high Zn doses resulted in reduced Fe uptake. Applying Zn upto 12 kg Zn ha^{-1} increased net return, however value cost ratio (VCR) decreased by increasing Zn doses beyond 4 kg Zn ha^{-1}.

Key Words: Zn; NPK fertilizer; Nutrient uptake; Pakistan

INTRODUCTION

The growth and yield of a plant is determined by the availability of some specific mineral nutrients that are absolutely essential for the completion of their life cycle (Marshner, 1995). That is why, the application of these essential nutrients to plants in the form of chemical fertilizers is necessary for intensive agriculture. Zinc is an essential micronutrient for plant growth and is absorbed by the plant roots in the form of Zn^{2+}. It is involved in diverse metabolic activities, influences the activities of hydrogenase and carbonic anhydrase, synthesis of cytochrome and the stabilization of ribosomal fractions and auxin metabolism (Tisdale *et al*., 1984). Due to the deficiency of zinc plants exhibits poor growth, interveinal chlorosis and necrosis of lower leaves. Reddish or brownish spot often occurs on the older leaves and ultimately seed production is strikingly reduced due to its deficiency (Throne, 1957).

Zinc deficiency is a worldwide nutritional constraint for crop production, as Zn removed by crops is usually not fully replenished by fertilization in agricultural soils. Its deficiency is particularly widespread in cereals that are grown on calcareous soil (Graham *et al*., 1992). Deficiency of zinc in wheat has been reported from various parts of the world, Pakistan soils are not exception to this. Almost 50% of the world soils used for cereal production are Zn deficient (Gibbson, 2006). This percentage is even higher in areas with calcareous soils as the proportion of sorbed Zn that could be desorbed back into solution decreased substantially as pH increased to more than 5.5 (Singh *et al*., 2008), which reduces not only grain yield, but also nutritional quality of grains. As a result, approximately two billion people suffer from Zn deficiency all over the world.

Zinc deficiency in Pakistan soils was first recognized by Yoshida and Tanaka (1969). Since them, Zinc deficiency has been reviewed by many researchers (Yoshida *et al.*, 1973; Hadi *et al*., 1997). Although zinc deficiency was first reported in the rice areas in Pakistan (Kausar *et al*., 1976), later on survey revealed that 70% of the cultivated soils are Zn deficient in Pakistan. Zinc deficiency is the third most serious crop nutrition problem in the Pakistan, ranking after N and P deficiency (Rashid & Rafique, 1996). Kausar *et al*. (1979) analyzed the 152 soil samples from four provinces of Pakistan and confirmed the possibility of a wide incidence of Zn deficiency. Zinc deficiency is common in both warm and cold climate. Despite of being graded as less sensitive (Clark, 1990), wheat is severely affected by Zn deficiency in Pakistan. Kausar *et al*. (1976) indicated that 86% of soil

To cite this paper: Abbas, G., M.Q. Khan, M. Jamil, M. Tahir and F. Hussain, 2009. Nutrient uptake, growth and yield of wheat (*Triticum aestivum*) as affected by zinc application rates. *Int. J. Agric. Biol.*, 11: 389–396

samples from the four provinces were Zn deficient. Similarly, Sillanapaa (1982) found that out of 242 soil sampled, 62% of those in Punjab, 100% in Sindh and 77% in NWFP were deficient in zinc. Khattak and Parveen (1986b) also reported that, out of 320 soil samples collected from NWFP, 23% were deficient in Zn.

Zinc deficiency is widespread in wheat grown on alkaline calcareous soils; therefore, a large population of the world as result of this also lacks adequate Zn nutrition (Maqsood *et al*., 2009). Bhutta *et al*. (1999) reported Zn deficiency in Pakistan in children less than five years of age and women of reproductive age. In Pakistan, a national nutrition survey revealed Zn deficiency in 41% of mothers and 37% of children (Anonymous, 2004). In such circumstances, any increases in the amount of Zn soil and consequently in grain could contribute positively to human wellbeing.

