SOIL SECRETS
Unlocking the Secrets of Healthy Soil!
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Can Mycorrhizae Inoculation Help a Landscape or Crop Use Less Water and Less Fertilizer?

By Michael Martin Meléndrez – founder of Soil Secrets LLC

This list of abstracts is to verify statements for the mycorrhizal products of Soil Secrets™, defending the claim that inoculating a plant, crop or landscape with the mycorrhizae will make that system dramatically more drought tolerant, therefore requiring less water. The overall goal of Soil Secrets is to prime the Pedogenesis (soil creation) contributing to 'soil carbon sequestering', sustainability and a healthier terrestrial soil biosphere.

The objective of this document is to show and examine mycorrhizal research papers published in Journals of Science to validate the current evidence that support the statements and claims of water conservation and fertilizer management in **TerraPro®** and **Earth Magic®** manufactured by Soil Secrets.

The statements to verify are:

- Uses up to 30% less water,
- Increased root mass and
- Increased fertilizer efficiency.

The research studies were performed in Brazil, Canada, China, Greece, India, Jordan, Poland, Spain, and USA. These research studies were published from 1981-2006.
All papers presented sections on material and methods including experimental design, results and discussions. The studies were performed in diverse environments that range from complete sterile systems, to greenhouse and nurseries to agricultural soils. The number of species used varied in each study but the most commonly used species were *G. intraradices* and *G. deserticola*.

This compilation of research published in peer review journals of science will show clear evidence that the mycorrhization of a landscape, crop, slope revegetation site, and even a permaculture project will indeed benefit from mycorrhization of the plants in those landscapes helping them becoming more tolerant of water stress along with needing less fertilization input.

Soil Secrets LLC is a commercial producer and source for the mycorrhizae and complimentary products. **TerraPro (**commercial name) & **Earth Magic (**retail name), is our Humus based product that is charged with beneficial mutualistic microbes including the Mycorrhizae and the helper bacteria that are associated with plant roots and the mycorrhizae. The bulk of the product is humus, a bio-chemical known in science to be a product of soil chemistry that is essential for a healthy and productive soil. It's the rich and black aromatic complex of polymers that are the definition of topsoil, giving soil its dark color. Humus has a huge cation exchange capacity which helps soil hold onto the cation's preventing those nutrients from leaching. In addition, Humus has an electromagnetic quality that helps soil retain moisture keeping water available for plants. Research shows that humus is capable of improving the drought tolerance of a soil by over 30 percent compared to soil without humus! Under most man made situations, such as farms, landscapes and even organic farms that have been organic for many years, there is a negative humus pipeline in the soil that is making humus slower than its loss from erosion and other factors. Therefore we are confident that supplementing humus is prudent. Furthermore, Humus is not ‘rapid cycling carbon’ like the organic matter of compost or other decomposing organic substances of soil, therefore the carbon in Humus will remain in soil for many decades since the chemical half life is predicted to be many decades if not centuries, while compost and soil amendments made from organics will decompose rapidly releasing the carbon into the atmosphere as Carbon dioxide (CO_2). **Be clear that Humus is not truly the same as organic matter and organic matter is not Humus!**   Humus in fact is a complex of several stable chemicals that as a group are called **Humic acids**.

TerraPro, Earth Magic and all the products of Soil Secrets are derived from ingredients that are ‘Rapidly Renewable’!

WATER USE

Auge, R. M., Kurt A. Schekel and R.L. Wample. 1987. Leaf water and carbohydrate status of VA mycorrhizal rose exposed to drought stress. Plant and Soil 99:291-302.
This paper looked at the impact of drought and P nutrition on shoot water relation, carbohydrate and chlorophyll levels of VA mycorrhizal on rose.
The mycorrhizal fungi used were *Glomus intraradices* and *Glomus deserticola*.
Regardless of phosphorus (P) fertilization, leaf and osmotic and bulk water potentials were higher in mycorrhizal than nonmycorrhizal plants. Leaf starch, chlorophyll and water contents were higher in *G. intraradices*-colonized plants than in the high-phosphorus nonmycorrhizal plants, while fructose, glucose and other carbohydrates were lower. Level of P fertilization had no effect on water relations or soluble carbohydrate content of nonmycorrhizal roses.
The water status of water-stressed rose was improved more by *G. intraradices* (leaf diffusive conductance 55%, leaf water status 20%) and than by *G. deserticola*. Under dry soil conditions, the influence of the fungus became more pronounced than under moist conditions, at least in the case of the high-P *G. intraradices*-colonized roses.
The root and plant P content increased with increased P fertilization in mycorrhizal roses, without producing effect on most water status parameters.
THIS PAPER SUPPORTS THE STATEMENT ON WATER USE.

Al-Karaki, G.N. 1998. Benefit, cost and water-use efficiency of arbuscular mycorrhizal durum wheat grown under drought stress. Mycorrhiza 8:41-45.
This study determined the effects of arbuscular mycorrhizal fungal (AMF) inoculation on growth, benefit/cost and water-use efficiency (grams dry matter produced per kilogram water evapotranspired) in two wheat genotypes (drought sensitive and drought tolerant) under water-stressed and well-watered conditions.
Shoot and root dry matter and root AMF colonization were higher for well watered than for water-stressed plants. The mycorrhizal plants were more water-use efficient than nonmycorrhizal plants. Shoot Dry matter differences between mycorrhizal and nonmycorrhizal plants represent the benefit derived by plants from Arbuscular mycorrhizal fungal -root associations.
The mycorrhizal plants used less water to produce one unit of shoot of Dry matter (WUE-Water Use Efficiency) than nonmycorrhizal plants, but water-stressed and well-watered plants did not differ in Water Use Efficiency. Also, these plants had higher shoot and root dry matter than nonmycorrhizal plants regardless of water stress level.

AMF colonization increased total P uptake by both genotypes regardless of water-stress level. This likely occurred because mycorrhizal plants had enhanced root growth and thus a greater P absorption surface area. Enhanced growth effects on mycorrhizal plants have been attributed to improved water relations resulting from enhanced P nutrition.
The calculated benefit/cost values of arbuscular mycorrhizal fungi on host plant dry matter were higher for wheat grown under water-stressed than under well-watered conditions.
THIS PAPER SUPPORTS THE STATEMENT ON WATER USE.

Al-Karaki, G.N. and R. B. Clark. 1998. Growth, mineral acquisition, and water use by mycorrhizal wheat grown under water stress. Journal of Plant Nutrition 21:263-276.
This study determined effects of water stress vs. no water stress and the arbuscular mycorrhizal (AM) fungi *Glomus monosporus* on growth, acquisition of phosphorus (P), zinc (Zn), copper (Cu), manganese (Mn), and iron (Fe), and water use in two wheat cultivars exhibiting differences in resistance to water stressed (WS).
Shoot and root dry matter, leaf areas, total root length and root colonization with AM for plants grown under non-WS were higher than for plants grown under WS. Much of the reduction in dry matter was overcome by AM plants grown under WS. Nutrients contents were greater under WS than under non-WS conditions. The AM plants had higher water efficiency values than non-AM plants when grown under WS. Their results of this study indicated that AM plants had greater tolerance to drought stress than non-AM plants.
THIS PAPER SUPPORTS THE STATEMENT ON WATER USE.

