Pak. J. Bot., 43(1): 607-616, 2011.

NUTRIENT UPTAKE, GROWTH AND YIELD OF WHEAT (*TRITICUM AESTIVUM* L.) AS AFFECTED BY MANGANESE APPLICATION

GHULAM ABBAS[1*], MUHAMMAD QASIM KHAN[2], MUHAMMAD JAMIL KHAN[2], MUHAMMAD TAHIR[3], MUHAMMAD ISHAQUE[4] AND FIDA HUSSAIN[5]

[1]*Adaptive Research Farm, Karor district Layyah, Punjab, Pakistan*
[2]*Faculty of Agriculture, Gomal University D.I. Khan, NWFP, Pakistan*
[3]*Institute of Soil & Environmental Sciences, University of Agriculture, Faisalabad*
[4]*Department of Forestry, University of Agriculture, Faisalabad*
[5]*Department of Plant Breeding, University of Agriculture, Faisalabad (D.G. Khan Campus)*
[*]*Correspondence author E-mail: mlkabs_dd@yahoo.com*

Abstract

The study was carried out for two consecutive years (2005-06 to 2006-07) to evaluate the wheat response to five different levels (0, 4, 8, 12 and 16 kg ha^{-1}) of manganese (Mn) alongwith 150-100-60 kg NPK ha^{-1} application. The experiment was laid out in randomized complete block design (RCBD) with three repeats under irrigated conditions at Agriculture Research Farm Karor, District Layyah. NPK was applied in the form of urea, triple super phosphate and sulphate of potash while Mn was applied in the form of manganese sulphate (30% Mn). Wheat variety BK-2002 was tested for both the years. Average of two years results showed a positive and significant response of wheat to Mn application. The highest grain yield of 4.59 t ha^{-1} was achieved with the highest application of 16 kg Mn ha^{-1} along with NPK against 3.96 t ha^{-1} from NPK alone. Maximum wheat straw yield of 6.11 t ha^{-1} was obtained with the 16 kg Mn ha^{-1} while lowest (5.67 t ha^{-1}) with the NPK alone. The uptake of N, K and Mn was significantly increased with the application of Mn except P.

Introduction

Wheat (*Triticum aestivum* L.) is one of the leading cereals, which rank first, both in acreage and in production among the grain crops of the world (Anon., 1971). It is used to feed about one-third of the world population. It also occupies a supreme position in food grains of Pakistan as it covers 66% of the total area under food grains and contributes 74% of the total food grain production. Wheat was cultivated on an area of 8414 thousand hectares, showing 1.9% decrease over last year's area of 8578 thousand hectares. Wheat was cultivated on an area of 9062 thousand hectares, showing an increase of 5.9% over last year's area of 8550 thousand hectares. The size of wheat crop is provisionally estimated at 23.4 million tons, 11.7 % more than last year crop. (Anon., 2008-09).

While green revolution technologies have caused rapid increases in the cereal production of South Asia, however, rotation's productivity growth has slowed, and factor productivity, i.e., the cereal produced per kg of fertilizer, may be decreasing (Abrol, *et al.*, 1997). With rising cropping intensities in South Asia, nutrient management is a major issue being addressed by agricultural scientists for understanding any decline in yields.

Over 40% of the world's population is currently micronutrient deficient, resulting in numerous health problems, inflated economic costs borne by society and learning disabilities for children (Sanchez & Swaminathan, 2005). Micronutrient deficiencies in the Indo-Gangetic Plains (IGP) started emerging with the adoption intensive agriculture in the region. Decreased use of organic manure, imbalanced use of macronutrient fertilizers, reduced recycling of crop residues, and bumper harvests in the past three decades have induced secondary and micronutrient deficiencies in the IGP. The severity of these deficiencies depended on the soil conditions and the crop grown. Increase in fertility levels progressively increases the total removal of micronutrients due to increased dry matter production (Nayyar *et al.*, 2001).