Low soil Zn is attributed to a number of soil and environmental factors including low soil organic matter, high soil pH, calcareousness, water logging and arid climate (Mortvedt *et al.,* 1991; Tandon, 1995). Soils of Pakistan are generally alkaline in reaction and calcareous in nature. These types of soils usually contain lower amounts of available Zn so, soil fertilization with Zn as $ZnSO_4$ is widely recommended but its use as a soil additive is not a common practice of farmers in Punjab. Fewer than 5% of farmers in Pakistan use zinc fertilizer (FAO, 2004b). Although about 5000 t of Zn fertilizers are produced every year in Pakistan, almost all of it is applied to rice (NDFC, 1998).

Pakistan is a wheat-growing nation and wheat is the main staple food and major cereal crop in Pakistan. Average per hectare yield of wheat crop at present is far below than its actual potential 6450 kg ha^{-1}, which provides tremendous scope for increased out put (Agric. Stat. Pakistan, 2000-2001). So, application of micronutrient i.e., Zn is an option for increasing yield. It is evident that for obtaining increased yield of wheat, Zn status of the soils should be improved using Zn fertilizers (Shaheen *et al*., 2007). Higher rates of Zn may be required for calcareous soils of Pakistan, as evident from the results of Gupta and Kalra (2006) study, who indicated that rates of 50 kg of Zn ha^{-1} were not toxic and did not cause yield reductions in wheat and second year barley crops. Similarly, Math and Trivedi (2000) described that increasing application of Zn upto 50 kg zinc sulphate ha^{-1} increased the content and uptake of Zn in wheat crop. Pots experiments conducted using Zn deficient soil showed the reduction in dry matter yield of wheat (Aslam *et al*., 1997). Khan *et al.* (2004) in a pot trial evaluated the effect of different levels of Zn (0, 5, 10 & 15 kg ha^{-1}) in 8 different calcareous soil series and concluded that maximum Zn content of rice leaf before and after flowering was observed with 15 kg Zn ha^{-1} in the soil series. Dwivedi and Tiwari (1992) also reported that application of zinc increased zinc uptake in wheat grain and straw. Likewise, Singh and Singh (l989) also observed significant increase in grain yield of wheat due to the application of zinc to the soil. Twenty-five years old long-term fertilizer experiment of Singh *et al.* (2005) also revealed that wheat responded well to applied Zn and removal of micronutrients by the annual cropping cycle depleted the availability of Zn.

Different nutrients may interact with Zn by affecting the availability of each other from soils and their status in the plant through the process of growth or absorption, distribution and utilization. These interactions may reduce or enhance plant growth as a response to Zn (Longragan & Webb, 1993). Yilmaz *et al*. (1997) concluded that over use of P-fertilizers resulted in even lower levels of Zn in wheat grain and human diets. Rathore *et al.* (1974) showed Increasing either element (Zn or Mn) decreased the toxic effect of others and implied a mutual antagonistic effect on Zn uptake.

It is evident from the above that use of both macro and micro nutrients including Zn is an important factor for wheat crop cultivation and these essential nutrients should be used in correct doses for increasing soil fertility and to boost up crop production. The present investigation was undertaken to study the effect of added zinc on different growth parameters, grain and straw yields, Zn uptake, soil Zn status and also the effect of added Zn in soils.

MATERIALS AND METHODS

This research work was carried out at Adaptive Research Farm Karor, District, and Layyah, which lies between 30°-45' to 31°-24', North Latitude and 70°-44' to 71°-50', East Longitude, during the year, 2005-2006 and 2006-2007. The experiment was laid out in randomized complete block design with three replications. The experimental soil (0-15 cm depth) was analyzed for initial soil physicochemical properties. Soil texture was loam having the following characteristics: sand 40.70%, silt 37.30%, clay 22%, pH 8.1, Organic matter 0.85%, $CaCO_3$ 5.5%, EC 1.5 dSm^{-1}, available N 0.60 g kg^{-1}, available P 10.5 mg kg^{-1}, exchangeable K 125 mg kg^{-1}, AB-DTPA extractable Zn 0.93 mg kg^{-1}, AB-DTPA extractable Fe 2.95 mg kg^{-1} and AB-DTPA extractable Mn 1.15 mg kg^{-1}. Wheat variety Bhakkar, 2002 was sown during Rabi season, 2005-2006 and 2006-2007 on 15 November with hand drill using seed rate 125 kg ha^{-1}. The recommended doses of N, P and K were applied @ 150:100:60 kg $N:P_2O_5:K_2O$ ha^{-1} as urea, triple super phosphate and sulphate of potash, respectively in all treatments, through broadcast at the time of sowing, while N was applied in two equal doses after 25 days and 40 of sowing at the time of irrigation. Zn was applied @ 0, 4, 8, 12 and 16 kg ha^{-1} in the form of zinc sulphate, by broadcasting in powder form mixed with soil at the time of seedbed preparation. All crop management and protection measures were followed. Weed control practices were included physical method i.e., hoeing along with weedicides application [Buctril Super 60 EC (Bromoxynil + MCPA) @ 750 mL ha^{-1} & Puma Super (Fenoxaprop) @ 1250 mL ha^{-1})]. The crop was harvested at maturity, 150 days after sowing and straw and grain yield was determined. The samples of grains and straws were kept at 65°C for 48 h and then ground with a grinding mill and concentration of NPK and micronutrients i.e., Zn, Fe and Mn was obtained.

