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Role of foliar feeding of micronutrients in yield maximization of cotton in Punjab

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Abstract: Deficiency of micronutrients, particularly of zinc, boron, and iron, in calcareous soils is of great concern. Results indicate a reduction in yield of seed-cotton due to an imbalance of nutrients, particularly micronutrients, on calcareous soils in the last decade. About 90% of Pakistani soils are deficient in micronutrients, particularly zinc, boron, and iron. This paper highlights efforts to overcome these deficiencies in cotton through foliar feeding of micronutrients. The results of this study indicated a marked improvement in seed-cotton yield with foliar application of a spray containing Zn, B, Mn, Cu, and Fe on cotton crops grown on calcareous soils in the presence of the recommended doses of farmers' soil applied NPK fertilizers. Foliar application also improved the nutrient status of leaves compared to soil applied fertilizers alone. This improvement in nutrient status resulted in an increase in the number of flowers, number of bolls, and ultimately of seed-cotton yield. The increased yield resulted in 20%–30% more economic benefit over NPK fertilizers alone.

Key words: Cotton, foliar feeding, micronutrients, nutrient uptake

1. Introduction

Adequate levels of micro- and macroinorganic nutrients are required for optimal growth (Ahmad et al. 2009, 2011), and supplements give improvements in yield if only suboptimal levels are otherwise available. Six micronutrients (boron, manganese, iron, copper, zinc, and molybdenum) play distinct and vital roles in plant physiology and biochemical processes (Putra et al. 2012; Rab and Haq 2012). The scarcity of any nutrient in the soil can be a barrier to growth, even when all other nutrients are in excess in the soil (Soleymani and Shahrajabian 2012).

Extensive farming of crops with high micronutrient demands on alkaline calcareous soils that are low in organic matter has made Pakistan's soils deficient in Zn (60%–70%), B, and Fe (50%–60%), with localized deficiency in micronutrients (Jiskani 2011) depending upon the cropping intensity (Memon et al. 2012). The field scale deficiency of these nutrients in Pakistan has hampered seed-cotton productivity during the last decade (Ali 2012; Soleymani and Shahrajabian 2012) and it is predicted to get worse in the future.

Soil application of Zn, B, Fe, Mn, and Cu on calcareous soils is less efficient, as these nutrients remain inaccessible to plant roots due to the higher soil pH (Rashid and Ryan 2004; Sajid et al. 2008). However, an alternative approach under such circumstances is foliar application of these nutrients (Rab and Haq 2012), for 2 reasons. First, it eliminates the effects of soil pH on the availability of these nutrients (Ali 2012). Second, it is more effective and less costly (Ali et al. 2007). For that reason, it has gained significant attention in agriculture worldwide (Leiw et al. 2012). Usually, it is recommended for horticultural crops, e.g. tomato (Rab and Haq 2012), but it has also been found as a more effective technique for correcting micronutrient deficiency in cereal crops like wheat (Yassen et al. 2010; Bameri et al. 2012) and sorghum (Soleymani and Shahrajabian 2012). Moreover, this technique generated additional benefits, in terms of cash, when applied in the right dose at the right time admixed with an appropriate surfactant (Oosterhuits et al. 2010). On the other hand, the use of micronutrients for fiber crops, particularly cotton, is very rare in Pakistan (Jiskani 2011).

Keeping these aspects in mind, a series of demonstration experiments were conducted for 2 years to evaluate the effectiveness of foliar feeding of micronutrients on cotton crops grown on calcareous soils.

2. Materials and methods

The field demonstration trials were conducted in the Toba Tek Singh district, Punjab (Pakistan) in collaboration with the Endowment Fund Secretariat (EFS) at the

