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REVIEW ARTICLE

Application of mycorrhizae in sustainable date palm cultivation

Ghazi N. Al-Karaki[1,2*]

[1]*Department of Agricultural Development, Ministry of Environment and Water, P.O. Box 1509, Dubai, United Arab Emirates*
[2]*Faculty of Agriculture, Jordan University of Science and Technology, P.O. Box 3030, Irbid, Jordan*

Abstract

Date palm (*Phoenix dactylifera*) is a significant and developing crop especially in the Arabian Peninsula, the Middle East and North Africa regions. The area under cultivation of this tree is increasing annually. Date palms usually grown under harsh and unfavorable growing conditions with low rainfall and high rates of evaporation as well as in soils with low organic matter and nutrient deficiencies. Hence, date palm cultivation becomes dependent on application of high levels of fertilizers as well as on irrigation. This may lead to salinization of soil and leaching of nutrients to deep soils that might affect ground water. Therefore, it is important that date palm plantations are managed in a sustainable way to reduce the impact of date palm cultivation on ecosystems while maximizing dates yield through using such practices as mycorrhizal fungi technology. The application of mycorrhizal fungi technology is an option that can benefit both agronomic plant health and ecosystems. Mycorrhizae confer numerous benefits to host plants including improved plant growth and mineral nutrition, water uptake, tolerance to diseases and stresses such as drought, temperature fluctuation, metal toxicity and salinity. Mycorrhizae may also play a role in the formation of stable soil aggregates, building up a macro porous structure of soil that allows penetration of water and air and prevents erosion. All of these beneficial effects on plant health and soil fitness mean that mycorrhizae have the potential to increase agricultural productivity and are crucial for the sustainable functioning of agricultural ecosystems. This study provides an insight into the application of mycorrhizae in date palm cultivation.

Key words: Arabian Peninsula, Dry lands, Jordan, *Phoenix dactylifera*, Sustainable agriculture

Introduction

Date palm (*Phoenix dactylifera* L.) is grown widely in hot, dry, desert regions of the Arabian Peninsula, North Africa and the Middle East, and its fruit used as important source of nutrition. During the past three centuries, dates were introduced for cultivation in many parts of the world like India/Pakistan, South America and United States (Chao and Krueger, 2007). Date production is a world agricultural industry producing about 6.8 million metric tons of fruit (FAO 2007). Over 100 million date palm trees are currently grown worldwide on an estimated area of 1 million ha (El-Hadrami and Al-Khayri, 2012). Date palms have been used also for ornamental and landscape purposes in all Arabian Gulf countries and anywhere freezing temperatures are non-existent or of brief duration (Chao and Krueger, 2007). The area of date cultivation in the Arabian Peninsula and the Middle East has increased dramatically during the past few decades and is expected to continue to increase. In United Arab Emirates, for example, there were about 1.5 million date palms in 1971 has increased more than 27-folds to an estimated 41 million date palms in 2005 (MEW, 2005). While in Jordan, the area cultivated with date palms has increased by about 20-folds during the last 15 years (from 108 ha in 1994 to 2200 ha in 2010) (Anonymous, 2011). This expansion may put pressure on limited natural resources (land and water) because date palms are planted under harsh and unfavorable growing conditions, such as low organic matter and nutrient deficiencies in soil, coupled with low rainfall and high rates of evaporation. Therefore, date palm cultivation becomes dependent on high levels of chemicals for production (fertilizers) and for protection (pesticides) from diseases and insects, as well as on irrigation which has led to the salinization of many soils. Hence it is important that new plantations (and even established ones) of

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*Corresponding Author

Ghazi N. Al-Karaki
Department of Agricultural Development, Ministry of Environment and Water, P.O. Box 1509, Dubai, United Arab Emirates

Emails: alkarakig@yahoo.com

date palms are managed in a sustainable way to maximize yields and reduce the impacts on ecosystems. The application of mycorrhizal fungi technology is an option that can benefit both agronomic plant health and ecosystems. This paper provides an insight into how mycorrhizae application might benefit date palm cultivation through more sustainable management and the practical use of mycorrhizal technology for date palm plantations.

