The Journal of Animal & Plant Sciences, 22(1): 2012, Page: 113-119
ISSN: 1018-7081

RESPONSE OF WHEAT (*Triticum aestivum* L.) TO DIFFERENT MICRONUTRIENTS AND THEIR APPLICATION METHODS

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ABSTRACT

Growth and yield response of wheat variety Gomal-8 was evaluated using micronutrients and their application methods. The trial was laid out in a randomized complete block design with split-plot arrangements. Five different micronutrients were placed in main plot while their three application methods were assigned to sub-plots. Results revealed that application of boron @ 2 kg ha^{-1} produced higher crop growth rate (23.58 g m^{-2} day^{-1}), net assimilation rate (2.82 mg m^{-2} day^{-1}), number of tillers (234.5 m^{-2}), number of grains (52.92 $spike^{-1}$) and grain yield (3.14 t ha^{-1}). The use of iron @ 12 kg ha^{-1} also showed encouraging results similar to boron. Among various application methods, side dressing at 4 weeks after sowing (WAS) showed the best results as compared to soil application and foliar spray. Higher leaf area index and crop growth rate was obtained with the application of zinc @ 10 kg ha^{-1}. Also, different micronutrients had significant interaction with application methods for physiological and agronomic traits including number of tillers, leaf area index (LAI), crop growth rate (CGR), net assimilation rate (NAR) and grain yield. Side dressing best interacted with boron for producing higher number of tillers, grains per spike, net assimilation rate and grain yield. This method showed better combination with iron for higher number of tillers, LAI and grain yield.
Key words: Wheat, micronutrients, application methods, growth, LAI.

INTRODUCTION

Wheat is the major source of plant based human nutrition and a part of daily dietary need in one form or the other. A conservative estimate illustrates two and half times low yield in Pakistan than other wheat producing countries of the world including China, India, USA, Russia and France (Khan *et al*., 2000). Low quality seed, salinity, water logging, inadequate use of fertilizers, lack of irrigation water, high input prices, low farmers' education and no use of micronutrients and organic fertilizers are the major reasons for low wheat production (Khan *et al*., 1999). Micronutrients play a pivotal role in the yield improvement (Rehm and Sims, 2006). They are needed in trace amounts but their adequate supply improves nutrients availability and positively affects the cell physiology that is reflected in yield as well (Taiwo *et al.,* 2001; Adediran *et al.,* 2004). Micronutrients deficiency is widespread in many Asian countries due to the calcareous nature of soils, high pH, low organic matter, salt stress, prolonged drought, high bicarbonate contents in irrigation water and imbalanced application of NPK fertilizers (Ahmadikhah *et al.,* 2010). Induced stress in plants including low crop yield and quality, imperfect plant morphological structure (such as fewer xylem vessels of small size), widespread infestation of various diseases and pests and lower fertilizer use efficiency are some of the adverse effects of micronutrient deficiency (Malakouti, 2008). Their lack greatly influences both the quantity and the quality of plant products (Ahmadikhah *et al.,* 2010). Kumar *et al.* (2009) depicted that Cu fluxes and its interactions with other micronutrients (Fe, Mn, Zn) affects the growth and yield of wheat plants while Cu excess may induce the deficiency of other micronutrients and adversely affect the yield. Micronutrient deficiency has become a major constraint for crop productivity that may either be primary, due to their low total contents or secondary, caused by soil factors that reduce their availability to plants (Sharma and Chaudhary, 2007). The use of micronutrients is also important because of increasing economic and environmental concerns (Siddiqui *et al.,* 2009). Khan *et al.* (2006) reported that Cu, Fe, Mn and Zn contents of leaf, straw and grain of wheat increased with the application of mineral fertilizers. Soleimani (2006) found that integrated application of Zn through soil and foliar spray affected the Mn and Cu contents of wheat grains. More to the point, application methods for trace elements also affect the crop growth and yield. Arif *et al.* (2006) advocated foliar sprays of nutrient solution at tillering, jointing and boot stages along with half of the recommended doses of N and P to increase yield and yield components of wheat. Kinaci and Gulmezoglu (2007) revealed that foliar treatments had positive effect on the yield attributes. With this in view, a research trial was conducted to utilize these rich sources of plant food in different ways as no attempts have ever been made to evaluate this issue under the agro-climatic conditions of the area.

