EFFECT OF MYCORRHIZA ON THE NUTRIENT UPTAKE OF SUGARCANE

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Abstract

Vesicular arbuscular mycorrhizae (VAM) fungi commonly infect plant roots, forming beneficial symbiotic relationships. The primary benefits of VAM plants are the enhanced acquisition and recycling of nutrients, particularly P, as well as soil moisture. This study compared the relationship between soil and leaf chemical elements of sugarcane variety N12 with low and high % mycorrhization (%myc). Seventy-one soil and leaf samples were selected from a 4000 m^2 area in a field of ratoon cane on a sandy soil on the KwaZulu-Natal north coast, and were analysed for major plant available nutrients by the Fertiliser Advisory Service laboratory of the South African Sugar Association Experiment Station. Percentage mycorrhization was determined using the Gridline Intersect method. Data from the soil and leaf analyses were divided into two categories: those from plots with low %myc (9-26%) and those from plots with high %myc (32-53%). Relationships between soil and leaf factors were then determined using multivariate analysis (ADE-4 software). Results from high %myc plants indicated enhanced relationships between soil pH and leaf Ca, soil pH and leaf N, soil Ca/Mg and leaf N, and soil Na and leaf K while the relationship between Mg/Ca and leaf K was depressed in high %myc plants. Ca exists in the middle lamella as calcium-pectate, which helps with resistance to fungal infection. Nitrogen and Mg are required for photosynthesis, while Na may increase stomatal regulation under water limiting conditions. VAM colonisation therefore, may play a role in plant physiology in terms of resistance to bacterial and fungal pathogens, increased photosynthetic rates and enhanced stomatal regulation under water stressed conditions.

Keywords: sugarcane, mycorrhization, soil, leaf, relationships, plant physiology, root system

Introduction

Vesicular arbuscular mycorrhizae (VAM) fungi commonly infect plant roots, including those of sugarcane, forming beneficial symbiotic relationships (Kelly *et al*., 1997). The primary benefit to the plant of this symbiosis is enhanced acquisition of water, phosphorous and other minerals. VAM fungal hyphae provide a greater, effective absorbtive root surface able to explore larger volumes of soil, thus overcoming nutrient and water depletion zones (Clark and Zeto, 1996; Hetrick *et al.*, 1988).

It is well established that (i) Improvements in plant growth are attributed to an enhanced access of mycorrhizal root to soil P located beyond the rhizosphere (Sanders and Tinker, 1973), and (ii) infection by mycorrhizal fungi is significantly reduced at high soil phosphorus levels (Amijee *et al*., 1989; Koide and Li, 1990). Although information on the acquisition of minerals by plants is available, information on nutrients other than P is limited.

The beneficial effects of VAM fungi have been known for some time, but many fundamental questions concerning this symbiotic relationship and its management are as yet unsolved. For example, what are the major factors that determine interactions between VAM fungi and sugarcane, and are these interactions beneficial for the sugarcane? The aim of this study was to determine the potential effect of mycorrhization on sugarcane physiology.

Materials and methods

Seventy-one leaf and soil samples were randomly selected from 14-month old variety N12 ratoon cane in a 4000 m^2 field of non-P-fixing sandy soil at La Mercy on the KwaZulu-Natal north coast, and analysed for nutrients by the Fertiliser Advisory Service laboratory of the South African Sugar Association Experiment Station. Percentage mycorrhization (%myc) was determined using the Gridline Intersect method (Brundette et al., 1996).

Soil physio-chemical analysis included pH, P (ppm), K (ppm), S (ppm), Ca (ppm), Mg (ppm), Na (ppm), Zn (ppm), Fe (ppm), Mn (ppm), Al (ppm) and C. The soil comprised a deep grey acid (pH 5.2) sandy soil of the Fernwood form with satisfactory levels of P (±39 ppm) but with low levels of K (±65 ppm), Ca (±110 ppm), Mg (23 ppm) and S (±11 ppm). In the leaves N (%), P (%), K (%), S (%), Ca (%), Mg (%), Zn (ppm), Mn(ppm), Cu (ppm), Fe (ppm), N/S (ppm) and Si (%) contents were analysed (Meyer *et al*., 1997). To study the effect of percentage mycorrhization on the physiology of sugarcane, data were classified into two categories. Twenty-four samples with low %myc (9-26%) and 27 samples with high %myc (32-53%) were selected. Relationships between soil and leaf factors were then determined using the ADE-4 statistical computer program (Thioulouse *et al*., 1997).

Results and discussion

The PCA (a function of the ADE-4 stats program) performed on the soil factors showed that the cloud corresponding to the low %myc plants (1) and high %myc plants (2) overlap strongly, indicating that the soil characteristics were similar (Figure 1).

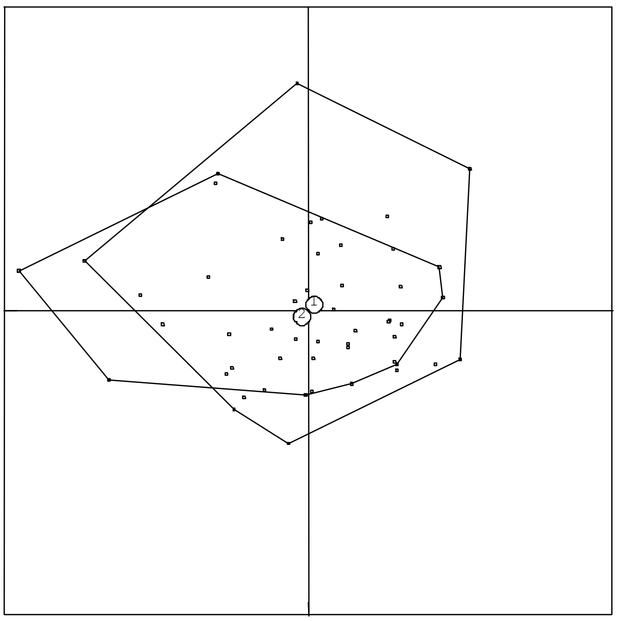

Figure 1. The PCA factor map/convex hulls overlap strongly between low %myc (1) and high %myc (2), indicating similar soil characteristics.