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University of Agriculture, Faisalabad, Pakistan. Ten sites were selected and at each a grid plot (5 × 2.8 m^2) was used as the experimental unit. The soil was a calcareous sandy clay loam with alkaline pH and very low organic matter (Table 1). Three replicates of each treatment were randomized using a randomized complete block design. Cotton (*Gossypium hirsutum* L.) cv. Neelam-121 or NS-121 was selected as it was frequently grown in the area. After seedbed preparation, cotton seeds were sown by drill, maintaining a spacing of 76 cm between rows, and then thinned to 38 cm between plants. Fertilizers were applied to the soil at the rate of 150, 125 and 100 kg ha^{-1} nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O), respectively, as urea, diammonium phosphate, and sulfate of potash. A micronutrient mixture (MNM) of the registered brand Uni Micropower® was used for foliar application. The formulation of the foliar spray contained Zn (4.7%), Fe (2%), Cu (0.3%), B (1%), and Mn (2%), amended with surfactant to curtail water desertion during the spray process, to ensure the nutrients adhered to the leaf surface, and to maximize uptake by foliage. The treatment plan was as follows: T_1 = control (NPK fertilizers applied to the soil) plus spray of 250 L water ha^{-1}; T_2 = NPK plus 625 mL ha^{-1} MNM dissolved in 250 L of water (117.5 mg ha^{-1} Zn, 50 mg ha^{-1} Fe, 7.5 mg ha^{-1} Cu, 25 mg ha^{-1} B, 50 mg ha^{-1} Mn); T_3 = NPK plus 1250 mL ha^{-1} MNM dissolved in 250 L of water (235 mg ha^{-1} Zn, 100 mg ha^{-1} Fe, 15 mg ha^{-1} Cu, 50 mg ha^{-1} B, 100 mg ha^{-1} Mn); T_4 = NPK plus 1875 mL ha^{-1} MNM dissolved in 250 L of water (352.5 mg ha^{-1} Zn, 150 mg ha^{-1} Fe, 22.5 mg ha^{-1} Cu, 75 mg ha^{-1} B, 150 mg ha^{-1} Mn); T_5 = NPK plus 2500 mL ha^{-1} MNM dissolved in 250 L of water (470 mg ha^{-1} Zn, 200 mg ha^{-1} Fe, 30 mg ha^{-1} Cu, 100 mg ha^{-1} B, 200 mg ha^{-1} Mn); T_6 = NPK plus 3750 mL ha^{-1} MNM dissolved in 250 L of water (705 mg ha^{-1} Zn, 300 mg ha^{-1} Fe, 45 mg ha^{-1} Cu, 150 mg ha^{-1} B, 300 mg ha^{-1} Mn). The MNM at 625 and 1250 mL ha^{-1} mixed into 250 L of water were applied as a single spray (at the 8 to 10 leaves stage, which is nearly 50 days after emergence), whereas MNM at 1875 and 2500 mL ha^{-1} were applied in 2 splits; half of the 1875 and 2500 mL was sprayed 50 days after emergence and half 65 days after emergence. However, MNM at 3750 mL ha^{-1} mixed into 250 L of water was divided into 3 splits (1250 mL per split), with the first split 50 days after emergence, the second split 15 days after the first, and the third split 15 days after the second.

Data regarding plant height, monopodial and sympodial branches, number of flowers, closed squares, and opened squares $plant^{-1}$, chlorophyll contents (measured periodically with the help of portable chlorophyll meter SPAD-504), and seed cotton yield $plant^{-1}$ were recorded from 20 tagged plants and subjected to statistical scrutiny. To determine the macro- and micronutrients in leaves and petioles, 100 fully expanded new leaves with petioles were picked from tagged plants and preserved in polythene bags. Furthermore, economic analysis was performed according to CIMMYT (1988) and the benefit–cost

Table 1. Physico-chemical characteristics of soil at the 10 experimental sites.

Parameters	Value	Characteristics	Values
Sand	53.16%	CO_3^{--}	12 ± 3 me L^{-1}
Silt	29.13%	HCO_3^{-}	0.9 ± 0.2 me L^{-1}
Clay	17.71%	Cl^{-}	14.7 ± 0.7 me L^{-1}
Textural class	Sandy clay loam	SO_4^{--}	9.1 ± 0.2 me L^{-1}
Saturation	33 ± 2%	Na^{+}	14.1 ± 0.2 me L^{-1}
pHs	7.8 ± 0.2	Ca^{++} + Mg^{++}	8.38 ± 1.0 me L^{-1}
ECs	2.41 ± 0.5 dS m^{-1}	Total N	0.030 ± 0.004%
CEC	4.35 $cmol_c$ kg^{-1} soil	Available P	6.23 ± 0.9 mg kg^{-1} soil
Organic matter	0.61 ± 0.08%	Extractable K	146 ± 8 mg kg^{-1} soil
Available Micronutrients			
Ca^{++}	220.2 mg kg^{-1}	Mg^{++}	60.4 mg kg^{-1}
Fe^{++}	8.90 mg kg^{-1}	Mn^{++}	7.20 mg kg^{-1}
Zn^{++}	0.90 mg kg^{-1}	Cu^{++}	1.50 mg kg^{-1}
B	0.31 mg kg^{-1}		

ratio (BCR) and value–cost ratio (VCR) were calculated according to methods used by Dash et al. (1995) and Hussain et al. (2008) for the economic feasibility of the foliar feeding technology. Fisher's analysis of variance was used to analyze data regarding different parameters at 5% probability level (Steel et al. 1997).

