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Effects of five Glomus spp. (Zygomycetes) on growth and mineral nutrition of Triticum aestivum L.

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In a pot experiment conducted in a growth chamber, the influence of five species of arbuscular fungi (*Glomales*) on growth and mineral nutrition of winter wheat (*Triticum aestivum*) cv. Salwa was investigated. After nine weeks of growth, plants inoculated with *Glomus caledonium* and *G. mosseae* were significantly higher than those from control pots and those with *G. constrictum*, *G. deserticola* and *G. macrocarpum* mycorrhizae. All fungi significantly increased root dry weights, although *G. caledonium* was the most effective species. Except for *G. constrictum*, the other fungi significantly increased shoot dry weights of plants, with *G. caledonium* being the most effective species. *G. caledonium*, *G. macrocarpum* and *G. mosseae* significantly decreased root: shoot ratios. Inoculations significantly affected shoot and root N, P, K, Ca, and Mg concentrations. Except for *G. constrictum*, all the other fungi significantly increased shoot N and Ca contents. Shoot P and K contents were significantly higher in plants harbouring only *G. caledonium* mycorrhizae. *G. caledonium*, *G. deserticola* and *G. mosseae* significantly increased shoot Mg contents. Except for *G. constrictum*, the other fungi significantly enhanced root N and P contents. The fungi significantly increasing root K supplies were *G. caledonium*, *G. macrocarpum*, and *G. mosseae*. Root Ca contents was significantly increased only in *G. constrictum* treatment. Except for *G. constrictum* and *G. mosseae*, the other fungi significantly increased root Mg contents, with *G. macrocarpum* ranking the first. Shoot and root dry weights and shoot N and K as well as root N and P contents in *T. aestivum* were significantly correlated with mycorrhizal colonization.

INTRODUCTION

Arbuscular fungi (*Glomales*) form mycorrhizal associations with ca. 80 % of vascular plants of the Earth (Gianinazzi, Gianinazzi-Pearson, 1986). The presence of arbuscular infections in *Triticum aestivum* L. roots have commonly been found in both plants growing in field conditions (Błaszkowski, 1991; Buwalda et al., 1985; Hetrick, Bockus, Bloom, 1984; Sreenivasa, Rajashekhara, 1989) and pot cultures (Azcon, Ocampo, 1981; Graham, Menge, 1982; Hetrick, Bockus, Bloom, 1984). However, the extent of mycorrhizal colonization in this plant species has highly differed, depending on the variety used (Azcon, Ocampo, 1981), stage of development (Sreenivasa, Rajashekhara, 1989), and culture conditions (Daniels, Bloom, 1983; Hayman, 1970).

Arbuscular fungi may significantly improve plant growth (Gerdemann, 1968) due to the increased root absorptive surface offered by extramatrical hyphae (Rhodes, Gerdemann, 1975), and possibility to the use of soil mineral resources being poorly or unavailable for roots of autotrophic plants (Hayman, 1983), and increased tolerance to physical (Allen, Cunningham, 1983; Sieverding, Toro, 1988), chemical (Garcia-Romera, Ocampo, 1988; Griffioen, Ernst, 1989), and biological (Ross, 1972; Schönbeck, 1978) stresses.

The main growth-improving mineral nutrients absorbed by arbuscular fungi are phosphorus (P) and nitrogen (N) (Hayman, 1983). Increased supplies of mycorrhizal plants with potassium (K), calcium (Ca), and magnesium (Mg) have been found (Allen, Cunningham, 1983; Koslowsky, Boerner, 1989), although neutral (Azcon, Ocampo, 1981) and negative (Gerdemann, 1964; Saif, 1987) influences of arbuscular fungi on the contents of these nutrients in plants have also been reported.

Arbuscular fungi differ in effectiveness in affecting plant growth both between species and within the same species (Boerner, 1990; Schroder, Hayman, Mosse, 1977). The main reasons of these differences may be innate properties of species and strains (Haas, Krikun, 1985), different sensitivity to changing soil environmental condition (Stahl, Christenen, 1991), and the degree of fungus x plant fitness (Dodd, Jeffries, 1989; Mosse, 1975).