MATERIALS AND METHODS

The present study was carried out at the Agricultural Research Institute, Dera Ismail Khan during the year 2009-10. The experiment was laid out in a randomized complete block design with split-plot arrangements and replicated 4 times. Micronutrients viz. Zinc (10 kg ha^{-1}), Copper (8 kg ha^{-1}), Iron (12 kg ha^{-1}), Manganese (12 kg ha^{-1}) and Boron (2 kg ha^{-1}) were assigned to main plot and applied in the form of $ZnSO_4$, $CuSO_4$, $FeSO_4$, $MnSO_4$ and Borax. The application methods viz. side dressing (4 WAS), foliar application (4 WAS) and soil application (at sowing) were assigned to sub-plot. Basel fertilizer dose @ 150-120-90 kg NPK ha^{-1} in the form of Urea, Di-Ammonium Phosphate and Potassium Sulphate, respectively were applied to all treatments. Half dose of nitrogen and full doses of P_2O_5 and K_2O were applied at the time of sowing while remaining half nitrogen was applied with first irrigation. Sowing was done by hand drill with plant to plant and row to row distance of 10 and 30 cm, respectively. The net plot size was 1.8 x 5 m^2. A seed rate of 100 kg ha^{-1} of wheat variety "Gomal-8" was used. Geographical coordinates of the experimental site was 31° north, 70° east having clay-loam soil of pH 7.6 and 0.68% organic matter. Soil fertility status showed 0.042% nitrogen, 10.11 ppm phosphorus and 400 ppm exchangeable potassium. The weather condition of the experimental site is given in Table-1.

All other cultural practices were followed according to standard recommendations for the locality. Data on leaf area index (49 and 98 DAS), leaf area duration (49 and 98 DAS), crop growth rate (g m^{-2} day^{-1}), relative growth rate (g g^{-1} day^{-1}), net assimilation rate (mg m^{-2} day^{-1}), number of tillers (m^{-2}), grains ($spike^{-1}$), 1000-seed weight (g) and grain yield (t ha^{-1}) were recorded and analyzed statistically using analysis of variance techniques (Steel and Torrie, 1984) and means were separated by Duncan's new multiple range test (Gomez and Gomez, 1976). Data were analyzed using MSTAT-C computer software program.

RESULTS AND DISCUSSION

Leaf area index (LAI) at 49 and 98 days after sowing: LAI is the ratio of total leaf area to ground cover and typically increases to a maximum after crop emergence. The data revealed that different micronutrients and their application methods did not affect leaf area index significantly at 49 days after sowing (Table-2). However, the maximum LAI of 0.16 was recorded in B and Cu treated plots. Application methods as well as their interaction with different micronutrients were non-significant statistically. The use of trace elements, however, significantly affected the leaf area index at 98 days after sowing (Table-3). It is evident from the results that leaf area index increased linearly from one growth phase to another. The maximum leaf area index (2.85) was observed in Zn application which was statistically at par with 2.68 and 2.52 recorded in B and Fe application, respectively. Availability of sufficient nutrients resulted in higher leaf area, which in turn boosted the photosynthetic activity and ultimately higher dry matter accumulation. These findings are supported by Nataraja *et al.* (2006) who observed significantly higher LAI by the combined application of P_2O_5 and $ZnSO_4$ at 90 DAS. Among the application methods, placement of micro-elements aside the rows facilitated the plants to absorb efficiently while foliar application also showed instant intake of nutrients by the plants which resulted the maximum leaf area indices of 2.63 and 2.48 in side dressing and foliar spray as compared to LAI of 2.32 in soil application. The interaction between micronutrients and application methods was significant statistically. Side dressing of Zn and Fe produced LAI of 3.29 and 3.16, respectively which was statistically at par with Zn (3.01 LAI) in soil application and B (2.98 LAI) in foliar spray. Ziaeian and Malakouti (2001) also showed that application of Zn and Fe significantly increased the concentration and total uptake of these nutrients in grain, flag leaves grain protein contents as well.

