# MYCORRHIZAS IN COTTON

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**Question:** When is a cotton plant not a cotton plant?
**Answer:** All the time. Healthy cotton plants are always part of a mycorrhiza.

**What is a mycorrhiza?** The term 'mycorrhiza' refers to symbiosis between a plant and a fungus. 'Symbiosis' literally means 'living together', but mycorrhizal relationships are much more than that. A mycorrhiza forms when fungi colonise plant roots. Both participants engage in intimate biochemical and physical interactions with each other. The fungi utilise carbohydrate provided by the plant as a substrate for their growth. In return, the fungal mycelium grows through the soil outside the root and provides the plant, in effect, with an extended 'root' system. The fungus absorbs nutrients and transports them back to the plant. Thus the plant's ability to take up nutrients is increased, especially for elements such as phosphorus and zinc which diffuse slowly through soil. Uptake of elements such as sulphur, copper, iron and boron, as well as water, is also greater in mycorrhizal plants. The fitness of both partners of the symbiosis is increased by engaging in mycorrhizal symbiosis.

Plants that are capable of forming mycorrhizas are described as being 'mycotrophic'. About eighty percent of flowering plants are mycotrophic (Trappe 1987). Most mycotrophic plants can be infected with more than one species of mycorrhizal fungus, even within the same section of a root. Mycorrhizal fungi occur wherever plants grow, in every terrestrial ecosystem throughout the world

The commonest type of mycorrhiza is the vesicular arbuscular mycorrhiza (VAM). VAMs are formed by a single group of fungi which is characterised by the formation of arbuscules. An arbuscule is a finely branched fungal structure which grows inside a cell in the cortex of the root (Fig. 1). The root cell membrane remains intact and envelops the arbuscule. This provides a large surface area for exchange of nutrients between the fungus and the plant. Most VAM fungi also form vesicles. Vesicles are balloon-like structures which grow in or between the cells in the root cortex (Fig. 1). Vesicles contain fats and oils and function as energy storage organs for the fungus. VAM fungi produce spores in the soil outside the root. These spores enable the fungi to disperse, through movement of soil by wind or water, and to survive in the absence of a host plant. Spores are the primary means of identification of VAM fungi. Spores, mycelium in the soil and infected roots all act as propagules that can infect new roots.