Manganese along with iron, copper, zinc, molybdenum and boron could be called “bioessential” element because of their essentiality to life. Micronutrients are as important as macronutrients for adequate plant nutrition and a deficiency of single nutrient can reduce yield. Among the trace elements needed for a normal growth of the plants, manganese is important, playing a definitive role in the metabolism of plants, animals and man. The trace elements found in plants are organically bound, complexed and free ions (Cioroi & Florea, 2003). Mn plays essential roles in the metabolism of isoprenoids, carotenoids, chlorophylls and phenolics. External application of Mn^{2+} increases photosynthesis, net assimilation and relative growth and yield (Lewis & McFarlane, 1986; Lidon & Teixerira, 2000; Sultana *et al.*, 2001).

Adequate plant nutrition with micronutrients depends on many factors; these factors include the ability of soil to supply these nutrients, rate of absorption of nutrients to functional sites and nutrients mobility within the plants. High soil pH reduces Mn availability while low soil pH will increase availability, even to the point of toxicity. Manganese deficiencies occur most often on soils with a high pH and/or naturally low Mn content. In general the critical value of AB-DTPA extractable Mn in soil is 1.8 as reported by Ryan *et al.,* (2001) and Rashid (2005). However, Ziaeian & Malakouti (2006) studied the effects of micronutrients on wheat production in calcareous soils and based on the DTPA method and found the critical soil levels of 0.9 mg Mn kg^{-1} for soil.

The soils of Punjab-Pakistan are generally alkaline and calcareous in nature, having low organic matter, nutrient mining with intensive cultivation and imbalanced fertilization which caused macro and micronutrient deficiencies (Rafique *et al.,* 2006). Similarly, In Indian Punjab, Mn deficiency is severe on coarse textured soils; with alkaline and calcareous reaction where wheat is followed by rice due to reduction and leaching losses of Mn in soil. A major difficulty in managing severe Mn deficiency is the low efficiency of soil applied Mn at high soil pH (Nayyar *et al.*, 1985). Similarly, Fageria *et al.,* (1995) found that increasing levels of lime tend to reduce uptake of Mn in all the crop species.

Manganese fertilizers are commonly used to correct Mn deficiencies, but it is of significance that several macronutrient fertilizers, especially those of N and P can greatly increase the availability of Mn.

Keeping in view the above discussion, the objectives of the study was to examine the effect of Mn on the growth and yield of wheat crop and uptake of NPK and Mn.

Materials and Methods

A field experiment was conducted at Govt. Agriculture Adaptive Research Farm Karor district, Layyah during the year 2005-2006 and 2006-2007. The experiments was laid out in randomized complete block design (RCBD) having three replications and five treatments, to study the influence of manganese on growth, nutrients uptake and yield of wheat. Five rates of Mn *viz*., 0, 4, 8, 12 and 16 kg ha^{-1} were applied in the form of manganese sulphate. A composite soil samples was taken before commencement of the study to visualize the physico-chemical characteristics of the soil (Table 1). Soil was dried, ground, sieved (<2mm) and analyzed for the physico-chemical characteristics. Soil particle size distribution was determined by Hydrometer method (Moodie *et al.*, 1959) and textural class according to USDA system. Phosphorus and Potassium was determined by the method of Black (1965). Organic matter was determined by the method of Walkely & Black (1934) and $CaCO_3$ by Puri's (1966). AB-DTPA extractable Mn was measured on Atomic Absorption spectrophotometer. The basal doses of NPK @ 150-100-60 kg ha^{-1} along with Mn levels were applied in the form of urea, TSP and SOP respectively. All P, K and Mn were applied at sowing time while nitrogen fertilizer was applied in three equal splits (1^{st} at sowing time, 2^{nd} at first irrigation and 3^{rd} at third irrigation), while canal water was used for irrigation. Wheat variety BK-2002 was tested and sown with the help of hand drill. All the other cultural practices were followed uniformly throughout the growing season. The crop was harvested at maturity with the net plot of $1m^2$. The samples of grains and straw were taken and dried in oven at 65°C to determine dry matter yield, N, P, K and Mn analysis. Sub samples of grain and straw were ground, sieved and analyzed by wet digestion method (Walsh & Beaten, 1973). The agronomic data were recorded for grain yield, straw yield, 1000-grain weights, number of tillers, spike lets and spike length. Data were statistically analyzed by using MSTATC software.