Sampled leaves and petioles of cotton were oven dried to a constant weight, ground, and analyzed for macro- and micronutrients as described by Wolf (1982). Nitrogen was analyzed according to Jackson (1962), while phosphorus was analyzed using the vanadate–molybdate spectrophotometric procedure (Jones et al. 1991). Potassium was determined by a flame photometer (Chapman and Pratt 1961). Zinc, iron, copper, and manganese concentrations in di-acid digested solution were identified using an atomic absorption spectrophotometer (Jones et al. 1991). Boron was determined on a spectrophotometer (Gaines and Mitchell 1997). The uptake of nutrients was calculated by multiplying N, P, and K concentrations by dry mass (Ameri and Tehranifar 2012).

3. Results

Ninety days after germination, the data showed smaller plants with fewer monopodial and sympodial branches from the control plots that had only N, P, and K fertilizers. Conversely, these smaller plants turned into significantly ($P \leq 0.01$) larger plants with more branches per plant due to the foliar application of Zn, B, Fe, Cu, and Mn in the presence of NPK fertilizers (Figures 1 and 2). The plants provided with supplementary doses of these micronutrients bore more flowers per plant because of the corresponding increase in monopodial and sympodial branches per plant (Figure 3a). Those plants eventually offered a fruitful base for additional square bolls (fruit of cotton) on the micronutrient-fed plants (Figure 3b).

Plants in T_1 produced the smallest number of monopodial and sympodial branches per plant (Figure 2b). Branches per plant were higher in those plots that had foliar application of MNM solutions having Zn ≥ 235 mg ha^{-1}, Fe ≥ 100 mg ha^{-1}, Cu ≥ 15 mg ha^{-1}, B ≥ 50 mg ha^{-1}, and Mn ≥ 100 mg ha^{-1} in the presence of soil-applied

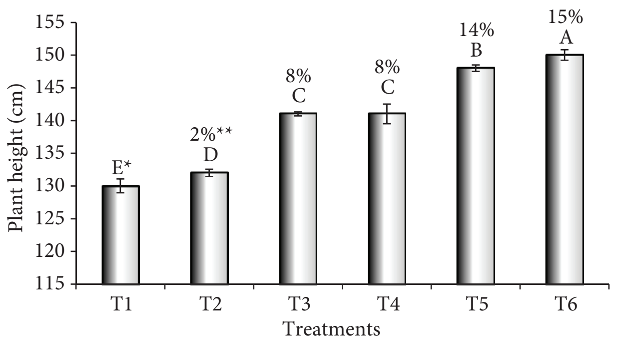

Figure 1. Plant height of cotton at different dosages of MNM integrated with soil-applied NPK fertilizers under farmers' field conditions. (Each value is the mean of 20 tagged plants taken 90 days after germination from 10 experimental sites per treatment over 2 years).

*Bars sharing same letter(s) do not differ from one another at $P \leq 0.05$ according to DMR test **percent increase over control (NPK fertilizers alone) due to foliar application of micronutrients in the presence of NPK fertilizers, T_1 = Control (NPK fertilizers applied to the soil) plus spray of 250 L of water; T_2 = NPK plus foliar application of 625 mL ha^{-1} MNM solution containing 117.5 mg ha^{-1} Zn, 50 mg ha^{-1} Fe, 7.5 mg ha^{-1} Cu, 25 mg ha^{-1} B, and 50 mg ha^{-1} Mn; T_3 = NPK plus foliar application of 1250 mL ha^{-1} MNM solution containing 235 mg ha^{-1} Zn, 100 mg ha^{-1} Fe, 15 mg ha^{-1} Cu, 50 mg ha^{-1} B, and 100 mg ha^{-1} Mn; T_4 = NPK plus foliar application of 1875 mL ha^{-1} MNM solution containing 352.5 mg ha^{-1} Zn, 150 mg ha^{-1} Fe, 22.5 mg ha^{-1} Cu, 75 mg ha^{-1} B, and 150 mg ha^{-1} Mn; T_5 = NPK plus foliar application of 2500 mL ha^{-1} MNM solution containing 470 mg ha^{-1} Zn, 200 mg ha^{-1} Fe, 30 mg ha^{-1} Cu, 100 mg ha^{-1} B, and 200 mg ha^{-1} Mn; T_6 = NPK plus foliar application of 3750 mL ha^{-1} MNM solution containing 705 mg ha^{-1} Zn, 300 mg ha^{-1} Fe, 45 mg ha^{-1} Cu, 150 mg ha^{-1} B, and 300 mg ha^{-1} Mn.