After harvesting of crop, soil samples were taken, air dried and analyzed for determination of NPK, micronutrients and soil organic carbon. Hydrometer method (Bouyoucos, 1962) was followed for particle size analysis. Nitrogen in soil was determined using macro Kjehldhal's apparatus by Gunning and Hibbard's method of sulphuric acid digestion and distillation of ammonium into 4% boric acid (Jackson *et al*., 1962). Phosphorous was determined by taking 5 g soil and 10 mL, 0.5 N $NaHCO_3$ solutions. Solution pH was adjusted at 8.5. Five mL of aliquot of clear filtrate was taken in 25 mL volumetric flask and potassium tartrate and sulphuric acid were added. Color intensity of filtrate was measured on spectrophotometer at 880 nm (Watanabe & Olsen, 1965). Soil was extracted with ammonium acetate solution (1.0 N of pH 7.0) and potassium was determined in the extract by Jenway PFP-7 flame photometer (Hand Book 60, Method 18). Soil organic carbon was determined by the modified method of walkly and Black (Nelson & Sommers, 1982). The AB-DTPA extracting solution was prepared by dissolving 79.06 g NH_4HCO_3 and 1.97 g of DTPA in a liter volume of solution. The pH of the solution was adjusted to 7.60 with the help of HCl. Soil (10 g) was placed in a 250 mL Erlenmeyer flask, added 20 mL of freshly prepared extracting solution, shook on reciprocating shaker at 180 cycles per minute for 15 min by keeping flasks open (Soltanpour, 1985). The mixture was filtered and metals were determined with atomic absorption spectrophotometer (Model Thermo Electron S-Series). The dried and ground shoot material (0.1 g) was digested with sulphuric acid and hydrogen peroxide according to Wolf (1982) method. Nitrogen was determined using micro Kjeldhal's apparatus by Gunning and Hibbard's method (Jackson *et al.*, 1962). Total phosphorus was determined by spectrophotometer using 400 nm wavelengths and comparing the sample concentration against standard curve (Hand Book 60, Method 61). Potassium in the digested material was determined by Jenway PFP-7 flame photometer (Hand Book 60, Method 5). For micronutrients analysis, plant samples were subjected to digestion (Rashid, 1986) and then Zn, Fe and Mn were determined with atomic absorption spectrophotometer (Model Thermo Electron S-Series). There was kept one reagent blank (no plant material) for each bath of samples. The experiment was carried out following randomized complete block statistical fashion (Steel *et al*., 1997). The data thus obtained was subjected to analysis (Gomez & Gomez, 1999).