Results and Discussions

Wheat grain yield and yield components: Wheat grain yield was significantly increased by the application of Mn with NPK over NPK alone during both years (Table 2). Highest grain yield was recorded with the application of 16 kg Mn ha^{-1} (T5), however yield increased due to T3 (8 kg Mn ha^{-1}), T4 (12 kg Mn ha^{-1}) and T5 (16 kg Mn ha^{-1}) were at par with each. Mean grain yield of both the years revealed that T5 (16 kg Mn ha^{-1}) increased the yield from 3.97-to 4.59 t ha^{-1}. All this reflects that wheat grain yield was increased maximum up to 15.8% over NPK. Similarly, Hoyt & Myovella (2005) applied Manganese, N and P fertilizers to wheat in field experiments on a soil so deficient in Mn that it caused the wheat to die before heading. Their results showed that yields of wheat were increased linearly by soil banded Mn to 44.8 kg/ha, giving a yield of 3.03 tonnes ha^{-1}. Likewise, Krahmer & Sattelmacher (2001) reported that wheat had the strongest yield decrease under Mn deficiency conditions and thus the lowest Mn efficiency amongst 16 crop species tested in pot culture experiment on Mn deficient peat soil.

Data showed that straw yield of wheat was significantly increased by the T4 and T5 over NPK alone (T1) in both the years (Table 2). The straw yield ranged from 5.67 to 6.12 and 5.68 to 6.10 t ha^{-1} during both the years. Mean straw yield of both the year ranged between 5.67 to 6.12 t ha^{-1}. The highest straw yield was recorded in T5 (16 kg Mn ha^{-1}) and lowest from NPK alone. Percent increase in straw yield due to 16 kg Mn ha^{-1} was 7.8% over NPK alone (Table 2).

The 1000-grain weight was significantly increased with different levels of Mn over NPK, alone which ranged from 33.70 to 37.27 and 33.97 to 38.13 during both the years (Table 2). The increase in 1000-grain weight due to T3, T4 and T5 was significant over T1 (NPK alone) during 2005-06 while T4 and T5 were significant over T1 during 2006-07. The mean grain weight of both the years revealed that highest grain weight of 37.70 g was achieved from T5 (16 kg Mn ha^{-1}), while lowest with the NPK alone (33.83 g). The weight record in T3, T4 and T5 was statistically at par with each other (Table 2).

Table 1. Physico-chemical characteristics of soil.

Parameter	Unit	Value
Textural class		Loam
Sand	%	40.70
Silt	%	37.30
Clay	%	22
pH_s		8.1
EC_e	dS m^{-1}	1.5
$CaCO_3$	%	5.5
Organic matter	%	0.85
Amm; acetate extractable K	mg kg^{-1}	125
Available phosphorus	mg kg^{-1}	10.5
AB-DTPA extractable Mn	mg kg^{-1}	1.15

Data showed that the number of tillers m^{-2} were significantly increased by the application of Mn with NPK over NPK alone which ranged from 271.67 to 310 and 276.0 to 319.67 during 1st and 2nd year, respectively (Table 3). Maximum number of tillers m^{-2} were recorded with T5 (16 kg Mn ha^{-1}) while lowest from T1 (NPK alone). The mean number of tillers m^{-2} for both the years were increased from 273.84 to 314.83 with 16 kg Mn ha^{-1} over NPK alone. The number of tillers in T4 and T5 were statistically at par in both the years (Table 3). Similarly, Cioroi & Florea (2003) described that the manganese content of the soil is significant for the growth of wheat plants. They also noticed that the wheat plants have grown slowly in distillated water, for ten days but the growth became even slower afterwards.

The mean number of spikelets per spike of both the years ranged from 14.95 to 16.80, the highest were obtained in T5 (16 kg Mn ha^{-1}) and lowest from T1 (NPK alone). Different levels of Mn significantly increased number of spikelets per spike over NPK alone, however T5 (16 kg Mn ha^{-1}) was significantly differed from T1 (NPK alone) in both the years (Table 3).