Al-Karaki, G.N. and R. B. Clark. 1999. Varied rates of mycorrhizal inoculums on growth and nutrient acquisition by barley grown with drought stress. Journal of Plant Nutrition 22:1775-1784.
The objective of this research was to determine effects of varied rates of arbuscular mycorrhizal fungi (AMF) inoculums on plant growth and acquisition of phosphorus (P), zinc (Zn), copper (Cu), and manganese (Mn) by barley grown with and without drought stress. Root AMF colonization increased as inoculum rate increased in plants grown with water stress (WS) and non-water stressed (NWS). Leaf area and shoot, root dry matter, and plant contents of P, Zn, Cu and Mn increased as inoculum rate increased up to 240 spores of *Glomus mosseae* per 100 g dry soil regardless of soil moisture.
The response of barley to different rates of AMF inoculum depended on soil moisture.
THIS PAPER SHOWS CLEAR RESULTS ON EFFICIENCY OF ARBUSCULAR MYCORRHIZAL FUNGI ON NUTRIENT UPTAKE REGARDLESS OF SOIL MOISTURE.

Al-Karaki, G.N., B. McMichael and John Zak. 2004. Field response of wheat to arbuscular mycorrhizal fungi and drought stress. Mycorrhiza14:263-269.
This study was to determine the effects of arbuscular mycorrhizal (AM) fungi inoculation on growth, grain yield and mineral acquisition of two winter wheat cultivars grown in the field under well-watered and water-stressed conditions.
Water management treatments were 1) water-stressed (WS) plants grown under rainfed` conditions with 50 mm irrigation applied at planting, and 2) well-watered (WW) plants grown under rainfed conditions with irrigation scheduled to prevent symptoms of water stress. The total seasonal irrigation for the WW treatment was 408.5 mm. Therefore, the water stress treatment was equivalent to 72% less water than well water treatment.
Mycorrhizal colonization was higher in well-watered plants colonized with AM fungi than water-stressed plants. Biomass and grain yields were higher in mycorrhizal than non mycorrhizal plots irrespective of soil moisture, and *G. eutunicatum* inoculated plants generally had higher biomass and grain yields than those colonized by G. mosseae under either soil moisture condition. The mycorrhizal plants had higher shoot P and Fe concentration than non mycorrhizal plants at all samplings regardless of soil moisture conditions. Enhanced plant growth and yield following AM fungal inoculation was related to improved uptake of P and Cu, especially under WS conditions. Mycorrhizal fungi may improve nutrient uptake by increasing the exploration of the soil pore space.
The improved growth, yield and nutrient uptake in wheat plants reported here demonstrate the potential of mycorrhizal inoculation to reduce the effects of drought stress on wheat grown under field conditions in semiarid areas of the world.
THIS PAPER SUPPORTS THE STATEMENT ON WATER USE.

Bethlenfalvay, G.J. M.S. Brown, R.N. Ames and R.S. Thomas. 1988. Effects of drought on host and endophyte development in mycorrhizal soybeans in relation to water use and phosphate uptake. Physiologia plantarum 72:565-571.

The aim of this study was to test the hypothesis of P as the major factor in VAM response to drought, and to determine the relationship between unavailable soil water and the response of the host plant to colonization by VAM fungi under drought stress.

They found that the dry weights of VAM plants were greater at severe stress and smaller at no stress than those of non-VAM plants. Colonization of roots by *G. mosseae* did not vary with stress, but the biomass and length of the extraradical mycelium was greater in severely stressed than in non-stressed plants. Growth enhancement of VAM plants relative to P-fertilized non-VAM plants under severe stress was attributed to increased uptake of water as well as to more efficient P uptake. The ability of VAM plants to deplete soil water to a greater extent than non-VAM plants suggests lower permanent wilting potentials for the former.

THIS PAPER SUPPORTS THE STATEMENT ON WATER USE.

Borkowska, B. 2002. Growth and photosynthetic activity of micropropagated strawberry plants inoculated with endomycorrhizal fungi (AMF) and growing under drought stress. Acta Physiologiae Plantarum 24:365-370.

This study found that mycorrhization strongly affected growth and tolerance to water deficiency of the plants cultivated in greenhouse. Mycorrhizal plants showed higher biomass accumulation (crowns and roots) and larger leaf area. The mycorrhizal plants fully recovered their photosynthetic activity when watering was restored. Their results suggest positive role of AMF in protecting photochemical systems against water deficiency. **THIS PAPER SUPPORTS THE STATEMENT ON WATER USE.**

Amico, J.D., A. Torrecillas, P. Rodrigiez, A. Morte and M.J. Sanchez-Blanco. 2002. Responses of tomato plants associated with the arbuscular mycorrhizal fungus *Glomus clarum* during drought and recovery. Journal of Agricultural Science 138:387-393.

This study tested whether *Glomus clarum* could enhance tomato plant growth and improve the water relations affecting the ability of the plant to extract water from the soil under well-watered and water stressed conditions, and to examine the ability of water-stressed tomato plants to recover.

They concluded that under the growth conditions used in this study, and in spite of a relatively low level of root colonization, mycorrhizal symbiosis had a beneficial effect on tomato plant water status, enhancing water uptake by improving root hydraulic conductivity and increasing leaf conductance and photosynthetic activity.

THIS PAPER SUPPORTS THE STATEMENT ON WATER USE.

Fidelibus M.W., C.A. Martin and J.C. Stutz. 2001. Geographic isolates of *Glomus* increase root growth and whole-plant transpiration of Citrus seedlings grown with high phosphorus. Mycorrhiza 10:231-236.

This study tested the hypothesis that growth and water-use characteristic of AM plants would differ from those of non-AM plants that were well supplied with P. They used AM fungal isolates of different geographic origins, therefore they also tested that inoculation of citrus seedlings with *Glomus* isolates from arid, semi-arid or mesic areas would result in different patterns of plant growth and water use. AM plants and non-AM plants had similar shoot size (dry weight and canopy area), but all AM fungus treatments stimulated root growth (dry weight and length). Leaf P concentration were 12-56% higher in AM plants than non-AM plants. Enhanced root growth was positively correlated with leaf P concentration. In general, AM plants had greater whole-plant transpiration than non-AM plants under well-watered conditions, under mild water stress and during recovery from moderate and severe soil drying. This suggests a faster recovery from moisture stress by AM plants. AM plants had lower leaf conductance than non-AM plants when exposed to severe soil drying. Although the greatest differences were between AM and non-AM plants, plants treated with *Glomus* isolates differed in colonization level, leaf P concentration, root length, transpiration flux and leaf conductance. Also, they suggested that *Glomus* isolates that increase root growth and whole-plant transpiration might improve the field performance if young citrus rootstock and mitigate against desiccation after soil drying by amplifying the potential for root exploration of soil for water.

THIS PAPER SUPPORTS THE STATEMENT ON WATER USE.

