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COPPER AS A YIELD LIMITING NUTRIENT FOR WHEAT

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ABSTRACT

Two field trials on bread wheat (*Triticum aestivum* L.) cv. Sakha-69 were conducted during the consecutive seasons of 2000/2001 and 2001/2002 on clay soil at the Agricultural Research Station of the NRC in Shalakan, Qualubia, Egypt. The objective was to investigate the response of wheat plants to foliar application of $CuSO_4$ solution (0.5% Cu) and multi-micronutrients compound (MN) containing 4.2, 2.8, 1.4 and 0.013% W/V EDTA-Zn, Mn, Fe and Cu; respectively, at the rates of 1 and 2ml/l (200 l/fed. at 45 and 60 days after sowing) as well as their mixture at the same rates. Leaf analysis of the top 2-leaves showed an increase with varying degrees in K/Ca and K/(Ca + Mg) implying better cationic equilibrium in the plants due to more K-uptake as compared with the control. Improvement of the plant nutrient balance due to foliar treatments followed the descending order of Cu-enriched-MN > MN > Cu. Consequently, significant increases were obtained with means of both seasons reached 39.1, 24.3 and 12.2% for grain yield and 24.5, 18.3 and 12.5% for straw yield over the control due to foliar application of Cu-enriched-MN, MN and Cu; respectively, at 2ml/l. The results of this study may s··ggest that Cu-nutrition must be regarded as another micronutrient in wheat cultivations and other Cu-sensitive crops. Levels of Cu in soil evaluated in the literature as adequate for wheat, should be reconsidered.

Key words: *copper, macronutrients, micronutients, wheat.*

1. INTRODUCTION

Copper is a constituent of plastocyanin and several enzymes; e.g. amine oxidases, phenolases, cytochrome oxidase, ascorbic acid oxidse and others, participating mainly in carbohydrate and protein metabolism (Mengel and Kirkby, 1987). Insufficient Cu-supply to plants can lead to sub-clinical or hidden deficiency, which may be as severe to cause yield losses of around 20% with no symptoms can be obviously recognized (Baker and Senft, 1995). Wheat, barley, oats and onions are sensitive to Cu-deficiency and thus are the most responsive crops to Cu-fertilizers (Robinson, 1983). Pollen sterility has been shown as the cause for failure of flower set in Cu-deficient wheat plants (Graham, 1980). The rate of leaf emergence in wheat plant was found to be decreased due to low soil Cu-supply (Longnecker *et al.*, 1993). Soils deficient in Cu are commonly found in many countries; e.g. Saudi Arabia (El-Shamlan, 1995), Iraq (Seddyk *et al.*, 1995) and Pakistan (Ahmad, 1998). It is well documented that the deficiency of micronutrients (Zn, Mn, Fe and Cu) in soils of arid and semi-arid regions forms one of the major yield limiting factors. The use of micronutrient foliar fertilizers has been recommended as a must in these regions due to the acute high pH and / or high $CaCO_3$ content of soils (El-Fouly,1983 and Amberger, 1991). Practically, in Egypt for example, most of the foliar multi-micronutrient compounds; which are commonly used, contain negligible Cu-content or free of it (NRC-GTZ, 1996). Therefore, the objective of this study was to investigate the response of bread wheat plants (*Triticum aestivum* L.) to Cu-enriching compound under field conditions in soils theoretically containing Cu levels considered as adequate.

2. MATERIALS AND METHODS

Two field trials on bread wheat cv. Sakha-69 (cultivated in most areas) were preformed during the consecutive seasons of 2000/2001 and 2001/2002. In both seasons, the work was conducted on clay soil at the Agricultural Research Station of the National Research Centre (NRC), Cairo (located in Shalakan, Qualubia Governorate, Egypt). Prior to any practices, a composite soil sample was taken from the soil surface (0-30 cm) of the experimental site, air-dried, sieved by 2mm sieve and analyzed (Table 1). The basic NPK fertilization was soil-applied in the whole experimental site as recommended (MoA, 1998). The rates were 75, 15 and 25 kg/fed. as N, P_2O_5 and K_2O in the forms of ammonium sulphate (20.6% N), calcium superphosphate (15.5% P_2O_5) and potassium sulphate (48-52% K_2O).; respectively, with no organic manure application. The amount of calcium superphosphate was broadcasted during land preparation. The amount of ammonium sulphate was applied in three splits; 20% before sowing, 40% before the first irrigation (*i.e.* 25 days after sowing) and 40% before the second irrigation (*i.e.* 50 days after sowing). The amont of potassium sulphate was applied in two splits; 50% at sowing and 50% before the first irrigation. Sowing took place on mid November. No pesticides were used.