Arbuscular mycorrhizal fungi

Arbuscular mycorrhizal fungi (AMF) are abundant and available in almost all natural communities and can form associations with over than 80% of higher plants (Smith and Read, 1997). AMF is considered an integral component of plant communities in both natural and agricultural ecosystems (Redecker et al., 2000). The AMF confers numerous benefits to host plants including improved plant growth and mineral nutrition, tolerance to diseases and stresses such as drought, temperature fluctuation, metal toxicity and salinity (Al-Karaki, 2000; Al-Karaki et al., 2004; Borowicz, 2001). Mycorrhizal plants have more nutrient and water uptake from soil in comparison with nonmycorrhizal plants, because AMF develop an extensive network of external fungal filaments (hyphae) that act as an extension of the root absorbing area. Furthermore, AMF may play a role in the formation of stable soil aggregates, building up a macro porous structure of soil that allows penetration of water and air and prevents erosion (Jeffries et al., 2003). All of these beneficial effects on plant health and soil fitness mean that AMF are crucial for the sustainable functioning of terrestrial ecosystems. The benefits of inoculating a wide array of agronomic plant species with AMF have been documented in numerous studies including date palms (Al-Whaibi and Khalil, 1994; Bouhired et al., 1992; Jaiti et al., 2007; Al-Karaki, 2000; Al-Karaki et al., 2004).

Occurrence of mycorrhizae in date palms

Since date palm grows mainly in areas that are characterized by harsh and unfavorable growing conditions, such as in soils with low organic matter and nutrient deficiencies coupled with low rainfall and a high rates of evaporation, mycorrhizal association could be helpful for the plant survival and growth. Many reports indicated that the presence of fungi that form mycorrhizae in date palm plants and their activities which is very important to these plants. One of the earliest observations about the presence of AMF in date palm was in the Crescent desert near Baghdad (Iraq) where it seemed to contribute in the plant mineral nutrition and supply water when it takes the place of root hairs as absorbing structures (Khudairi 1969). Similar observations were recorded for date palm growing in oasis of Qassim, Saudi Arabia indicating the presence of mycorrhiza (Khaliel and Abou-Hailah, 1985). A survey of AMF diversity and date palm tree root colonization in arid areas undertaken in Southwestern Morocco found a total of ten AMF species were trapped from palm groves (Bouamri et al., 2006).

In a preliminary survey conducted in Bahrain in 2008 (Al-Karaki, unpublished data), fresh, young roots collected from around well-established date palm were found extensively colonized by AMF (Figure 1A and B). Six AMF species were identified as present in the rhizosphere soils of date palm trees: *Glomus arenarium, Glomus etunicatum, Glomus versiforme, Glomus fasciculatem, Glomus pulvinatum* and *Acaulospora longula* (Figure 2). The outcome of these observations in regard to the presence of mycorrhizae in date palm could be a general case for this important tree in other areas and hence, this association speculatively increases the tolerance of this species to harsh environments.

How mycorrhizae may benefit date palms?

Many crops could potentially benefit from mycorrhizal symbiosis, although the degree to which plant benefit from mycorrhizae might vary greatly due to variation in plant species dependency on mycorrhizae (Janos, 2007). In the case of date palm, the limited development of the root system (low densities of root hairs), along with field observations of high levels of mycorrhizal colonization, suggest that they benefit greatly from mycorrhizal relationship. It becomes especially more important under harsh climatic conditions prevailing in arid and semi-arid regions like the Arabian Peninsula. The climatic conditions of Arabia are characterized by high temperature, low rainfall, poor soil conditions in terms of nutrients and organic matter and various biotic and abiotic stresses. These conditions may result in loss of indigenous mycorrhizal fungi that reside in the top soil. The combination of poor soil and low nutrient content means that the land is less capable to support the growth of plants without the application of high amounts of fertilizer and water. Although date palms can withstand long periods of drought under high temperatures, large amounts of water are required for vigorous growth, high yield and high quality fruit (Chao and Krueger, 2007). Often, slightly saline water is used for irrigation of crops in hot and dry regions of the world. Even though

drip irrigation is often used in newer plantations, flood irrigation is still highly practiced by farmers in many countries (e.g., Arabian Peninsula), which result in high water consumption and hence high accumulation of salts in the root zone of palms. This might lead to soil degradation and may negatively affect date palm production. Palms are susceptible to nutrient deficiencies (Downer, 2004). Large amount of mineral fertilizers (e.g., N, P) is added annually to the soils in order to enhance establishment of young plantations and/or adult trees to attain high yields and good quality of dates (Barreveld, 1993). However, much of the P and N may not be taken up by plants and thus large amounts are leached down escape into the ground water. This has led to environmental concerns which require attention.

