Plant and Soil 94, 439–443 (1986). Ms. 6391

Relationship of mycorrhizal growth enhancement and plant growth with soil water and texture

S. DAKESSIAN, M. S. BROWN and G. J. BETHLENFALVAY*
U S Department of Agriculture, Agricultural Research Service, Albany, CA 94710, USA

Received 21 May 1985. Revised December 1985

Key words Glomus soybean

Summary Soybean plants were grown in pots with or without vesicular-arbuscular mycorrhizal (VAM) fungi in three soils of low plant-available P content, different texture and different water-holding capacities. Mineral nutrients, except P, were provided in a complete nutrient solution. The biomass of non-VAM plants was positively and fungal colonization negatively correlated with increasingly coarse soil texture. There was no correlation of soil P with host or endophyte growth. Plant growth enhancement was positively correlated with soil water content at − 1.5 MPa. These observations suggest soil water status and the mycorrhizal condition interact in influencing plant growth.

Introduction

Vesicular-arbuscular mycorrhizal (VAM) fungi have been shown to improve plant water relations[14,20]. Since the early observations of VAM effects on plant water status[18,22] a number of factors which affect this phenomenon (transpiration rates, root hydraulic conductivity, interactions between P and water availability) have been investigated[1,8,13,14,17,24] but their role was not elucidated conclusively[22,23]. Enhanced exploitation of water present in a given soil volume was observed by Hardie and Leyton[14], who found that VAM plants wilted at lower soil water potentials than non-VAM plants. Our note presents a strong relationship between soil water at the wilting potential and plant growth enhancement by a VAM fungus in different soils.

Materials and methods

Soybean (*Glycine max* L. Merr. cv. Amsoy) plants inoculated with the VAM fungus *Glomus mosseae* (Nicol. and Gerd.) Gerd. and Trappe or left uninoculated were grown in 1.5 L pots in three different soils. The VAM fungus was collected from a desert environment[5] and recultured on *Sorghum bicolor* L. in a mixed sand-soil medium to produce a soil inoculum. Non-VAM plants were initially watered with a filtrate of this inoculum, free of VAM propagules, in order to introduce a comparable mircrobiota. The initially sterilized (ethylene oxide) soils, of the Corning sandy loam (Typic Palexeralf), Balcom heavy silt loam (Typic Xerorthent) and Josephine loam (mesic Typic Haploxerult) types had different pH values and water holding characteristics but were similarly deficient in available P (Table 1). The plants were watered with P-free nutrient solution otherwise equivalent to one-quarter strength Hoagland solution twice a week during the first five weeks of growth, and as needed to prevent wilting during the final three weeks. Saturation of the soil was insured by adding enough solution to cause a slight excess to drip from the drain holes of the pots. Thus, growth conditions tended to become increasingly droughty with increasing plant size. Plants were grown in a greenhouse under conditions described elsewhere[6].

* To whom requests for reprints should be addressed.

Table 1. Soil characteristics

Soil parameters	Soil Series		
	Corning	Balcom	Josephine
Water potential (-MPa)	Water content (%, w/w)		
0.03	12.4	24.3	27.0
1.5	5.9	12.3	16.1
Texture (particle size distribution)	%		
sand	58.1	20.5	44.6
silt	29.3	55.6	36.3
clay	12.6	23.9	19.1
Phosphorus content*	(μg p/g soil)		
Available	3.5	3.3	4.6
Total	650	750	600
pH*	6.1	8.0	6.9

* Determined by methods reported previously[6]