Table (1): Soil analysis of the experimental sites, NRC-Agricultural Research Station.

	2000/2001	2001/2002
Sand%	**14.20**	**13.00**
Silt %	**28.80**	**28.00**
Clay %	**57.00**	**59.00**
Texture	**Clay**	**Clay**
pH	**8.20 H**	**7.85 H**
E.C. (dS/m)	**0.70 VL**	**0.58 VL**
O.M.%	**1.30 M**	**1.60 M**
Total $CaCO_3$ %	**2.80 M**	**3.20 M**
Available-P (mg/100g)	**2.10 M**	**2.14 M**
Available-K (mg/100g)	**27.50 M**	**25.00 M**
Available-Ca (mg/100g)	**196.20 H**	**230.00 H**
Available-Mg (mg/100g)	**56.60 M**	**65.00 M**
Available-Fe (ppm)	**11.50 M**	**12.30 M**
Available-Mn (ppm)	**12.20 M**	**9.70 M**
Available-Zn (ppm)	**1.20 L**	**0.90 L**
Available-Cu (ppm)	**2.00 H**	**2.20 H**
meq/100g- K /Mg	**0.15**	**0.12**
meq/100g- Ca /Mg	**2.11**	**2.15**

VL =very low, L = Low, M =medium, H = high (Ankerman and Large, 1 974).
Texture: hydrometer method (Bouyoucos, 1954).
pH and E.C.: in 1: 2.5 soil/water suspension (Jackson,1973).
O.M.: Black method (Walkley and Black, 1934).
$CaCO_3$: Collin's calcimeter (Alison and Moodle, 1965).
P: $NaHCO_3$ extract. at pH 8.5 (Olsen *et al.*, 1954).
K, Ca and Mg: NH_4 - Aoc extract. at pH 7.0 (Jackson,1973).
Micronutrients: DTPA extract. at pH 7.3 (Lindsay and Norvell, 1978).

2.1. Treatments and experimental design

A multi-micronutrient fertilizer (suspension) containing 4.2, 2.8, 1.4 and 0.013% W/V EDTA-Zn,Mn, Fe and Cu; respectively (referred as MN) as well as 0.5% Cu-solution (referred as 0.5% Cu) was used through foliar application. Cu-solution was freshly prepared using pure copper sulfate (19.64 g $CuSO_4.5H_2O$ /l). The foliar spray was carried out using tap-water (200 l/fed./spray) to apply 7 treatments as follows:

A. Control (tap-water), B. 1 ml MN/l, C. 2 ml MN/l, D. 1 ml 0.5% Cu/l, E. 2 ml 0.5% Cu/l, F. 1 ml MN + 1 ml 0.5% Cu/l and G. 2 ml MN +2 ml 0.5% Cu/l.

These treatments were arranged in a randomized complete block design (Snedecor and Cochran, 1967), with four replicates; each of $40m^2$ (4X10m).

Wheat plants were sprayed twice; the first spray at 45 days after sowing (*i.e.* during the tillering stage), followed by the second one at 15 days later (*i.e.* before heading). The total micronutrient amounts, which were foliar-applied each season, are given in Table (2).

Table (2): Total micronutrient amounts (g/fed./season) used as foliar spray.

Treatment	Zn	Mn	Fe	Cu
A. control (tap water)	-	-	-	-
B. 1ml MN/l	16.8	11.2	5.6	0.052
C. 2ml MN/l	33.6	22.4	11.2	0.104
D. 1ml 0.5% Cu/l	-	-	-	2.000
E. 2ml 0.5% Cu/l	-	-	-	4.000
F. (B) + (D)	16.8	11.2	5.6	2.052
G. (C) + (E)	33.6	22.4	11.2	4.104

