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RELATIONSHIP BETWEEN MYCORRHIZAE AND UPTAKE OF SOME ELEMENTS IN CORN AND GUAR

Said Abbas Mohammed El-Sayed

Soil and Water Sciences Department, Faculty of Agriculture in Assiut, Al-Azhar University.

ABSTRACT :

Mycorrhizae increase the uptake of Zn and Cu by many plants, but mycorrhizal activity is suppressed by P fertilization. Guar (*Cyamopsis tetragonoloba* L. Taub.) variety Giza 1 and two varieties of corn (Zea mays L.) single cross 10 and 120 were used to determine if this mechanism is a major cause of P-induced Zn and Cu deficiencies. Shoot dry weights and concentrations of total uptake of P, Zn, Cu, Fe, Mn, K, Ca and Mg were determined for mycorrhizal and nonmycorrhizal plants given 0, 20, 70, or 175 ppm P. Phosphorus fertilization significantly reduced Zn and Cu concent-rations in mycorrhizal guar, but concentrations in nonmycorrhizal treatments were not affected. Concentrations of Zn and Cu in mycorrhizal and nonmycorrhizal corn were reduced by P fertilization, but the reduction for mycorrhizal plants was significantly greater than the decrease for nonmycorrhizal plants. Reductions in Zn and Cu concentrations in nonmycorrhizal corn were the result of a dilution effect and could be attributed to increased plant size rather than increased P fertility per se. The concentations of the other analyzed elements were all affected by P level and/or mycorrhizal condition. In general, mycorrhizal and nonmycorrhizal dry weights of plants and elemental concentrations converged as soil P was increased. Patterns of response to P and mycorrhizae differed slightly between corn varieties, and such differences were marked for certain elements when corn was compared with guar.

INTRODUCTION :

Reductions of Zn and Cu concentrations in plants by P fertiliz- ation have been recognized for many years. They occur in numerous monocots, dicots, and conifers (Olsen, 1972; Van Lear and Smith, 1972 and El-Sayed, 1999 a,b,c) although deficiency symptoms appear infrequently. The mechanisms by which P reduces the uptake or translocation of these elements are still unclear, although there is general agreement that P has its major effects within the plant rather than in the soil (Olsen, 1972 and El-Sayed, 1996). Nevertheless, the growth medium is an important variable. In the literature reviewed by the authors, increasing P reduced concentrations of Zn and/or Cu in 41 of 45 cases if plants were grown in natural, unsterilized soil. In 18 cases where various plant species were grown in solution or sand cultures or in sterilized soil, the P effect occurred consistantly in only two cases with variable responses in five instances (Adriano *et al.*,1971; Bingham, 1963; Clark, 1970; Edwards & Kamprath, 1974; Halim *et al.*, 1968; Labanauskas *et al.*, 1978; Ross, 1971; Snehi *et al.*, 1975; Watanabe *et al.*, 1965 and El-Sayed, 1998 & 2001). These results suggest that a microbial factor is also involved. Nearly all instances of P-Zn or P-Cu interactions have been reported for plants which form mycorrhizae, and species such as citrus and other fruit trees, legumes, corn, etc.. for which marked responses to mycorr-hizae have been demonstrated, constitute the large majority of such reports. In 45 of the cases mentioned above where P reduced Zn or Cu, 41 were for plants with mycorrhizae. Out of the 12 instances in which no effect was observed, in only one case were the plants mycorrhizal.