Hardie, K. and L. Leyton. 1981. The influence of vesicular-arbuscular mycorrhizal on growth and

water relations of red clover. I. In phosphate deficient soil. New Phytologist 89:599-608.
This study found that VA mycorrhizal colonization of red clover grown in phosphate deficient soils enhanced the concentration of P in the tissues, stimulated growth of root and shoot but reduced the root/shoot ratio. Addition of phosphate to well below the optimum level also stimulated growth and enhanced P status of non-mycorrhizal plants, but their yields and P concentrations were much smaller than those of mycorrhizal plants and their root/shoot ratios were unaffected. The hydraulic conductivities of the root systems were much higher in mycorrhizal than non-mycorrhizal plants. The conductivities of the mycorrhizal roots were still two to three times higher, suggesting that this was mainly due to hyphal growth in the soil. Mycorrhizal plants were able to extract soil moisture down to lower water potentials than non-mycorrhizal plants and recovered turgor more rapidly than non-mycorrhizal plants when soil water was restored. Thus, the mycorrhizal habit is an advantage to the host plant in times of moisture stress. **THIS PAPER SUPPORTS THE STATEMENT ON WATER USE.**

Tobar, R. R. Azcon and J.M. Barea. 1994. Improved nitrogen uptake and transport from 15Nlabelled nitrate by external hyphae of arbuscular mycorrhizal under water-stressed conditions. New Phytologist 126:119-122.
This study determined the importance of the external mycelium of arbuscular mycorrhizal for uptake and transport of N from 15N labeled nitrate in benefiting plant nutrition under either well-irrigated or waterstressed conditions. They found evidence that AM fungi provided transport of N from nitrate source though the hyphal network and can be important for the N-nutrition of plants in relatively dry agricultural soils where nitrate is actually the predominant nitrogen form.
THIS PAPER DOES NOT SUPPORT THE STATEMENT ON WATER USE.

HOWEVER, IT IS IMPORTANT FOR STATEMENT ON FERTILIZING EFFICIENCY.
Tobar, R.M., R. Azcon, J.M. Barea. 1994. The improvement of plant N acquisition from an ammonium-treated, drought-stressed soil by the fungal symbiont in arbuscular mycorrhizae. Mycorrhiza 4:105-108.
The objective of this study was to determine that mycorrhizal activity on N uptake under water-stressed conditions and effects on plant growth. They used a neutral agricultural soil and the arbuscular fungi were *Glomus mosseae* and *G. fasciculatum*. They found that under water-stressed conditions both fungal species increased the 15N enrichment of plant tissues. This indicates a direct effect of arbuscular mycorrhizal fungi on N acquisition in relatively dry soils. *G. mosseae* had more effect on N uptake than *G. fasciculatum* on P uptake under water-stressed conditions, but both fungi improved plant biomass production relative to nonmycorrhizal plants.
THIS PAPER SUPPORTS THE STATEMENT ON WATER USE.

Ruiz-Lozano, J.M., R. Azcon and M.Gomez. 1995. Effects of Arbuscular-Mycorrhizal Glomus species on drought tolerance: Physiological and nutritional plant responses. Applied and Environmental Microbiology 61:456-460.
This study compared seven *Glomus* species to determine their effects on plant growth, mineral uptake, the CO2 exchange rate, water use efficiency, transpiration, stomatal conductance, photosynthetic P use efficiency, and proline accumulation under well-watered and drought stress conditions. AM fungal species showed diverse effectiveness at increasing host plant drought tolerance. The different effects of these fungi on alleviating stress appeared to be based on physiological processes rather than nutrient uptake by the host. The protection of mycorrhizal plants against water stress was related to the effects that the endophytes had on increasing leaf conductance and transpiration as well as P and K uptake. *Glomus deserticola* was the most adapted and aggressive colonizer as well as the most effective species for increasing drought tolerance of the host plant both in terms of maintaining growth under stress conditions and in permitting more efficient use of water. Also, they observed that plant nutrient uptake was strongly influenced by the fungal symbiont involved in the association. The differences in shoot and root growth stimulation between the least effective fungal isolate (*G. occultum*) and the most effective fungal isolate (*G. deserticola*) ranged from 270% under well-watered conditions to more than 821% under drought stress conditions. They concluded that selection of AM fungi for introduction into dry environments to address specific problem situations is a promising but usually neglected strategy.
THIS PAPER SUPPORTS THE STATEMENT ON WATER USE.

Nikolaou, N., K. Angelopoulos, and N. Karagiannidis. 2003. Effects of drought stress on

mycorrhizal and non-mycorrhizal cabernet sauvignon grapevine, grafted onto various rootstocks. Expl. Agric 39:241-252.

The objective of this study was to assess the effects of drought stress on leaf photosynthesis and water relations of Cabernet Sauvignon grapevine scion grafted onto eight different rootstocks.

Foliar growth, leaf phosphorus concentrations and drought tolerance were greater in the inoculated than in the non-inoculated plants. Some drought-sensitive rootstocks colonized with mycorrhizal fungi and subjected to drought for eight days showed much-improved drought resistance compared with non infected rootstocks of the same varieties. They concluded that mycorrhizal colonization may improve the water status of non-irrigated vines.

THIS PAPER SUPPORTS THE STATEMENT ON WATER USE.

Subramanian, K.S., C. Charest, L.M. Dwyer and R.I. Hamilton. 1995. Arbuscular mycorrhizas and water relations in maize under drought stress at tasselling. New Phytologist 129:643-650.

This study hypothesized that under drought conditions inoculation of AM fungi in maize improves water relations that may play an important role in drought tolerance of the host plant. They measured leaf water potential, stomatal resistance, transpiration rate and green leaf area in mycorrhizal and non-mycorrhizal plants of drought sensitive and resistant maize cultivars when irrigation was withheld for 3 weeks following tasselling.

Mycorrhizal inoculation had a significant effect in improving water relations and in retaining more green leaf area, leaf water potential and stomatal resistance and transpiration rates in drought-stressed maize plants. The response was more pronounced in drought sensitive than the drought-resistant cultivars. These findings suggest that AM association improves plant water relations and contributes to drought tolerance in maize.

THIS PAPER SUPPORTS THE STATEMENT ON WATER USE.

Subramanian, K.S., C. Charest. 1999. Acquisition of N by external hyphae of an arbuscular mycorrhizal fungus and its impact on physiological response in maize under drought-stressed and well-watered conditions. Mycorrhiza 9:69-75.

This study examined the uptake of nitrogen by external hyphae of an arbuscular mycorrhizal (AM) fungus (*Glomus intraradices*) and its impact on physiological response in maize plants subjected to well-watered or drought-stressed conditions.

Mycorrhizal colonization by *G. intraradices* improved nutritional status and N assimilation in maize plants exposed to moderate drought stress. The increased capacity for N acquisition and assimilation may enable the host plant to sustain moderate drought stress conditions. Glutamine synthetase activity in AM plants increased by 30% under drought conditions, which may be attributed to the hyphal transport of N in the form of NO3 or NH4. They also found that AM colonization conferred a higher P status under drought conditions. In summary, they suggested a positive relationship between N hyphal contribution and metabolic/nutritional status of the host plant. These changes may assist the host plant to withstand drought conditions.