2.2. Plant sampling and analysis

At 15 days after the second spray, a leaf sample/plot was randomly taken from the top 2-leaves (Jones *et al*., 1991) of about 30 plants. Leaf samples were washed in running tap water, then with 0.001M HCl for 30 seconds followed by distilled water twice. Thereafter, they were dried in a ventilated-oven at 70 °C till the constant weight; and ground by a stainless steel mill with 0.5-mm mesh sieve. One gram/ sample was wet-digested with a mixture of 8 : 1:1by volume conc. nitric, perchloric and sulphoric acids, respectively (Chapman and Pratt, 1978). Nutrient concentrations in the soil and leaf extractants were measured using the spectrophotometer (Perkin-Elmer Lambda 2) for P through vanado-molybdate method (ADAS, 1981), flamephotometer (Jenway PFP7) for K and Ca; and atomic absorption spectrophotometer(GBC 932 AA) for Mg and micronutrients.

2.3. Parameters and statistical analysis

K/Ca and K/(Ca+Mg) ratios were calculated after converting their concentrations (%) into meq/100g through multiplying them by 25.57, 49.9 and 82.24 for K, Ca and Mg, respectively. Ratios of P to Zn and Fe were considered (Jones *et al*., 1991). On the first of May, plants of a random 1 m^2/plot were harvested to estimate1000-grain weight (g), the number and weight (g) of grains/spike of the main stem as well as grain yield (ardab/fed.) and straw yield (ton/fed.). Data related to yield were subjected to statistical analysis using a Costat 2.00 computer program, Copyright Cohort Software (1986).

3. RESULTS AND DISCUSSION

3.1. Experimental soil characteristics

In both seasons, the data in Table (1) show that the experimental clay soil was of high pH, medium $CaCO_3$ and low organic matter content; and very low EC, reflecting no salinity problems. Available nutrient contents were high for Ca and Cu; medium for P, K, Mg, Fe and Mn; and low for Zn (Ankerman and Large, 1974). Ratios related to K, Ca and Mg cations might reveal the imbalance among them. The optimum K/Mg for field crops is < 1.5 (Doll and Lucas, 1973), and that of Ca/Mg for most crops is in a range of 3-4 (Landon, 1991). Besides, low available Zn might be due to high pH (Amberger, 1991), Zn is increasingly the most commonly deficient micronutrient in many regions (IFDC, 1996). Generally, similar soil characteristics were found to be prevailing in wheat and maize fields of the Nile-Valley and Delta (Sillanpää, 1982).

3.2. Plant nutritional status

Data presented in Tables (3) and (4) show; for all treatments in both seasons, that the concentrations of P, K, Mg, Mn and Fe were sufficient (with few exceptions of P), and those of Ca were high. The slightly low P-concentrations in the top 2-leaves might be attributed to the dilution effect resulting from plant growth. However, Ca/Mg ratios in the soil of the experimental sites (Table 1) were lower than 3 suggesting the inhibition of P-uptake (Yates, 1964).High available-Ca in the soil can precipitate P; especially, with high pH, where, soluble-P declines as the pH rises from 6.5 to 8.3 (Jones *et al.*, 1991).

Concerning Zn and Cu-concentrations (Table 4), no visual deficiency symptoms were obviously observed in both seasons. In this connection, Ward *et al.* (1973) reported that a range of 15-70 ppm Zn in the uppermost leaves of wheat and barley is optimum. Also, Davies *et al.* (1971) suggested that Cu levels in wheat and barley plants less than 2 ppm are indicative of deficiency, and levels over 3 ppm may be adequate.

Table (3): Mean (± SD) of macronutrient concentrations (%)* at heading start in the top 2-leaves of wheat plants cv. Sakha-69 due to foliar application.