Co-inertia analysis (CoI) was used to describe and test the existence of relationships between the soil and leaf factors. Permutation tests revealed that the relationships between soil and leaf components were highly significant for both low (P=0) and high (P=0.02) %myc plants, indicating that the level of elements in the soil influenced the elements found in the leaves. However, the correlations between certain soil and leaf elements were different in the plants with high or low levels of mycorrhization. This result indicated that mycorrhization had an impact on plant physiology as seen through plant and soil relationships (Table 1).

VAM plants modify the acquisition of Ca compared with non-VAM plants, depending on VAM fungal isolates present in the soil. VAM maize grown on acidic soil had enhanced acquisition of Ca compared with maize grown in alkaline soils (Clark and Zeto, 1996). Table 1 indicates an enhanced relationship between soil pH and leaf Ca. Increasing soil pH usually decreases the availability of Ca-phosphates (Lindsay and Moreno, 1960). A decrease in rhizosphere pH in the presence of VAM fungi, should therefore favour the uptake of Ca in high %myc plants more than in low %myc plants.

Table 1. Relationships found to be enhanced or depressed by high and low % mycorrhization.

	Favoured		Depressed	
	Soil	Leaf	Soil	Leaf
High % myc	pH	N	pH	K
	pH	S		
	pH	Ca/Mg		
	Ca/Mg	N	Ca/Mg	K
	Al	N	Al	K
	Al	Ca/Mg	Al	S
	Na	K	Na	N
	Ca	Mg/Ca		
Low % myc	S	S	S	Cu
	S	Mg		
	C	S	C	Cu
	C	Mg		
	K	Cu	K	S
			K	Mg
			Ca	Mg

The Ca content of plants affects the incidence of plant disease in two ways: (i) it is essential for the stability and permeability of bio-membranes, and (ii) it strengthens and stabilises the middle lamella of cell walls. In cell walls Ca exists as calcium pectate, which can determine tissue susceptibility to fungal and bacterial infection (Marschner, 1986). Enhanced acquisition of Ca in high %myc plants suggests that these plants may have an increased resistance to fungal and bacterial pathogens. VAM fungi may also increase the uptake of Si, where this has been added in the form of calcium silicates.

VAM plants are found in soils were N and P limit photosynthesis, i.e. there is an excess of plant carbon. Photosynthetic rates depend on the concentrations of N, P (for ATP and ADP), Fe and Mg (for chlorophyll), internal CO_2 and water. VAM modify the acquisition of nutrients in exchange for plant excess C (Agren and Bosatta, 1996). Since photosynthetic rates also depend on N and Mg, the positive relationship between soil pH and leaf N should enhance this process in high %myc plants compared with low %myc plants. This is further supported by the positive relationship between soil pH and leaf Mg, as well as the relationship between soil Mg and leaf N in high %myc plants.

Potassium also has an important role in the photosynthetic processes in sugarcane (Hartt and Burr, 1965). In sugarcane the relationship between soil Mg/Ca and leaf K was found to be depressed in high %myc plants compared with low %myc plants, whereas the relationship between soil K and leaf Mg was depressed in low %myc plants compared with high %myc plants. Antagonistic interactions among K, Ca and Mg are common, because these ions have specific chemical properties that are sufficiently similar to compete for absorption and transport sites on the plant root surfaces (Fageria *et al*., 1991). The translocation of one of these ions will reduce the translocation of the other ions (Schimansky, 1981). Results indicate that the translocation of K from the soil to the leaves was depressed in high %myc plants, probably because of a high Ca uptake by fungi, whereas the translocation of Mg from the soil to the leaves was depressed in low %myc plants. Cell extension in leaves is closely related to their K level. The enhancement of stem elongation by gibberellic acid (GA) is dependent on the K supply. GA also acts synergistically together with the reduced sugars to produce the turgor potential required for cell extension and guard cell of the stomata (Marschner, 1986). Reduced K translocation would therefore reduce the cell extension and turgor pressure in the stomata, ultimately affecting photosynthesis.

The relationship between soil Na and leaf K is enhanced in high %myc plants. The acquisition mechanism of Na is considered similar to the acquisition of Mg, Ca and K. The acquisition of Na was synergistically enhanced in mycorrhizal barley and soybean plants grown with polyethylene glycol (added to induce osmotic stress) (El-Shourbagy and Malibari, 1988). Na improves the water balance in plants when the water supply is limited, i.e. via stomatal regulation by maintaining higher water levels in the leaves. Stomata of plants with high Na levels close more rapidly than plants supplied with K only and, after stress release, exhibit a substantial delay in opening (Willmer and Mansfield, 1970). Other relationships between other leaf and soil elements are currently being studied.

Conclusion

VAM colonisation may play a role in plant physiology in terms of resistance to bacterial pathogens, fungal pathogens and nutrient acquisition by the plant, leading to increased photosynthetic rates and enhanced stomatal regulation under water stressed conditions. Due to information on VAM and sugarcane being limited, the study of the effects of VAM on sugarcane should be continued.

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