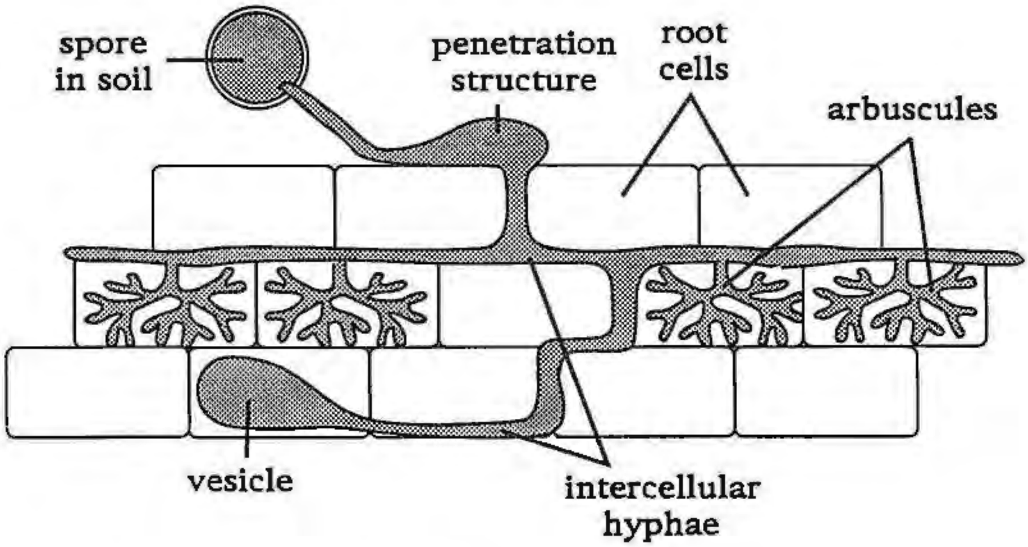


**Figure 1 Diagramatic representation of a vesicular arbuscular mycorrhizal infection in root cells.**

Many crop plants are often heavily infected with VA mycorrhizal fungi, including barley, beans, cacao, cassava, clover, coffee, cowpea, lettuce, maize, oil palm, onions rubber, sorghum, soybean, sugarcane, tea, tobacco, upland rice, (Hayman, 1987) sunflower, wheat (Thompson, 1987). The health and vigour that a mycotrophic plant shows above the ground is closely related to interactions that occur below the ground. Many plants rely on mycorrhizal fungi for successful growth. Similarly, the VAM fungi are totally dependant on living plants. Despite the fact that the fungal partners are not obvious to the naked eye, a mycorrhiza is a multiple organism and should be considered as such.

**Problems with mycorrhizas in agricultural systems.** VAM fungi cannot grow without a host plant. In undisturbed ecosystems, including pastures, VAM fungi have no trouble in finding suitable hosts because they show virtually no specificity among mycotrophic plants. In cultivated fields there is selection pressure in favour of those fungi that can survive the bare inter-crop period when no host plant is available. Thus the number of species of VAM fungi in cropped soils is likely to be less than that in uncropped soils. Whether those fungi that remain are those that would best stimulate growth of the crop is the subject of ongoing research around the world.

When land is kept bare of weeds during a long fallow the number of viable propagules of VAM fungi is greatly reduced and this causes what is called 'long fallow disorder' (Thompson, 1987). The VAM fungi simply cannot survive long enough as spores or in dead root pieces in the soil and plants grown in this soil cannot become sufficiently mycorrhizal. When a totally non-myctotrophic plant species (eg. canola, lupin) is grown as a rotation crop then effectively the VAM fungi are receiving conditions similar to a long fallow; there is no host for them to colonise.

**Mycorrhizas in cotton.** Cotton forms mycorrhizas with VAM fungi wherever it grows (Rich and Bird, 1974). Observations of cotton in N.S.W. have shown that cotton is always heavily colonised by mycorrhizal fungi. A limited examination of soils and roots from cotton fields in the Namoi valley has shown the presence of at least four or five different species of VAM fungi. It is probable that further surveys will find more species of VAM fungi associated with cotton.

**Mycorrhizal dependancy of cotton.** The effect of mycorrhizal fungi on cotton growth and nutrition was examined in a pot experiment in a glasshouse using a cracking clay soil, collected at the start of the 1991/92 season, from a field near Narrabri Agricultural Research Station. The experiment was a 2x2 factorial design (Fig. 2). Pots were filled with 750g (dry weight) of either steam sterilised (80°C for 1 h) or unsterilised soil. A layer of inoculum, either sterilised (autoclaved at 121°C for 1.5h) or unsterilised, was placed in the centre of each pot (Fig. 2). The inoculum was soil (50 g dry weight) containing mycorrhizal roots, and was taken from pots containing cotton plants (cv. DeltaPine 90) prior to the experiment. The soil used to grow inoculum had been collected from the same site but at the end of the previous season. Cotton seeds (DeltaPine 90) were sown five to a pot and thinned to two seedlings per pot after germination.