Data showed that spike length was significantly increased with different levels of Mn over NPK alone during 2005-06 (Table 3). The mean spike length of both the years ranged from 13.69 to 14.53 cm. The highest length was achieved with T3 (8 kg Mn ha^{-1}) while lowest from T1 (NPK alone). Similar to our findings, Ziaeian & Malakouti (2001) results showed that Fe, Mn, Zn and Cu fertilization caused significant increase in grain yield, straw yield, 1000 grain weight, the number of seeds per spikelet, concentration and total uptake in grain, and flag leaves and the grain protein content increased significantly. Data regarding economic analysis revealed that T4 (12 kg Mn ha^{-1}) gave the maximum net return of (564.37) followed by T3 (8 kg Mn ha^{-1}) and T5 (16 kg Mn ha^{-1}) respectively, however, maximum value cost ratio of 1:1.45 was observed in T2 (4 kg Mn ha^{-1}). Similarly, Hussain *et al*., (2005) studied the effect of micronutrient mixture at different physiological growth stages of wheat in a field experiment and found that the maximum net profit was gathered in foliar spray of micronutrients at tillering+booting+milking growth stages of wheat.

Table 2. Effect of manganese on grain, straw yield and 1000-grain weight of wheat.

Treatments	Grain yield (Mg ha^{-1})			Straw yield (Mg ha^{-1})			1000-grains wt. (g)		
¶Mn kg ha^{-1}	2005-6	2006-7	Mean	2005-6	2006-7	Mean	2005-6	2006-7	Mean
¤Control (0)	4.05 b*	3.88 d	**3.97**	5.66 b	5.68 b	**5.67**	33.70 b	33.97 b	**33.84**
4	4.22 b	4.17 c	**4.20**	5.97ab	5.98 ab	**5.98**	34.73 b	35.77ab	**35.25**
8	4.47 a	4.33 bc	**4.40**	6.17 a	5.97 ab	**6.07**	36.43 a	35.82b	**36.13**
12	4.53 a	4.58 ab	**4.56**	6.07 a	6.13 a	**6.10**	36.93 a	37.37 a	**37.15**
16	4.557 a	4.623 a	**4.59**	6.13 a	6.1 a	**6.12**	37.27 a	38.13 a	**37.70**

*Means followed by same letter do not differ significantly at $p \leq 0.05$; ¤N, P and K fertilizers were applied @ 150:100:60 kg N: P_2O_5:K_2O ha^{-1}, respectively in all the treatments; ¶The Mn was applied in the form of Manganese Sulphate by broadcasting in powder form and mixed with soil

Table 3. Effect of manganese on No. of tillers m^{-2}, spike lets Spike^{-1}and spike length of wheat.

Treatments	No. of tillers m^{-2}			Spike lets spike^{-1}			Spike length (cm)		
¶Mn kg ha^{-1}	2005-6	2006-7	Mean	2005-6	2006-7	Mean	2005-6	2006-7	Mean
¤Control (0)	271.67 c*	276.00 d	**273.84**	14.80 c	15.10 b	**14.95**	13.57 b	13.80 a	**13.69**
4	283.00 b	286.67 c	**284.84**	15.47 bc	15.40 b	**15.44**	14.43 ab	14.57 a	**14.50**
8	290.33 b	296.67 b	**293.50**	15.73 abc	15.82 b	**15.78**	14.33 ab	14.73 a	**14.53**
12	306.00 a	320.33 a	**313.17**	16.07 ab	16.00 ab	**16.04**	14.55 a	14.37 a	**14.46**
16	310.00 a	319.67 a	**314.84**	16.50 a	17.07 a	**16.79**	14.27 ab	14.63 a	**14.45**

*Means followed by same letter do not differ significantly at $p \leq 0.05$; ¤N, P and K fertilizers were applied @ 150:100:60 kg N: P_2O_5:K_2O ha^{-1}, respectively in all the treatments; ¶The Mn was applied in the form of Manganese Sulphate by broadcasting in powder form and mixed with soil.

Total uptake of N, P, K and Mn by wheat: The uptake of N was significantly increased with different levels of Mn over NPK alone except T2 (4 kg Mn ha^{-1}) during both the years (Table 4), however highest N uptake was recorded with T5 (16 kg Mn ha^{-1}) and lowest with NPK alone in both the years. Mean data showed that N uptake ranged from 105.87 to 116.23 kg ha^{-1} (Table 4). Similarly, Parylak & Waclawowicz (2000) in their field experiment in 1998-1999 showed that increasing N fertilizer rates increased Mn content and its uptake particularly by grain yield.