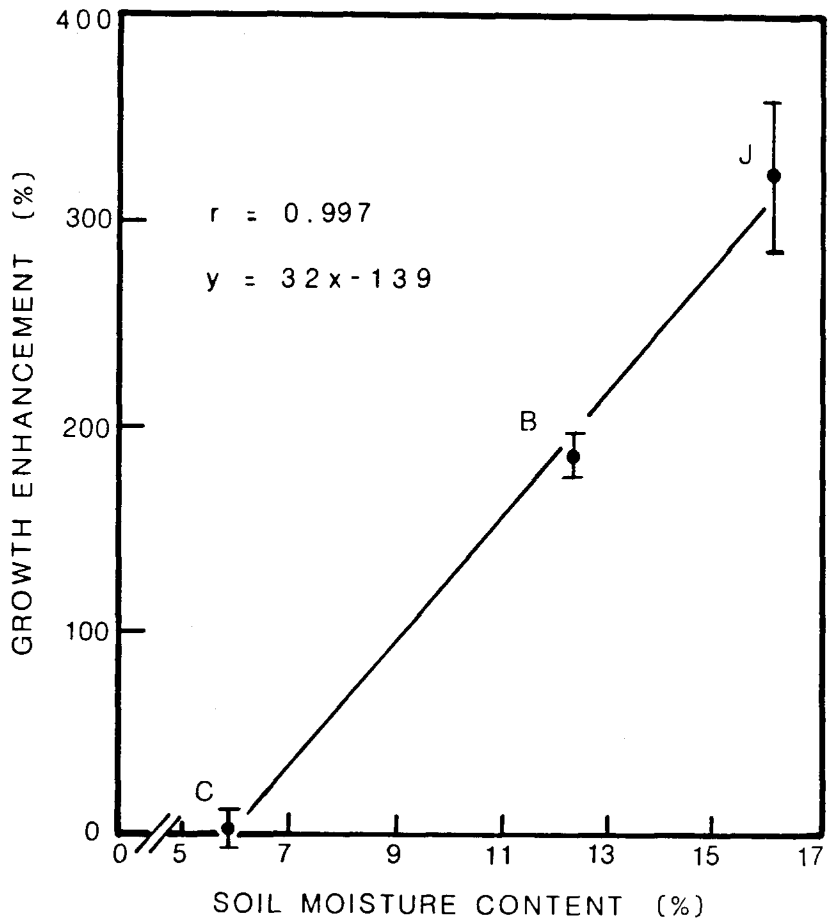

Fig. 1. Growth enhancement of plants by *Glomus mosseae* relative to uncolonized controls as a function of bound water (soil moisture content at − 1.5 MPa) in Balcolm (B), Corning (C) or Josephine (J) soils.

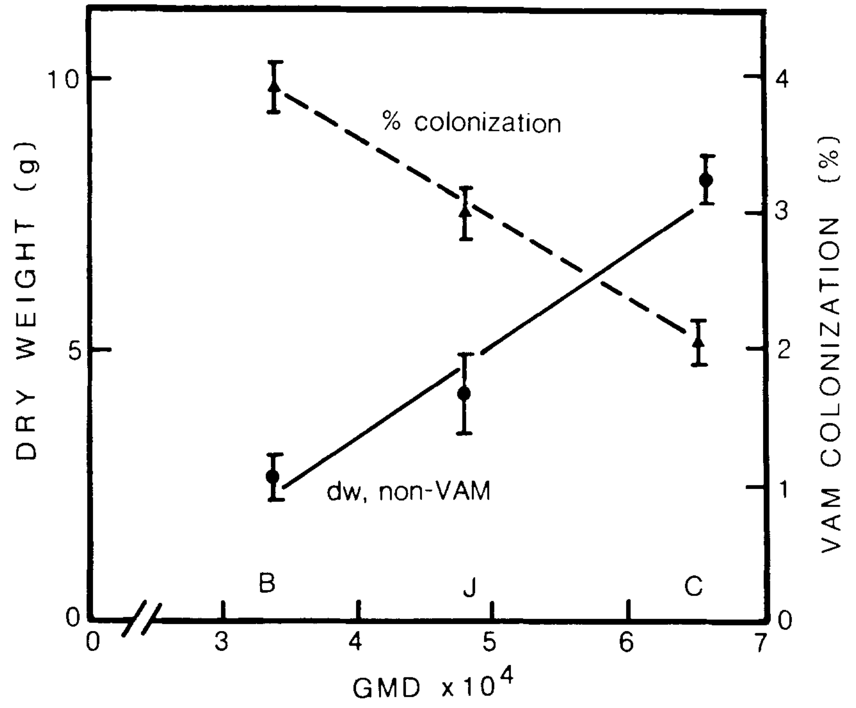

Fig. 2. Plant growth and fungal colonization as a function of soil texture. Plants were grown in the absence of the vesicular-arbuscular mycorrhizal (VAM) fungus *Glomus mosseae* in Balcolm (B), Corning (C) or Josephine (J) soils. Soil texture was expressed as the geometric mean diameter (GMD) calculated as

$$\sum_{i=1}^{n} W_i \log \bar{x}_i / \sum_{i=1}^{n} W_i,$$

where W_i is the aggregate mass in the fraction with an average diameter $\bar{x}_i$. Bars denote standard errors of five replications.

Plants were evaluated at harvest (8 weeks) for growth enhancement by VAM fungi (percent dry weight increase) relative to non-VAM plants and for VAM-fungal colonization (percent root length colonized) as described previously[3]. Soil water contents at field capacity and at the conventionally accepted permanent wilting potential[9] were determined gravimetrically with soil samples equilibrated at −0.03 and −1.5 MPa in a pressure plate apparatus and dried at 110°C[21]. Soil texture was determined by standard analytical methods[11], and expressed in terms of a particle-size distribution (Table 1) or as the geometric mean diameter (GMD, Fig. 2). There were five replications of VAM and non-VAM plants in each of the 3 soils, for a total of 30 units.

Results and discussion

Development of the VAM fungus and of VAM and non-VAM plants in the three soils was evaluated in terms of three soil parameters: plant available P, waterholding capacity at the permanent wilting potential ("bound water"), and texture. Soil structure and nutrients other than P were omitted from consideration because the former was largely destroyed by using a sieved, mixed substrate, while the latter were supplemented by a complete (but P free) nutrient solution. Nutrients added exceeded the levels of plant-available nutrients at least ten-fold. Soil pH varied from slightly acid to slightly alkaline in the three soils (Table 1). Although *G.*

mosseae is known to prefer neutral to slightly alkaline soils, the strain used here was isolated from a soil of pH 6[5], which was closest to the soil with the least VAM development in this experiment. Soil pH was therefore not likely to be a factor in VAM-fungal colonization.