Leaf area duration (LAD) at 49 and 98 days after sowing: Leaf area duration expresses the magnitude and persistence of leaf area or leafiness during the crop growth period. The data on LAD at 49 days after sowing showed that different micronutrients, application methods and their interaction was non-significant statistically (Table-4). Among micro-elements, the use of Cu, however, produced the maximum LAD (1.16) while 1.09 LAD was recorded in foliar spray. As far as the interaction is concerned, Cu in foliar spray and B in soil application produced the highest LAD (1.25 and 1.24). Leaf area duration provides a means for comparing treatments on the basis of leaf persistence which reflects the extent of light interception, higher the leaf area index more will be the LAD (Reddy, 2004). The data presented in Table-5 indicated that micronutrients and their application methods had significant effect on LAD at 98 days after sowing. Higher persistence of leaves and leaf area index by Zn application resulted into the maximum LAD (39.90) which was statistically at par with B (37.54), Fe (35.22) and Cu (33.08) application. Nataraja *et al.* (2006) also reported that combined application of P_2O_5 and $ZnSO_4$ produced significantly higher LAD at 60-90 days after sowing. Similarly, side dressing produced 36.88 which was statistically at par with foliar spray (34.76 LAD). The interaction between two factors was significant statistically. Side dressing of Zn and Fe showed the maximum LAD (46.03 and 44.28) that was statistically similar to soil application of Zn (42.12), foliar and soil application of B (41.72 and 39.91). The minimum leaf area duration (24.49) was observed in soil application of Cu.

Crop growth rate (g m^{-2} day^{-1}): Crop growth rate refers to the dry matter production in a unit of time. Various factors including temperature, solar radiation, age of cultivar and water/nutrient supply affect the CGR. The data exhibited that application of micronutrients had non-significant effect on crop growth rate (Table-6). The higher CGR (23.58) was, however, recorded by the application of B followed by Zn application (20.59 g m^{-2} day^{-1}) while the minimum CGR (19.47) was recorded in Cu treated plots. Among different application methods, side dressing after four weeks of sowing showed better results due to sufficient availability of nutrients at the time when plants required nutritional supplement which influenced the size and efficiency of leaf canopy and hence the ability of crop to convert solar energy into economic growth (Reddy, 2004). Significantly higher CGR (22.15) was observed in side dressing while soil application and foliar spray had statistically similar (20.30 and 19.24 g m^{-2} day^{-1}) crop growth rate. As far as the interaction is concerned, foliar spray of B had CGR (26.39) similar to the soil application of the same element (25.13) and side dressing of Zn (23.11 g m^{-2} day^{-1}). Nataraja *et al.* (2006) recorded significantly higher CGR by the soil application of Zn at 60-90 days after sowing. It was also noticed that foliar application of Cu initially caused leaves burning which subsequently reduced the CGR. Toxicity of the same element (Cu) also affected the soil status thereby producing the lowest CGR (16.13) in soil application method.

Relative growth rate (g g^{-1} day^{-1}): Growth parameters such as germination, leaf area index, relative growth rate and net assimilation rate are very important to assess the plant growth. Relative growth rate (RGR) expresses the dry weight increase in time interval in relation to the initial weight. Since crop growth rate is an absolute measure of growth, similar values could be expected for different initial weights (Reddy, 2004). The data regarding RGR was not significantly affected by micronutrients, application methods and their interaction (Table-7). However, the plants treated with boron and iron accumulated more dry matter as compared to other micro elements. The highest relative growth rate (0.082 and 0.081 g g^{-1} day^{-1}) was obtained in B and Fe application. Similarly, side dressing and soil application had the same relative growth rate (0.081 g g^{-1} day^{-1}). The data further indicated that soil application of B and side dressing of Fe and Zn produced the highest relative growth rates of 0.086, 0.084 and 0.083 g g^{-1} day^{-1}, respectively. The lowest relative growth rate (0.074 g g^{-1} day^{-1}) was recorded in foliar application of Zn. These results are supported by Shukla and Warsi (2000) who reported that application of B and Fe had no significant effect on the relative growth rate and dry matter accumulation of wheat.