RESULTS

Result from two year study revealed that effect applied Zn application was statistically significant on all the growth and yield parameters of wheat and nutrients uptake. As regard growth and yield parameters, Zn application @ 16 kg ha^{-1} combined with recommended NPK gave best results. In year-1, a maximum increase of 4.49% was observed in plant height, over control (recommended NPK) in treatments, where Zn was applied @ 16 kg ha^{-1} combined with recommended NPK (Table I). In year-2, Zn application @ 12 kg ha^{-1} along with recommended NPK gave best results (5.06%, more plant height than control). However, overall effect of different Zn doses on plant height was statistically non-significant compared to control. The effect of Zn application on spike length was statistically significant. In year-1, maximum spike length was observed in treatment, where 12 kg Zn ha^{-1} was applied and it showed 10.50% increase over control, however this treatment was statistically similar with treatment receiving 16 kg Zn ha^{-1} (Table I). In year -2, Zn response was also significant. Maximum spike length (9.7% more than control) was observed with treatment receiving 16 kg Zn ha^{-1}. All other treatments receiving Zn doses were statistically at par compared to each other. As regard number of spikelets $spke^{-1}$ in year-1, statistically similar response was observed, however during year-2, increasing Zn doses significantly increased this parameter. During both the years, treatment receiving 12 kg Zn ha^{-1} showed best response causing 8.27 and 8.97% increase over control, during 1st and 2nd year, respectively (Table I). Data showed that increasing Zn doses along with recommended NPK increased the number of tillers per m^2, significantly as compared to recommended NPK alone (Table I). During both years, maximum number of tillers m^{-2} (12.25 & 12.19% more than control, during yarer-1 & -2, respectively) were observed in case of treatments, where 16 kg Zn ha^{-1} was applied along with recommended NPK (Table I).

Data revealed that 1000-grain weight and grain yields were significantly ($P \leq 0.05$) increased by the application of Zn, over the control (Table II). In year-1 and -2 maximum 1000-grain weight and grain yield was observed in treatments, where Zn was applied @ 16 kg ha^{-1} along with recommended NPK. This treatment increased the 1000-grain weight by 12.23 and 7.91%; grain yield by 13.66 and 16.16% more than control, during 1st and 2nd year, respectively. Effect of Zn application on straw yield was statistically significant compared to control, both the years, however all treatments receiving Zn doses showed statistically similar response compared to each other. Data showed that straw yield was maximum in treatments receiving 8 kg Zn ha^{-1} along with recommended NPK and this treatment showed 9.90 and 14.72% increase over control, during 1st and 2nd year, respectively. Increasing Zn rate beyond this rate showed decrease in straw yield. The increase in growth and yield of wheat could be attributed to the enhanced nutrient (macro & micro) use efficiency in the presence of Zn fertilizer (Table III & IV).

The results of our study revealed that the application of Zn increased the NPK uptake by wheat crop, over control. In year-1, maximum N uptake (7.98% more than control) was observed in case of treatment receiving 16 kg Zn ha^{-1} along with recommended NPK, while in year-2, treatment receiving 12 kg Zn ha^{-1} along with recommended NPK gave maximum N uptake (9.09% more than control). This study demonstrated a maximum increase of P, 7.91 and 12.48%; K, 9.56 and 9.93% in year-1 and -2, respectively over control, in case of treatments, where 16 kg Zn ha^{-1} was applied (Table V). As for significance of different Zn rates on soil NPK concentration, results revealed that effect of Zn rates on soil N and P was non-significant, while it affected the K contents in soil, significantly. This study demonstrated a maximum decrease of N, 10.34 and 3.13%; P, 6.15 and 4.17%; K, 8.90 and 6.26%, in year-1 and -2 respectively, over control, in case of treatment, where 16 kg Zn ha^{-1} was applied (Table V). The decrease in NPK contents in soil could be attributed to the enhanced nutrient (NPK) uptake by wheat crop (Table III). The results of our study revealed that all treatments receiving Zn doses combined with recommended NPK were statistically non-significant with each other and also compared to treatment receiving recommended NPK only, in changing soil organic matter (Table V).