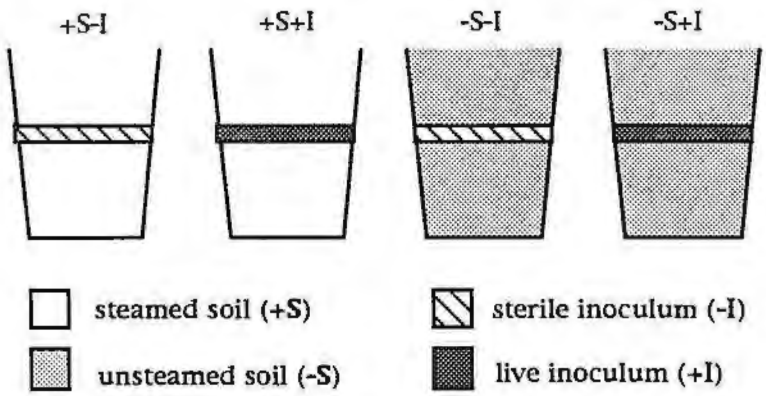


**Figure 2. Arrangement of soil and inoculum in pots.**

Plants grown in sterilised soil with sterilised inoculum had significantly ($P<0.01$) lower dry weights than those in the non-sterilised 'living' soil (Fig. 3a). Plants grown in totally sterile soil did not form mycorrhizas and had half the phosphorus and zinc content when compared to plants that formed mycorrhizas (Fig 3b,c,d). Inoculation of the sterile soil restored VAM formation to a level significantly higher ($P<0.01$) than that of the unsteamed treatments and this was reflected in shoot dry weight.

The above experiment demonstrated the beneficial effects that mycorrhizas have on growth and phosphorus and zinc nutrition of cotton. The fact that inoculation of the sterilised soil restored growth and nutrition to equal or better than that of the live soil demonstrates that the reduced growth in sterilised soil was due to a lack of biological factors, namely the mycorrhizal fungi.

To determine wether these observations in pots reflected field conditions the experiment was repeated in the field (at the same site where the soil was collected for pots) during February and March, 1992. Cotton plants already growing in the plot area were pulled out 33 days prior to the experiment. Soil was then sterilised with methyl bromide gas. Cores of soil (12 x 9.5 cm) were removed and replaced over a layer of inoculum (50 g dry weight). Inoculum was soil taken from beneath cotton growing adjacent to the plot site.