Net assimilation rate (mg m^{-2} day^{-1}): NAR expresses plant's capacity to increase dry weight in terms of the area of its assimilatory surface. The term, therefore, represents the photosynthetic efficiency in the overall sense and in connection with LAR and RGR (Reddy, 2004). Different micronutrients and their application methods had significant effect on net assimilation rate (Table-8). Higher concentrations of B in the leaves and leaf tips resulted in increased photosynthesis and more chlorophyll formation. Among the micronutrients, B application accumulated the maximum (2.82) and statistically similar assimilates to Mn (2.62 mg m^{-2} day^{-1}). These were followed by rest of three micronutrients i.e. Cu, Fe and Zn showing statistically similar NAR (2.40, 2.37 and 2.26 mg m^{-2} day^{-1}). Among the application methods, side dressing and soil application of micro-elements resulted in the maximum NAR (2.62 and 2.59 mg m^{-2} day^{-1}). Micronutrients and their application methods significantly interacted with each other. Side dressing of B had significantly higher NAR (3.36) followed by soil application of the same element (2.77 mg m^{-2} day^{-1}). Foliar spray of Zn showed the minimum net assimilation rate (2.06 mg m^{-2} day^{-1}). These results are in line with Shukla and Warsi (2000) who reported that all the growth parameters including NAR were highest with the application of NPK along with micronutrients.

Number of tillers (m^{-2}): The number of tillers depends on the genotype, environment as well as the plant nutrition. The data presented in Table-9 revealed significant variations in micronutrients and their application methods. Among treatments, application of B produced the maximum tillers (234.5) which were statistically at par with 228.6 tillers m^{-2} recorded in Fe treatment. These treatments were significantly different from Zn (217.5) and Cu (211.8 tillers m^{-2}) treated plots while the lowest number of tillers (201.3) was recorded by the use of Mn. The placement of micronutrients around the plants greatly influenced the crop status, particularly the way and time of application. Amongst different methods, side dressing produced significantly the highest tillers (237.1) as compared to 204.1 tillers m^{-2} recorded in soil application method. As far as the interaction is concerned, side dressing was best interacted with B producing 291.3 tillers m^{-2} followed by the same method with Fe (259.8 tillers m^{-2}). These results coincide with Uddin *et al.* (2008) who reported that application of boron significantly increased the number of tillers over control. Soil application had poor interaction with Fe producing 173.3 tillers m^{-2}.

Number of grains ($spike^{-1}$): Generally the spikes per unit area and number of grains $spike^{-1}$ are the most important determinants of the yield which are affected by various factors including balanced nutrition. As shown in Table-10, different micronutrients significantly affected, however, their application methods had non-significant effect on number of grains spike^{-1}. Among trace elements, the use of B produced the highest number of grains (52.92) followed by Fe application (46.17 grains spike^{-1}). Boron is basically responsible for fruit setting and qualitative improvement which resulted in increased number of grains. Plots receiving Cu produced 46.08 grains which were statistically at par with Mn (45.50 spike^{-1}). Among different application methods, side dressing showed 47.20 grains spike^{-1}. Though non-significant statistically, the application of B produced the highest number of grains spike^{-1} in foliar spray (54.25), side dressing (53.75) and soil application (50.75), respectively. The highest number of grains recorded in B treated plots was because of the reason that this element is responsible for the grain formation and fruit setting in crop plants. The results are in line with Uddin *et al.* (2008) who obtained higher number of grains (spike^{-1}) by the application of boron. The present results are further supported by Tahir *et al.* (2009) who recorded significant increase in number of grains spike^{-1} with the foliar application of boron.

Table 1. Average monthly and seasonal meteorological data during the year 2009-10.

Month	Temp. (^{0}C) Max	Temp. (^{0}C) Min	Relative Humidity 0800 Hrs.	Relative Humidity 1400 Hrs.	Rainfall (mm)
October	33	16	82	57	13
November	25	10	80	55	-
December	22	5	81	63	-
January	16	5	88	76	9.2
February	22	8	76	58	1.1
March	30	15	63	63	22
April	37	19	74	45	-

Table 2. Leaf area index (49 DAS) as affected by different micronutrients and their application methods in wheat.