Table (IV & VI) shows the effect of different doses of soil application of Zn on Zn uptake by wheat crop and it's built up in soil. Data trend shows that increasing the Zn upto 16 kg Zn ha^{-1} increased its uptake and also its concentration in soil. Maximum Zn uptake (1030 & 1085 g ha^{-1} in year-1 & -2, respectively) was evident at 16 kg Zn ha^{-1} and it showed 29.83 and 34.23% increase over control. Similarly, maximum Zn contents (2.23 & 2.22 mg kg^{-1} in year-1 & -2, respectively) in soil were observed in case of treatments, where 16 kg Zn ha^{-1} was applied along with recommended NPK and it showed 213.62 and 245.26% increase over recommended NPK. Regarding the effect of different Zn application rates on Fe and Mn uptake, data are presented in Table IV. Data showed that increasing Zn levels upto 8 kg Zn ha^{-1} significantly increased the uptake of Fe by 5.63 and 3.24% over control in year-1 and -2, respectively, while application of high doses of Zn reduced Fe the uptake compared to this treatment. However, in year-2 all treatments receiving Zn doses were statistically non-significant compared to control. Regarding Mn uptake by wheat crop, in year-1, maximum Mn uptake (8.64% more than control) was observed with 12 kg Zn ha^{-1}, while this treatment was at par with all other treatments receiving Zn doses. In year-2, increasing rates of Zn increased the Mn uptake by wheat crop. Maximum Mn uptake (8.0% more than control) was observed by the application of 16 kg Zn ha^{-1}. The results of our study revealed that in year-1, the application of Zn did not have any significant effect on Fe uptake, but in year-2, Zn application significantly affected the Fe uptake. Data showed that increasing Zn doses in soil increased the Fe contents in soil. It was due to decreased uptake of Fe at higher Zn rates. As for as effect of Zn application rate on Mn contents in soil is concerned, Zn application upto 8 kg ha^{-1} decreased Mn uptake, while high doses of Zn increased its concentration in soil and this was due to reduced uptake of Mn at higher Zn levels.

Table VII shows the economics of average of two years, using different Zn doses along with recommended NPK, for wheat production. Applying Zn @ 16 kg Zn ha^{-1}, increased the total income upto 119.35 US $ ha^{-1}, while net return was maximum (546.08 US $ ha^{-1}) in case of treatment receiving 12 kg Zn ha^{-1}. As for as value cost ratio (VCR) is concerned, applying Zn @ 4 kg Zn ha^{-1} showed maximum VCR, while increasing Zn doses showed a decrease in it.

DISCUSSION

This study demonstrated the effectiveness of different Zn doses for improving growth, yield and nutrients (N, P, K, Zn, Fe & Mn) uptake of wheat in the presence of recommended NPK fertilizer. Our results indicated that best results were obtained with application of 16 kg Zn ha^{-1} combined with recommended NPK. Maximum wheat yield was observed by the application of 16 kg Zn ha^{-1} i.e., 13.66 and 16.16% more than control, in year-1 and 2, respectively. These results are in accordance with Hussain and Yasin (2004), who reported 12% increase in wheat yield by the application of 5 kg Zn ha^{-1}, over control. Increasing Zn dose upto 16 kg Zn ha^{-1} increased spike length, number of spikelets spke^{-1}, number of tillers per m^2 and 1000 grain weight, significantly over control, while highest straw yield was obtained with the application of 8 kg Zn ha^{-1}. These results are in accordance with Singh *et al.* (1999) and Ravankar *et al.* (2000 & 2003), who in field experiments obtained higher yield by the application of inorganic fertilizers in combination with organic fertilizers, S and Zn than treatments with inorganic fertilizers only in various crops. Similarly, Khan *et al.* (2007) in an experiment on wheat and rice using two levels of zinc (5 & 10 kg ha^{-1}) reported an increase in the number of tillers, spike m^{-2}, spike length, plant height and 1000 grain weight of wheat significantly, over control. Likewise, Razvi *et al.* (2005) recorded significantly higher grain yield (27.72 q ha^{-1}), straw yield (44.07 q ha^{-1}), harvest index (0.366) and dry matter production at harvest (202.72 g m^{-1} row length) by the application of Zn, over the rest of the treatments.

The results of our study revealed that increasing the Zn rates in the form of zinc sulphate also increased the NPK uptake by wheat crop, over control and highest uptake was observed with 16 kg Zn ha^{-1} combined with recommended NPK. Similarly, Pederson *et al.* (2002) revealed that nitrogen concentration was highly correlated with P and Zn concentrations in aboveground plant parts, suggesting that improvements in N fertility would improve P and Zn concentration in plants. Contradictory to our findings, Lehoczky *et al.* (2005) data indicated no correlation between Zn and NPK fertilization treatments. Fertilization of NPK had no significant effect on the plant-available Zn content of soils. Our results showed that application of Zn resulted in a little decrease in PK contents that may due to an increase uptake by wheat crop. Our findings support the

Table I. Effect of different Zn doses on growth parameters of wheat. The data are average of three replications