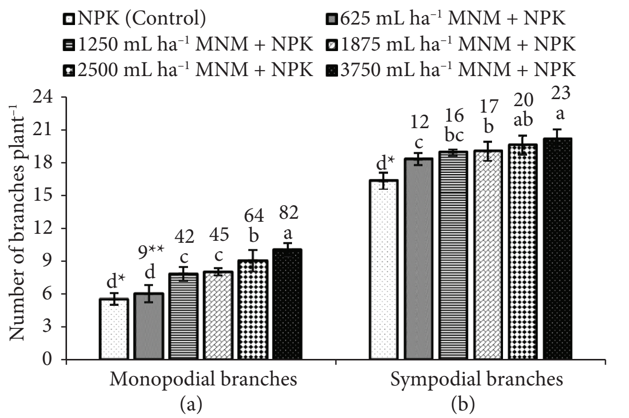

Figure 2. Branching in cotton at different dosages of MNM under farmers' field conditions (Each value is the mean of 20 tagged plants taken 90 days after emergence from 10 experimental sites per treatment over 2 years).

(MNM = mixture of micronutrients)

*Bars sharing same letter(s) do not differ from one another at $P \leq 0.05$ according to DMR test **percent increase over control (NPK fertilizers alone) due to foliar application of micronutrients in the presence of NPK fertilizers, T_1 = Control (NPK fertilizers applied to the soil) plus spray of 250 L of water; T_2 = NPK plus foliar application of 625 mL ha^{-1} MNM solution containing 117.5 mg ha^{-1} Zn, 50 mg ha^{-1} Fe, 7.5 mg ha^{-1} Cu, 25 mg ha^{-1} B, and 50 mg ha^{-1} Mn; T_3 = NPK plus foliar application of 1250 mL ha^{-1} MNM solution containing 235 mg ha^{-1} Zn, 100 mg ha^{-1} Fe, 15 mg ha^{-1} Cu, 50 mg ha^{-1} B, and 100 mg ha^{-1} Mn; T_4 = NPK plus foliar application of 1875 mL ha^{-1} MNM solution containing 352.5 mg ha^{-1} Zn, 150 mg ha^{-1} Fe, 22.5 mg ha^{-1} Cu, 75 mg ha^{-1} B, and 150 mg ha^{-1} Mn; T_5 = NPK plus foliar application of 2500 mL ha^{-1} MNM solution containing 470 mg ha^{-1} Zn, 200 mg ha^{-1} Fe, 30 mg ha^{-1} Cu, 100 mg ha^{-1} B and 200 mg ha^{-1} Mn; T_6 = NPK plus foliar application of 3750 mL ha^{-1} MNM solution containing 705 mg ha^{-1} Zn, 300 mg ha^{-1} Fe, 45 mg ha^{-1} Cu, 150 mg ha^{-1} B, and 300 mg ha^{-1} Mn.