Data showed that P uptake was not significantly increased with the various levels of Mn over NPK alone. The mean data was also in the same pattern (Table 4). The total potassium uptake was significantly increased in T5 (16 kg Mn ha^{-1}) over NPK alone during 2005-06, while all the treatments were significantly increased over NPK alone during 2006-07 (Table 4). The mean data of both the years revealed that K uptake was significantly increased with T4 (12 kg Mn ha^{-1}) and T5 (16 kg Mn ha^{-1}) over NPK alone. However K uptake ranged from 138.67 to 149.33 kg ha^{-1}. The highest K uptake was achieved in T5 (16 kg Mn ha^{-1}) while lowest from NPK alone (Table 4). Contradictory to our results, Ghasemi-Fasaei & Ronaghi (2008) found that soil application of manganese (Mn) increased the dry matter yield (DMY) but its application of Mn increased only Mn uptake and had no significant effect on the uptake of the other cationic micronutrients.

Manganese uptake was significantly increased with the increasing levels of Mn over NPK alone in both the years. All the treatments significantly differed from each other except T4 (12 kg Mn ha^{-1}) and T5 (16 kg Mn ha^{-1}) during both the years. The highest uptake of Mn was achieved in T5 (16 kg Mn ha^{-1}) while lowest from NPK alone (Fig. 1).

Our results are contradictory with Lehoczky & Szalai (2005) who stated no correlation or tendency between the NPK fertilization treatments and available Mn content of soils. There was linear increase in Mn uptake with increasing dose of manganese fertilizer. Our results are in line with Shukla & Warsi (2000) who investigated the effect of micronutrients on the growth and nutrient content of wheat. They applied Mn (0.2% $MnSO_4$ solution) at 25, 37 and 49 DAS, with medium fertilizer levels. Their results showed that the contents of Mn were higher in the grains.

Our findings are also similar to Mosier *et al*., (2004) who reviewed that the available information on the interaction of applied nitrogen (N) with other nutrients such as phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), and trace elements (Zn, Mn and Cu). He described that nitrogen use efficiency (NUE) could be improved with optimum and balanced use of different plant nutrients. Similarly, Fageria *et al*., (1997) showed that manganese application significantly increased Mn uptake in wheat plants. However, it was much higher in wheat plants especially at higher Mn levels. This means Mn requirement for wheat is higher as compared to others crops. Manganese application significantly improved uptake of Mn in wheat. Likewise, Singh & Bharti (2006) using electron spin resonance spectroscopy showed that the Mn^{a+} content of seeds show a direct linear relationship with the height of the wheat cultivars, so, the Mn^{2+} content of the seeds may be taken as a parameter to determine the height of the mature plant.

Present results showed that Mn addition had significant synergistic effect on the uptake of N, P, K and manganese; however Mn had antagonistic effect on uptake of P in wheat plants. Similarly, Modaihsh (1997) found that foliar application of micronutrients (Fe, Cu, Zn and Mn) in the form of sulfate than chelate (either EDTA or EDDHA) generally resulted in higher concentrations of these elements in grain of wheat (*Triticum aestivum* L.) and both Zn and Mn concentrations were considered to be higher than others.

Table 4. Effect of manganese on nitrogen, phosphorus and potassium uptake (kg ha^{-1}) by wheat.

Treatments	Nitrogen			Phosphorus			Potassium		
¶Mn kg ha^{-1}	2005-6	2006-7	Mean	2005-6	2006-7	Mean	2005-6	2006-7	Mean
¤Control (0)	106.03 b	105.71 c	**105.87**	36.20 a	37.00 a	**36.6**	136.67 b	140.67 c	**138.67**
4	109.99 ab	110.49 bc	**110.24**	36.97 a	37.10 a	**37.035**	139.33 ab	147.00 b	**143.165**
8	113.02 a	113.48 ab	**113.25**	37.30 a	37.67 a	**37.485**	141.00 ab	150.33 ab	**145.665**
12	114.40 a	115.28 ab	**114.84**	37.93 a	38.53 a	**38.23**	143.67 ab	153.67 a	**148.67**
16	115.8 a	116.66 a	**116.23**	37.87 a	38.64 a	**38.255**	144.67 a	154.00 a	**149.33**

*Means followed by same letter do not differ significantly at $p \leq 0.05$; ¤N, P and K fertilizers were applied @ 150:100:60 kg N: P_2O_5:K_2O ha^{-1}, respectively in all the treatments; ¶The Mn was applied in the form of Manganese Sulphate by broadcasting in powder form and mixed with soil

Table 5. Effect of manganese on the economics of wheat.