Zn application (kg ha^{-1})	Plant height (cm)		Number of tillers m^{-2}		Spike length (cm)		Number of spikelets $spike^{-1}$	
	2005-2006	2006-2007	2005-2006	2006-2007	2005-2006	2006-2007	2005-2006	2006-2007
[a]Control (no Zn)	89.00 a†	92.33 a	272.00 d	279.00 c	12.70 b	13.37 b	15.27 a	15.30 c
[b]4	91.67 a	94.67 a	276.67 cd	278.67 c	13.37 ab	13.80 ab	15.47 a	15.53 bc
8	92.67 a	95.67 a	286.00 bc	290.67 b	13.50 ab	14.20 ab	16.00 a	16.20 ab
12	92.67 a	97.00 a	295.67 ab	297.00 b	14.03 a	14.07 ab	16.53 a	16.67 a
16	93.00 a	96.67 a	305.33 a	313.00 a	13.93 a	14.67 a	16.43 a	16.63 a

[a]The N, P and K fertilizers were applied @ 150:100:60 kg $N:P_2O_5:K_2O$ ha^{-1}, respectively in all the treatments
[b]The Zn was applied in the form of zinc sulphate by broadcasting in powder form and mixed with soil at the time of seedbed preparation
†Means sharing similar letter (s) in a column do not differ significantly at p=0.05

Table II. Effect of different Zn doses on yield and yield contributing parameters of wheat. The data are average of three replications

Zn application (kg ha^{-1})	1000-grain weight (g)			Straw yield (Mg ha^{-1})		
	2005-2006	2006-2007	2005-2006	2006-2007	2005-2006	2006-2007
[a]Control (no Zn)	32.67 b†	33.67 d	5.53 b	5.47 b	3.93 c	3.92 b
[b]4	34.33 ab	34.33 cd	6.00 ab	6.10 a	4.14 bc	4.28 ab
8	34.67 ab	35.00 bc	6.08 a	6.28 a	4.26 ab	4.36 a
12	36.53 a	36.00 ab	6.05 a	6.16 a	4.44 a	4.54 a
16	36.67 a	36.33 a	5.94 ab	6.10 a	4.47 a	4.55 a

[a]The N, P and K fertilizers were applied @ 150:100:60 kg $N:P_2O_5:K_2O$ ha^{-1}, respectively in all the treatments
[b]The Zn was applied in the form of zinc sulphate by broadcasting in powder form and mixed with soil at the time of seedbed preparation
†Means sharing similar letter (s) in a column do not differ significantly at p=0.05

Table III. Effect of different Zn doses on total N, Pand K uptake by wheat. The data are average of three replications

Zn application (kg ha^{-1})	Total N uptake (kg ha^{-1})		Total P uptake (kg ha^{-1})		Total K uptake (kg ha^{-1})	
	2005-2006	2006-2007	2005-2006	2006-2007	2005-2006	2006-2007
[a]Control (no Zn)	107.61 b†	109.25 c	37.13 a	36.63 c	131.13 c	134.33 c
[b]4	111.23 ab	112.42 bc	38.73 a	38.47 bc	137.20 b	141.67 b
8	112.52 ab	114.13 abc	39.17 a	39.10 ab	139.67 ab	142.00 b
12	115.32 a	119.19 a	39.73 a	40.03 ab	141.00 ab	145.67 a
16	116.20 a	117.62 ab	40.07 a	41.20 a	143.67 a	147.67 a

[a]The N, P and K fertilizers were applied @ 150:100:60 kg $N:P_2O_5:K_2O$ ha^{-1}, respectively in all the treatments
[b]The Zn was applied in the form of zinc sulphate by broadcasting in powder form and mixed with soil at the time of seedbed preparation
†Means sharing similar letter (s) in a column do not differ significantly at p=0.05

Table IV. Effect of different Zn doses on total Zn, Fe and Mn uptake by wheat. The data are average of three replications