Glomus caledonium (Nicol. et Gerd.) Trappe et Gred., *G. constrictum* Trappe, *G. deserticola* Trappe et al., *G. macrocarpum* Tul. et Tul., and *G. mosseae* (Nicol. et Gerd.) Gerd. et Trappe are the most frequently occurring arbuscular fungi in cultivated soils of Poland (Błaszkowski, 1991). However in Poland no investigations determining the effectiveness of these fungi on the productivity of plants were so far conducted. Therefore, the aim of this study was to determine the effects of the five above listed species of arbuscular fungi on the growth and mineral nutrition of winter wheat (*T. aestivum*).

MATERIAL AND METHODS

The influence of five species of arbuscular fungi on growth and mineral nutrition of winter wheat cv. Salwa was examined in a pot experiment conducted in 1989. Pots were grouped in a randomized complete design with five replicates. Pots of a diameter of 15 cm and a height of 13 cm were filled with an autoclaved loamy soil and sand quartz mixture (1:2, v/v; pH 6, 7; 10, 21 mg/kg P and K, respectively). The potting media were subsequently inoculated with 100 g of a mixture containing 200 spores, mycelia, and infected *Trifolium pratense* L. roots from 2-year-old *G. caledonium*, *G. constrictum*, *G. deserticola*, *G. macrocarpum*, and *G. mosseae* pot cultures. Control pots received 100 g of autoclaved inoculum, to which 25 ml of filtered washing from a living culture of each fungal species were added. The inoculum was placed as a layer 3 cm below the soil surface. Ten seeds of *T. aestivum* were sown per pot at a depth of 0.5-1 cm. Seven days later, seedlings were thinned to five. The plants were grown in a growth chamber at 22 ± 2°C with 16/8 h light/dark periods at a light intensity of 450 µmol m^2 s^{-1}. The relative humidity was 90 ± 3 %. Plants were watered daily and fertilized weekly with Florovit, a multiple fertilizer lacking P. Plants were harvested 11 weeks after sowing. Shoots and roots were dried at 70°C for 48 h, weighed and analysed for mineral nutrients and mycorrhizal colonization. Chemical analysis of plants were conducted in the Regional Chemical and Agricultural Station in Szczecin. Mycorrhizal colonization of plants for each pot was determined by the Giovannetti and Mosse (1973) method. Each replication consisted of 100 1-cm stained (Phillips, Hayman, 1970) root segments. Data were processed by analysis of variance. The statistical significance of differences between means was determined using the least significant difference (LSD) at P = 0.05 calculated from the Tukey test.

RESULTS

Significant enhancement of plant height due to inoculation with arbuscular fungi was first observed at five weeks after the experiment establishment and continued throughout the sampling period. At five weeks the highest plants were found in treatments with *G. mosseae*, and lowest in those with *G. constrictum* and *G. deser-ticola*. At seven and nine weeks, with plants inoculated *G. caledonium* and *G. mosseae* were significantly higher than the control plants and those inoculated with the other fungal species examined (Fig. 1, Table 1).