THIS PAPER SUPPORTS THE STATEMENT ON WATER USE.

Subramanian, K.S., P. Santhanakrishnan, P. Balasubramanian. 2006. Responses of field grown tomato plants to arbuscular mycorrhizal fungal colonization under varying intensities of drought stress. Scientia Horticulturae 107:245-253.

The objective of this study was to examine the effects of mycorrhizal inoculation with AM fungus on the growth, reproductive behavior, water status, nutrient content, fruit yield and quality attributes of field grown tomatoes drought under stress conditions. Their 2 year- field study suggested that the inoculation with *Glomus intraradices* improves drought tolerance of tomato plants as secondary consequence of enhanced nutritional status of the host plant, especially N and P. Mycorrhizal association improved tomato fruit quality by enhancing ascorbic acid content and reducing the acidity. Drought impact on deteriorating fruit quality can be lessened through mycorrhizal colonization. Their data revealed that AM colonization enhances nutritional status and leaf relative water content and enables the host plant to withstand varying intensities of drought stress under field conditions.

THIS PAPER SUPPORTS THE STATEMENTS ON WATER USE AND INCREASED FERTILIZER EFFICIENCY.

Runjin, L. 1989. Effects of vesicular-arbuscular mycorrhizas and phosphorus on water status and growth of apple. Journal of Plant Nutrition 12:997-1017.

The objective of this study was to determine the influence of VAM fungi on the water status, mineral uptake, and growth of the seedlings of apple and to establish the probable mechanism by which arbuscular mycorrhiza (AM) changes water relations of their host plant under ample moisture supply and water stress conditions.
The found that sterilized soil inoculated with *Glomus versiforme* and *G. macrocarpum* enhanced element uptake, improved water status, drought tolerance and growth of the plants. Colonized plants grew rapidly two months after inoculation. Phosphorus added to the soil had a negative effect on the development and function of AM. In sterilized soil, AM colonization increased the transpiration rate of the leaves, reduced the stomatal resistance and the permanent wilting as well enhanced the rate of recovery of the plant from the water stress and the plant growth. This was probably due to enhancing absorption and translocation of water by the external hyphae. It also increased absorption of most minerals, especially Zn and Cu by the roots and weakened the P-Cu and P-Zn interactions. Under natural conditions, growth, mineral nutrition, water relations are interlinked with the effects of soil microorganisms that includes AM fungi.
THIS PAPER SUPPORTS THE STATEMENTS ON WATER USE AND INCREASED FERTILIZER EFFICIENCY.

Tarafdar, J.C. and Praveen-Kumar. 1996. The role of vesicular arbuscular mycorrhizal fungi on crop, tree and grasses grown in an arid environment. Journal of Arid Environments 34:197-203.
This study evaluated the effects of different arbuscular mycorrhizal fungi on the tree *Prosopis juliflora*, the grass *Cenchrus ciliaris* and the crop *Vigna aconitifolia* under field conditions. Plants were grown in poor fertility sandy soil with low indigenous mycorrhizal fungal populations. At maturity of crop and after 1-year growth of grass and trees, their shoot biomass, N, P, K, Fe, Zn and Cu concentration were significantly improved in all cases of inoculated plants. In general, the effect was most pronounced in *Prosopis juliflora* and *Glomus fasciculatum* was the most effective under arid conditions. Their results suggested that increased uptake of nutrients by plants with arbuscular mycorrhizal fungi under filed conditions would have important implications for elemental composition of plants.
THIS PAPER SUPPORTS PARTIALLY THE STATEMENT ON WATER USE.

ROOT MASS

Al-Karaki, G.N. 1998. Benefit, cost and water-use efficiency of arbuscular mycorrhizal durum wheat grown under drought stress. Mycorrhiza 8:41-45.
This study determined the effects of AMF inoculation on growth, benefit/cost and water-use efficiency (grams dry matter produced per kilogram water evapotranspired) in two wheat genotypes (drought sensitive and drought tolerant) under water-stressed and well-watered conditions.
Shoot and root dry matter and root AMF colonization were higher for well watered that for water-stressed plants. The mycorrhizal plants were more water-use efficient than nonmycorrhizal plants. Shoot Dry matter differences between mycorrhizal and nonmycorrhizal plants represent the benefit derived by plants from Arbuscular mycorrhizal fungal -root associations.
The mycorrhizal plants used less water to produce one unit of shoot of Dry matter (WUE-Water Use Efficiency) than nonmycorrhizal plants, but water-stressed and well-watered plants did not differ in Water Use Efficiency. Also, these plants had higher shoot and root dry matter than nonmycorrhizal plants regardless of water stress level.
Enhanced growth effects on mycorrhizal plants have been attributed to improved water relations resulting from enhanced P nutrition.
The calculated benefit/cost values of Arbuscular mycorrhizal fungi on host plant dry matter were higher for wheat grown under water-stressed than under well-watered conditions.
THIS PAPER SUPPORTS THE STATEMENT ON INCREASED ROOT BIOMASS.

Al-Karaki, G.N. and R. B. Clark. 1999. Varied rates of mycorrhizal inoculums on growth and nutrient acquisition by barley grown with drought stress. Journal of Plant Nutrition 22:1775-1784.
The objective of this research was to determine effects of varied rates of arbuscular mycorrhizal fungi (AMF) inoculums on plant growth and acquisition of phosphorus (P), zinc (Zn), copper (Cu), and manganese (Mn) by barley grown with and without drought stress. Root AMF colonization increased as inoculum rate increased in plants grown with water stress (WS) and non-water stressed (NWS). Leaf area and shoot, root dry matter, and plant contents of P, Zn, Cu and Mn increased as inoculum rate increased

up to 240 spores of *Glomus mosseae* per 100 g dry soil regardless of soil moisture. The response of barley to different rates of AMF inoculum depended on soil moisture.
THIS PAPER SUPPORTS THE STATEMENT ON INCREASED ROOT BIOMASS.

Aguilera-Gomez, L., F.T. Davies, Jr., V. Olalde-Portugal, S.A. Duray and L. Phavaphutanon. 1999. Influence of phosphorus and endomycorrhiza (*Glomus intraradices*) on gas exchange and plant growth of chile ancho pepper (*Capsicum annum* L. cv. San Luis).
The objectives of this research were: 1) to determine the influence of endomycorrhizal in alleviating low P effects of mycorrhizal chile ancho pepper plants based on plant growth and gas exchange characteristics and 2) to evaluate the influence of P on mycorrhizal development of arbuscules, vesicles, and intraradical and extraradical hyphae formation. Their long-term goal is to demonstrate the usefulness of mycorrhiza for more efficient utilization of P fertilization in sustainable production systems for this pepper variety. Mycorrhizal colonization increased leaf number, leaf area, shoot, root and fruit mass at low P rates compared to non-VAM plants. Reproductive growth was enhanced by 450% in mycorrhizal plants at high P levels. The enhanced growth and gas exchange of mycorrhizal plants was in part due to greater uptake of P and greater extraradical hyphae development.
THIS PAPER SUPPORTS THE STATEMENT ON INCREASED ROOT BIOMASS.