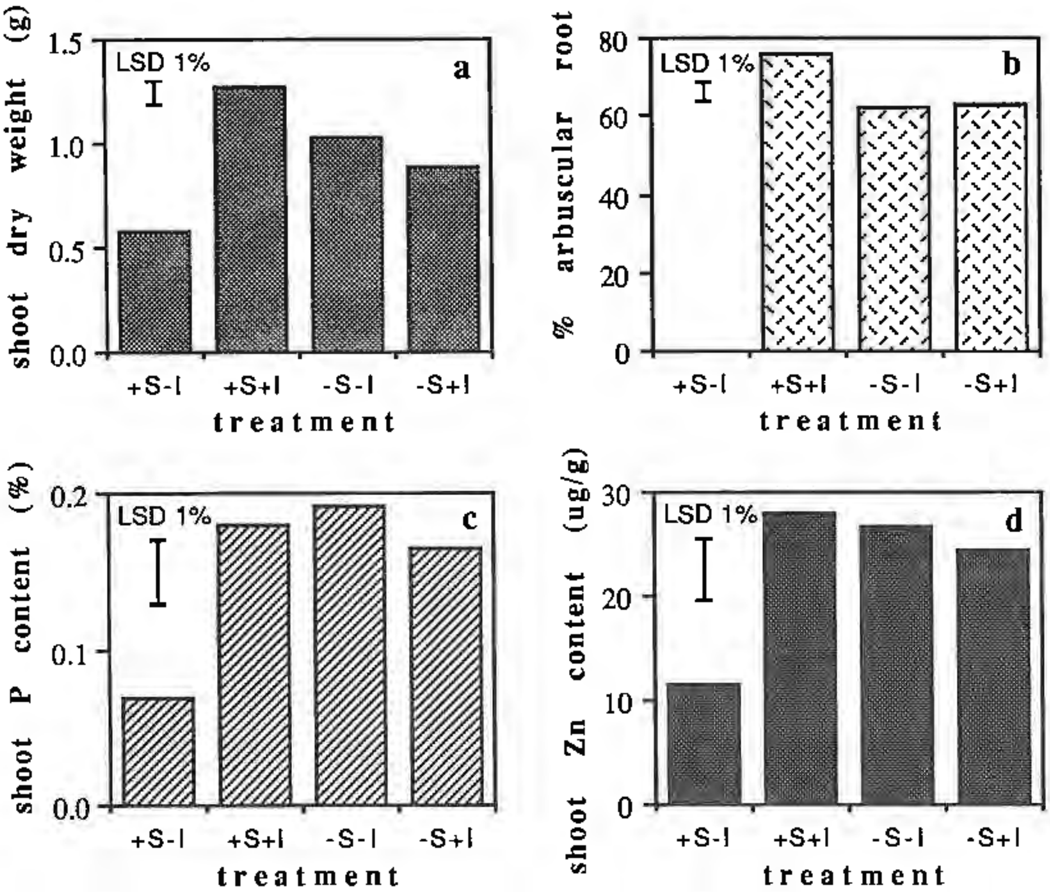


**Figure 3. Growth, nutrition and VAM colonisation (expressed as the percentage of roots with arbuscules) of cotton at six weeks after sowing in steam sterilised (+S) or non steamed (-S) soil, with mycorrhizal inoculum that was sterilised (-I) or unsterilised (+I).**

Plants growing in the sterilised soil were stunted, showed symptoms of zinc deficiency on their leaves and had no mycorrhizal fungi in their roots (Fig. 4). At six weeks after sowing the dry weight of mycorrhizal plants grown in live soil, with or without inoculum, was six to eight times that of the non-mycorrhizal plants grown in sterilised soil with no inoculum (Fig. 4). The non-mycorrhizal plants ceased growth at four weeks.

The results of these experiments show that cotton has a high degree of dependancy on VAM fungi for good growth. At other locations the degree of response to VAM fungi may vary according to chemical, physical and biological characteristics of individual soils.

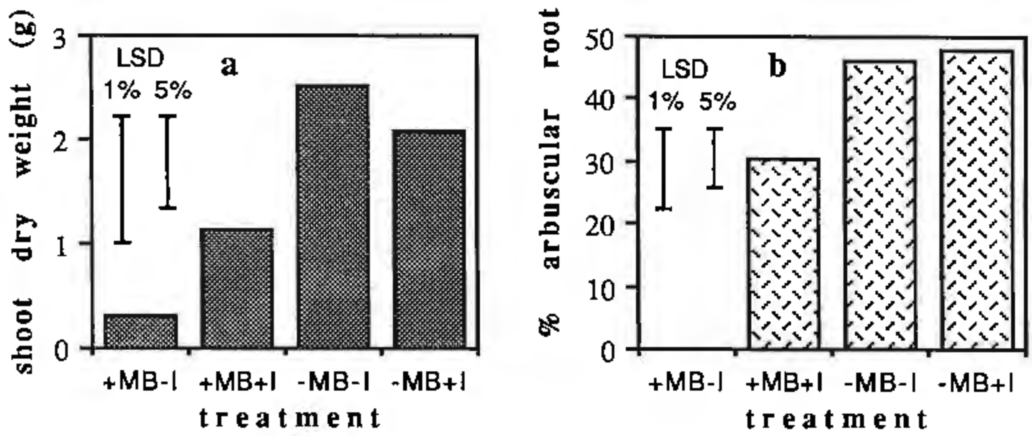


**Figure 4. Growth and VAM colonisation (expressed as the percentage of roots with arbuscules) of cotton at (a) six weeks and (b) four weeks after sowing in methyl bromide sterilised (+MB) or non sterilised (-MB) soil, with mycorrhizal inoculum that was sterilised (-I) or unsterilised (+I).**

**Cotton disorders involving mycorrhizas.** The mycorrhizal dependancy of cotton shown here is consistent with reports of cotton's susceptibility to long fallow disorder. Long fallow disorder has been reported in cotton in Australia (Brown, Allen and Constable, 1990) and in the United States (Smith, Hicks, Lloyd, Gannaway and Zak, 1989).

A second type of growth disorder in cotton, a syndrome involving a deficiency in mycorrhiza development, has been identified in the Namoi valley. This disorder is known locally as 'early season growth disorder' or 'Galathera syndrome' after the Galathera Creek north of Narrabri Agricultural Research Station. Plants sown late in the season are subject to the disorder and it now appears that the disorder occurs in areas other than those near Galathera creek. 'Mycorrhizal deficiency syndrome' is perhaps a better description for the syndrome.

