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MICRONUTRIENT USE EFFICIENCY IN WHEAT AS AFFECTED BY DIFFERENT APPLICATION METHODS

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Abstract

The present research was carried out to investigate the effect of micronutrients and their application methods on wheat variety Gomal-8 under the agro-ecology of Dera Ismail Khan, Pakistan, during the year 2010-11. The trial was laid out in a randomized complete block design with split-plot arrangements. Main plot possessed five micronutrients viz., Zn, Cu, Fe, Mn and B while application methods (side dressing, foliar application and soil application) were assigned to sub-plots. The results revealed that boron application @ 2 kg ha^{-1} recorded higher crop growth rate (30.14 g m^{-2} day^{-1}), net assimilation rate (2.78 mg m^{-2} day^{-1}), number of tillers (307.00 m^{-2}), number of grains $spike^{-1}$ (61.08) and grain yield (5.63 t ha^{-1}). The use of copper @ 8 kg ha^{-1} also showed encouraging results similar to boron. Among various application methods, soil application (at sowing) showed the best results as compared to side dressing and foliar application both at 4 weeks after sowing (WAS). Also, different micronutrients significantly interacted with the application methods for physiological and agronomic traits including leaf area index (LAI), crop growth rate (CGR), net assimilation rate (NAR) and grain yield. Soil application best interacted with boron for producing higher number of tillers, grains $spike^{-1}$, grain yield and almost all the physiological traits. This combination also resulted in the best net returns with higher benefit cost ratio.

Introduction

Wheat is the chief source of plant based human nutrition and is a part of our daily dietary needs. Being a staple food, it is cultivated on about eight million hectares in the country with 13.7% contribution to the value addition in agriculture sector and 3% in the gross domestic products (Nawab *et al*., 2011). Wheat yield in Pakistan is almost two and half times low as compared to other wheat producing countries of the world while bridging up this gap is a challenging scenario for the scientists as well as the farmers (Nadim *et al*., 2011; Hussain *et al.,* 2012). Different factors such as seed quality, soil salinity, water logging, higher prices, poor management and distribution of irrigation water, improper and inadequate use of fertilizers supplied with no additional micronutrients are the limiting factors towards higher production (Iftikhar *et al.,* 2010). In Pakistan, generally the use of NP is only required for growth and development whilst micronutrients are neglected because the farmers are poor and illiterate (Nawab *et al*., 2011; Babar *et al.,* 2011). Many researchers reported that the use of micronutrients have a promising role in growth and development of crop plants which resulted in improved quality and quantity of the agricultural produce. Micronutrients have been well documented to be involved in photosynthesis, N-fixation, respiration and other biochemical pathways. Reddy (2004) stated that micronutrients help in chlorophyll formation, nucleic acid, protein synthesis and play an active role in several enzymatic activities of photosynthesis. Although, micronutrients are required in trace amounts but their adequate supply improves nutrient availability and positively affect the cell physiology that is reflected in yield as well (Taiwo *et al*., 2001; Adediran *et al*., 2004). Under increased cropping intensity, emerging deficiencies of iron, zinc, sulfur and manganese have become critical which can be managed by soil fertility restoration practices (Rekhi *et al*., 2000). Their lack greatly influences the quantity and quality of plant products (Ahmadikhah *et al*., 2010). Micronutrient deficiency has become a major yield limiting factor that may either be primary, due to their low total contents or secondary, caused by soil factors that reduce their availability to plants (Sharma & 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. More to the point, application methods for the use of micronutrients also affects the crop growth and yield. Chaudry *et al*., (2007) reported that micronutrients (Zn, Fe, B) significantly increased the wheat yield over control while Chowdhury *et al*., (2008) revealed that application of boron (soil + foliar) was the best method to increase grain yield of wheat. Therefore, by supplying plants with micronutrients, either through soil application, foliar spray or side dressing, the quality and yield of crops is improved (Malakouti, 2008). Arif *et al*., (2006) reported that foliar application of micronutrients at tillering, jointing and booting stages help in improving yield of wheat. While zinc, copper, iron and manganese contents of leaf, straw and grain of wheat increased with the application of conditioner and mineral fertilizers. Keeping this in view, the present research was undertaken to utilize these rich sources of plant food nutrients in different ways as no such attempts have ever been made under the agro-climatic conditions of the area.