Treatments	Expenditure			†Income from wheat			Increased income	Net	*Value/cost
Mn kg ha^{-1}	°Mn treatment	"Sowing + 'NPK	Total	Grain	Straw	Total	over control	return	(VCR) ratio
[a]Control (0)	0.00	351.51	351.51	717.78	146.63	864.41	0.00	512.90	0.00
4	22.15	351.51	373.66	759.42	154.51	913.93	49.52	540.27	1.45
8	44.31	351.51	395.82	796.53	156.97	953.50	89.09	557.68	1.41
12	66.46	351.51	417.97	824.59	157.75	982.34	117.93	564.37	1.35
16	88.62	351.51	440.13	825.50	158.13	983.63	119.22	543.51	1.23

'Expenditures on NPK sources were as follows: N, 0.276 US$ kg^{-1}; P_2O_5, 0.464US$ kg^{-1}; K_2O, 0.585US$ kg^{-1} (NFDC, 2006)

°Expenditures on Mn source was 5.54 US$ kg^{-1}

"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 was as follows: wheat grain, 181.03 US$ Mg^{-1}; wheat straw = 25.86 US$ Mg^{-1}.

*Value/cost (VCR) ratio = Total income/ Total expenditure

[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 Mn was applied in the form of Manganese sulphate (30 %) by broadcasting in powder form and mixed with soil at the time of seedbed preparation