Micronutrients	Application Methods: Side Dress	Foliar Spray	Soil Appl.	Means
Zinc (Zn)	0.15 NS	0.15	0.14	0.15 NS
Copper (Cu)	0.17	0.18	0.14	0.16
Iron (Fe)	0.17	0.14	0.14	0.15
Manganese (Mn)	0.15	0.15	0.14	0.15
Boron (B)	0.13	0.16	0.16	0.16
Means	**0.15 NS**	**0.15**	**0.14**	

NS = Non significant

1000-seed weight (g): Thousand grain weight depends on the genetic makeup of genotypes. It is an absolute value which is seldom changed or affected by the environmental behavior. Similar results were obtained in the present study where different micronutrients, their application methods as well as the interaction of these two factors had no significant effect on seed weight of

Table 3. Leaf area index (98 DAS) as affected by different micronutrients and their application methods in wheat.

Micronutrients	Application Methods: Side Dress	Foliar Spray	Soil Appl.	Means
Zinc (Zn)	3.29^{a}	2.26^{def}	3.01^{ab}	2.85^{a}
Copper (Cu)	2.69^{bcd}	2.65^{bcd}	1.75^{f}	2.36^{ab}
Iron (Fe)	3.16^{ab}	2.35^{cde}	2.03^{ef}	2.52^{a}
Manganese (Mn)	1.82^{ef}	2.17^{def}	1.96^{ef}	1.99^{b}
Boron (B)	2.21^{def}	2.98^{ab}	2.85^{abc}	2.68^{a}
Means	**2.63^{a}**	**2.48^{ab}**	**2.32^{b}**	

$LSD_{0.05}$ for micronutrients = 0.469.
$LSD_{0.05}$ for application methods = 0.210.
$LSD_{0.05}$ for micronutrients x application methods = 0.470
Any two means in their respective group sharing no common letter(s) are significant (P<0.05).

Table 4. Leaf area duration (49 DAS) as affected by different micronutrients and their application methods in wheat.

Micronutrients	Application Methods: Side Dress	Foliar Spray	Soil Appl.	Means
Zinc (Zn)	1.04 NS	1.07	1.00	1.04 NS
Copper (Cu)	1.22	1.25	1.01	1.16
Iron (Fe)	1.17	0.98	0.99	1.05
Manganese (Mn)	1.03	1.02	0.99	1.01
Boron (B)	0.88	1.15	1.24	1.09
Means	**1.07 NS**	**1.09**	**1.05**	

NS = Non significant

Table 5. Leaf area duration (98 DAS) as affected by different micronutrients and their application methods in wheat

Micronutrients	Application Methods: Side Dress	Foliar Spray	Soil Appl.	Means
Zinc (Zn)	46.03^{a}	31.57^{def}	42.12^{ab}	39.90^{a}
Copper (Cu)	37.63^{bcd}	37.11^{bcd}	24.49^{f}	33.08^{ab}
Iron (Fe)	44.28^{ab}	32.93^{cde}	28.45^{ef}	35.22^{a}
Manganese (Mn)	25.49^{ef}	30.49^{def}	27.52^{ef}	27.83^{b}
Boron (B)	30.98^{def}	41.72^{ab}	39.91^{abc}	37.54^{a}
Means	**36.88^{a}**	**34.76^{ab}**	**32.50^{b}**	

$LSD_{0.05}$ for micronutrients = 6.560
$LSD_{0.05}$ for application methods = 2.940
$LSD_{0.05}$ for micronutrients x application methods = 6.575
Any two means in their respective group sharing no common letter(s) are significant (P<0.05).

wheat (Table-11). Among trace elements, the highest grain weight (43.43 g) was recorded in Mn treated plots and 42.91 g in side dressing method. As far as the interaction is concerned, Mn in side dressing and Cu in foliar spray produced higher seed weight of 43.82 and 43.62 g.

Table 6. Crop growth rate (g m^{-2} day^{-1}) as affected by different micronutrients and their application methods in wheat.