Plant growth enhancement by the VAM fungus correlated significantly with bound soil water ($r = 0.997$, $P < 0.05$, Fig. 1), but not with available P ($r = 0.67$, $P > 0.50$) or GMD ($r = -0.61$, $P > 0.50$). These findings suggest that the fungus confers a growth advantage on plants in proportion to the amount of soil water not available to the plant alone. In the absence of the fungus, plant growth was not significantly correlated with either bound water ($r = 0.925$, $P > 0.20$) or P ($r = 0.04$, $P > 0.50$). The closest relationship ($r = 0.982$, $0.10 < P < 0.20$) to non-VAM plant growth was found with soil texture (Fig. 1). In view of the equalized soil biota and the apparent absence of nutritional effects (Corning soil had the smallest holding capacity for nutrient solution but supported the best non-VAM plant growth) we attribute this growth pattern to differences in texture-related soil resistance to root penetration[10]. The tendency of soils of finer texture to be droughty under predominantly dry conditions[7] may have contributed to impaired growth of these drought-sensitive plants in the heavier soils.

Like non-VAM plant growth, the development of the intraradical VAM-fungal mycelium was not significantly correlated with bound water ($r = 0.66$, $P > 0.50$) and P ($r = -0.23$, $P > 0.50$). However, there was a significant negative correlation of soil texture with colonization ($r = -0.999$, $P < 0.01$), but not with non-VAM plant growth. This suggests that conditions promoting non-VAM plant growth did not favor endophyte development (Fig. 1). The fungi developed least where root penetration was easiest and bound water was scarcest (Corning soil) The observations confirm the findings of others[2,15] that the role of VAM fungi in host-plant growth is not restricted to a simple effect of P availability, but is influenced by other factors. They also reaffirm indications[4,12,13] that the intraradical VAM-fungal mycelium is an unreliable measure of endophyte benefits to the host.

Soil water status was not monitored during the experiment, but the growth of plants in a fixed rooting volume necessarily imposed an increasingly severe moisture regime on the system. Fungal growth coincided with this development and reached a level of maximum colonization (70 to 80% of root length) during week 5. The close correlation between VAM-fungal growth enhancement and bound soil water observed here was apparently a consequence of this coincidence in the water regime imposed and the stage of fungal development. It is probably further modified in other systems by the drought sensitivity of the host, host-endophyte preference[17] and fungal adaptation to edaphic conditions[16], and does not always occur[6]. However, should such a relationship be the rule, it would be of value in experimentation under controlled conditions, and in field applications as well.

References

1 Allen M F and Boosalis M G 1983 New Phytol. 93, 67–76.
2 Barea J M and Azcon-Aguilar C 1983 Adv. Agron. 36, 1–54.
3 Bethlenfalvay G J *et al.* 1981 Soil Sci. Soc. Amer. J. 45, 871–875.
4 Bethlenfalvay G J *et al.* 1982 New Phytol 90, 537–543.
5 Bethlenfalvay G J *et al.* 1984 Can. J. Bot. 62, 519–524.
6 Bethlenfalvay G J *et al.* 1985 Soil Sci. Soc. Am. J. 49, 1164–1168.
7 Black C A 1968 *In* Plant-Soil Relationships, John Wiley and Sons, Inc. New York. pp. 1–69.
8 Bolgiano N C *et al.* 1983 J. Am. Soc. Hort. Sci. 108, 819–825.
9 Briggs L J and H L Shantz 1912 Bot. Gaz. 53, 229–235.
10 Davies D B and Runje E C A 1969 Agron. J. 61, 518–521.
11 Day P R 1965 *In* Methods of Soil Analysis, Vol. 1, Am. Soc. Agron. Inc. Madison pp. 545–567.
12 Graham J H *et al.* 1982 New Phytol. 91, 183–189.
13 Graham J H and J P Syversten 1984 New Phytol 97, 277–284.
14 Hardie K and Leyton L 1981 New Phytol. 89, 599–608.

15 Harley J L and Smith S E 1983 Mycorrhizal Symbiosis. Academic Press London pp. 94–96.
16 Mosse B 1972 Rev. Ecol. Biol. Sol. 9, 509–520.
17 Mosse B 1975 *In* Endomycorrhizas. Academic Press, London pp. 469–484.
18 Mosse B and Hayman D S 1971 New Phytol. 70, 29–34.
19 Nelsen C E and Safir G R 1982 Planta 154, 407–413.
20 Reid C P P 1984 *In* Microbial-Plant interactions. Am. Soc. Agron. Special Publication No. 47, Madison. pp. 29–59.
21 Richards L A 1965 Agronomy 9, 128–152.
22 Safir G R *et al.* 1971 Science 172, 581–583.
23 Sieverding E 1984 Z. Acker-Pflanzenbau 153, 52–61.
24 Sweatt M R and Davies F T, Jr. 1983 J. Am. Soc. Hort. Sci. 109, 210–213.