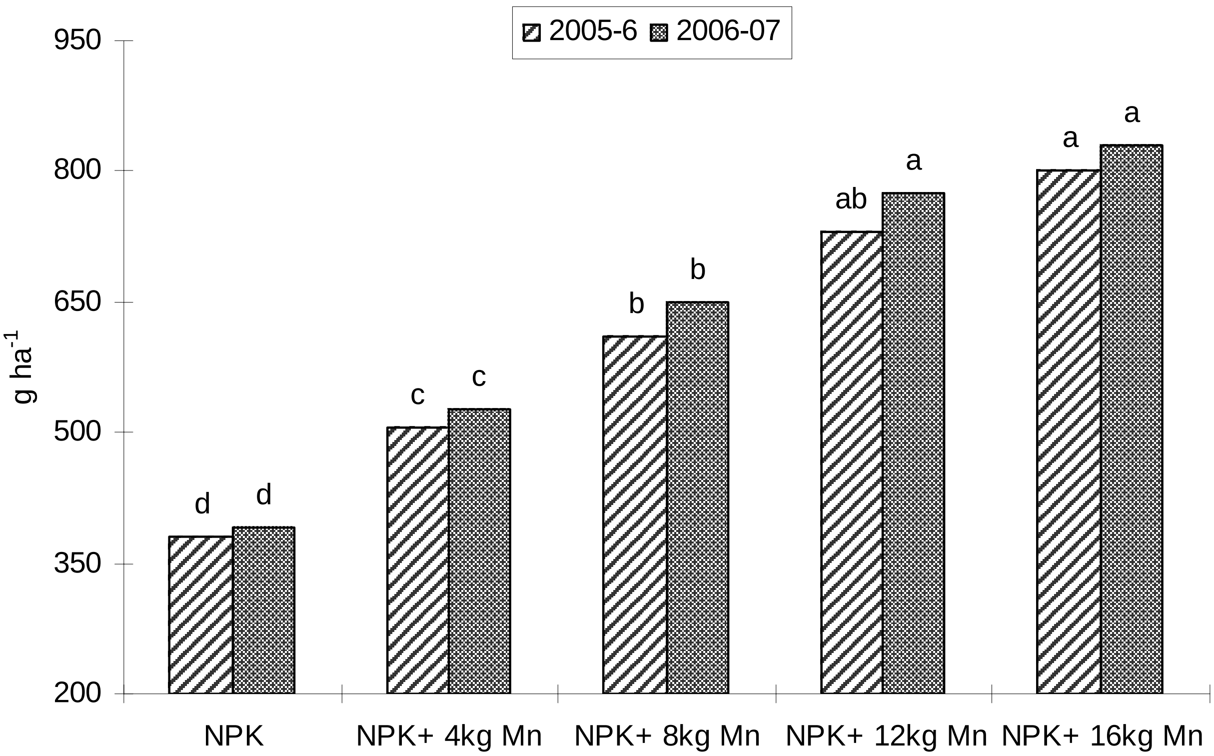

Fig. 1. Effect of different treatments on uptake of Mn by wheat.

Conclusion

The findings suggest that the Mn supplied along with the basal dose of NPK fertilizers resulted in sustainable and high crop production. The application of 12 kg Mn ha^{-1} proved to be the most economical giving highest net return, whereas to achieve maximum yield, Mn can be applied @ 16 kg ha^{-1}.

References

Abrol, I.P., K.F. Bronson, J.M. Duxbury and R.K. Gupta. 1997. Long-term soil fertility experiments in rice-wheat cropping systems: Proceedings of a workshop. October 15-18, India on *Rice-wheat Consortium for the Indo-Gangetic Plains*. pp. 23.

Anonymous. 1971. *Production year Book*, FAO, Rome. 25: 37-41.

Anonymous. 2006. *Fertilizer Review 2005-2006*. NFDC publication No. 2/2006. National Fertilizer Development Centre, Islamabad, Pakistan.

Anonymous. 2007-08. *Economic Survey*. Government of Pakistan, Finance Division, Economic Adviser's Wing, Islamabad, Pakistan.

Cioroi, M. and T. Florea. 2003. The study of manganese content in soil, wheat grain and wheat plants. *Ovidius Univ. Annals Chem.,* 14(1): 9-11.

Fageria, N.K. and V.C Baligar. 1997. Response of common bean, upland rice, corn, wheat and soybean to fertility of an Oxisol. *J. Plant Nutr*., 20: 1279-1289.

Fageria, N.K., F.J.P. Zimmermann and V.C. Baligar. 1995. Lime and phosphorus interactions on growth and nutrient uptake by upland rice, wheat, common bean and corn in an oxisol. *J. Plant Nutr.,* 18: 2519-2532.

Ghasemi-Fasaei, R. and A. Ronaghi. 2008. Interaction of Iron with Copper, Zinc and Manganese in Wheat as Affected by Iron and Manganese in a Calcareous Soil.*J. Plant Nutr.,* 31: 839-848.

Hoyt, P.B. and G.G.S. Myovella. 2005. Correction of severe manganese deficiency in wheat with chemical fertilizers. *Plant & Soil*, 52: 437-444.

Hussain, N., M.A. Khan and M.A. Javed. 2005. Effect of foliar application of plant micronutrient mixture on growth and yield of wheat (*Triticum aestivum* L.). *Pak. J. Biol. Sci*., 8(8): 1096-1099.

Khan, Z.I., A. Hussain, M. Ashraf, E.E. Valeem and I. Javed. 2005. Evaluation of variation in soil and forage micro-mineral concentrations in a semiarid region of Pakistan. *Pak. J. Bot.*, 37: 921-931.

Krahmer, R. and B. Sattelmacher. 2001. Determination of Cu and Mn efficiency of crop plants in pot experiments. In: *Plant Nutrition: Food Security and Sustainability of Agro-Ecosystem through Basic and Applied Research*. (Ed.): W.J. Horst. Kluwer Academic Publishers: The Netherlands. p. 118-119.

Lehoczky, E., K. Debreczeni and T. Szalai. 2005. Available micronutrient contents of soils in long-term fertilization experiments in Hungary. *Comms. Soil Sci. Plant Anal.,* 36: 423-430.

Lewis, D.C. and J.D. McFarlane. 1986. Effect of foliar applied manganese on the growth of safflower (*Carthamus tinctorious* L.) and the diagnosis of manganese deficiency by plant tissue and seed analysis. *Aust. J. Agric. Res*., 37: 567-572.