Treatment	P	K	Ca	Mg
	2000/2001			
A. control	0.27 ± 0.05	2.05 ± 0.04	1.54 ± 0.08	0.23 ± 0.03
B. 1ml MN/l	0.23 ± 0.01	2.16 ± 0.02	1.45 ± 0.04	0.21 ± 0.01
C. 2ml MN/l	0.22 ± 0.01	2.12 ± 0.05	1.40 ± 0.07	0.20 ± 0.01
D. 1ml 0.5% Cu/l	0.22 ± 0.01	2.00 ± 0.02	1.48 ± 0.13	0.21 ± 0.01
E. 2ml 0.5% Cu/l	0.20 ± 0.01	1.97 ± 0.05	1.44 ± 0.08	0.20 ± 0.01
F. (B) + (D)	0.20 ± 0.01	2.07 ± 0.02	1.35 ± 0.04	0.22 ± 0.02
G. (C) + (E)	0.19 ± 0.02	2.11 ± 0.08	1.32 ± 0.04	0.21 ± 0.01
	2001/2002			
A. control	0.31 ± 0.04	2.25 ± 0.08	1.44 ± 0.08	0.22 ± 0.02
B. 1ml MN/l	0.27 ± 0.01	2.29 ± 0.05	1.35 ± 0.04	0.21 ± 0.01
C. 2ml MN/l	0.26 ± 0.01	2.14 ± 0.05	1.17 ± 0.10	0.17 ± 0.05
D. 1ml 0.5% Cu/l	0.24 ± 0.01	2.26 ± 0.08	1.40 ± 0.13	0.18 ± 0.01
E. 2ml 0.5% Cu/l	0.21 ± 0.02	2.18 ± 0.11	1.33 ± 0.03	0.18 ± 0.01
F. (B) + (D)	0.22 ± 0.02	2.19 ± 0.05	1.18 ± 0.05	0.17 ± 0.01
G. (C) + (E)	0.21 ± 0.01	2.20 ± 0.03	1.13 ± 0.03	0.17 ± 0.01

* Sufficient ranges (%) in the top 2-leaves of winter wheat (*Triticum aestivum* L.) just before heading are:
P = 0.21 - 0.50, K = 1.51 - 3.00, Ca = 0.21 - 1.00 and Mg = 0.16 – 1.00
(after: Jones *et al.*, 1991)

3.3. Nutrient balance in plant leaves

Data in Table 5 show that K/Ca and K/ (Ca+Mg) ratios were increased, whilst P/Zn and P/Fe ratios were decreased as compared with the control in both seasons. The increment in K/Ca ratio implies a better cationic equilibrium among K, Ca and Mg cations in the plants

(Jones *et al.*, 1991 and Perez-Sanz and Lucena, 1998). However, despite of the interfering presence of high available-Ca in soil (Table 1), K/(Ca+Mg) ratio increases in the plant revealing more K-availability in soil; *i.e.* more K-uptake, since Mg is the poorest competitor among these cations.

Table (4): Mean (± SD) of micronutrient concentrations (ppm)* at heading start in the top 2-leaves of wheat plants cv. Sakha-69 due to foliar application.

Treatment	Zn	Mn	Fe	Cu
	2000/2001			
A. control	21.3 ± 1.6	57 ± 6	245 ± 31	6.8 ± 2.1
B. 1ml MN/l	21.0 ± 1.9	64 ± 4	224 ± 16	5.6 ± 0.5
C. 2ml MN/l	19.9 ± 1.0	54 ± 3	235 ± 10	5.8 ± 0.9
D. 1ml 0.5% Cu/l	17.8 ± 0.7	65 ± 7	267 ± 32	4.4 ± 1.6
E. 2ml 0.5% Cu/l	16.6 ± 0.9	63 ± 6	252 ± 30	4.0 ± 0.9
F. (B) + (D)	19.0 ± 0.9	53 ± 6	259 ± 10	3.8 ± 0.3
G. (C) + (E)	19.5 ± 1.3	71 ± 8	246 ± 8	4.8 ± 1.0
	2001/2002			
A. control	21.1 ± 1.8	43 ± 2	273 ± 37	7.5 ± 1.2
B. 1ml MN/l	20.8 ± 1.6	50 ± 3	244 ± 19	6.3 ± 0.9
C. 2ml MN/l	20.6 ± 1.0	37 ± 6	248 ± 5	5.6 ± 0.8
D. 1ml 0.5% Cu/l	17.6 ± 1.3	33 ± 3	275 ± 31	5.8 ± 0.5
E. 2ml 0.5% Cu/l	15.5 ± 0.7	35 ± 3	252 ± 10	5.3 ± 0.7
F. (B) + (D)	19.4 ± 1.4	45 ± 2	286 ± 38	5.9 ± 0.5
G. (C) + (E)	19.3 ± 1.6	56 ± 4	277 ± 12	5.3 ± 0.3

* Sufficient ranges (ppm)in the top 2-leaves of winter wheat (*Triticum aestivum* L.) just before heading are:
Zn = 21 - 70, Mn = 16 - 200, Fe = 10 - 300 and Cu = 5 – 50 (after: Jones *et al.*, 1991)

Often, plant Zn or Fe concentrations (especially Fe) are just as high in the deficient plants. Therefore, deficiency symptoms are associated with the high ratios of P to Zn (critical P/Zn = 200/1) or Fe rather than their concentrations alone (Jones *et al.*, 1991). According to the positive effects on plant nutrient balance (Table 5), the micronutrient treatments could be arranged in a descending order of: Cu-enriched-MN > MN alone >Cu alone; and each at 2ml/l is better than 1 ml/l.