Brejeda, J.J., L.E. Moser and K.P. Vogel. 1998. Evaluation of Switchgrass rhizosphere microflora for enhancing seedling yield and nutrient uptake. Agron. J. 90:753-758.
Seedlings inoculated with rhizosphere microflora produced up to 15-fold greater shoot and root yields, and recovered up to 6-fold more N and 36-fold more P than seedlings inoculated with rhizosphere bacteria only. These responses were consistent for all four cultivars and were probably due to arbuscular mycorrhizal fungi. Seedlings inoculated with rhizosphere populations from seeded switchgrass stands averaged 1.5-fold greater shoot and root yields than seedlings inoculated with rhizosphere populations from native prairies. Plant growth promoting rhizosphere, AM fungi and nonmycorrhizal fungi may be responsible for the large increases in shoot and root weights and in N and P uptake following inoculation of seedlings with rhizosphere microflora.
THIS PAPER SUPPORTS THE STATEMENT ON INCREASED ROOT BIOMASS.

Fidelibus M.W., C.A. Martin and J.C. Stutz. 2001. Geographic isolates of *Glomus* increase root growth and whole-plant transpiration of *Citrus* seedlings grown with high phosphorus. Mycorrhiza 10:231-236.
This study tested the hypothesis that growth and water-use characteristic of AM plants would differ from those of non-AM plants that were well supplied with P. They used AM fungal isolates of different geographic origins, therefore they also tested that inoculation of citrus seedlings with *Glomus* isolates from arid, semi-arid or mesic areas would result in different patterns of plant growth and water use. AM plants and non-AM plants had similar shoot size (dry weight and canopy area), but all AM fungus treatments stimulated root growth (dry weight and length). Leaf P concentration were 12-56% higher in AM plants than non-AM plants. Enhanced root growth was positively correlated with leaf P concentration. In general, AM plants had greater whole-plant transpiration than non-AM plants under well-watered conditions, under mild water stress and during recovery from moderate and severe soil drying. This suggests a faster recovery from moisture stress by AM plants. AM plants had lower leaf conductance than non-AM plants when exposed to severe soil drying. Although the greatest differences were between AM and non-AM plants, plants treated with *Glomus* isolates differed in colonization level, leaf P concentration, root length, transpiration flux and leaf conductance. Also, they suggested that *Glomus* isolates that increase root growth and whole-plant transpiration might improve the field performance if young citrus rootstock and mitigate against desiccation after soil drying by amplifying the potential for root exploration of soil for water. The mycorrhizal effects reported in this study may have been a secondary consequence of AM-enhanced host P nutrition because root growth was highly correlated with leaf P concentration.
THIS PAPER SUPPORTS THE STATEMENT ON INCREASED ROOT BIOMASS.

Hardie, K. and L. Leyton. 1981. The influence of vesicular-arbuscular mycorrhizal on growth and water relations of red clover. I. In phosphate deficient soil. New Phytologist 89:599-608.
This study found that VA mycorrhizal colonization of red clover grown in phosphate deficient soils enhanced the concentration of P in the tissues, stimulated growth of root and shoot but reduced the root/shoot ratio. Addition of phosphate to well below the optimum level also stimulated growth and

enhanced P status of non-mycorrhizal plants, but their yields and P concentrations were much smaller than those of mycorrhizal plants and their root/shoot ratios were unaffected. The hydraulic conductivities of the root systems were much higher in mycorrhizal than non-mycorrhizal plants. The conductivities of the mycorrhizal roots were still two to three times higher, suggesting that this was mainly due to hyphal growth in the soil. Mycorrhizal plants were able to extract soil moisture down to lower water potentials than non-mycorrhizal plants and recovered turgor more rapidly than non-mycorrhizal plants when soil water was restored. Thus, the mycorrhizal habit is an advantage to the host plant in times of moisture stress.
THIS PAPER SUPPORTS THE STATEMENT ON INCREASED ROOT BIOMASS.

Corkidi, L., E.B. Allen, D. Merhaut, M.F. Allen, J. Downer, J. Bohn and M. Evans. 2005. Effectiveness of commercial mycorrhizal inoculants on the growth of Liquidambar styraciflua in plant nursery conditions. J. Environ. Hort. 23:72-76.
In this study, several products were selected to evaluate their effect on the growth and development of *Liquidambar styraciflua*, an important commercial hardwood in the southern United States, which is highly dependent on mycorrhizal fungi.
The growth response of mycorrhizal and nonmycorrhizal plants was analyzed at two harvest times. Significant differences were found in the growth of sweetgum seedlings to mycorrhizal colonization with the different commercial products. Some products enhanced the growth of sweetgum relative to the nonmycorrhizal plants after fourteen weeks of transplanting.
THIS PAPER DOES SUPPORT THE STATEMENT ON INCREASED ROOT BIOMASS.

Scagel, C.F., K. Reddy and J.M. Armstrong. 2003. Mycorrhizal fungi in rooting substrate influences the quantity and quality of roots on stem cuttings of hick's yew. Hortechnology 13:62-66.
The objectives of this study were to determine if the addition of AM fungal (Glomus intraradices) inoculum into the rooting substrate during cutting propagation increases rooting of hick's yew and how the quantity of AM fungal inoculum influences the rooting of hick's yew under nursery production conditions. Adding AM fungal inoculum into the rooting substrate significantly influenced the number of initial roots their dry weight and size per cutting compared to controls. However, the highest level of inoculum tested increased adventitious root initiation without increased root growth. Also, they determined that adding inoculum into the rooting substrate of cuttings treated with rooting hormones is equal to or better than the rooting response obtained by using hormone under nursery production conditions.
THIS PAPER SUPPORTS THE STATEMENT ON INCREASED ROOT BIOMASS.

Yano-Melo, A.M., O.J. Saggin Jr., J.M. Lima-Filho, N.F. Melo and L.C. Maia. 1999. Effect of arbuscular mycorrhizal fungi on the acclimatization of micropropagated banana plantlets. Mycorrhiza 9:119-123.
This study evaluated the effects of the inoculation of three native AM fungal species isolated from irrigated banana plantations of the Brazilian semiarid region on growth, nutrition and physiology of banana plantlets developed in vitro. After three months of acclimatization, statistically significant differences in plant height, leaf area, fresh and dry matter of shoot, and fresh weight of roots between inoculated and non-inoculated plants were recorded. Leaf area and height of inoculated plants were approximately 57% and 32% higher, respectively, than non-inoculated plants. Dry matter of shoots increased 45-64% in mycorrhizal plants. Plants inoculated with *Glomus clarum* showed an increment of around 45% in the fresh weights of shoots and roots over non-inoculated plants. Inoculation with AM fungi increased growth of micropropagated banana plantlets during acclimatization period, and this may benefit rates of photosynthesis and also nutrient transport by mass flow.
THIS PAPER SUPPORTS THE STATEMENT ON INCREASED ROOT BIOMASS.