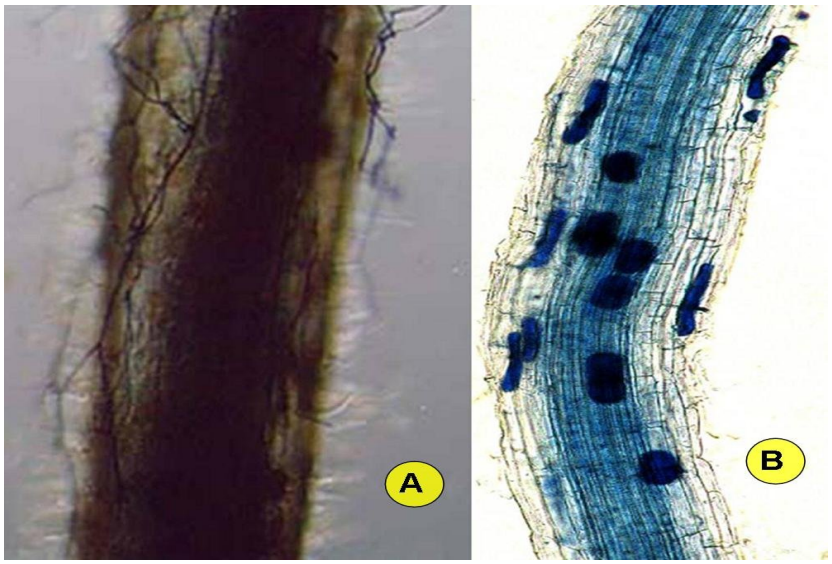

Figure 1. A: Stained root of date palm with associated soil mycelium of AMF. B: Stained root of date palm with intercellular mycelium and arbuscules of AMF.

Figure 2. AMF species found in the rhizosphere soils of a palm date in Bahrain. A: *Glomus arenarium*, B: *Glomus etunicatum*, C: *Glomus versiforme*, D: *Glomus fasciculatem* E: *Glomus pulvinatum* and F: *Acaulospora longula.*

Worldwide, there are efforts to include AMF technology into the processes of agricultural production. AMF may have the potential to make date palm cultivation more sustainable and reduce the impacts of ecosystems on their plantations. Since AMF could form an enormous hyphae network system in the rhizosphere, it could enhance the stability of soil aggregates, fix dune, and improve soil conditions physically and chemically (Bearden and Petersen, 2000). Some scientists explained the role of AMF as enhancement of establishing plants in soil by increasing the plant resistance to environmental stresses, enhance nutrient uptake and improe soil quality (Al-Karaki, 2000; Jeffries and Barea, 2000). Also, a main benefit of mycorrhiza is that the root-fungus network in the soil builds an excellent soil structure through glomalin, improving water storage as a reserve during times of no irrigation (Sieverding, 2008). Through mycorrhiza, roots are kept healthy and the soil is well structured helping plants resist short periods of water stress. In fact, AMF is considered a method for saving irrigation water through enhancing the efficient use of applied water (Sieverding, 2008).

Relatively few reports have been published on the interaction of AMF and date palm. Inoculation of date palm seedlings with AMF has been reported to enhance their growth (Bouhired et al., 1992) and increased the absorption of both P and K over uninoculated seedlings (Al-Whaibi and Khaliel, 1994). Desert soils are generally low in K, P and N where these ions are enhanced in the presence of mycorrhiza (Al-Karaki et al., 2007). In other palm species, Blal et al. (1990) reported that the utilization of P fertilizer in oil palm seedlings increased by 4–5-folds after mycorrhization. This finding is supported by results of experiments conducted by Blal and Gianinazzi-Pearson (1990) who showed that oil palm seedlings grow well and used phosphate fertilizer efficiently in the presence of AMF. In their study, AMF inoculation resulted in a 2.7–5.6 folds increase in P fertilizer use efficiency.