Materials and Methods

The trial was laid out in a randomized complete block design with split-plot arrangements having four replications. The sub-plot size was 1.8 × 5 (9 m^2) with 6 rows of 5 m length and 30 cm apart. Main plot consisted five micronutrients (Zn, Cu, Fe, Mn and B) while the application methods viz. side dressing (4 WAS), foliar application (4 WAS) and soil application (at sowing) were assigned to the sub-plots. These micronutrients were used in the form of zinc sulphate, copper sulphate, iron sulphate, manganese sulphate and borax. The recommended fertilizer doses of NPK @ 150-120-90 kg ha^{-1} in the form of urea, di-ammonium phosphate and potassium sulphate were uniformly applied to all treatments. Half dose of nitrogen and full 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 using recommended seed rate of 100 kg ha^{-1}. High yielding, well adopted wheat variety Gomal-8 was used in this experiment. 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. Herbicides Buctril Super @ 750 ml ha^{-1} and Puma Super @ 625 ml ha^{-1} were used to control weed flora in the experiment. Detail of the experimental treatments is presented as under;

Factor-A (Main plot)

M_1 = Zinc @ 10 kg ha^{-1}
M_2 = Copper @ 8 kg ha^{-1}
M_3 = Iron @ 12 kg ha^{-1}
M_4 = Manganese @ 12 kg ha^{-1}
M_5 = Boron @ 2 kg ha^{-1}

Factor-B (Sub-plots)

S_1 = Side dressing (4 weeks after sowing)
S_2 = Foliar application (4 WAS)
S_3 = Soil application (at sowing)

Data on leaf area index (49 and 98 DAS), crop growth rate (g m^{-2} 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 *et al*., 1997) and subsequently the individual treatment means were compared by Tukey HSD Test (Gomez and Gomez, 1984). The analysis was performed by using "Statistix 8.1" computer software program.

Results and Discussion

Leaf area index (m^{-2}) at 49 days after sowing: The data given in Table-1 revealed that different micronutrients significantly affected leaf area index (LAI) 49 DAS while no statistical difference was noted among the application methods. The maximum LAI (0.35) was recorded in boron treatment. The use of copper, manganese and iron produced LAI of 0.32, 0.31 and 0.30, respectively. These treatments were, however, statistically at par with each other. The application of zinc produced the minimum LAI (0.28). Methods of micronutrients application had no significant effect on LAI. As far as the interaction of micronutrients and their application methods is concerned, significantly higher LAI (0.44) was obtained in soil application of boron. This was statistically at par with LAI of 0.42 & 0.40 recorded in side dressing (4 WAS) of iron and foliar application (4 WAS) of boron, respectively. However, foliar application of zinc exhibited the minimum LAI (0.21). Higher LAI in boron treated plots might be due to better translocation of food as well as its higher concentrations in the apical portion of the leaves which enhanced the plant growth. Likewise, the use of boron helped plants in chlorophyll formation with increased photosynthetic activities (Manal *et al.,* 2010).

Leaf area index (m^{-2}) at 98 days after sowing: The trend of producing LAI at 98 DAS was similar to that of LAI at 49 DAS. The data shown in Table-2 revealed that use of trace elements significantly affected LAI while non-significant variations were noted in different application methods. It is evident from the results that LAI increased linearly from one growth phase to another. The maximum LAI (3.25) was recorded in boron treatment. It was statistically at par with LAI of 3.12 & 3.04 recorded in copper and manganese treatments, 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 Tahir *et al*., (2009) who reported that boron application is essential for cell division, elongation of meristematic tissues and leaves expansion. The minimum LAI (2.62) was recorded in zinc treatment. Among the application methods, soil application (at sowing) showed instant intake of nutrients by the plants which resulted in maximum LAI of 2.99. The placement aside the rows (4 WAS) also facilitated the plants to absorb micronutrients efficiently and produce LAI of 2.99. The interaction between micronutrients and their application methods was significant statistically. Soil application (at sowing) of boron produced higher LAI (3.94). It was, however, statistically at par with side dressing of iron (3.79) and foliar application of boron (3.39 LAI). The minimum LAI (1.98) was produced in foliar application of zinc.