FERTILIZER EFFICIENCY

Aguilera-Gomez, L., F.T. Davies, Jr., V. Olalde-Portugal, S.A. Duray and L. Phavaphutanon. 1999. Influence of phosphorus and endomycorrhiza (*Glomus intraradices*) on gas exchange and plant growth of chile ancho pepper (*Capsicum annum* L. cv. San Luis).
The objectives of this research were: 1) to determine the influence of endomycorrhizal in alleviating low

P effects of mycorrhizal chile ancho pepper plants based on plant growth and gas exchange characteristics and 2) to evaluate the influence of P on mycorrhizal development of arbuscules, vesicles, and intraradical and extraradical hyphae formation. Their long-term goal is to demonstrate the usefulness of mycorrhiza for more efficient utilization of P fertilization in sustainable production systems for this pepper variety.
Mycorrhizal colonization increased leaf number, leaf area, shoot, root and fruit mass at low P rates compared to non-VAM plants. Reproductive growth was enhanced by 450% in mycorrhizal plants at high P levels. The enhanced growth and gas exchange of mycorrhizal plants was in part due to greater uptake of P and greater extraradical hyphae development.
THIS PAPER SUPPORTS THE STATEMENT ON INCREASED FERTILIZER EFFICIENCY.

Al-Karaki, G.N. 1998. Benefit, cost and water-use efficiency of arbuscular mycorrhizal durum wheat grown under drought stress. Mycorrhiza 8:41-45.
This study determined the effects of AMF inoculation on growth, benefit/cost and water-use efficiency (grams dry matter produced per kilogram water evapotranspired) in two wheat genotypes (drought sensitive and drought tolerant) under water-stressed and well-watered conditions.
Shoot and root dry matter and root AMF colonization were higher for well watered than for water-stressed plants. The mycorrhizal plants were more water-use efficient than nonmycorrhizal plants. Shoot Dry matter differences between mycorrhizal and nonmycorrhizal plants represent the benefit derived by plants from Arbuscular mycorrhizal fungal -root associations.
The mycorrhizal plants used less water to produce one unit of shoot of Dry matter (WUE-Water Use Efficiency) than nonmycorrhizal plants, but water-stressed and well-watered plants did not differ in Water Use Efficiency. Also, these plants had higher shoot and root dry matter than non mycorrhizal plants regardless of water stress level.
AMF colonization increased total P uptake by both genotypes regardless of water-stress level. This likely occurred because mycorrhizal plants had enhanced root growth and thus a greater P absorption surface area. Enhanced growth effects on mycorrhizal plants have been attributed to improved water relations resulting from enhanced P nutrition.
The calculated benefit/cost values of Arbuscular mycorrhizal fungi on host plant dry matter were higher for wheat grown under water-stressed than under well-watered conditions.
THIS PAPER SUPPORTS THE STATEMENT ON INCREASED FERTILIZER EFFICIENCY.

Al-Karaki, G.N. and R. B. Clark. 1999. Varied rates of mycorrhizal inoculums on growth and nutrient acquisition by barley grown with drought stress. Journal of Plant Nutrition 22:1775-1784.
The objective of this research was to determine effects of varied rates of arbuscular mycorrhizal fungi (AMF) inoculums on plant growth and acquisition of phosphorus (P), zinc (Zn), copper (Cu), and manganese (Mn) by barley grown with and without drought stress. Root AMF colonization increased as inoculum rate increased in plants grown with water stress (WS) and non-water stressed (NWS). Leaf area and shoot, root dry matter, and plant contents of P, Zn, Cu and Mn increased as inoculum rate increased up to 240 spores of *Glomus mosseae* per 100 g dry soil regardless of soil moisture.
The response of barley to different rates of AMF inoculum depended on soil moisture.
THIS PAPER SUPPORTS THE STATEMENT ON INCREASED FERTILIZER EFFICIENCY.

Al-Karaki, G.N., B. McMichael and John Zak. 2004. Field response of wheat to arbuscular mycorrhizal fungi and drought stress. Mycorrhiza14:263-269.
This study was to determine the effects of arbuscular mycorrhizal (AM) fungi inoculation on growth, grain yield and mineral acquisition of two winter wheat cultivars grown in the field under well-watered and water-stressed conditions.
Water management treatments were 1) water-stressed (WS) plants grown under rainfed` conditions with 50 mm irrigation applied at planting, and 2) well-watered (WW) plants grown under rainfed conditions with irrigation scheduled to prevent symptoms of water stress. The total seasonal irrigation for the WW treatment was 408.5 mm. Therefore, the water stress treatment was equivalent to 72% less water than well water treatment.
Mycorrhizal colonization was higher in well-watered plants colonized with AM fungi than water-stressed plants. Biomass and grain yields were higher in mycorrhizal than nonmycorrhizal plots irrespective of soil moisture, and *G. eutunicatum* inoculated plants generally had higher biomass and grain yields than those colonized by G. mosseae under either soil moisture condition. The mycorrhizal plants had higher shoot P and Fe concentration than nonmycorrhizal plants at all samplings regardless of soil moisture conditions. Enhanced plant growth and yield following AM fungal inoculation was related to improved

uptake of P and Cu, especially under WS conditions. Mycorrhizal fungi may improve nutrient uptake by increasing the exploration of the soil pore space.

The improved growth, yield and nutrient uptake in wheat plants reported here demonstrate the potential of mycorrhizal inoculation to reduce the effects of drought stress on wheat grown under field conditions in semiarid areas of the world.

THIS PAPER SUPPORTS THE STATEMENT ON INCREASED FERTILIZER EFFICIENCY.

Bethlenfalvay, G.J. M.S. Brown, R.N. Ames and R.S. Thomas. 1988. Effects of drought on host and endophyte development in mycorrhizal soybeans in relation to water use and phosphate uptake. Physiologia plantarum 72:565-571.

The aim of this study was to test further the hypothesis of P as the major factor in VAM response to drought, and to determine the relationship between unavailable soil water and the response of the host plant to colonization by VAM fungi under drought stress.

They found that the dry weights of VAM plants were greater at severe stress and smaller at no stress than those of non-VAM plants. Colonization of roots by *G. mosseae* did not vary with stress, but the biomass and length of the extraradical mycelium was greater in severely stressed than in non-stressed plants. Growth enhancement of VAM plants relative to P-fertilized non-VAM plants under severe stress was attributed to increased uptake of water as well as to more efficient P uptake. The ability of VAM plants to deplete soil water to a greater extent than non-VAM plants suggests lower permanent wilting potentials for the former.

THIS PAPER SUPPORTS THE STATEMENT ON INCREASED FERTILIZER EFFICIENCY.

Brejeda, J.J., L.E. Moser and K.P. Vogel. 1998. Evaluation of Switchgrass rhizosphere microflora for enhancing seedling yield and nutrient uptake. Agron. J. 90:753-758.

Seedlings inoculated with rhizosphere microflora produced up to 15-fold greater shoot and root yields, and recovered up to 6-fold more N and 36-fold more P than seedlings inoculated with rhizosphere bacteria only. These responses were consistent for all four cultivars and were probably due to arbuscular mycorrhizal fungi. Seedlings inoculated with rhizosphere populations from seeded switchgrass stands averaged 1.5-fold greater shoot and root yields than seedlings inoculated with rhizosphere populations from native prairies. Plant growth promoting rhizosphere, AM fungi and nonmycorrhizal fungi may be responsible for the large increases in shoot and root weights and in N and P uptake following inoculation of seedlings with rhizosphere microflora.