Mycorrhizae are symbiotic associations of plant roots with certain fungi. The fungal partner functions analogously to root hairs, but may extend as far as 7 cm from the root surfaces of vesicular- arbuscular mycorrhizae (Rhodes & Gerdemann, 1975 and Koreish *et al.*, 1998), increasing the volume of soil from which nutrients can be extracted. This function is disproportionately important for nutrients which have narrow diffusion zones around roots, particularly P, Zn and Cu, and indeed these are the three elements whose concentrations are most consistantly increased by mycorrhizae. The benefits of mycorrhizae vary, decreasing by P fertility increases (Mosse, 1973a&b; Barsoom, 1998 and Negm & Zahran, 2001). Crop species range from nonmycorrhizal to mycorrhizal but minimally benefitted to others which are obligately mycorrhizal under natural conditions. Fungal infection and/or efficiency in improving nutrient uptake are adversely affected by a number of variables, including soil fumigation, low temperatures, wet soil mass, and P fertilization (Bauer & Lindsay, 1965; Mosse,1973a&b; Ross, 1971; Schenck, 1974; El-Kalla *et al.*, 1997 and Attia & Saad, 2001). These factors are all associated with reduced uptake of Zn and sometimes Cu (Ellis *et al.*,1964; Martin *et al.*, 1963; Wilhelm *et al.*, 1967 and Shahaby *et al.*, 2000). As a rule, increasing the availability of P suppresses mycorrhizal colonization (Hall, 1978; Hayman *et al.*, 1975; Jackson *et al.*, 1972; Menge *et al.*, 1978; Mosse, 1973a&b; Rhodes & Gerdemann, 1975; Ross, 1971; Sanders, 1975; Shuman *et al.*, 1976; Mohamed *et al.*, 1999; Ismail *et al.*, 2000 and El-Sayed & Salem, 2001). Mosse (1973a&b) first suggested that this P effect might alter the performance of mycorrhizae with respect to the uptake of elements other than P, and this has been demonstrated for Cu in the data of Ross (1971) with soybean.

This paper reports an investigation of the role that mycorrhizal fungi play in the uptake of various elements. The effect of plant size on element concentrations is analyzed because plant weight may vary greatly over a range of P levels and elements may be more conc- entrated in smaller, stunted plants.

MATERIALS AND METHODS :

A silt loam soil material was used which had, prior to treatment, a pH of 7.6, 8.5 ppm Bray no.1 P, a cation exchange capacity (CEC) of 14.1 meq/100g, K, Mg, and Ca saturations of 1.7, 5.7 and 63.5% respectively, and DTPA (diethylenetriaminepentaacetic acid) extract-able (Baker, 1973 and Page *et al.*, 1982) concentrations of 0.1 ppm Cu, 0.2 ppm Zn, 0.4 ppm Mn, and 3 ppm Fe. This soil was pasteurized with aerated steam for 30 min at 76°C to kill indigenous mycorrhizal fungi. Phosphorus was added as ground calcium monophosphate at rates of 0, 20, 70 and 175 ppm. Potassium sulfate, magnesium sulfate, and calcium hydroxide were added in amount that could raise the native K, Mg and Ca to 4, 15 and 70% saturations of the exchange capacity, respectively and 90 ppm N was added as NH_4NO_3 . At the end of the experiment, the pH of a composite soil sample was 7.6, and micronutrient concentr-ations were 0.7 ppm Cu, 0.8 ppm Zn, 19 ppm Mn and 17 ppm Fe. Guar was inoculated with *Rhizobium* strain ARC 800 G and not given fertilizer N. Mycorrhizal inoculum was prepared by wet-sieving of soil from the root systems of sorghum plants (*Sorghum bicolor* L. Moench) variety RS-610 infected with the mycorrhizal fungus *Gigaspora gigantea* to obtain fungal spores falling in the 0.05-0.25 mm range. This intermediate fraction was added to sand (for bulk) and mixed into the soil of mycorrhizal treatments. A portion of the filtrate, which did not contain mycorrhizal spores, was added to both mycorrhizal and nonmycorrhizal treatments. One-liter pots of soil were planted with pregerminated seeds of either Giza 1 guar or the single cross corn hybrids 10 and 120 (Shuman *et al.*, 1976). The guar experiment was replicated 10 times and the corn experiment was replicated 5 times in a 4 P level × +/– mycorrhizae factorial design with 8 treatments.

After 45 days in the greenhouse of the Faculty of Agriculture in Assiut, Al-Azhar University, all plants were harvested and the shoot dry weights were recorded. Root samples were stained with lactophenol - Trypan Blue (Phillips & Hayman, 1970; Page *et al.*, 1982 and Evenhuis & DeWaard, 1978) to determine the extent of mycorrhizal colonization. Percentage colonization was calculated as the number of 1.2 mm – wide microscope fields per 100 containing any mycorrhizal fungus structure. Percentage colonization is not a quantitative indicator of mycorrhizal activity, but colonization figures are included to demonstrate the adverse effects of P on fungal growth in the roots.

Plant tops were dry-ashed and analyzed by atomic absorption or emission for Zn, Cu, Fe, Mn, K, Ca and Mg concentrations. Phosphorus was determined colorimetrically with a molybdenum-Vanadate reagent (Cottenie, 1980 and FAO, 1980).