Table 1. Leaf area index (m^{-2}) at 49 days after sowing of wheat as affected by different micronutrients and their application methods.

Micronutrients	Application methods			
	Side dressing	Foliar application	Soil application	Means
Zinc (Zn)	0.25 cde	0.21 e	0.37 a-e	0.28 b
Copper (Cu)	0.24 de	0.29 a-e	0.37 a-d	0.32 ab
Iron (Fe)	0.42 ab	0.25 cde	0.29 a-e	0.30 ab
Manganese (Mn)	0.26 be	0.38 a-d	0.28 b-e	0.31 ab
Boron (B)	0.23 de	0.40 abc	0.44 a	0.35 a
Means	**0.31** ^{NS}	**0.31**	**0.31**	

$LSD_{0.05}$ Micronutrients = 0.06
Micronutrients × application methods = 0.16
NS = Non-significant
Any two means in their respective group sharing no common letter(s) are significant (p<0.05)

Table 2. Leaf area index (m^{-2}) at 98 days after sowing of wheat as affected by different micronutrients and their application methods.

Micronutrients	Application methods			
	Side dressing	**Foliar application**	**Soil application**	**Means**
Zinc (Zn)	2.67 bcd	1.98 d	3.20 abc	2.62 b
Copper (Cu)	2.48 cd	3.04 a-d	3.27 abc	3.12 ab
Iron (Fe)	3.79 ab	2.51 cd	3.05 a-d	2.93 ab
Manganese (Mn)	2.71 bcd	3.36 abc	3.04 a-d	3.04 ab
Boron (B)	2.42 cd	3.39 abc	3.94 a	3.25 a
Means	**2.99 ^{NS}**	**2.98**	**2.99**	

$LSD_{0.05}$ Micronutrients = 0.54

Micronutrients × application methods = 1.16

NS = Non-significant

Any two means in their respective group sharing no common letter(s) are significant ($p<0.05$)

Crop growth rate (g m^{-2} day^{-1}): One of the important physiological traits of the plants is crop growth rate (CGR) which is influenced by temperature, radiation, cultivar usage and water/nutrient supply. The data presented in Table-3 revealed that CGR was significantly affected by micronutrients. Among different trace elements, the maximum CGR (30.14 g m^{-2} day^{-1}) was recorded in boron treatment. It was statistically similar to copper (28.06) application while slightly lesser and statistically non-significant CGR (27.78 g m^{-2} day^{-1}) was recorded in manganese treatment. The minimum CGR (24.61 g $m^{-2}day^{-1}$) was produced in zinc application. Methods of micronutrients application had no significant effect on CGR. However, the maximum CGR (27.75) was recorded in soil application while the foliar treatment (4 WAS) produced minimum CGR (27.01 g m^{-2} day^{-1}). The findings of Tahir *et al*., (2009) revealed that boron application causes more leaf expansion and increases photosynthetic activities which improve plant growth. Moreover, soil application at sowing showed better results due to sufficient availability of nutrients at the time when plants were in need of 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). The interaction of variable factors was significant statistically. Soil application of boron produced the maximum CGR (37.58) which was statistically similar to side dressing of iron (31.98) and foliar application of boron (31.71) and manganese (31.63 g m^{-2} day^{-1} CGR). The minimum CGR (20.50 g m^{-2} day^{-1}) was recorded in foliar application of zinc.

Table 3. Crop growth rate (g m^{-2} day^{-1}) of wheat as affected by different micronutrients and their application methods.