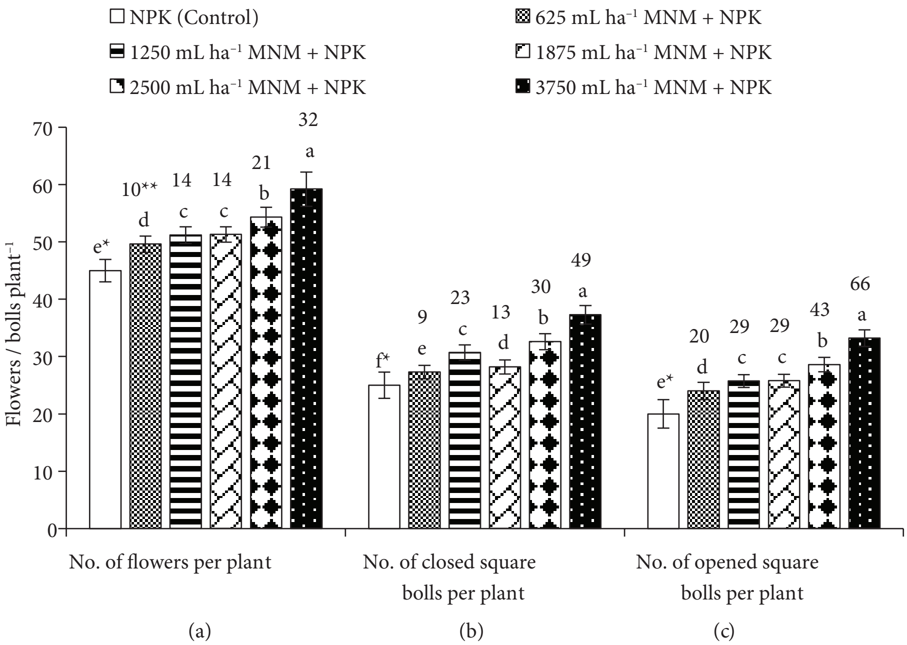

Figure 3. Number of flowers and bolls at different dosages of MNM under farmers' field conditions (Each value is the mean of 20 tagged plants taken 90 days after emergence from 10 experimental sites per treatment over 2 years).
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NPK fertilizers (Figures 2a and 2b). Correspondingly, there was a significant difference in the development and count of flowers as well as square bolls per plant due to the foliar feeding of micronutrient solutions (Figure 3). Finally, improvements in yield parameters due to foliar feeding led to higher seed-cotton yield per hectare and income (Figure 4; Table 2). The effect of MNM in T_6 on seed-cotton yield was statistically at a peak (Figure 4) and resulted in a clear-cut distinction between revenues from plots with and without application of Zn, B, Fe, Cu, and Mn (Table 2). Economic analysis reveals that T_6 broadens the BCR the most effectively (Table 2). Similarly, Table 2 also demonstrates that the VCR improved as the concentration of Zn, B, Fe, Mn, and Cu in the MNM solution increased. These results are further supported by the contents of Table 3. Improvement in the concentration of macro- and micronutrients in cotton leaves and petioles was noted due to foliar application of MNM in the presence of soil-applied NPK fertilizers. This happened due to effective absorption of Zn, B, Fe, Mn, and Cu through the leaves. Correspondingly, improvement in the chlorophyll contents (given in Figure 5) additionally supported the findings. Micronutrient-sprayed cotton fields looked more vigorous, healthy, and lush green as compared to surrounding control cotton fields.

4. Discussion

B, Mn, Fe, Cu, and Zn are usually deficient in calcareous soils. As these micronutrients have a significant effect on plant physiology and are involved in biochemical processes (Putra et al. 2012; Rab and Haq 2012), their deficiency caused a reduction in plant yield due to lack of proper growth. According to SAAESD (2009), Fe, Mn, Zn, Cu, and B must be present in the leaves of cotton plants at ≥50, ≥25, ≥20, ≥5, and ≥20 mg kg^{-1}, respectively. Table 3 shows that foliar application of Zn, B, Fe, Cu, and Mn improved plant height, monopodial and sympodial branches per plant, flowers and bolls per plant, chlorophyll content, and ultimately seed-cotton yield due to meeting sufficient levels of these nutrients in cotton leaves and petioles (Table 3). Meeting the sufficient amount of these nutrients stimulated enzymatic activities (Oosterhuits et al. 2010), leading to an improvement in biochemical processes like photosynthesis, respiration, and protein

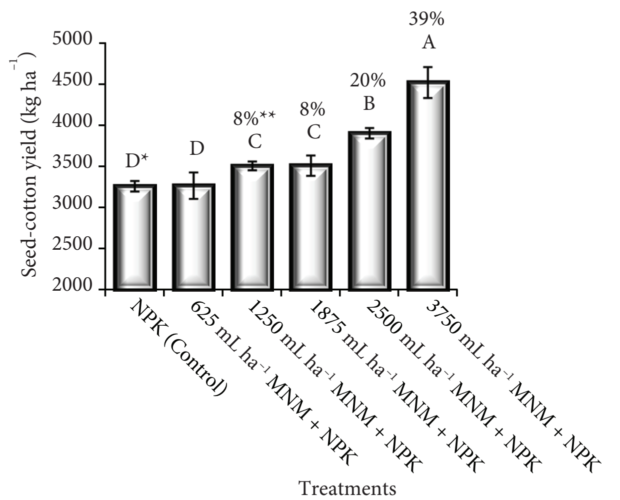

Figure 4. Seed-cotton yield at different dosages of MNM under farmers' field conditions (Each value is the mean of 20 tagged plants taken 90 days after emergence from 10 experimental sites per treatment over 2 years).

(MNM = mixture of micronutrients)

*Bars sharing same letter(s) do not differ from one another at $P \leq 0.05$ according to DMR test **percent increase over control (NPK fertilizers alone) due to foliar application of micronutrients in the presence of NPK fertilizers, T_1 = Control (NPK fertilizers applied to the soil) plus spray of 250 L of water; T_2 = NPK plus foliar application of 625 mL ha^{-1} MNM solution containing 117.5 mg ha^{-1} Zn, 50 mg ha^{-1} Fe, 7.5 mg ha^{-1} Cu, 25 mg ha^{-1} B, and 50 mg ha^{-1} Mn; T_3 = NPK plus foliar application of 1250 mL ha^{-1} MNM solution containing 235 mg ha^{-1} Zn, 100 mg ha^{-1} Fe, 15 mg ha^{-1} Cu, 50 mg ha^{-1} B, and 100 mg ha^{-1} Mn; T_4 = NPK plus foliar application of 1875 mL ha^{-1} MNM solution containing 352.5 mg ha^{-1} Zn, 150 mg ha^{-1} Fe, 22.5 mg ha^{-1} Cu, 75 mg ha^{-1} B, and 150 mg ha^{-1} Mn; T_5 = NPK plus foliar application of 2500 mL ha^{-1} MNM solution containing 470 mg ha^{-1} Zn, 200 mg ha^{-1} Fe, 30 mg ha^{-1} Cu, 100 mg ha^{-1} B, and 200 mg ha^{-1} Mn; T_6 = NPK plus foliar application of 3750 mL ha^{-1} MNM solution containing 705 mg ha^{-1} Zn, 300 mg ha^{-1} Fe, 45 mg ha^{-1} Cu, 150 mg ha^{-1} B, and 300 mg ha^{-1} Mn.