In addition to standard analysis of variance, all element concentration data were submitted to regression analysis with either: 1) each of the eight individual treatments was analyzed separately with the dry weight of each replicate as an independent variable ; 2) each of the four P levels was analyzed separately with dry weight and +/ – mycorrhizal inoculation as the independent variables ; 3) all data within each of the two inoculation treatments were analyzed together with P level as an independent variable ; and 4) all data within each of the two inoculation treatments were analyzed with both P level and dry weight as independent variables.

These methods of analysis were used : a) to determine if concentrations of elements were inversely associated with plant size (weight), indicating that some variation in concentration resulted from a growth dilution effect ; b) to determine is differences in elemental concentrations are due, directly, or indirectly to mycorrhizae with the appropriate corrections for dry weight ; c) to determine if element concentrations were significantly affected by the level of P in the mycorrhizal and nonmy-corrhizal treatments without corrections for plant size and d) to determine if element concentration was still a function of P level if corrections were made for any growth dilution effect.

The fourth type of analysis presents statistical problems since the independent variables (P level and dry weight) are not truely independent. To determine the reliability of results from this analysis, the regression equations generated by the first analysis method were used to correct element concentrations to the expected values for plants of an arbitrary standard weight (2 g for guar, 5 g for corn). In cases where the dry weight variable was not statistically significant, the original data were used. The tendency of these individual means elemental concentration are increase or decrease as a function of the level of P was then compared to the response of element concentrations to P as determined by method, in which the data for all four levels of P were analyzed together. Any lack of corresp- ondence between the two methods were noted. In a fifth analysis, the independent variables in foliar P concentration and shoot dry weight were regressed on Zn and Cu concentrations. For all regression analysis, data for the two corn varieties were combined to provide ten replicates, and an additional variable (variety) was added to regression models (Steel & Torrie, 1982 and SAS, 1988). Total uptake of the eight elements were also analyzed for differences between means and significance of factors and factors interactions.

RESULTS AND DISCUSSION :

Dry Weight :

The response of guar to P was parabolic for mycorrhizal plants and sigmoidal for nonmycorrhizal plants (Table 1). Corn yields differed from guar yields in two major respects. The range of dry weights over the four levels of P was much greater for corn than for guar, and the response of corn to mycorrhizae was poorer. Only the variety having single cross 10 as a maternal parent, demonstrated a yield response to mycorrhizae, despite the fact that P, Zn and Cu concentrations were increased by mycorrhizae in both varieties (Table 1). Yield differences might have been greater if the plants had developed for a longer time (Murdoch *et al.*, 1967; El-Sayed, 1999 a,b,c; Shahaby *et al.*, 2000 and Negm & Zahran, 2001), although Hall (1978) reported similar variation in yield responses to mycorrh- izae among corn varieties after 89 days growth.

Within the 128 data cells for each of the eight element × eight treatment × two species combinations, plant dry weights and element concentrations were inversely related in 86% of all cases, significantly so in 39% of the total. Of the 14% of cases where the relation- ship was positive, the association was statistically significant in only one instance.

Colonization :

Mycorrhizal colonization decreased as P availability increased. The exception to this trend was in the low P level for corn single cross 120; where infection was poorer than in the next two higher P levels (Table 1).

Phosphorus :

Concentration of P in mycorrhizal guar were approximately twice those of the nonmycorrhizal treatments, and these differences were significant at all levels of added P. As with yield, the P concentration of the nonmycorrhizal guar plants was not increased by the first increment of fertilizer P (Table 1). In corn, mycorrhizae significantly increased P concentrations at the three lower levels of P (Table 2). These results differ from those of Hall (1978) and Jackson *et al.* (1972), who, in most cases, did not find increased P conc- entrations in corn whose yields were increased by mycorrhizae. Mycorrhizal inoculation × P level (MR×P) interactions were significant for both crops and for the total P uptake of guar and single cross 120 corn. Mycorrhizae increased the total uptake of P in guar and both varieties of corn (P= 0.01 as determined by analysis of variance). Mycorrhizal P uptake was higher in

three of the four levels of P in single cross 10, but was not significant at any level for the other variety [P = 0.05 by Duncan's Modified LSD test (Table 3)].