Micronutrients	Application methods			
	Side dressing	**Foliar application**	**Soil application**	**Means**
Zinc (Zn)	24.33 cd	20.50 d	29.00 bc	24.61 c
Copper (Cu)	23.05 cd	27.14 bcd	29.58 bc	28.06 ab
Iron (Fe)	31.98 ab	23.96 cd	28.25 bc	26.59 bc
Manganese (Mn)	24.61 cd	31.63 ab	27.10 bcd	27.78 abc
Boron (B)	21.12 d	31.71 ab	37.58 a	30.14 a
Means	**27.54 ^{NS}**	**27.01**	**27.75**	

$LSD_{0.05}$ Micronutrients = 3.26

Micronutrients × application methods = 6.77

NS = Non-significant

Any two means in their respective group sharing no common letter(s) are significant ($p<0.05$)

Net assimilation rate (mg m^{-2} day^{-1}): The use of micronutrients significantly affected net assimilation rate (NAR) while there was no significant difference among micronutrients application methods (Table-4). Higher concentrations of boron in the leaves and leaf tips resulted in increased photosynthesis and more chlorophyll formation. Among different micronutrients, boron produced the maximum NAR (2.78 mg m^{-2} day^{-1}). It was followed by copper and manganese treatments with 2.41 and 2.34 mg m^{-2} day^{-1} NAR, respectively. The minimum NAR (2.10 mg m^{-2} day^{-1}) was produced in zinc treatment. Among the micronutrients application methods, soil application (at sowing) resulted in the maximum NAR (2.48 mg m^{-2} day^{-1}). Net assimilation rate of plant is influenced by the dry matter accumulation within a specified time interval. As the dry weight of plants increased, the NAR is also increased. Micronutrients and their application methods significantly interacted with each other. Soil application of boron showed significantly higher NAR (3.84) followed by side dressing of iron (2.82) and foliar application of boron (2.70) and manganese (2.65 mg m^{-2} day^{-1} NAR). Foliar application of zinc had minimum NAR (1.70 mg m^{-2} day^{-1}).

Table 4. Net assimilation rate (mg m^{-2} day^{-1}) of wheat as affected by different micronutrients and their application methods.

Micronutrients	Application methods			
	Side dressing	**Foliar application**	**Soil application**	**Means**
Zinc (Zn)	2.07 c-f	1.70 f	2.52 bcd	2.10 c
Copper (Cu)	1.91 def	2.37 b-f	2.57 bcd	2.41 b
Iron (Fe)	2.82 b	1.94 def	2.47 b-e	2.28 bc
Manganese (Mn)	2.15 b-f	2.65 bc	2.23 b-f	2.34 bc
Boron (B)	1.79 ef	2.70 bc	3.84 a	2.78 a
Means	**2.35 ^{NS}**	**2.32**	**2.48**	

$LSD_{0.05}$ Micronutrients = 0.29

Micronutrients × application methods = 0.71

NS = Non-significant

Any two means in their respective group sharing no common letter(s) are significant ($p<0.05$)

Number of tillers (m^{-2}): Tillering is an important developmental stage that allows the plants to compensate under low plant populations or taking advantage of good growing conditions. The appearance of tillers is closely coordinated with leaves on the main stem while the number of tillers formed depends on the variety and growing conditions (Reddy, 2004). The data presented in Table-5 revealed significant effect of micronutrients on tillers production. Application of boron produced the maximum number of tillers (307.00) which was statistically at par with 301.25 and 299.92 tillers m^{-2} obtained in copper and manganese treatments, respectively. The minimum number of tillers (285.17 m^{-2}) was recorded in zinc treatment. Different application methods had non-significant effect on tillers/offshoots production; however, the maximum number of tillers (300.05) was recorded in soil application while foliar application showed the minimum tillers (296.15 m^{-2}). The results of the present study agreed with Uddin *et al*., (2008) who reported that application of boron significantly increased the number of tillers over control. Similarly, Holloway and Alston (2010) obtained increased number of tillers with boron application. The interaction of these two factors also showed significant results. Soil application of boron produced the maximum tillers (331.50 m^{-2}) while side dressing of iron (319.50) and foliar application of boron (317.00) and manganese (315.75 tillers m^{-2}) produced statistically similar number of tillers per unit area. The minimum tillers (266.25 m^{-2}) was recorded in foliar application method.