Micronutrients	Application Methods			Means
	Side Dress	Foliar Spray	Soil Appl.	
Zinc (Zn)	23.11^{ab}	15.97^{e}	22.68^{bc}	20.59^{NS}
Copper (Cu)	22.57^{bc}	19.72^{cd}	16.13^{e}	19.47
Iron (Fe)	23.14^{b}	16.52^{de}	18.91^{de}	19.53
Manganese (Mn)	22.70^{bc}	17.58^{de}	18.67^{de}	19.65
Boron (B)	19.22^{de}	26.39^{a}	25.13^{ab}	23.58
Means	**22.15^{a}**	**19.24^{b}**	**20.30^{b}**	

NS = Non significant
$LSD_{0.05}$ for application methods = 1.358
$LSD_{0.05}$ for micronutrients x application methods = 3.036
Any two means in their respective group sharing no common letter(s) are significant (P<0.05).

Table 7. Relative growth rate (g g^{-1} day^{-1}) as affected by different micronutrients and their application methods in wheat.

Micronutrients	Application Methods			Means
	Side Dress	Foliar Spray	Soil Appl.	
Zinc (Zn)	0.083^{NS}	0.074	0.081	0.079^{NS}
Copper (Cu)	0.077	0.078	0.077	0.078
Iron (Fe)	0.084	0.079	0.080	0.081
Manganese (Mn)	0.080	0.078	0.079	0.079
Boron (B)	0.078	0.081	0.086	0.082
Means	**0.081^{NS}**	**0.078**	**0.081**	

NS = Non significant

Table 8. Net assimilation rate (mg m^{-2} day^{-1}) as affected by different micronutrients and their application methods in wheat.

Micronutrients	Application Methods			Means
	Side Dress	Foliar Spray	Soil Appl.	
Zinc (Zn)	2.30^{b-e}	2.06^{e}	2.41^{b-e}	2.26^{b}
Copper (Cu)	2.47^{b-e}	2.20^{cde}	2.52^{b-e}	2.40^{b}
Iron (Fe)	2.33^{b-e}	2.11^{de}	2.65^{bc}	2.37^{b}
Manganese (Mn)	2.66^{bc}	2.72^{bc}	2.60^{bcd}	2.62^{a}
Boron (B)	3.36^{a}	2.32^{b-e}	2.77b	2.82^{a}
Means	**2.62^{a}**	**2.28^{b}**	**2.59^{a}**	

$LSD_{0.05}$ for micronutrients = 0.223
$LSD_{0.05}$ for application methods = 0.205
$LSD_{0.05}$ for micronutrients x application methods = 0.458
Any two means in their respective group sharing no common letter(s) are significant (P<0.05).

Table 9. Number of tillers (m^{-2}) as affected by different micronutrients and their application methods in wheat.

Micronutrients	Application Methods			Means
	Side Dress	Foliar Spray	Soil Appl.	
Zinc (Zn)	217.0^{ef}	200.0^{fgh}	234.5^{cde}	217.5^{b}
Copper (Cu)	231.8^{de}	191.5^{hi}	212.0^{fg}	211.8^{b}
Iron (Fe)	259.8^{b}	252.8^{bc}	173.3^{i}	228.6^{a}
Manganese (Mn)	185.5^{hi}	237.5^{cd}	181.0^{hi}	201.3^{c}
Boron (B)	291.3^{a}	193.3^{ghi}	219.0^{def}	234.5^{a}
Means	**237.1^{a}**	**215.0^{b}**	**204.1^{c}**	

$LSD_{0.05}$ for micronutrients = 8.075
$LSD_{0.05}$ for application methods = 8.087
$LSD_{0.05}$ for micronutrients x application methods =18.08
Any two means in their respective group sharing no common letter(s) are significant (P<0.05).

Table 10. Number of grains ($spike^{-1}$) as affected by different micronutrients and their application methods in wheat.