Zinc and Copper :

Zinc concentrations were higher in all mycorrhizal treatments and Cu concentrations were greater in all mycorrhizal treatments except for the two highest levels of P in corn (Table 2). With no correction for differences in plant size, an increase in soil P significantly decreased Zn and Cu in mycorrhizal guar but not in nonmycorrhizal plants (Table 4). In corn, concentrations of these elements were reduced in mycorrhizal and nonmycorrhizal treat- ments as soil P was increased. With corrections for differences in plant size, P significantly decreased mycorrhizal guar Cu and Zn concentrations but increased nonmycorrhizal Cu and Zn (Table 4). Because no attempt was made to correct for any decrease in soil pH resulting from the addition of calcium monophosphate, it is possible that the significant increase in Zn, Cu, and other elements may have resulted from an increased availability at lower pH`s rather than a direct effect of improved P nutrition. In corn, with compensation for variation in plant size, P decreased Zn only in mycorrhizal plants and Cu concentrations were not affected by increasing P. These results indicate that mycorrhizae are an important component in the uptake of Zn and Cu and that the major causes of the effects of P on Zn and Cu occurred for the same reason, i.e. a P-induced suppression of uptake by mycorrhizal fungi. In some cases, as with corn, the apparent antagonism of Zn and Cu by P results from a growth dilution effect and is a function of plant size rather than P fertility per se. In this regard, foliar P concentrations were correlated with both Cu and Zn concentrations in all four mycorrhizal guar treatments but were unrelated in the nonmycorrhizal treatments. In corn, which did not respond well to mycorrhizae, P and Zn were correlated in only two of the mycorrhizal treatments, and P and Cu were not correlated in any treatments. This positive correlation of P with Zn and Cu is consistent with random variability in the quantity or efficiency of element uptake by mycorrhizae. In terms of total uptake per plant, all MR × P interactions were significant ($P = 0.05$) as were the main effects of mycorrhizal inoculation alone.

Table (1): Dry weight, mycorrhizal colonization, and shoot elemental analysis for mycorrhizal and nonmycorrhizal guar and corn.

	Added Soil P (ppm)	Shoot dry weight (g)	P (%)	Zn (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)	K (%)	Ca (%)	Mg (%)	Mycorrhizal Colonization (%)
Guar											
NMR*	0	1.07d**	0.071 g	16.5 d	5.6bc	56 d	63 d	2.16bc	1.71bc	0.59cd	
	20	0.99 d	0.079 g	15.9 d	6.3b	63 cd	72 c	2.31bc	1.66bc	0.60bc	
	70	2.22 b	0.119 f	14.3 d	5.8bc	72abc	89 a	2.05 c	1.85a	0.65ab	
	175	2.82 a	0.237 c	17.7 d	5.3 c	81 ab	93 a	3.09 a	1.74bc	0.65 a	
MR	0	1.73 c	0.143 e	56.6 a	8.3 a	68 bc	74 bc	2.41 b	1.81ab	0.55 d	87a
	20	2.45 ab	0.182 d	35.8 b	7.5 a	77 ab	74 bc	3.04 a	1.57 c	0.58cd	82 ab
	70	2.65 a	0.272 b	28.6 c	6.1 b	74abc	76 bc	3.14 a	1.62 c	0.57cd	80 ab
	175	2.68 a	0.360 a	28.5 c	6.3 b	84 a	82 b	3.29 a	1.60 c	0.58cd	76 b
Corn single cross 10											
NMR	0	0.95 h	0.081 f	30.1 c	7.5 c	86 ab	77 b	6.31bc	1.24 b	0.47 a	
	20	2.81 f	0.108cde	17.4 ef	4.5 e	59 c	58 de	6.27bc	0.99 d	0.37cd	
	70	6.14 bc	0.118 cd	19.2de	4.9 e	44 efg	44 g	4.07 d	0.75efg	0.33de	
	175	8.65 a	0.203 a	11.6 f	4.2 e	44 efg	52 ef	2.79 f	0.61 i	0.40bc	
MR	0	1.42 g	0.097 e	65.6 a	10.2a	88 a	72 bc	6.93 b	1.12 c	0.46 a	67a
	20	4.99 cd	0.121 bc	34.8bc	6.3d	55 cd	49 fg	4.05 d	0.71fgh	0.37cd	65a
	70	7.28 ab	0.145 b	24.5 d	4.9 e	41 fg	45 g	3.13 ef	0.58 i	0.37cd	51ab
	175	8.09 ab	0.203 a	15.0 ef	4.5 e	42 fg	52 ef	2.85 f	0.57 i	0.40bc	22c
Corn single cross 120											
NMR	0	0.84 h	0.085 f	30.9 c	7.4 c	60 a	87 a	6.77 b	1.42 a	0.41bc	
	20	3.71 ef	0.111cde	19.3de	4.3 e	48 def	69 c	6.83 b	1.08 c	0.33de	
	70	6.76abc	0.114cde	17.0 ef	4.5 e	45 efg	61 d	3.89de	0.77 ef	0.30 e	
	175	8.99 a	0.190 a	12.7 f	4.1 e	43 fg	60 d	2.77 f	0.63 hi	0.34de	
MR	0	1.07 h	0.111 de	64.2 a	8.8b	84 ab	89 a	7.97 a	1.42 a	0.42ab	42 b
	20	4.18 de	0.146 b	38.1 b	5.9d	51 de	62 d	5.79 c	0.84 e	0.36cd	60 a
	70	7.42 ab	0.126 bc	20.9de	4.4 e	38 g	53 ef	3.07 e	0.64 hi	0.33de	50 ab
	175	6.85abc	0.200 a	16.0 ef	4.9 e	47 ef	71 bc	3.09 e	0.66ghi	0.39bc	11 c