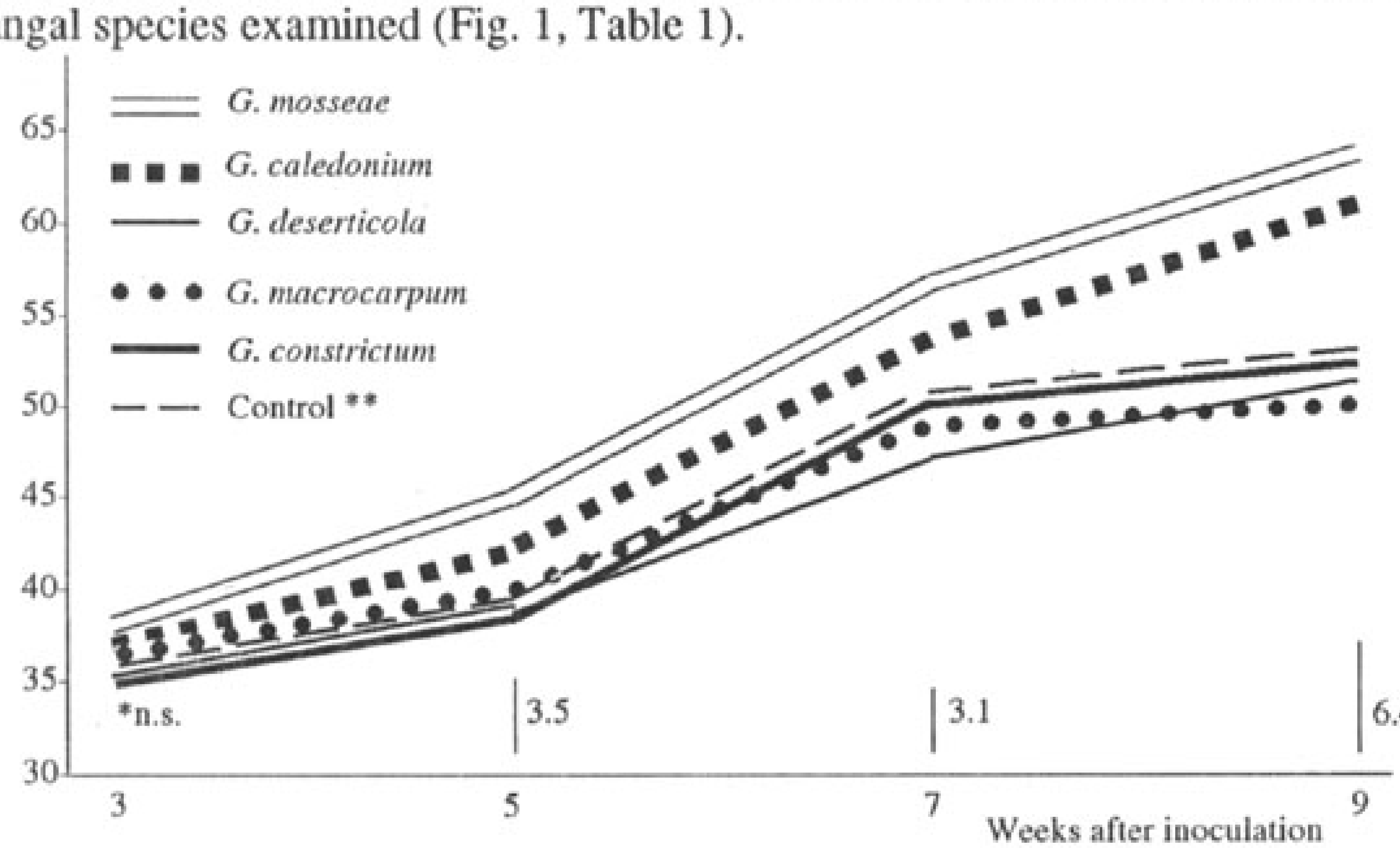

Fig. 1. The influence of *Glomus* spp. on height of *Triticum aestivum*
* n.s. – not significant difference (P = 0.05); ** – noninoculated plants

Table 1

The influence of five *Glomus* species on morphological features and mycorrhizal colonization of *Triticum aestivum*

Inoculum	Plant height cm	Dry weight (g)		Root : shoot ratio	Mycorrhizal colonization %
		roots	shoots		
Glomus caledonium	63.8	1.61	1.11	1.45	41.1
Glomus constrictum	52.6	1.53	0.71	2.15	16.2
Glomus deserticola	52.5	1.60	1.01	1.58	26.7
Glomus macrocarpum	51.8	1.49	0.98	1.52	24.2
Glomus mosseae	64.2	1.58	1.07	1.48	38.6
Control*	52.9	1.21	0.67	1.81	0.0
LSD (P = 0.05)	6.4	0.15	0.09	0.25	4.2

* – noninoculated plants

In comparision with control plants, inoculation with all the arbuscular fungal species used significantly increased the dry weight of roots (Table 1). The highest root dry weights were found in plants with *G. caledonium* mycorrhizae, whereas plants associated with *G. macrocarpum* produced roots with lowest dry weights. Except for *G. constrictum*, the other fungal species also increased significantly the dry weight of shoots; the most effective fungus was *G. caledonium*. Root : shoot dry weight ratios were significantly lower for plants inoculated with *G. caledonium*, *G. mosseae*, and *G. macrocarpum* than those both of control pots and harbouring *G. constrictum* mycorrhizae. The roots of *T. aestivum* were most abundantly colonized by *G. caledonium* and *G. mosseae*; control plants lacked mycorrhizal infections. The dry weights of shoots and roots were significantly correlated with mycorrhizal colonization, but were not significantly related to the plant height (Table 3).