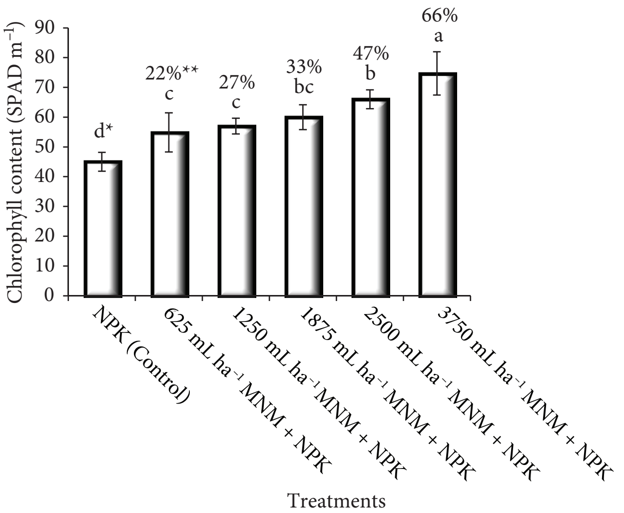

Figure 5. Chlorophyll contents at different dosages of MNM under farmers' field conditions (Each value is the mean of 20 tagged plants taken 90 days after emergence from 10 experimental sites per treatment over 2 years).

(MNM = mixture of micronutrients)

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synthesis, as reported by Cheniae and Martin (1970). Improved growth due to foliar application of B was also reported by Amad et al. (2009), Oosterhuits (2010), and Ali et al. (2012). The improved concentration of B in leaves might be involved in cell wall properties related to cell enlargement (Edwards and Walker 1983; Leiw et al. 2012), thus leading to longer stems loaded with more branches and flowers per plant. According to Putra et al. (2012), the availability of boron to plants directly correlated with the affected stomatal morphology, conductance, and transpiration. Therefore, inadequate level of Zn, Mn, Cu, Fe, and particularly of B in leaves might be the right explanation for lower plant growth and seed-cotton yield in the control plots that had only the application of soil NPK fertilizers. Accordingly, adequate absorption and utilization of these nutrients is essential to accelerate plant growth and get a higher yield of seed-cotton, as was observed due to foliar feeding of a solution containing Zn, B, Cu, Fe, and Mn (Figures 2a and 2b; Tables 1 and 2). Similar observations were also highlighted by Ali (2012) as being due to foliar application of micronutrient. According to Korzeniowska (2008) and Leiw et al. (2012), infertility of flowers and premature falling of flowers are the consequence of Zn and B insufficiency in plants, and ultimately reduction in yields occurs. This paper showed that inadequate or imbalanced use of micronutrients is one of the foremost factors that bring the potential of high yielding cotton cultivars down. For that reason, foliar feeding of micronutrients is highly advisable for cotton regions with calcareous soils. This paper also suggests that foliar feeding of micronutrients, particularly of Zn, B, Fe, Mn, and Cu, is an effective technology for increasing the yield of cotton, particularly on calcareous soils with a high pH like in Pakistan.

Table 2. Economic feasibility of foliar feeding technology for the production of cotton tested on the farmers' field (Each value is the mean of 10 experimental sites per treatment over 2 years).

Treatments	Harvest index		Net income*		Benefit–cost ratio*		Value–cost ratio*
	%	Percent incr.**	Rs. ha^{-1}	Percent incr.**	Rs. ha^{-1}	Percent incr.**	
T_1	21.7 d***	---	189,341 d**	---	2.38 d**	---	---
T_2	21.7 d	0	189,752 d	0	2.38 d	0	1.04 e
T_3	23.5 c	8	209,335 c	11	2.62 c	10	36.79 c
T_4	23.5c	8	209,518 c	11	2.61 c	10	21.50 d
T_5	25.3 b	17	241,749 b	28	3.00 b	26	48.22 b
T_6	28.3 a	30	292,275 a	54	3.61 a	52	63.14 a
LSD Value	0.0688		1083.4		0.0130		0.7040