*** NMR = nonmycorrhizal, MR = mycorrhizal**

****Means followed by the same letter do not differ significantly at the 5% level. All corn data were analyzed together.**

Table (2): Statistical significance (P=0.05) of difference between element concentrations of mycorrhizal and nonmycorrhizal guar and corn when corrections are made for plant size.

P added to soil (ppm)	Element (ppm)							
	P	Zn	Cu	Fe	Mn	K	Ca	Mg
Guar								
0	+*	+	+	+	+	+	+	NS
20	+	+	+	+	NS	+	+	+
70	+	+	+	+	NS	+	NS	NS
175	+	+	+	NS	—	NS	—	—
Corn								
0	+	+	+	+	NS	+	NS	+
20	+	+	+	NS	—	—	—	NS
70	+	+	NS	NS	NS	—	—	+
175	NS	+	NS	NS	NS	NS	NS	NS

+* , + , NS and — indicate that the element concentration in the mycorrhizal treatment is either higher, not significantly different, or lower than that of the corresponding nonmycorrhizal treatment.

Table (3) : Shoot element content of mycorrhizal and nonmycorrhizal guar and corn.

	Added soil P (ppm)	P (mg)	Zn (μg)	Cu (μg)	Fe (μg)	Mn (μg)	K (mg)	Ca (mg)	Mg (mg)
	Guar								
NMR*	0	0.73 e**	18 d	6.0 d	60 d	67 e	2.4 c	1.9 e	0.63 d
	20	0.76 e	16 d	6.0 d	60 d	68 e	2.3 c	1.7 e	0.58 d
	70	2.12 d	27 c	10.3 c	144 c	154 cd	3.7 b	3.6 cd	1.44 c
	175	6.63 b	45 c	14.6 b	223 a	259 a	8.7 a	5.0 a	2.23 a
MR	0	2.45 d	98 a	14.1 b	116 c	128 d	4.3 b	3.2 d	1.16 c
	20	4.36 c	87 ab	18.0 a	188 b	176 bc	7.4 a	4.0 bc	1.88 b
	70	7.22 b	77 b	16.0 ab	193 ab	200 b	8.5 a	4.4 ab	1.93 ab
	175	9.52 a	75 b	16.5 b	213 ab	215 ab	8.7 a	4.3 ab	2.13 ab
	Corn single cross 10								
NMR	0	0.76 e	29 d	7.0 c	81 e	73 e	6.1 c	1.3 d	0.44 f
	20	2.98 d	49 d	12.5 b	162 d	160 d	17.6 b	2.8 c	1.00 d
	70	6.87 c	113 bc	28.4 a	260 c	259 bc	23.7 a	4.4 ab	1.89 bc
	175	13 96 a	85 c	33.5 a	363 a	374 a	21.1ab	4.7 a	2.70 a
MR	0	1.35 d	96 bc	14.2 b	148 d	102 de	9.8 c	1.7 d	0.64 e
	20	5.92 c	170 a	30.2 a	278 bc	239 c	20.0ab	3.6 bc	1.76 c
	70	10.00 b	170 a	33.7 a	289 bc	309 b	21.9 a	4.2 ab	2.49 ab
	175	16.09 a	119 b	35.1 a	313 b	407 a	22.7 a	4.6 ab	3.14 a
	Corn single cross 120								
NMR	0	0.70 d	26 d	5.9 d	65 e	72 d	5.8 c	1.3 d	0.33 d
	20	3.83 c	71 c	14.9 c	175 d	250 c	24.9ab	4.1 bc	1.12 c
	70	7.42 b	109 c	24.2 b	289 bc	297 b	25.5 a	5.2 ab	1.94 b
	175	16.78 a	113 b	35.6 a	873 a	531 a	24.8ab	5.7 a	2.90 a
MR	0	1.04 d	69 c	9.0 d	86 e	94 d	8.4 c	1.6 d	0.44 d
	20	5.74 c	161 a	23.2 c	199 d	254 c	22.6ab	3.6 c	1.43 c
	70	9.25 b	154 a	32.0 ab	265 c	387 b	22.7ab	4.7abc	2.37 ab
	175	13.36 a	106 b	33.6 a	334 ab	467 a	20.6 b	4.5 bc	2.56 a