Inoculation significantly affected shoot and root contents of N, P, K, Ca, and Mg (Table 2). The highest and statistically significant shoot N contents was found in plants inoculated with *G. caledonium*, then in those harbouring mycorrhizae of *G. mosseae*, *G. deserticola*, and *G. macrocarpum*, respectively. Shoot P and K contents were significantly higher only after inoculation of plants with *G. caledonium*. Except for *G. constrictum*, all the other fungal species significantly increased shoot supply with Ca, with *G. macrocarpum* being the most effective fungus. Significantly higher shoot Mg contents occurred in plants with *G. caledonium*, *G. deserticola*, and *G. mosseae* mycorrhizae.

Except for *G. constrictum*, inoculation with the other arbuscular fungi resulted in significantly higher N and P contents in roots of *T. aestivum* compared with the control. The highest root N contents was in plants inoculated with *G. caledonium* and *G. mosseae*. Plants with *G. caledonium* mycorrhizae had the highest level of root P. The arbuscular fungi which significantly increased the supply of roots with K were *G. caledonium, G. macrocarpum*, and *G. mosseae*. The root Ca content significantly increased the growth of *G. constrictum*. The highest root Mg content were found in plants associated with *G. macrocarpum*. Compared with control plants, significantly higher levels of roots Mg supply occurred in treatments with *G. caledonium* and *G. deserticola*. Only shoot N and K and root N and P contents were significantly correlated positively with *T. aestivum* mycorrhizal colonization (Table 3).

Table 2

The influence of *Glomus* spp. on concentration of mineral nutrients in shoots and roots of *Triticum aestivum* (%)

Fungi	Mineral nutrients				
	N	P	K	Ca	Mg
Shoots					
Glomus caledonium	2.68	1.54	2.08	1.03	0.29
Glomus constrictum	1.52	1.24	1.78	0.72	0.19
Glomus deserticola	2.22	1.46	1.89	1.09	0.27
Glomus macrocarpum	2.00	1.48	1.93	1.13	0.23
Glomus mosseae	2.51	1.50	2.00	1.01	0.25
Control*	1.60	1.36	1.80	0.73	0.20
LSD (P = 0.05)	0.30	0.17	0.27	0.25	0.04
Roots					
Glomus caledonium	1.40	0.66	1.64	0.67	0.26
Glomus constrictum	0.96	0.36	1.26	1.16	0.23
Glomus deserticola	1.10	0.47	1.47	0.62	0.25
Glomus macrocarpum	1.12	0.50	1.62	0.66	0.28
Glomus mosseae	1.38	0.50	1.59	0.64	0.22
Control*	0.92	0.36	1.37	0.61	0.21
LSD (P = 0.05)	0.16	0.08	0.20	0.30	0.04

* – noninoculated plants

Table 3

Correlations between variables of mycorrhizal colonization, morphological features, and concentrations of mineral nutrients in *Triticum aestivum* inoculated with five species of *Glomus*

Variables		Mycorrhizal colonization	Plant height
N	shoots	0.91*	0.81
	roots	0.96*	0.01
P	shoots	0.74	0.60
	roots	0.86*	0.70
K	shoots	0.94*	0.87*
	roots	0.74	0.57
Ca	shoots	0.70	0.24
	roots	– 0.19	– 0.25
Mg	shoots	0.72	0.53
	roots	0.43	– 0.11
Dry weight	shoots	0.92*	0.65
	roots	0.89*	0.45
Plant height		0.76	–