*Values are calculated on the basis of prices of fertilizer inputs and pesticides used, labor, machinery used charges, irrigation charges, seed-cotton prices during 2010 (1 Rs = $0.01), **Percent increase over control (NPK fertilizers alone) due to foliar application of micronutrients in the presence of NPK fertilizers ***Values sharing same letter(s) within the column do not differ at P = 0.05 according to LSD test,
T_1 = Control (NPK); T_2 = NPK plus foliar application of 625 mL ha^{-1} MNM solution; T_3 = NPK plus foliar application of 1250 mL ha^{-1} MNM solution; T_4 = NPK plus foliar application of 1875 mL ha^{-1} MNM solution; T_5 = NPK plus foliar application of 2500 mL ha^{-1} MNM solution; T_6 = NPK plus foliar application of 3750 mL ha^{-1} MNM solution

Table 3. Integrated effect of soil-applied NPK and foliar feeding of micronutrients on concentrations of macro- and micronutrients in cotton leaves and petioles on farmers' fields (Each value is the mean of 20 tagged plants taken 90 days after emergence from 10 experimental sites per treatment over 2 years).

Treatments	**Macronutrients (%)**				**Micronutrients (mg kg^{-1})**				
	N	P	K	Ca	Zn	B	Mn	Cu	Fe
T_1	3.0 d*	0.47 e*	2.7 b*	2.51c*	20.4 e*	64.2 f*	27.3f*	5.16e*	102.5 f*
T_2	3.0 d	0.47 e	2.7 b	2.57c	22.4 e	64.4 e	27.4e	5.21e	102.8 e
T_3	3.1 c	0.51c	2.9 a	2.72bc	52.8 d	73.8 d	29.5d	5.32d	108.4 d
T_4	3.2 b	0.52 c	2.9 a	2.81b	66.0 c	75.3 c	30.1c	5.40c	110.2 c
T_5	3.2 b	0.53 b	2.9 a	3.00b	82.1 b	77.0 b	30.8b	5.44b	110.9 b
T_6	3.3 a	0.58 a	3.0 a	3.31 a	135.4 a	79.5 a	33.8a	5.56a	111.1 a
LSD value	0.0632	0.036	0.170	0.232	0.0110	0.1670	0.0668	0.0329	0.1098

*Values sharing same letter(s) within the column do not differ at P = 0.05 according to LSD test
T_1 = Control (NPK); T_2 = NPK plus foliar application of 625 mL ha^{-1} MNM solution; T_3 = NPK plus foliar application of 1250 mL ha^{-1} MNM solution; T_4 = NPK plus foliar application of 1875 mL ha^{-1} MNM solution; T_5 = NPK plus foliar application of 2500 mL ha^{-1} MNM solution; T_6 = NPK plus foliar application of 3750 mL ha^{-1} MNM solution

It can be concluded that foliar application of a Zn, Fe, B, Mn, and Cu solution definitely affected cotton growth and seed-cotton yield of Bt cotton, and improved the income of farmers. Therefore, foliar application of a micronutrient solution with formulation containing 705 mg ha^{-1} Zn, 300 mg ha^{-1} Fe, 45 mg ha^{-1} Cu, 150 mg ha^{-1} B, and 300 mg ha^{-1} Mn is necessary for better plant growth and getting maximum seed cotton yield from the Bt cotton cultivar.

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References

Ahmad I, Asif M, Amjad A, Ahmad S (2011) Fertilization enhances growth, yield, and xanthophyll contents of marigold. Turk J Agric For 35: 641–648.

Ahmad S, Akhtar LH, Ahmad S, Iqbal N, Nasim M (2009) Cotton (*Gossypium hirsutum* L.) varieties responded differently to foliar applied boron in terms of quality and yield. Soil Environ 28: 88–92.

Ali A, Mahmood IA, Hussain F, Salim M (2007) Response of rice to soil and foliar application of K_2SO_4 fertilizer. Sarhad J Agric 23: 15–19

Ali EA (2012) Effect of iron nutrient care sprayed on foliage at different physiological growth stages on yield and quality of some durum wheat (*Triticum durum* L.) varieties in sandy. Soil Asian J Crop Sci. 4: 139–149.

Ali L, Ali M, Mohyuddin Q (2011) Effect of foliar application of zinc and boron on seed cotton yield and economics in cotton-wheat cropping pattern. J Agri Res 49: 173–179.

Ameri A, Tehranifar A (2012) Effect of humic acid on nutrient uptake and physiological characteristic *Fragaria ananassa* var: Camarosa. J Biol Environ Sic 6: 77–9.

Bameri M, Abdolshahi R, Mohammadi-Nejad G, Yousefi K, Tabatabaie SM (2012) Effect of different microelement treatment on wheat (*Triticum aestivum*) growth and yield. Int Res J App Basic Sci 3:219–223.

Chapman HD, Pratt PF (1961) Methods of analysis for soils, plants and waters. Division of Agricultural Sciences, University of California Riverside, USA.

Cheniae GM, Martin JF (1970) Site of manganese within photosystem II. Roles in O_2 emission. Biochem and Biophy Acta 197: 219–239.