*NMR = nonmycorrhizal , MR = mycorrhizal.

** Means followed by the same letter do not differ significantly at the 5% level. Corn varieties analyzed separately.

Iron, Manganese, Potassium, Calcium and Magnesium :

Iron and potassium were the two elements, other than P, Zn and Cu whose concentrations were generally higher in mycorrhizal guar shoots (Table 2). These elements were also the only two, other than P itself, to be increased by fertilization in both mycorrhizal and nonmycorrhizal guar (Table 4). Therefore, it is not possible to differentiate increased uptake of Fe and K by mycorrhizae from increased uptake or translocation as a result of improved P nutrition for these species. Higher Fe (Daft *et al.,* 1975; El-Sayed, 1995 and El-Kalla *et al.,* 1997) and K (El-Sayed, 1996 and Ghanem *et al.,* 1998) concentrations in mycorrhizal plants have been reported in a few instances, but the effects of mycorrhizae on the uptake of these elements and on Mn, Ca and Mg are not always consistent. Mycorrhizae usually increase P uptake, which requires some charge compensation by the major cations. Differences in plant size resulting from differ-ences in P nutrition may also be accompanied by the growth dilution effect. A mycorrhizal condition can favor the uptake of K relative to Ca and Mg, which diffuse more rapidly in soil than K. This occurred with guar (Table 1) but was less evident in corn. Mycorrhizal infection dramatically alters the lipid composition of the root (Cooper & Loesel, 1978 and El-Sayed, 1998), and mycorrhizal infection, either directly or by improving P nutrition, has been reported to increase root amino acids (Baltruschat & Schonbeck, 1975 and Koreish *et al.,* 1998). These

effects could also alter cation requirements. Improved P nutrition, the primary effect of mycorrhizae, alters the plant in various ways, increasing the amount of vascular tissue (Mohamed *et al.*, 1999) and altering the compositing of soluble molecules (Labanauskas *et al.*, 1978 and Ismail *et al.*, 2000). Presumably, the cations required to balance these bound or soluble charged species are also affected. The ratio of neutral dry matter (e.g. cellulose) to charged dry matter might also be changed by P fertilization. The uptake and translocation of Fe and Mn can be antagonized by P, Cu and Zn (Olsen, 1972), whose concentrations are increased by mycorrhizae, but this is more likely if the amounts of these three elements are excessive. Within-treatment analysis of the corn and guar, data do not indicate any consistent inverse relationship between P, Cu and Zn with Fe and Mn (Barsoom, 1998; El-Akabawy, 2000; Attia & Saad, 2001; El-Sayed & Salem, 2001 and El-Sayed, 2001).

Table (4): Regression analysis of significance (P = 0.05) of the level of soil P for shoot concentrations of several elements with and without corrections for difference in plant size.

Crop / Element	Without dry weight as an independent variable		With dry weight as an independent variable			
	Significance of soil P level		Significance of soil P level		Significance of plant size	
	NMR*	MR	NMR	MR	NMR	MR
Guar /						
P	+**	+	+	+	NS	—
Zn	NS	—	+	—	—	—
Cu	NS	—	+	—	—	—
Fe	+	+	+	+	NS	NS
Mn	+	NS	+	NS	—	NS
K	+	+	+	+	—	NS
Ca	NS	—	+	NS	—	—
Mg	+	NS	+	NS	—	NS
Corn /						
P	+	+	+	+	—	—
Zn	—	—	NS	—	—	—
Cu	—	—	NS	NS	—	—
Fe	—	—	—	NS	NS	—
Mn	—	—	(NS)	(+)	—	—
K	—	—	—	—	NS	—
Ca	—	—	—	(NS)	NS	—
Mg	—	NS	(+)	(+)	—	—