The 'mycorrhizal deficiency syndrome' of cotton is characterised by stunted plants, slow growth of young plants and visual symptoms of zinc deficiency in badly affected plants. During the 1991/92 season intensive observations were made in two syndrome affected fields, either side of Galathera creek, where gradients from poor to better cotton growth had been identified. Mycorrhizal infection decreased approaching Galathera creek (Fig. 5). Plant height followed a similar trend with plateaus of good growth away from the creek (Fig. 6). This pattern in plant growth also reflected the sand content of the soil (Fig.7). Apart from two high phosphorus values at 0.2 and 0.5 km from the creek (Fig. 8b), the phosphorus content of shoots also followed the trends shown in shoot height and mycorrhizal infection (Figs. 5,6,8).

These observations indicate that the 'mycorrhizal deficiency syndrome' is associated with heavier, less sandy soils and that depressed mycorrhiza development is associated with poor cotton nutrition. The precise cause of this syndrome is yet to he confirmed.

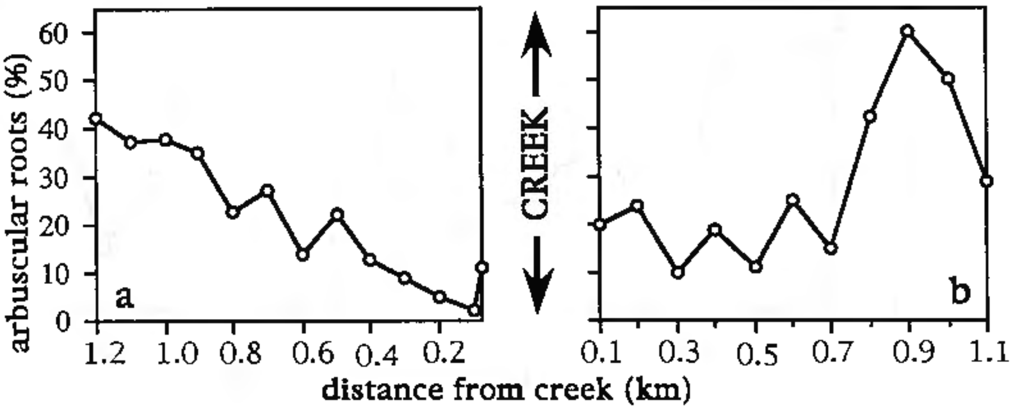


**Figure 5. Variation in VAM colonisation (expressed as percentage of roots with arbuscules) in cotton roots across two fields either side of the Galathera creek on 1st December, 1991.**

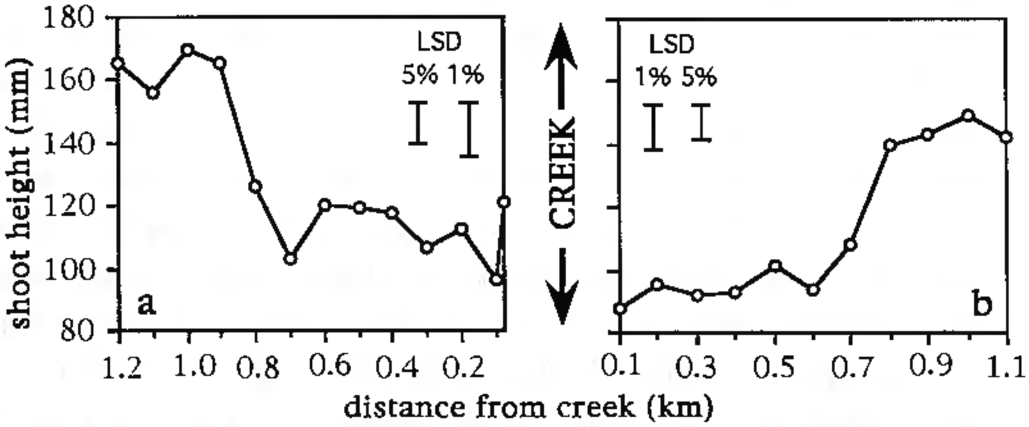


**Figure 6. Variation in the height of cotton plants across two fields either side of the Galathera creek on 1st December, 1991.**