Organic material addition to soils been practiced in date desert areas as the soils are always lacking in organic matter. However, the uptakes of nutrients, fruit growth and yields of date palms have shown to increase when the chemical fertilizers were applied together with the organic fertilizers (Bacha and Abo-Hassan, 1983). Organic fertilizers are generally compatible with mycorrhizae, whereas phosphorus-rich inorganic fertilizers inhibit the fungi activity (Amaya-Carpio et al., 2009). Phosphate is the form of P that is directly utilized by plants which is usually added as inorganic P. The organic P is made available to plants mostly when hydrolyzed or after its mineralization into inorganic P. Hydrolysis and mineralization of organic P is mediated by the enzymatic activity of phosphatase. It has been reported that enzymatic activity of phosphatase has greatly enhanced in the roots of mycorrhizal compared to nonmycorrhizal plants (Fries et al., 1998; Tawaraya and Saito, 1994). However, studies indicated that AMF can have the ability to acquire N directly from organic sources by both enhancing decomposition of and increasing N capture from complex organic material in soil. Hyphal growth of the mycorrhizal fungi was found to increase in the presence of the organic material, independently from the host plant (Hodge et al., 2001). Therefore, AMF might be able to substitute for low fertilizer inputs in organic farming systems.

Mycorrhizal fungi as bioprotectants in date palms

Date palms are affected with many diseases and pests. Most reported diseases of date palm that can be associated with a pathogen are attributed to fungi (Zaid et al., 2002) and nematode (Eissa et al. 1998). In North Africa, bayoud disease incited by *Fusarium oxysporuym* f. sp. *Albedinis* was found as one of the most serious fungal diseases associated with date palms (Jaiti et al., 2007). The red palm weevil (*Rhynchophorus ferrugineus*) is considered as one the most important pests of date palms in the world especially in the Arabian peninsula (Abraham et al., 1998). It has been found that the chemical treatments are not efficient in controlling these diseases and pests. AMF has been demonstrated to have high biocontrol potential of plants against many pests (Quarles, 1999), especially for plant diseases caused by *Phytophtora* and *Fusarium* pathogens (Vigo et al., 2000). These observations suggest that AMF may affect plant and soil microbial activities by stimulating the production of root exudates, phytoalexins, and phenolic compounds (Morandi, 1996; Jaiti et al., 2007). Some studies indicated that existence of mycorrhiza in plant roots discourages their invasion by some pathogens by producing structures that prevent diseases from entering roots or producing antibiotics that attack diseases (Harrison, 1997). Other, more active, mechanisms are used by AMF to trap and strangle root-feeding nematodes.

Utilization of commercial AMF in date palm cultivation

Due to difficulties at the biological system (cannot be axenically cultured fungus), AMF application in agriculture are not possible until recently, when certain companies have totally or partially achieved a procedure for production of AMF inoculants commercially. However, AMF utilization on a commercial scale in Arabian Peninsula is still very limited because of inappropriate information regarding the advantages of mycorrhiza and of their incompatibility with the application of high rates of fertilizers and pesticides. Therefore, to promote utilization of AMF inoculants, it is important to determine beforehand the optimal conditions compatible with their utilization. BioMyc International Corporation (BioMyc) has registered in UAE as the first company in the region produces a range of commercial AMF inoculants (German BioMyc™ Vital) in a granular form using expanded clay as carrier, well adapted to be used in nursery and field, in different systems of plant production. To promote utilization of these inoculants, BioMyc has set up a wide range of experiments in cooperation with some technical centers in the region [e.g., International Center for Biosaline Agriculture (ICBA)/UAE, and Jordan University of Science and Technology, Jordan] to determine the potential of AMF application in enhancing the survival and development of nursery seedlings and hence the success of plantations under field conditions. The utilization of the commercial inoculant BioMyc in the nursery permits overcoming many problems such as low survival and low growth rate to ensure a better rate of success in plant production and guaranty plant survival along with more growth when transplanting into field. Albers (2009) found that inoculation of tissue-cultured seedlings of date palms with a commercial mycorrhizae inoculum (German BioMyc™ Vital) resulted in larger shoots and roots over that uninoculated seedlings (Figure 3).