THIS PAPER SUPPORTS THE STATEMENT ON INCREASED FERTILIZER EFFICIENCY.

Fidelibus M.W., C.A. Martin and J.C. Stutz. 2001. Geographic isolates of *Glomus* increase root growth and whole-plant transpiration of *Citrus* seedlings grown with high phosphorus. Mycorrhiza 10:231-236.

This study tested the hypothesis that growth and water-use characteristic of AM plants would differ from those of non-AM plants that were well supplied with P. They used AM fungal isolates of different geographic origins, therefore they also tested that inoculation of citrus seedlings with *Glomus* isolates from arid, semi-arid or mesic areas would result in different patterns of plant growth and water use. AM plants and non-AM plants had similar shoot size (dry weight and canopy area), but all AM fungus treatments stimulated root growth (dry weight and length). Leaf P concentration were 12-56% higher in AM plants than non-AM plants. Enhanced root growth was positively correlated with leaf P concentration. In general, AM plants had greater whole-plant transpiration than non-AM plants under well-watered conditions, under mild water stress and during recovery from moderate and severe soil drying. This suggests a faster recovery from moisture stress by AM plants. AM plants had lower leaf conductance than non-AM plants when exposed to severe soil drying. Although the greatest differences were between AM and non-AM plants, plants treated with *Glomus* isolates differed in colonization level, leaf P concentration, root length, transpiration flux and leaf conductance. Also, they suggested that *Glomus* isolates that increase root growth and whole-plant transpiration might improve the field performance if young citrus rootstock and mitigate against desiccation after soil drying by amplifying the potential for root exploration of soil for water. The mycorrhizal effects reported in this study may have been a secondary consequence of AM-enhanced host P nutrition because root growth was highly correlated with leaf P concentration.

THIS PAPER SUPPORTS THE STATEMENT ON INCREASED FERTILIZER EFFICIENCY.

Ruiz-Lozano, J.M., R. Azcon and M.Gomez. 1995. Effects of Arbuscular-Mycorrhizal Glomus

species on drought tolerance: Physiological and nutritional plant responses. Applied and Environmental Microbiology 61:456-460.
This study compared seven *Glomus* species to determine their effects on plant growth, mineral uptake, the CO2 exchange rate, water use efficiency, transpiration, stomatal conductance, photosynthetic P use efficiency, and proline accumulation under well-watered and drought stress conditions.
AM fungal species showed diverse effectiveness at increasing host plant drought tolerance. The different effects of these fungi on alleviating stress appeared to be based on physiological processes rather than nutrient uptake by the host. The protection of mycorrhizal plants against water stress was related to the effects that the endophytes had on increasing leaf conductance and transpiration as well as P and K uptake. *Glomus deserticola* was the most adapted and aggressive colonizer as well as the most effective species for increasing drought tolerance of the host plant both in terms of maintaining growth under stress conditions and in permitting more efficient use of water. Also, they observed that plant nutrient uptake was strongly influenced by the fungal symbiont involved in the association. The differences in shoot and root growth stimulation between the least effective fungal isolate (*G. occultum*) and the most effective fungal isolate (*G. deserticola*) ranged from 270% under well-watered conditions to more than 821% under drought stress conditions. They concluded that selection of AM fungi for introduction into dry environments to address specific problem situations is a promising but usually neglected strategy.
THIS PAPER SUPPORTS THE STATEMENT ON INCREASED FERTILIZER EFFICIENCY.

Subramanian, K.S., C. Charest. 1999. Acquisition of N by external hyphae of an arbuscular mycorrhizal fungus and its impact on physiological response in maize under drought-stressed and well-watered conditions. Mycorrhiza 9:69-75.
This study examined the uptake of nitrogen by external hyphae of an arbuscular mycorrhizal (AM) fungus (*Glomus intraradices*) and its impact on physiological response in maize plants subjected to well-watered or drought-stressed conditions.
Mycorrhizal colonization by *G. intraradices* improved nutritional status and N assimilation in maize plants exposed to moderate drought stress. The increased capacity for N acquisition and assimilation may enable the host plant to sustain moderate drought stress conditions. Glutamine synthetase activity in AM plants increased by 30% under drought conditions, which may be attributed to the hyphal transport of N in the form of NO3 or NH4. They also found that AM colonization conferred a higher P status under drought conditions. In summary, they suggested a positive relationship between N hyphal contribution and metabolic/nutritional status of the host plant. These changes may assist the host plant to withstand drought conditions.
THIS PAPER SUPPORTS THE STATEMENT ON INCREASED FERTILIZER EFFICIENCY.

Tobar, R. R. Azcon and J.M. Barea. 1994. Improved nitrogen uptake and transport from 15Nlabelled nitrate by external hyphae of arbuscular mycorrhizal under water-stressed conditions. New Phytologist 126:119-122.
This study determined the importance of the external mycelium of arbuscular mycorrhizal for uptake and transport of N from 15N-labeled nitrate in benefiting plant nutrition under either well-irrigated or waterstressed conditions. They found evidence that AM fungi provided transport of N from nitrate source though the hyphal network and can be important for the N-nutrition of plants in relatively dry agricultural soils where nitrate is actually the predominant nitrogen form.
THIS PAPER SUPPORTS THE STATEMENT ON INCREASED FERTILIZER EFFICIENCY.

Yano-Melo, A.M., O.J. Saggin Jr., J.M. Lima-Filho, N.F. Melo and L.C. Maia. 1999. Effect of arbuscular mycorrhizal fungi on the acclimatization of micropropagated banana plantlets. Mycorrhiza 9:119-123.
This study evaluated the effects of the inoculation of three native AM fungal species isolated from irrigated banana plantations of the Brazilian semiarid region on growth, nutrition and physiology of banana plantlets developed in vitro. After three months of acclimatization, statistically significant differences in plant height, leaf area, fresh and dry matter of shoot, and fresh weight of roots between inoculated and non-inoculated plants were recorded. Leaf area and height of inoculated plants were approximately 57% and 32% higher, respectively, than non-inoculated plants. Dry matter of shoots increased 45-64% in mycorrhizal plants. Plants inoculated with *Glomus clarum* showed an increment of around 45% in the fresh weights of shoots and roots over non-inoculated plants. Inoculation with AM fungi increased growth of micropropagated banana plantlets during acclimatization period, and this may benefit rates of photosynthesis and also nutrient transport by mass flow.

THIS PAPER SUPPORTS THE STATEMENT ON INCREASED FERTILIZER EFFICIENCY.

Jin, H., P.E. Pfeffer, D.D. Douds, E. Piotrowski, P.J. Lammers and Y. Sachar-Hill. 2005. The uptake, metabolism, transport and transfer of nitrogen in an arbuscular mycorrhizal symbiosis. New Phytologist 168:687-696.