Zn application (kg ha^{-1})	Total Zn uptake (g ha^{-1})		Total Fe uptake(g ha^{-1})		Total Mn uptake (g ha^{-1})	
	2005-2006	2006-2007	2005-2006	2006-2007	2005-2006	2006-2007
[a]Control (no Zn)	793.33 c†	808.33 d	3520.00 bc	3600.00 a	817.67 b	828.67 c
[b]4	861.67 bc	873.67 cd	3646.67 ab	3670.00 a	845.00 ab	835.67 c
8	886.67 b	915.00 bc	3718.33 a	3716.67 a	878.33 ab	861.67 b
12	973.00 a	979.00 b	3625.00 ab	3658.33 a	888.33 a	861.67 b
16	1030.00 a	1085.00 a	3463.33 c	3603.33 a	881.67 ab	895.00 a

[a]The N, P and K fertilizers were applied @ 150:100:60 kg $N:P_2O_5:K_2O$ ha^{-1}, respectively in all the treatments
[b]The Zn was applied in the form of zinc sulphate by broadcasting in powder form and mixed with soil at the time of seedbed preparation
†Means sharing similar letter (s) in a column do not differ significantly at p=0.05

results of Singh *et al.* (2005), who reported that a highest removal of Zn by crops was observed with 100% NPK+Zn.

Application of Zn increased its total uptake by wheat crop and also resulted in a built-up of Zn in the upper 15 cm layer, to be available for next crop. Highest Zn uptake was observed by the application of 16 kg Zn ha^{-1}. Similarly, Dvorak *et al.* (2003) noted a greater accumulation of Zn in wheat and barley after its addition into the soils by sludge and inorganic salt. In another experiment Gupta *et al.* (2006) also showed that Zn applications for 2 years in succession, resulted crop tissue Zn levels as high as 105 mg kg^{-1}, but did not cause any phytotoxicity in cereals. Likewise, Shaheen *et al.* (2007) reported that the number of tillers per hill, grain and straw yield of wheat, zinc concentrations and zinc uptake both in grain and straw and zinc concentrations of pre-sowing and post-harvest soils were significantly increased with the application of Zn. Dewal and Pareek (2004) opined that wheat fertilized with Zn and sulphur improved the nutritional environment of rhizosphere, which resulted in greater uptake of nutrients by the crop and this

Table V. Effect of different Zn doses on soil organic matter and NPK contents in soil; the data are average of three replications

Zn application (kg ha^{-1})	Soil organic matter (%)		N content in soil g kg^{-1}		P content in soil (mg kg^{-1})		K content in soil (mg kg^{-1})	
	2005-2006	2006-2007	2005-2006	2006-2007	2005-2006	2006-2007	2005-2006	2006-2007
[a]Control (no Zn)	0.70 a†	0.70 a	0.60 b	0.64 a	13.00 a	12.87 a	168.67 a	165.00 a
[b]4	0.69 a	0.70 a	0.60 b	0.65 a	12.87 a	12.83 a	162.00 b	158.67 ab
8	0.68 a	0.71 a	0.60 b	0.65 a	12.97 a	12.77 a	157.00 bc	160.33 ab
12	0.71 a	0.72 a	0.61 ab	0.66 a	12.33 a	12.70 a	156.00 bc	157.33 b
16	0.71 a	0.71 a	0.66 a	0.66 a	12.20 a	12.33 a	153.67 c	154.67 b

[a]The N, P and K fertilizers were applied @ 150:100:60 kg N:P_2O_5:K_2O ha^{-1}, respectively in all the treatments
[b]The Zn was applied in the form of zinc sulphate by broadcasting in powder form and mixed with soil at the time of seedbed preparation
†Means sharing similar letter (s) in a column do not differ significantly at p=0.05

Table VI. Effect of different Zn doses on Zn, Fe and Mn contents in soil; the data are average of three replications

Zn application (kg ha^{-1})	Zn contents in soil (mg kg^{-1})		Fe contents in soil (mg kg^{-1})		Mn contents in soil (mg kg^{-1})	
	2005-2006	2006-2007	2005-2006	2006-2007	2005-2006	2006-2007
[a]Control (no Zn)	0.71 e†	0.64 e	2.91a	2.98 ab	0.76 ab	0.79 b
[b]4	0.85 d	0.88 d	2.72 a	2.79 bc	0.72 b	0.67 c
8	1.25 c	1.32 c	2.75 a	2.65 c	0.69 b	0.68 c
12	1.58 b	1.49 b	2.77 a	2.77 bc	0.76 ab	0.77 b
16	2.23 a	2.22 a	2.83 a	3.05 a	0.85 a	0.88 a