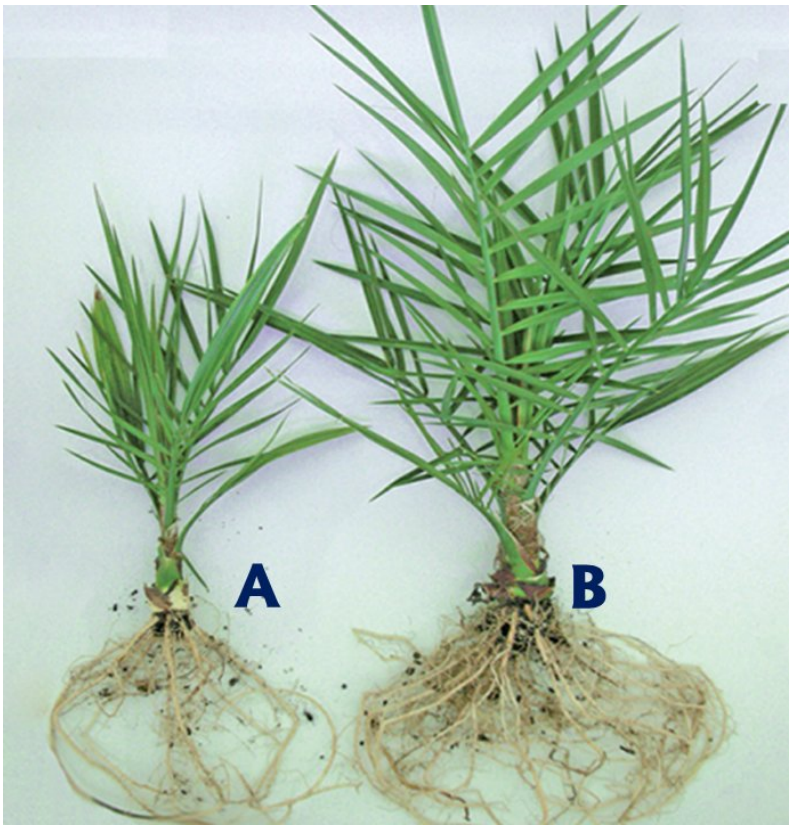

Figure 3. Date palm seedlings inoculated (B) or uninoculated (A) with a commercial mycorrhizae inoculum (German BioMyc™ Vital, Germany).
(Albers, 2009).

Table 1. Plant height and trunk diameter of date palm seedlings as affected by AMF inoculation after 60 days of transplanting.

AMF status	Plant height (cm)	Trunk diameter (mm)
AMF inoculated	30	31
Uninoculated	23	24
Significance	**	**

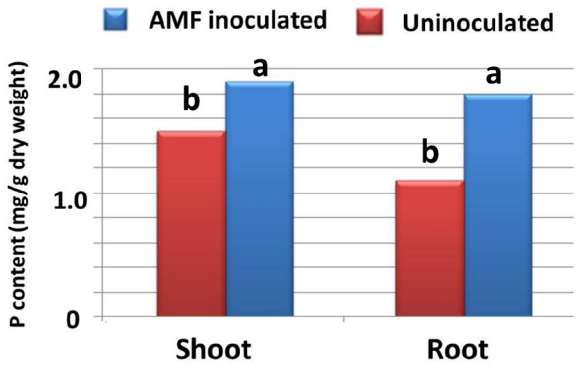

Figure 4. P content of roots and shoots of date palm seedlings after 6 months of AMF treatment. Columns with different letters within a plant organ are statistically different at P = 0.05.

An experiment has been conducted at ICBA to determine the potential effects of inoculation with commercial AMF (German BioMyc™ Vital) on the establishment and growth of date palms at various salinity and fertility levels (Shabbir et al., 2011). Results of this study indicated that growth of plants given low fertilizer rates was higher than plants fertilized with full fertilizer rates over salinity and mycorrhizae levels. However, seedlings inoculated with AMF could grow better than nonmycorrhizal seedlings under saline conditions. Another experiment conducted at Jordan University of Science and Technology (G. Al-Karaki, unpublished data), aimed to study the effects of AMF inoculation (German BioMyc™ Vital) on growth and nutrients uptake of date palm (cv. Mekfazy). A 10x10 cm planting hole was made in the center of the planting pot (20 L plastic pots), putting mycorrhizal inoculum at the bottom of the planting hole and covered with a thin layer of soil. Seedlings were then transplanted exactly at the top of inoculum, to ensure quick root colonization with mycorrhizae. Results revealed that AMF inoculated plants had higher plant height (30 cm) and trunk diameter (31 mm) than uninoculated plants (23 cm and 24 mm, respectively) (Table 1). Bouhired et al. (1992) reported that inoculation with AMF enhanced the growth of date palm seedlings. Moreover, it was found that P content in both roots and shoots of date palm seedlings increased significantly in seedlings inoculated by AMF over those not inoculated, 60 days after transplanting (Figure 4, unpublished data). Thus introducing mycorrhizal inoculum into date palm farming is considered a potentially positive feature in the development of this important tree.