Micronutrients	Application Methods			Means
	Side Dress	Foliar Spray	Soil Appl.	
Zinc (Zn)	44.50^{NS}	38.75	48.50	43.92c
Copper (Cu)	45.75	47.00	45.50	46.08^{bc}
Iron (Fe)	46.25	49.00	43.25	46.17^{b}
Manganese (Mn)	45.75	46.25	44.50	45.50^{bc}
Boron (B)	53.75	54.25	50.75	52.92^{a}
Means	**47.20^{NS}**	**47.05**	**46.50**	

NS = Non significant
$LSD_{0.05}$ for micronutrients = 2.085
Any two means in their respective group sharing no common letter(s) are significant (P<0.05).

Table 11. 1000-seed weight (g) as affected by different micronutrients and their application methods in wheat.

Micronutrients	Application Methods			Means
	Side Dress	Foliar Spray	Soil Appl.	
Zinc (Zn)	43.11^{NS}	42.18	42.21	42.50^{NS}
Copper (Cu)	43.15	43.65	41.77	42.85
Iron (Fe)	42.07	41.60	42.56	42.08
Manganese (Mn)	43.82	42.92	43.54	43.43
Boron (B)	42.38	42.28	42.80	42.49
Means	**42.91^{NS}**	**42.53**	**42.58**	

NS = Non significant

Grain yield (t ha^{-1}): Crop productivity is the rate at which a crop accumulates organic matter which depends primarily on the rate of photosynthesis and conversion of light energy to chemical energy by green plants (Reddy, 2004). The yield of wheat is composed of three components i.e. number of spikes, kernels spike^{-1} and kernels weight. Though, kernel weight does exert an influence on grain yield but its effect is lower than spikes and kernels spike^{-1}. The data given in Table-12 revealed significant differences in grain yield due to micronutrients, their application methods as well as the interaction between two factors. Among micronutrients, the use of B produced grain yield (3.14 t ha^{-1}), which was statistically at par with Fe that produced grain yield of 3.07 t ha^{-1}. The higher grain yield in B treated plots was because of more number of tillers as well as number of grains spike^{-1}. Among the application methods, side dressing produced the highest grain yield (3.04 t ha^{-1}) while foliar spray and soil application methods had statistically similar grain yield of 2.97 and 2.94 t ha^{-1}, respectively. Several reports indicated that either soil or foliar application of micronutrients had positive correlation with wheat yield (Habib, 2009; Wroble, 2009). The interaction between micronutrients and application methods showed that side dressing of B produced significantly highest grain yield (3.58 t ha^{-1}). These results are supported by Chaudry *et al.* (2007) who reported that Fe and B, either single or in combination, along with basal dose of NPK significantly increased the wheat yield. Abbas *et al*. (2009) reported increased grain yield of wheat by the application of Fe whereas the higher rate of Fe had no significant effect on crop yield. Uddin *et al.* (2008) also obtained 50% increase in grain yield by the application of boron.

Table 12. Grain yield (t ha^{-1}) as affected by different micronutrients and their application methods in wheat.

Micronutrients	Application Methods			Means
	Side Dress	Foliar Spray	Soil Appl.	
Zinc (Zn)	2.57^{k}	2.86^{g-j}	3.01^{def}	2.82^{d}
Copper (Cu)	2.77^{ij}	2.92^{e-h}	3.05^{de}	2.92^{cd}
Iron (Fe)	3.44^{b}	2.79^{hij}	2.99^{d-g}	3.07^{ab}
Manganese (Mn)	2.81^{hij}	3.20 c	2.90^{f-i}	2.97^{bc}
Boron (B)	3.58^{a}	3.09^{cd}	2.74^{j}	3.14^{a}
Means	**3.04^{a}**	**2.97^{b}**	**2.94^{b}**	

$LSD_{0.05}$ for micronutrients = 0.134
$LSD_{0.05}$ for application methods = 0.055
$LSD_{0.05}$ for micronutrients x application methods = 0.129
Any two means in their respective group sharing no common letter(s) are significant (P<0.05).

Conclusion: The present research revealed varying results in wheat production. Various micronutrients and their application methods had significant effect on plant growth and yield. Boron application boosted plant growth with higher crop growth rate, relative growth rate and net assimilation rate. Among yield contributing parameters, plots treated with same element showed the best results while side dressing was the best application method. The said method also significantly interacted with boron application and combination gave the best results for number of tillers, number of grains (spike^{-1}) and grain yield as well.

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