This study determined the nitrogen path in arbuscular mycorrhizal formed by *Glomus intraradices* with carrot roots grown in vitro. They found that three weeks after supplying 15NH4 to the system the fungal synthesized predominantly the amino acid arginine (Arg). Also, it was determined that NH4 is the most likely form of N transferred to host cells following its generation from Arg breakdown. This study confirms the importance of extrametrical mycelium formed by arbuscular mycorrhizal fungi.

THIS PAPER SUPPORTS THE STATEMENT ON INCREASED FERTILIZER EFFICIENCY.

Waterer, D.R. and R.R Coltman. 1989. Response of mycorrhizal bell peppers to inoculation timing, phosphorus, and water stress. HortScience 24:688-690.

The objectives of this study were to examine the influence of inoculation timing on the development and yields of AM fungi colonized bell peppers grown with low and high sol P and water availability. They used *Glomus aggregatum* under greenhouse and filed conditions. Inoculation did not affect tissue P concentrations, growth, or yields in high P soil in either the greenhouse or field. In low P soil inoculation increased tissue P concentrations, plant weights, and fruit yields relative to non inoculated plants. Tissue P concentrations increased more rapidly after transplanting when seedlings were inoculated at seeding than when inoculation was delayed until transplanting. In the field, total fruit yields and final shoot fresh weights also were higher when transplants were inoculated before transplanting. Inoculation with AM fungi potentially could substitute for a significant portion of the P fertilizers commonly applied in pepper production.

THIS PAPER SUPPORTS THE STATEMENT ON INCREASED FERTILIZER EFFICIENCY.

Tobar, R.M., R. Azcon, J.M. Barea. 1994. The improvement of plant N acquisition from an ammonium-treated, drought-stressed soil by the fungal symbiont in arbuscular mycorrhizae. Mycorrhiza 4:105-108.

The objective of this study was to determine that mycorrhizal activity on N uptake under water-stressed conditions and effects on plant growth. They used a neutral agricultural soil and the arbuscular fungi were *Glomus mosseae* and *G. fasciculatum*. They found that under water-stressed conditions both fungal species increased the 15N enrichment of plant tissues. This indicates a direct effect of arbuscular mycorrhizal fungi on N acquisition in relatively dry soils. *G. mosseae* had more effect on N uptake than *G. fasciculatum* on P uptake under water-stressed conditions, but both fungi improved plant biomass production relative to nonmycorrhizal plants.

THIS PAPER SUPPORTS THE STATEMENT ON INCREASED FERTILIZER EFFICIENCY.

Tarafdar, J.C. and Praveen-Kumar. 1996. The role of vesicular arbuscular mycorrhizal fungi on crop, tree and grasses grown in an arid environment. Journal of Arid Environments 34:197-203.

This study evaluated the effects of different arbuscular mycorrhizal fungi on the tree *Prosopis juliflora*, the grass *Cenchrus ciliaris* and the crop *Vigna aconitifolia* under field conditions. Plants were grown in poor fertility sandy soil with low indigenous mycorrhizal fungal populations. At maturity of crop and after 1-year growth of grass and trees, their shoot biomass, N, P, K, Fe, Zn and Cu concentration were significantly improved in all cases of inoculated plants. In general, the effect was most pronounced in *Prosopis juliflora* and *Glomus fasciculatum* was the most effective under arid conditions. Their results suggested that increased uptake of nutrients by plants with arbuscular mycorrhizal fungi under filed conditions would have important implications for elemental composition of plants.

THIS PAPER SUPPORTS THE STATEMENT ON INCREASED FERTILIZER EFFICIENCY.

Subramanian, K.S., P. Santhanakrishnan, P. Balasubramanian. 2006. Responses of field grown tomato plants to arbuscular mycorrhizal fungal colonization under varying intensities of drought stress. Scientia Horticulturae 107:245-253.

The objective of this study was to examine the effects of mycorrhizal inoculation with AM fungus on the growth, reproductive behavior, water status, nutrient content, fruit yield and quality attributes of field grown tomatoes drought under stress conditions. Their 2 year- field study suggested that the inoculation with *Glomus intraradices* improves drought tolerance of tomato plants as secondary consequence of enhanced nutritional status of the host plant, especially N and P. Mycorrhizal association improved

tomato fruit quality by enhancing ascorbic acid content and reducing the acidity. Drought impact on deteriorating fruit quality can be lessened through mycorrhizal colonization. Their data revealed that AM colonization enhances nutritional status and leaf relative water content and enables the host plant to withstand varying intensities of drought stress under field conditions.
THIS PAPER SUPPORTS THE STATEMENTS ON WATER USE AND INCREASED FERTILIZER EFFICIENCY.

Runjin, L. 1989. Effects of vesicular-arbuscular mycorrhizas and phosphorus on water status and growth of apple. Journal of Plant Nutrition 12:997-1017.
The objective of this study was to determine the influence of VAM fungi on the water status, mineral uptake, and growth of the seedlings of apple and to establish the probable mechanism by which arbuscular mycorrhiza (AM) changes water relations of their host plant under ample moisture supply and water stress conditions.
The found that sterilized soil inoculated with *Glomus versiforme* and *G. macrocarpum* enhanced element uptake, improved water status, drought tolerance and growth of the plants. Colonized plants grew rapidly two months after inoculation. Phosphorus added to the soil had a negative effect on the development and function of AM. In sterilized soil, AM colonization increased the transpiration rate of the leaves, reduced the stomatal resistance and the permanent wilting as well enhanced the rate of recovery of the plant from the water stress and the plant growth. This was probably due to enhancing absorption and translocation of water by the external hyphae. It also increased absorption of most minerals, especially Zn and Cu by the roots and weakened the P-Cu and P-Zn interactions. Under natural conditions, growth, mineral nutrition, water relations are interlinked with the effects of soil microorganisms that includes AM fungi.
THIS PAPER SUPPORTS THE STATEMENTS ON WATER USE AND INCREASED FERTILIZER EFFICIENCY.

PHYTOREMEDIATION

Yu, X., J. Cheng and M.H. Wong. 2005. Earthworm-mycorrhiza interaction on Cd uptake and growth of ryegrass. Soil Biology and Biochemistry 37:195-201.
This study evaluated the importance of earthworms and arbuscular mycorrhizal fungi on the phytoremediation of soils contaminated with Cadmium (Cd). Earthworms and mycorrhizal fungi survived in all treatments with added Cd. Earthworm activity significantly increased mycorrhizal colonization rate and ryegrass shoot biomass. Mycorrhizal inoculation increased shoot and root Cd concentration significantly, and the highest dosage of Cd decreased biomass of ryegrass. Inoculation of both earthworms and mycorrhizal fungi increased ryegrass shoot Cd uptake at low Cd concentrations when compared with inoculation of earthworms or mycorrhiza alone. They concluded that earthworms, mycorrhizal fungi, and their interaction may have a potential role in elevating phytoextraction efficiency in low to medium level metal contaminated soil.
THIS PAPER SUPPORTS THE IMPORTANCE OF MYCORHIZAL FUNGI ON PHYTOREMEDIATION OF CONTAMINATED SOILS WITH CADMIUM.