Table (5): K/Ca, K/(Ca+Mg), P/Zn and P/Fe ratios at heading start in the top 2-leaves of wheat plants cv. Sakha-69 due to foliar application (calculated from Tables 3 and 4).

Treatment	K/Ca*	K/(Ca+Mg)*	P/Zn	P/Fe
	2000/2001			
A. control	0.69	0.55	126.7	11.0
B. 1ml MN/l	0.76	0.62	109.5	10.3
C. 2ml MN/l	0.78	0.63	110.6	9.4
D. 1ml 0.5% Cu/l	0.69	0.56	123.6	8.2
E. 2ml 0.5% Cu/l	0.70	0.57	120.5	7.9
F. (B) + (D)	0.79	0.62	105.3	7.7
G. (C) + (E)	0.82	0.65	97.4	7.7
	2001/2002			
A. control	0.80	0.64	146.9	11.4
B. 1ml MN/l	0.87	0.69	129.8	11.1
C. 2ml MN/l	0.94	0.76	126.2	10.5
D. 1ml 0.5% Cu/l	0.83	0.68	136.4	8.7
E. 2ml 0.5% Cu/l	0.85	0.69	135.5	8.3
F. (B) + (D)	0.95	0.77	113.4	7.7
G. (C) + (E)	1.00	0.80	108.8	7.6

* calculations based on cation concentration as meq/100 g.

3.4. Grain and straw yields

Increments of grain yield were significant in both seasons (Fig. 1); meanwhile, those of the straw yield showed significance only in the second season (Fig. 2) due to foliar micronutrient treatments. These increments might be ascribed to the positive significant effects on yield components; *e.g*, the number and weight of grains per spike of the main stem, 1000-grain weight (Table 6). Similar results on wheat were obtained due to foliar application of Cu, Cu + Zn, Cu + Fe and Cu + Zn + Fe (El-Hefnawy *et al.*, 1989 and El-Kabbany *et al.*, 1996). Concerning the number of grains per spike, the treatments could be arranged in the descending order of: Cu-enriched-MN > Cu >MN. This sequence might be attributed to the importance of Cu to pollen fertility (Graham, 1980); coupled with the effect of the other foliar-sprayed micronutrients (*i.e.* Zn, Mn and Fe). The other investigated yield parameters followed the same descending order of Cu-enriched-MN > MN > Cu; reflecting tempo of the nutrient balance in plant leaves (Table 5). However, grain and straw yields (Figs. 1 and 2) were higher in the second season than in the first one for all treatments including the control. Such a trend might be due to the prevailing environmental conditions in each season (Horst, 1992). Percentage

A = Control B = 1ml MN/l D = 1 ml 0.5% Cu/l F = B + D
C = 2ml MN/l E = 2ml 0.5% Cu/l G = C + E

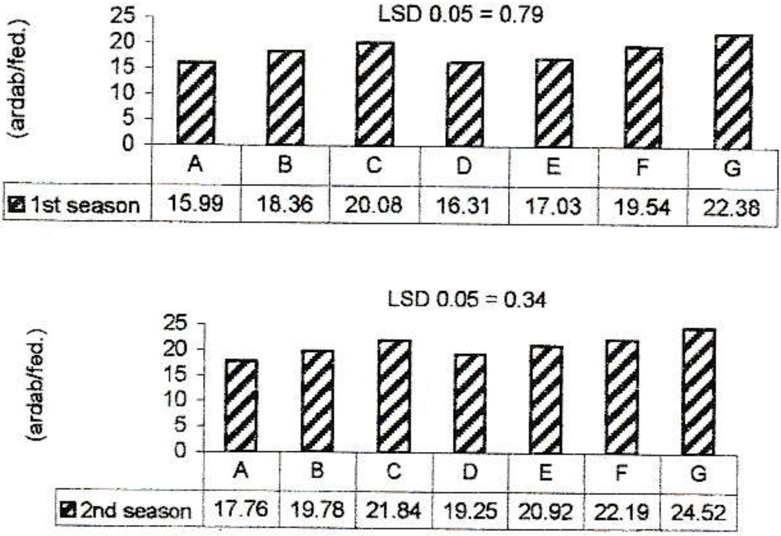

Fig.(1): Mean grain yield (ardab = 150 kg) of wheat cv. Sakha-69 due to foliar application.