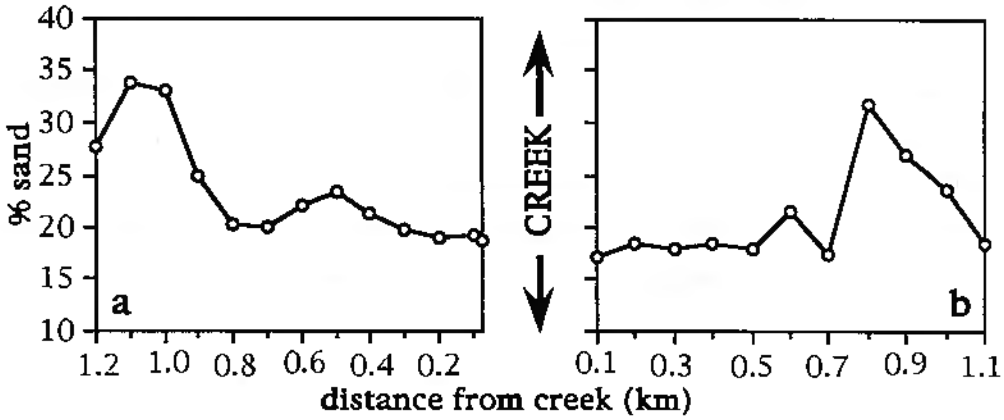


**Figure 7. Variation in percentage sand across two fields either side of the Galathera creek.**

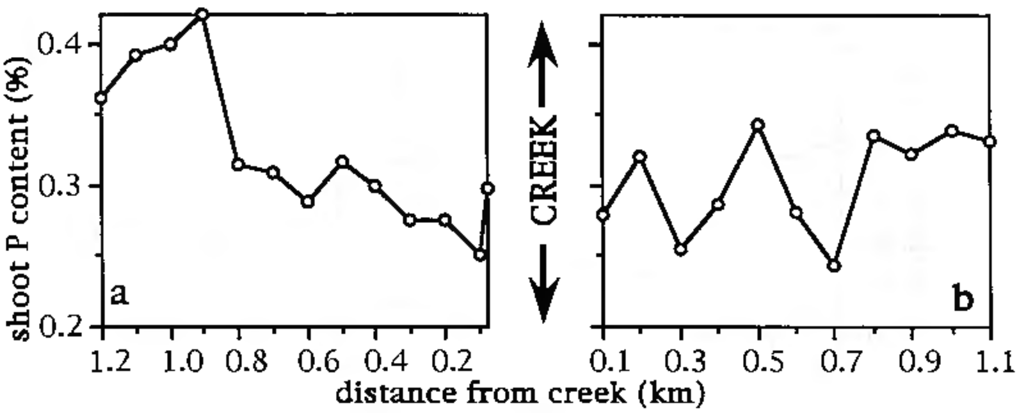


**Figure 8. Variation in phosphorus nutrition of cotton across two fields either side of the Galathera creek on 18th November, 1991.**

**Management of mycorrhizal fungi in cotton farming.** Preliminary research, not reported in this paper, indicates that the potential for VAM fungi to infect cotton is not diminished during the period between back to back cotton. Long fallows where the soil is kept bare of mycotrophic hosts should be avoided. Mycotrophic crop species should be used in rotations, rather than non mycotrophic species. In general the Brassicas (eg. canola) are non-mycotrophic and should not be planted in rotation with cotton. Most legumes are mycotrophic but one exception is lupin. If non-mycotrophic crops are used they should be followed by a crop that is less dependant on VAM fungi than cotton (eg. wheat).

Recent research has shown that soil disturbance reduces the subsequent development of VAM in plants sown into that soil (Jasper, Abbott and Robson, 1989a,b). This is because the fungal mycelium in the soil, which is able to infect new roots, is broken up during soil disturbance. Minimum tillage techniques should benefit cotton by allowing seedlings to tap into existing networks of VAM mycelium.