* P = 0.05

DISCUSSION

The increased growth of *T. aestivum* inoculated with arbuscular fungi found in this study supports the results of many investigators who examined the stimulating influence of this group of fungi on plant growth (e.g., A z c o n, O c a m p o, 1981; G e r d e m a n n, 1968; M o s s e, 1973). Of the fungal species compared, however, *G. caledonium* and *G. mosseae* markedly increased the growth and accumulation of dry matter in shoots and roots. This is in agreement with the findings of e.g., B o e r n e r (1990), S c h r o d e r et al. (1977), and S y l v i a and B u r k s (1988) who confirmed that species and even strains of the same species of arbuscular fungi differ in effectiveness in increasing plant growth. The reasons for these differences may have been (1) genetic properties of fungi (H a a s, K r i k u n, 1985); (2) different abilities of fungi to remain high physiological activity in changing environmental conditions (S t a h l, C h r i s t e n s e n, 1991); (3) the degree of plant x fungus fitness (D o d d, Jeffries, 1989; Mosse, 1975); and (4) seasonal variabilities in physiological activity of fungi (Gemma, Koske, Correiro, 1989).

Generally, the increase in plant growth was accompanied by a decrease in root: shoot ratios, these effects were frequently found by other investigators (e.g., Abbott, Robson, 1978; Saif, 1987). Lower root: shoot ratios of mycorrhizal plants have been attributed to the ability of fungal endophytes to substitute for the relatively greater amounts of root matter required by non¬mycorrhizal plants for P uptake, allowing mycorrhizal plants to apportion a greater proportion of assimilates to shoot production (Bethlenfalvay, Ulrich, Brown, 1985).

Inoculation of *T. aestivum* with the species of arbuscular fungi generally increased shoot and root N, P, K, Ca, and Mg contents, although the differences found were not always significant. The most effective fungi in this respect were *G. caledonium* and *G. mosseae*. They increased biomass production the most and generated the most extensive mycorrhizal infections. Additionally, the levels of mycorrhizal colonization significantly correlated with the shoot and root dry weights produced and with shoot N and K and root N and P contents. The relationships between mycorrhizal colonization and plant productivity and between mycorrhizal colonization and plant N and P supplies has earlier several times been found (e.g., Abbott, Robson, 1978; Reich, 1988). Changes in K contents in mycorrhizal plants probably result aboveal from root mass production rather than from absorption of K by extramatrical hyphae of arbuscular fungi (Powell, 1975). Thus, the results discussed here support the findings of many other investigators who proved that stimulation of plant growth mainly results from the better nutrition of mycorrhizal plants due to a grater absorption surface area offered by the extensive fungal hyphae and enhanced root growth (Hayman, 1983; Raju et al., 1990).

Of the arbuscular fungi tested, only *G. constrictum* generally remained neutral in the influence on the biomass production and plant supply with mineral nutrients. The only exception was its significant increase of root Ca content. The lack of inoculation effects of plants with *G. constrictum* may have resulted from the innate ineffectiveness of the strain of this species used, as shown with, e.g., *G. macrocarpum* (Haas, Krikun, 1985) and *G. deserticola* (Sylvia, Burks, 1988). This deviation may also have been due to the low inoculation potential of this fungal species, as has been demonstrated among several species using most-probable-number-methodology (Daniels, McCoot, Menge, 1981) and as suggested the lowest mycorrhizal colonization level formed by this species compared with the other arbuscular fungi examined in this study. However, poor mycorrhizal infections may sometimes be highly effective in increasing plant growth (Miller, Domoto, Walker, 1985; Plenchette, Furlan, Fortin, 1982). According to Sanders et al. (1977), the time of harvest is important when comparing different endophytes. Hence, the full effect of *T. aestivum* inoculation with *G. constrictum* might appear later than after 11 weeks of growth, as was in the study discussed here. Another explanation of the behavior of *G. constrictum* in this study may have been its high drain on host photosynthate, as Stribley et al. (1980) and Lamar and Davey (1988) suggested. Finally, the soil inoculum of

G. constrictum may have contained pathogens decreasing the amount of living root tissues needed to establish an infection by this obligate biotroph (Afek, Menge, Johnson, 1990) or a sufficient number of saprophytic microorganisms competing with the plant for nutrients (Wilson et al., 1988). No disease symptoms on roots were found by the author of this paper. However, the productivity of plants may have been decreased by subclinical pathogens generating no visible symptoms (Kloepper, Schroth, 1981).

The increase of root Ca content may have been a result of the accumulation of this nutrient in roots due to poor growth and small plant size, as Saif (1987) suggested.

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