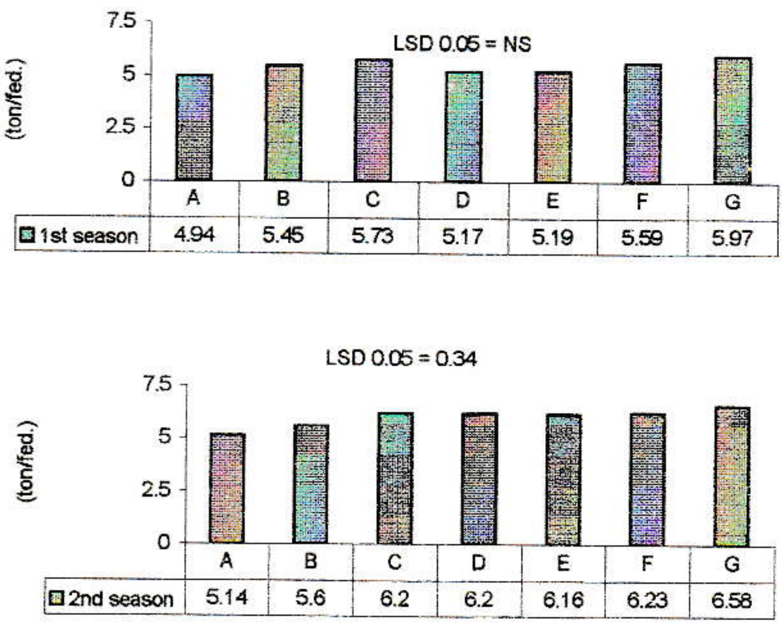

Fig.(2): Mean straw yield (ton/fed.) of wheat cv. Sakha-69 due to foliar application.

Table (6): Means of the number and weight of grains per spike on the main stem, and 1000-grain weight of wheat cv. Sakha 69 due to foliar application under field conditions.

Treatment	2000/2001			2001/2002		
	Grain no./spike	Grain wt./spike (g)	1000-grain wt. (g)	Grain no./spike	Grain wt./spike (g)	1000-grain wt. (g)
A. control	35.3	1.35	46.05	38.0	1.42	48.25
B. 1ml MN/l	41.3	1.78	53.50	42.0	1.88	58.08
C. 2ml MN/l	40.2	1.89	54.13	43.0	2.00	58.73
D. 1ml 0.5% Cu/l	45.0	1.58	52.38	46.0	1.62	56.55
E. 2ml 0.5% Cu/l	46.3	1.63	53.35	48.0	1.67	56.75
F. (B) + (D)	51.0	1.95	56.23	50.0	2.10	59.45
G. (C) + (E)	53.0	2.07	58.18	51.5	2.23	60.08
LSD 5%	4.3	0.16	1.76	4.2	0.15	1.52

Table (7): Percentage increases (over the control) of straw and grain yields due to foliar application.

Treatment		Grain yield			Straw yield		
		1st season	2nd season	Mean	1st season	2nd season	Mean
Cu-enriched-MN:	2 ml/l	40.0	38.1	39.1	20.9	28.0	24.5
	1 ml/l	22.2	24.9	23.6	13.2	21.2	17.2
MN alone	: 2 ml/l	25.6	23.0	24.3	16.0	20.6	18.3
	1 ml/l	14.8	11.4	13.1	10.3	9.0	9.7
Cu alone	: 2 ml/l	6.5	17.8	12.2	5.1	19.8	12.5
	1ml/l	2.0	8.4	5.2	4.7	20.6	12.7

increment means of both seasons (over the control) reached 39.1, 24.3 and 12.2% for grain yield; and 24.5, 18.3 and 12.5% for straw yield due to foliar application of Cu-enriched-MN, MN and Cu; respectively, at 2ml/l (Table 7). Approximately, half of these means were obtained with 1ml/l.