Interaction of AMF and agricultural practices

Agricultural practices such as fertilizer and biocide applications, soil tillage, cropping with a non-host plant species and crop rotation have been reported to affect the potential of AMF for root colonization and hence plant growth. For example, mycorrhizal efficiency in enhancing plants have been found to be too slowed down or inhibited under high levels of P fertilization (Ezawa et al., 2000). Moreover, mycorrhizal development in subsequent crop has been found to be delayed with cropping of a soil with a non-host plant species (e.g. canola) (Gavito and Miller, 1998). Higher soil infectivity with mycorrhizae was reported under no or reduced tillage (Mozafer et al., 2000). Plant dependency on AMF was found to vary considerably from one crop to another which consequently affects the crop requirements of fertilization (Plenchette et al., 1983). For example, under field conditions, leek has a much higher mycorrhizal dependency than wheat. Therefore, plant response to AMF has to be considered when managing a cropping system. The presence of AMF in date palm plants with high root colonization indicate that date palm highly benefit from relationship with this fungi (Bouamri et al., 2006).

Application of AMF in nurseries and plantations establishment

Under normal nursery conditions, young plants do not develop the beneficial mycorrhizal symbiosis. Likewise, when they are planted out into desert soils, their roots may not be colonized with mycorrhizal fungi, and they will grow more slowly, have lower survival rates and lower yields, while needing more water and fertilizer to survive. The introducing of mycorrhizal fungi technology to these plants at early stages of their lives might reverse these problems, resulting in higher plant

establishment, better growth and yields, with complementary reductions in water and fertilizer use (Sieverding, 2008).

In the last three decades, there has been an increasingly high demand in several countries for good quality cultivars of date palm trees. This demand has encouraged use of tissue culture to produce large number of transplants (Awad, 2008). In spite of the great potential of tissue culture techniques for plants, there are great reductions in survival rates (e.g. 40%) of produced plants of some cultivars when planted under field conditions (Zaid and de Wet, 1999). Under these conditions, inoculation with AMF has been considered as an important factor in enhancement of establishment and survival of date plants. However, so far most of the work on AMF effects on date palm has been concentrated on the potential of AMF to improve date palm growth. Schultz (2001) working on oil palm reported that the survival rate of *post vitro* growth ranged between 83-100% after 3 months of *in vitro* inoculation with AMF. While in the non-inoculated plants, only 55% of plants has survived this critical growth stage during the measured experimental period. From the economic perspective, AMF enhancement effects on survival rate and growth of date palms could lead to enormous savings in investment in the nursery (Schultz, 2001). Schultz (2001) also showed that AMF inoculation has positive effects on palm growth (shoot and root), development and plant nutrition (N, P contents). Given the high costs in terms of loss of nursery plants as well as high mortality and slow growth at out planting, experiments are needed to accurately address the saving potential made by AMF inoculation in date palms. Therefore, efficiency of commercial AMF application in date palm nurseries should be evaluated, not only for beneficial growth effects, but also for water-fertilizer comprehensive system designed for date palm production under field conditions.

Application of AMF in established date palm plantations

When mycorrhizae are applied to mature trees grown in the field, benefits of mycorrhizal inoculation become much less apparent, especially when palm trees were heavily fertilized (Al-Karaki personnel observation). This might be attributed to the inhibition of mycorrhizal infection to growing roots by high fertilizer level especially P (Amaya-Carpio et al., 2009). However, as the P levels drop with root absorption as the plant grows, AMF from the surrounding soil will begin to colonize and develop in the growing root system thus negating the need for inoculum. The benefits of AMF application under field conditions with adult trees are clearly less effective to achieve than in the nursery situation with young plants.