Table 5. Number of tillers (m^{-2}) of wheat as affected by different micronutrients and their application methods.

Micronutrients	Application methods			
	Side dressing	**Foliar application**	**Soil application**	**Means**
Zinc (Zn)	285.25 c-f	266.25 f	304.00 a-d	285.17 b
Copper (Cu)	276.25 def	297.75 b-e	310.50 abc	301.25 a
Iron (Fe)	319.50 ab	284.50 c-f	299.75 b-e	294.83 ab
Manganese (Mn)	287.25 c-f	315.75 ab	296.75 b-e	299.92 a
Boron (B)	272.50 ef	317.00 ab	331.50 a	307.00 a
Means	**296.70 ^{NS}**	**296.15**	**300.05**	

$LSD_{0.05}$ Micronutrients = 13.43

Micronutrients × application methods = 26.47

NS = Non-significant

Any two means in their respective group sharing no common letter(s) are significant ($p<0.05$)

Number of grains (spike^{-1}): It is an important yield contributing parameter which greatly influences the crop production. The data given in Table-6 revealed that micronutrients significantly affected the grains per spike. Among different micronutrients, the use of boron produced spikes with maximum number of grains (61.08). It was, however, statistically at par with copper (59.00) and manganese (58.66) treatments. The minimum number of grains (56.00) was recorded in zinc treatment. It is evident from the data that number of grains per spike was not significantly affected by different application methods; however, soil application (at sowing) produced the maximum number of grains (58.85 spike^{-1}). The minimum number of grains (58.05 spike^{-1}) was obtained when foliar application method was used. As far as the interaction between variable factors is concerned, the maximum number of grains (66.50 spike^{-1}) was recorded in soil application of boron. It was statistically at par with side dressing of iron (62.25) and foliar application of boron (62.00) and manganese (61.25 grains spike^{-1}), respectively. The minimum number of grains (51.50 spike^{-1}) was obtained by the foliar application of zinc. Boron is basically responsible for fruit setting and qualitative improvement which resulted in increased number of grains in the present study. These results are in line with Uddin *et al*., (2008) who obtained maximum number of grains per spike by the application of boron. The present results are further supported by Tahir *et al*., (2009) who reported significant increase in grains per spike with foliar application of boron.

Table 6. Number of grains (spike^{-1}) of wheat as affected by different micronutrients and their application methods.

Micronutrients	Application methods			
	Side dressing	Foliar application	Soil application	Means
Zinc (Zn)	57.75 bc	51.50 c	58.75 abc	56.00 c
Copper (Cu)	55.25 bc	58.00 bc	60.25 ab	59.00 ab
Iron (Fe)	62.25 ab	55.25 bc	58.50 abc	57.83 bc
Manganese (Mn)	57.75 bc	61.25 ab	58.00 bc	58.66 ab
Boron (B)	54.75 bc	62.00 ab	66.50 a	61.08 a
Means	**58.65 ^{NS}**	**58.05**	**58.85**	

$LSD_{0.05}$ Micronutrients = 2.63

Micronutrients × application methods = 9.34

NS = Non-significant

Any two means in their respective group sharing no common letter(s) are significant ($p<0.05$)

1000-grain weight (g): The genetic makeup of different genotypes controls the seed weight. Being an absolute value, it is seldom changed or affected by the environmental behavior. The data presented in Table-7 indicated that different micronutrients and their application methods had non-significant effect on grain weight. However, the use of boron produced heavier grains (42.83 g) than all other treatments. Among different micronutrients application methods, soil application (at sowing) produced higher grain weight (42.57) than foliar application (41.99 g) method. Different micronutrients and their application methods also had non-significant effect on grain weight.