Lidon, F.C. and M.G. Teixerira. 2000. Rice tolerance to excess Mn: implication in the chloroplast lamellae synthesis of a novel Mn protein. *Plant Physiol. Biochem.*, 38: 969-978.

Modaihsh, A.S. 1997. Foliar application of chelated and non-chelated metals for supplying micronutrients to wheat grown on calcareous soil, *Expl. Agric.,* 33(2): 237–345.

Moodie, D., H.W. Smith and R.A. Mc-Creary. 1959. *Laboratory manual for soil fertility*. Washington state college, Pullman, Washington, USA pp. 31-39.

Mosier, A.R., K.J. Syers, J.R. Freney, M.S. Aulakh and S.S Malhi. 2004. Fertilizer nitrogen use efficiency as influenced by interactions with other nutrients. In: *Agriculture and the Nitrogen Cycle:-Assessing-the Impacts of Fertilizer Use on Food Producion and the Environment*. Island Press. Washington, USA. p. 181-191.

Nayyar, V.K., U.S. Sadana and T.N. Thakkar. 1985. Methods and rates of application of Mn and its critical levels for wheat following rice on coarse texture soils. *Fert. Res*., 8: 173-178.

Parylak, D. and R. Waclawowicz. 2000. Manganese uptake by wheat under differentiated nitrogen fertilization rates. *Zeszyty Problemowe Postepow Nauk Rolniczych,* 471: 419-426.

Puri, A.N. 1966. A new method of estimating total carbonates in soils. *Pusa Bull*. (India): 206.

Rafique, E., A. Rashid, J. Ryan and A.U. Bhatti. 2006. Zinc deficiency in rain fed wheat in Pakistan: Magnitude, spatial variability, management and plant analysis diagnostic norms. *Comms. Soil Sci. Plant Anal.,* 37: 181-197.

Rashid, A. 2005. Establishment and management of micronutrient deficiencies in soils of Pakistan: A review. *J. Soil Environ*., 24(1): 1-22.

Ryan, J., G. Estefan and A. Rashid. 2001. *Soil and Plant Analysis Laboratory Manual, 2nd Ed.* International Centre for Agricultural Research in the Dry Areas (ICARDA). Aleppo and National Agricultural Research Centre (NARC), Islamabad, Pakistan. p. 172.

Sanchez, P.A. and M.S. Swaminathan. 2005. Cutting world hunger in half. *Science,* 307: 357-359.

Shukla, S.K. and A.S. Warsi. 2000. Effect of sulphur and micronutrients on growth, nutrient content and yield of wheat (*Triticum aestivum* L.). *Indian J. Agric. Res.,* 34: 203-205.

Singh, D.K. and S. Bharti. 2006. Seed manganese content and its relationship with the growth characteristics of wheat cultivars. *New Phytol.*, 101: 387-391.

Sultana, N., T. Ikeda and M.A. Kashem. 2001. Effect of foliar spray of nutrient solutions on photosynthesis, dry matter accumulation and yield in seawater-stressed rice. *Environ. Exp. Bot.,* 46: 129-140.

Walkley, A. and C.A. Black. 1934. An estimation of Degtareff methods for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.,* 37: 29-38.

Walsh. L.M and J.B. Beaton. 1973. Sampling, handling and analyzing plant tissue samples. In: **(**Ed.): L.M. Walsh and J.K. Beaton. Soil Testing and Plant Analysis. *Soil Sci. Soc. Am.,* Madisan. WI. 491 p.

Welch, R.M. 2002. The impact of mineral nutrients in food crops on global human health. *Plant Soil*, 247: 83-90.

Ziaeian A.H. and M.J. Malakouti. 2006. Effects of Fe, Mn, Zn and Cu fertilization on the yield and grain quality of wheat in the calcareous soils of Iran. *Plant Nutr. Food security sustainability agro-ecosysts.,* 92: 840-841.

Ziaeian, A.H. and M.J. Malakouti. 2001. Effects of Fe, Mn, Zn and Cu fertilization on the yield and grain quality of wheat in the calcareous soils of Iran. In: *Plant nutrition -Food security and sustainability of agro-ecosystems*. (Eds.): W.J. Horst, *et al.,* Kluwer Academic Publishers. Netherlands. p. 840-841.

(Received for publication 3 February 2009)