Generally, foliar application of Cu increases plant uptake of macronutrients (Jones *et al.*, 1991) due to its catalyzing effect through several enzymes with diverse functions in plant metabolism. Furthermore, Cu-foliar application is of a special importance with organic manuring or organic agriculture systems. More than 98% of Cu is tightly bound to the soil organic matter, and becomes un-available to plants (Mengel and Kirkby, 1987).

From the overall data of this investigation, it could be concluded that Cu is a yield-limiting nutrient and must be added to the other foliar-applied micronutrients (i.e. Zn, Mn and Fe) for wheat production in Egypt and other countries where, Cu deficiency or hidden deficiency might occur. Cu content of the soil, which is considered as optimum, should be reinvestigated as the results showed a positive effect on wheat yield inrespective of the fact that Cu in the soil was evaluated as high.

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ملخص

أجريت تجربتان حقليتان على القمح (صنف سخا ٦٩) خلال الموسمين الشتويين ٢٠٠٠/٢٠٠١ ، ٢٠٠١/٢٠٠٢ وذلك بمحطة التجارب الزراعية بشلقان، محافظة القليوبية والتابعة للمركز القومي للبحوث، القاهرة. وقد استندت هذه الدراسة على أن معظم أسمدة العناصر الصغرى الورقية المركبة الشائع استخدامها تحتوي على تركيز ضئيل جدا من النحاس أو خالية منه رغم أهميته بالنسبة للقمح بصفة خاصة.ولذلك، كان هدف هذه الدراسة التعرف على استجابة نباتات القمح للرش الورقي بأحد مركبات العناصر الصغرى المدعم بالنحاس، وذلك تحت ظروف التسميد الأرضي الموصي به في الأراضي الطينية (القديمة). ويحتوى مركب العناصر الصغرى المستخدم على زنك، منجنيز، حديد، نحاس (مخلبة على EDTA) بنسب (وزن/حجم) ٤,٢، ٢,٨، ١.٤، ٠,٠١٣ % على التوالي، وتم تدعيمه بالنحاس عند الرش باستخدام محلول كبريتات النحاس (٠,٥ % نحاس). وتضمنت معاملات الرش ٧ معاملات هي: المقارنة (الرش بماء الصنبور) والتباديل المختلفة بين ١، ٢ سم٣/ لتر ماء رش من كل من مركب العناصر الصغرى، محلول ٠,٥ % نحاس. وتم رش النباتات مرتين (٢٠٠لتر/فدان/رشة) وذلك عند ٤٥، ٦٠ يوماً من الزراعة. وكانت أهم النتائج ما يلي :

- تحسن التوازن العنصري داخل أوراق النبات، سواء بين البوتاسيوم والكالسيوم والمغنسيوم أو بين الفوسفور وكل من الزنك والحديد ، وذلك نتيجة للرش الورقي بمركب العناصر الصغرى أو النحاس أو مخاليطهما.
- انعكس ذلك التحسن في التوازن العنصري داخل النبات إيجابيا بزيادات معنوية في محصول الحبوب وبعض مكوناته وكذلك محصول القش.
- يمكن ترتيب أفضلية معاملات الرش الورقي من حيث أعلى محصول حبوب وقش على الترتيب التالي:

مركب العناصر الصغرى المدعم بالنحاس > مركب العناصر الصغرى > النحاس.

وقد تحققت زيادات معنوية بمتوسطات للموسمين مقدارها ٣٩,١، ٢٤,٣، ١٢,٢ % بالنسبة لمحصول الحبوب وكذلك ٢٤.٥، ١٨,٣، ١٢,٥ % بالنسبة لمحصول القش نتيجة للرش الورقي بنفس الترتيب المذكور أعلاه بمعدل ٢سم٣/لتر.

وعليه، يمكن إجمالا التوصية بضرورة الاهتمام بالتغذية بعنصر النحاس في زراعات القمح بصفة خاصة بنفس درجه الاهتمام بالعناصر الصغرى الأخرى، بغض النظر عن مستوى النحاس بالتربة حيث أن تقييم ذلك في حاجه إلى إعادة نظر.

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