Table 7. 1000-grain weight (g) of wheat as affected by different micronutrients and their application methods.

Micronutrients	Application methods			
	Side dressing	Foliar application	Soil application	Means
Zinc (Zn)	41.32 ^{NS}	38.42	43.17	40.97 ^{NS}
Copper (Cu)	40.33	42.46	43.24	42.77
Iron (Fe)	44.97	40.75	42.78	42.01
Manganese (Mn)	41.87	43.74	42.10	42.57
Boron (B)	38.67	44.59	45.06	42.83
Means	**42.13 ^{NS}**	**41.99**	**42.57**	

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). Grain yield is the most integrative trait of a particular genotype (Araus *et al.*, 2001). The data given in Table-8 indicated that micronutrients had significant effect on grain yield. The use of boron produced the maximum grain yield (5.63 t ha^{-1}). It was, however, at par statistically with copper (5.57) and manganese (5.54 t ha^{-1} grain yield) treatments. The minimum grain yield (5.47 t ha^{-1}) was obtained in zinc treatment. The data further revealed that micronutrients application methods had non-significant effect on grain yield. However, soil application produced the maximum grain yield (5.56) than the lowest (5.55 t ha^{-1}) in foliar application method. Micronutrients and their application methods significantly interacted with each other. The maximum grain yield (5.88 t ha^{-1}) was recorded in soil application of boron. The application of iron as side dressing and foliar application of boron and manganese produced statistically at par grain yield. The minimum grain yield (5.34 t ha^{-1}) was obtained in foliar application of zinc. Boron application produced the highest grain yield on account of producing more number of tillers, number of grains as well as grain weight. The present results are supported by Chaudry *et al*., (2007) who reported that boron application along with basal dose of NPK significantly increased the wheat yield. Uddin *et al*., (2008) also obtained 50% more yield with the application of boron. Several other reports indicated that micronutrients application either through soil or foliar had positive correlation with wheat yield (Habib, 2009; Wroble, 2009).

Table 8. Grain yield (t ha^{-1}) of wheat as affected by different micronutrients and their application methods.

Micronutrients	Application methods			
	Side dressing	Foliar application	Soil application	Means
Zinc (Zn)	5.47 c-f	5.34 f	5.61 b-e	5.47 b
Copper (Cu)	5.41 def	5.59 b-e	5.64 bcd	5.57 a
Iron (Fe)	5.70 ab	5.41def	5.59 b-e	5.54 ab
Manganese (Mn)	5.47 c-f	5.65 bc	5.51 b-f	5.54 ab
Boron (B)	5.39 ef	5.64 bc	5.88 a	5.63 a
Means	**5.55 ^{NS}**	**5.55**	**5.56**	

$LSD_{0.05}$ Micronutrients = 0.09

Micronutrients × application methods = 0.23

NS = non-significant

Any two means in their respective group sharing no common letter(s) are significant ($p<0.05$)

Benefit cost ratio (BCR): The economic analysis (BCR) presented in Table-9 showed the highest net income (Rs.80325/-) in soil application (at sowing) of boron treatment. It was followed by foliar application of boron with net income of Rs.75951/-. Zinc, in the same application method, produced minimum net income (Rs.60666/-). Considering the ratio of total income to the total expenses, higher benefit cost ratio (2.32) was recorded in soil application of boron. The higher BCR in this treatment was due to the lower dose of micronutrient as well as higher grain yield. The minimum benefit cost ratio (1.88) was recorded in foliar application of zinc.

Conclusion

The present research revealed that micronutrients and their application methods had significant effect on the growth and yield of wheat. The use of boron enhanced plant growth by producing higher LAI, CGR, NAR and other yield contributing parameters. Among different micronutrients application methods, soil application (at sowing) was found to be the most economical method. Soil application method was also significantly interacted with boron treatment for producing higher number of tillers, number of grains per spike and the grain yield of wheat.

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