[a]The N, P and K fertilizers were applied @ 150:100:60 kg N:P_2O_5:K_2O ha^{-1}, respectively in all the treatments
[b]The Zn was applied in the form of zinc sulphate by broadcasting in powder form and mixed with soil at the time of seedbed preparation
†Means sharing similar letter (s) in a column do not differ significantly at p=0.05

Table VII. Economics of using different Zn doses along with recommended NPK, for wheat production in the field; the data are average of two years

Zn application (kg ha^{-1})	Expenditure			†Income from wheat			Increased income	Net	*Value/cost
	'Nutrient sources	"Sowing expenses	Total	Grain	Straw	Total	over control	Return	(VCR) ratio
[a]Control (no Zn)	169.63	181.88	351.51	710.56	142.24	852.80	0.00	501.29	0.00
[b]4	194.01	181.88	375.90	762.16	156.47	918.62	65.81	542.73	2.70
8	218.39	181.88	400.28	780.26	159.83	940.09	87.28	539.81	1.79
12	242.77	181.88	424.66	812.84	157.89	970.73	117.93	546.08	1.61
16	267.15	181.88	449.04	816.47	155.69	972.15	119.35	523.12	1.22

'Expenditures on different nutrient sources were as follows: N, 0.276 US $ kg^{-1}; P_2O_5, 0.464 US $ kg^{-1}; K_2O, 0.585 US $ kg^{-1}; Zn, 4.42 US $ kg^{-1} (NFDC, 2006)
"Sowing expenditures were as follows: ploughing and seed bed preparation, 25.86 US $; seed, 28.87 US $; weedicide, 28.88 US $; irrigation, 34.47 US $; harvesting and threshing, 63.79 US $
†Price of the wheat produce is as follows: wheat grain, 181.03 US $ Mg^{-1}; wheat straw = 25.86 US $ Mg^{-1}
*Value/cost (VCR) ratio = Net return/expenditure due to Zn treatment
[a]The N, P and K fertilizers were applied @ 150:100:60 kg N:P_2O_5:K_2O ha^{-1}, respectively in all the treatments
[b]The Zn was applied in the form of zinc sulphate by broadcasting in powder form and mixed with soil at the time of seedbed preparation
†Means sharing similar letter (s) in a column do not differ significantly at p=0.05

caused higher metabolic and photosynthetic activity in plant leading to higher yield. Positive response of all doses in our experiment that was conducted in alkaline soil having pH 8.1 was supported by the work of Singh *et al*. (2008), who described that the proportion of sorbed Zn that could be desorbed back into solution decreased substantially as pH increased to more than 5.5.

The uptake of Fe increased by applying Zn upto 8 kg Zn ha^{-1}, while application of high Zn doses resulted in reduced Fe uptake. Similarly, application of Zn at high rates slightly increased Fe contents in soil as compared to control and this may be due to its decreased uptake by wheat crop. Our results are in line with Jabalpur Annual Report (1984), which showed that interactive effect of Zn on Fe was also positive. Increasing the dose of Zn showed a little increase in the uptake of Mn. Decrease in Mn concentration in soil was observed and this may be attributed to its increased uptake with the application of Zn showing synergistic effect with Zn. Our findings are contradictory to Rathore *et al.* (1974), who showed that increasing either element (Zn or Mn) decreased the toxic effect of others and implied a mutual antagonistic effect on Zn uptake. Applying Zn upto 12 kg Zn ha^{-1} increased the net return, however value cost ratio (VCR) was decreased by increasing Zn doses and this may be due to the fact that all applied Zn was not taken up by wheat crop, so residual effect of Zn can affect the yield next year. Similarly, Yilmaz *et al*. (1997) concluded that soil application of Zn was economical and had long-term effects on enhanced wheat grain grown on Zn deficient soils.

In conclusion, Zn supply along with recommended NPK fertilizers led to satisfactory crop production. The complimentary use of micronutrients is advantageous as it helps increase NPK uptake, maintain micronutrients levels in soil and increases crop productivity. It is possible to get higher crop yield with complimentary use of micronutrients along with recommended chemical fertilizers than the application of recommended chemical fertilizers alone.

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(Received 03 March 2009; Accepted 17 April 2009)