*** NMR = nonmycorrhizal , MR = mycorrhizal.**

+ , NS and — indicate that element concentrations either increase, are not significantly different at the 5% level, or decrease with increasing soil P or plant size (dry weight). Parentheses indicate that these results, based on four combined levels of P, do not correspond to trends determined from regression analysis for individual levels of soil P.**

CONCLUSIONS :

These experiments indicate two mechanisms for P-induced reductions in Cu and Zn concentrations, 1) the suppression of mycorrhizal uptake of these elements, and 2) a dilution effect in which the larger P-sufficient plants do not concentrate elements as much as smaller deficient plants. These two mechanisms operate for both Cu and Zn. Increasing P decreased mycorrhizal root colonization,

further indicating the adverse effects of P on mycorrhizae. The P level × mycorrhizal inoculation interaction was significant for dry weight, P, Cu, Zn and Mn concentrations, but not for Fe concentrations. There were interactions for Ca, Mg and K in one but not both crop species. In general, differences between mycorrhizal and nonmycorrhizal treatments decreased as P nutrition was increased.

Mycorrhizal infection is the natural condition of most plant species (Mosse, 1973a&b), and many crops benefit from mycorrhizae even at moderate to high levels of P. The use of nonmycorrhizal plants for nutrition experiments often may not be appropriate, particularly if P, Zn and Cu are being studied or if P is a variable. Because large proportions of these elements may be taken up through mycorrhizal fungi, mycorrhizae must be considered as a component in the analysis of environmental or nutritional effects on P, Cu, or Zn uptake.

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العلاقة بين الميكورهيزا وامتصاص بعض العناصر فى الذرة الشامية والجوار

سعيد عباس محمد السيد

كلية الزراعة بأسيوط – جامعة الأزهر – قسم علوم الأراضى والمياه

تزيد الميكورهيزا من امتصاص كل من Zn ، Cu فى كثير من النباتات ، ولكن هذا النشاط يقف عند التسميد بالفوسفور . استخدم الجوار صنف جيزة ١ ، وصنفين من الذرة الشامية هجين فردى جيزة ١٠ ، وهجين فردى جيزة ١٢٠ ، وذلك لمعرفة هل الميكانيكية هى السبب الرئيسى فى أن وجود الفوسفور يعمل على نقص كل من Zn ، Cu .

أوضحت النتائج ما يلى :

- **الوزن الجاف للسيقان، وتركيز أو الامتصاص الكلى لعناصر Mg, Ca, K, Mn, Fe, Cu, Zn, P التى تم تقديرها للنباتات فى وجود وعدم وجود الميكورهيزا عند تركيز صفر، ٢٠، ٧٠، ١٧٥ جزء فى المليون فوسفور .**
- **حدوث نقص معنوى فى تركيز كل من Cu, Zn فى ميكورهيزا الجوار عند تسميده بالأسمدة الفوسفاتية ، ولكن أظهرت النتائج أن تركيز هذه العناصر لا يتأثر فى حالة عدم وجود الميكورهيزا.**
- **حدوث نقص فى تركيز كل من Cu, Zn فى الذرة الشامية عند التسميد بالأسمدة الفوسفاتية فى وجود وعدم وجود الميكورهيزا ولكن هذا النقص فى وجود الميكورهيزا يكون أكثر معنوية عن النقص الحادث فى عدم وجودها بالذرة الشامية وسبب ذلك يرجع إلى حجم النبات وزيادة التسميد الفوسفاتى .**
- **يتأثر تركيز العناصر الأخرى وتقديرها بمستوى الفوسفور ، ووجود الميكورهيزا .**

وعلى وجه العموم فإن الوزن الجاف للنبات فى وجود وعدم وجود الميكورهيزا ، وكذلك تركيز العناصر يلتقيان فى نقطة واحدة عند زيادة الفوسفور بالتربة ، حيث تختلف استجابة الميكورهيزا للفوسفور اختلافاً بسيطاً فى صنفى الذرة الشامية ، بينما هذا الاختلاف يكون واضحاً وملحوظاً فى عناصر معينة عند مقارنة الذرة بالجوار .