There is evidence that the fitness of the cotton VAM symbiosis is reduced at temperatures below 18°C (Smith and Roncadori, 1986). Cultivation of cotton in raised beds is a practice used to raise soil temperature to reduce levels of *Verticillium* wilt. Similarly, raised beds should favour cotton symbiosis by promoting higher soil temperature.

Most cotton crops appear to achieve sufficient VAM development. The presence of VAM is made apparent by its absence in specific problems such as long fallow disorder and the 'mycorrhizal deficiency syndrome'. Rotation and tillage practices should enable the effects of long fallow disorder to be avoided or minimised and should also enhance VAM in otherwise healthy crops. Rotation and tillage practices may aid VAM development in the 'mycorrhizal deficiency syndrome' but specific recommendations cannot be made until the cause is fully understood. The future may see the discovery of ways to culture VAM fungi artificially. Mass production of VAM fungal inoculum may not only provide a 'cure' for long fallow disorder, but would enable manipulation of the species or strains of VAM fungi to maximise crop production.

The fitness of a VAM association will depend on a multitude of variable factors including the genotype of the host plant, the genotypes of the VAM fungi and the environment. Science has only just begun to understand the complexity of VAMs. It is clear that without the benefits of VAM fungi the cotton industry would not exist, except in soils with high available levels of the immobile nutrients. Farm management should incorporate an awareness of the requirements of VAM fungi.

**Question**: When are cotton farmers not cotton farmers?
**Answer**: all the time! They are mycorrhiza farmers.

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**References.**

Brown, J.F., Allen, S.J. and G.A. Constable, 1990. Mycorrhizas and plant nutrition: long fallow disorder and cotton. pp. 67-72. In *Proceedings of the 5th Australian Cotton Conference*, Broadbeach, Queensland, 452 p.

Hayman, D.S., 1987. VA mycorrhizas in field crop systems. pp.171-192. In Safir, G.R. (ed.) *Ecophysiology of VA Mycorrhizal Plants*, CRC Press, Boca Raton, 224 p.

Jasper, D.A., Abbott, L.K. and A.D. Robson, 1989a. Soil disturbance reduces the infectivity of external hyphae of vesicular-arbuscular mycorrhizal fungi. *New Phytologist*, **112**: 93-99.

Jasper, D.A., Abbott, L.K. and A.D. Robson, 1989b. Hyphae of vesicular-arbuscular mycorrhizal fungus maintain infectivity in dry soil, except when the soil is disturbed. *New Phytologist*, **112**: 101-107.

Rich, J.R. and G.W. Bird, 1974. Association of early-season vesicular-arbuscular mycorrhizae with increased growth and development of cotton. *Phytopathology*, **64**: 1421-1425.

Smith, G.S. and R.W. Roncadori, 1986. Responses of three vesicular-arbuscular mycorrhizal fungi at four soil temperatures and their effects on cotton growth. *New Phytologist*, **104**: 89-95.

Smith, R.G., Hicks, S.K., Lloyd, R.W., Gannaway, J.R. and J.Zak, 1989. VA mycorrhizal infection and its implication in the "fallow syndrome" associated with cotton grown in previously fallowed soils. pp. 127-128. *In* Brown, J. (ed) *1989 Proceedings Beltwide Cotton Production and Research Conferences*, vol 1, National Cotton Council, Memphis, Tennessee, 375 p.

Thompson, J.P., 1987. Decline of vesicular-arbuscular mycorrhizae in long fallow disorder of field crops and its expression in phosphorus deficiency of sunflower. *Australian Journal of Agricultural Research*, **38**: 847-67.

Trappe, J.M., 1987. Phylogenetic and ecologic aspects of mycotrophy in the Angiosperms from an evolutionary standpoint. pp. 5-25. In Safir, G.R. (ed.) *Ecophysiology of VA Mycorrhizal Plants*, CRC Press, Boca Raton, 224 p.