CIMMYT (1988) From Agronomic Data to Farmer Recommendations: An Economics Training Manual. Completely revised edition. Mexico, DF.

Dash JK, Singh RP, Pandey RK (1995) Economic analysis of summer rice production in Baharagora block of Singhbhum district, Bihar—A case study. J Res Birsa Agric Univ 7: 131–135.

Dixon GR, Webster MA (1988) Antagonistic effect of boron, calcium and pH on pathogenesis caused by *Plasmodiomorphora brassicae* (clubroot) - a review of recent work. Crop Res (Hort Res) 28: 83–95.

Edwards G, Walker D (1983) C_3, C_4: Mechanisms and Cellular and Environmental Regulation of Photosynthesis. Blackwell, London.

Gaines TP, Mitchell GA (1979) Boron determination in plant tissue by the azomethine H method. Commun Soil Plant Anal 10: 1099–1108

Graham RD, Welch RM, Bouis HE (2001) Addressing micronutrients malnutrition through enhancing the nutritional quality of staple foods: principles, perspectives and knowledge gaps. Adv Agron 70: 77–142.

Hussain A, Khattak NR, Khan AQ (2008) Cost benefit analysis of different rice varieties in District Swat. Sarhad J Agric 24: 745–748.

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

Jackson ML (1962) Chemical composition of soil. In: Chemistry of Soil, (Ed. FE Bean), Van Nostrand Co., New York. pp. 71–144.

Jiskani M (2011) Imbalanced nutrition causes a-biotic and increases biotic disease in crops. URL: http://www.pakissan.com/english/allabout/farminputs/fertilizers/imbalanced.nutrition.causes.shtml

Jones Jr JB, Wolf B, Mills HA (1991) Plant Analysis Handbook. Micro-macro Publishing Inc, Athens, GA, USA.

Korzeniowska J (2008) Response of ten winter wheat cultivars to boron foliar application in a temperate climate (South-West Poland). Agron Res 6: 471–476.

Liew YA, Omar SR, Husni MHA, Zainal AMA, Ashikin NPA (2012) Effects of foliar applied copper and boron on fungal diseases and rice yield on cultivar MR219. Pertanika J Trop Agric Sci 35: 339–349.

Memon M, Jamro GM, Memon N, Memon KS, Akhtar MS (2012) Micronutrient availability assessment of tomato grown in Taluka Badin, Sindh. Pak J Bot 44: 649–654.

Oosterhuits DM, Weir BL (2010) Foliar fertilization of cotton. In: Springer Physiology of Cotton (Ed. J. McD. Stewart), Science + Business Media B.V., California, USA, pp 225–237.

Phillips M (2004) Economic benefit from using micronutrients for the farmer and the fertilizer producer. IFA. International Symposium on Micronutrients. Feb. 23–25, New Delhi, India.

Putra ETS, Zakaria W, Abdullah NAP, Saleh GB (2012) Stomatal morphology, conductance and transpiration of Musa sp. cv. Rastali in relation to magnesium, boron and silicon availability. Amer J Plant Phys 7: 84–96.

Rab A, Haq I (2012) Foliar application of calcium chloride and borax influences plant growth, yield, and quality of tomato (*Lycopersicon esculentum* Mill.) fruit. Turk J Agric For 36: 695–701.

Ranjbar GA, Bahmaniar MA (2007) Effects of soil and foliar application of zinc fertilizer on yield and growth characteristics of bread wheat cultivars. Asian J Plant Sci 6: 1000–1005.

Rashid A, Ryan J (2004) Micronutrients constraints to crop production in soils with Mediterranean type characteristics: A review. J Plant Nutr 27: 959–975.

SAAESD (2009) Reference sufficiency ranges for plant analysis in the southern region of the United States. Updated and reformatted July. URL: www.ncagr.gov/agronomi/saaesd/scsb394.pdf

Sajid A, Khan AR, Mairaj G, Fida M, Bibi S (2008) Assessment of different crop nutrient management practices for yield improvement. Austr J Crop Sci 2: 150–157.

Soleymani A, Shahrajabian MH (2012) The effects of Fe, Mn and Zn foliar application on yield, ash and protein percentage of forage sorghum in climatic condition of Esfahan. Inter J Bio 4: 3–7.

Steel RGD, Torrie JH, Deekey DA (1997) Principles and Procedures of Statistics, A Biometrical Approach, 3rd edition, McGraw-Hill Book Co. Inc. New York, USA, pp. 400–428.

Vallee BL, Falchuk KH (1993) The biochemical basis of zinc physiology. Phys Reviews 73: 79–118.

Wolf B (1982) The comprehensive system of leaf analysis and its use for diagnosing crop nutrient status. Comm Soil Sci Plant Anal 13: 1035–1059.