Conclusions

There are continuous debates about whether mycorrhizal inoculation has a real potential to improve date palm plantations and especially if growers continue using high levels of fertilizers and pesticides. Nevertheless, the fact that date palm is very responsive to mycorrhizal inoculation. There is a clear rationale for mycorrhizal technology use in the nursery. This is especially important with tissue cultured date palms due to the great benefits of enhancing the health, survivorship and establishment when out planted under challenging environmental conditions. This is coupled with the enormous potential reduction in the overall costs due to avoiding high mortality of tissue cultured plants in addition to complementary reductions in fertilizer and water use.

References

Abraham, V. A., M. A. Al-Shuaibi, J. R. F. Aleiro, R. A. Abuzuhairah and P. S. Idyasagar. 1998. An integrated management approach for red date palm weevil, *Rhynchophorus ferrugineus* Oliv., a key pest of date palm in Middle East. Sultan Qabus Univ. J. Sci. Res. Agric. Sci. 3:77-84.

Albers, V. 2011. Date palm development. Joint Venture Business Plan. www.Biomyc.com.

Al-Karaki, G. N. 2000. Growth of mycorrhizal tomato and mineral acquisition under salt stress. Mycorrhiza 10:51-54.

Al-Karaki, G. N., B. McMichael and J. Zak. 2004. Field response of wheat to arbuscular mycorrhizal fungi and drought stress. Mycorrhiza 14:263-269.

Al-Karaki, G. N., Y. Othman and A. Al-Ajmi. 2007. Effects of mycorrhizal fungi inoculation on landscape turf establishment under Arabian Gulf region conditions. Arab Gulf J. Sci. Res. 25(3):147-152.

Al-Whaibi, M. H. and A. S. Khaliel. 1994. The effect of Mg on Ca, K and P content of date palm seedlings under mycorrhizal and non-mycorrhizai conditions. Mycosci. 35:213-217.

Amaya-Carpio, L., F. T. Davies, Jr., T. Fox and C. He. 2009. Arbuscular mycorrhizal fungi and

organic fertilizer influence photosynthesis, root phosphatase activity, nutrition, and growth of *Ipomoea carnea* ssp. *Fistulosa*. Photosynthetica 47:1-10.

Anonymous. 2011. Date palms in Jordan. In 19 June 2011. http://jo.qalbjo.com/vb/showthread.php?p=199767

Awad, M. A. 2008. Promotive effects of a 5-aminolevulinic acid-based fertilizer on growth of tissue culture-derived date palm plants (*Phoenix dactylifera* L.) during acclimatization. Sci. Hor. 118:48-52.

Bacha, M. and A. A. Abo-Hassan. 1983. Effects of soil fertilization on yield, fruit quality and mineral content of Khudairi date palm variety. Proc. 1st Symposium on the date palm in Saudi Arabia. pp. 174-179. Al-Hassa, Saudi Arabia.

Barreveld, W. H. 1993. Date palm products. Agricultural services Bull. No. 101, p. 216. FAO, Rome, Italy.

Bearden, B. N. and L. Petersen. 2000. Influence of arbuscular mycorrhizal fungi on soil structure and aggregate stability of a vertisol. Plant Soil 218:173-183.

Blal, B., C. Morel, V. Gianinazzi-Pearson, J. C. Fardeau and S. Gianinazzi. 1990. Influence of vesicular-arbuscular mycorrhizae on phosphate fertilizer efficiency in two tropical acid soils planted with micropropagated oil palm (*Elaeis guineensis* Jacq.). Biol. Fert. Soils 9:43–48.

Blal, B. and V. Gianinazzi-Pearson. 1990. Interest of endomycorrhizae for the production of micropropagated oil palm clones. Agric. Ecosys. Env. 29:39–43.

Borowicz, V. A. 2001. Do arbuscular mycorrhiza fungi alter plant–pathogen relations? Ecology 82:3057–3068.

Bouamri, R., Y. Dalpe, M. N. Serrhini and A. Bennani. 2006. Arbuscular mycorrhizal fungi Species associated with rhizosphere of *Phoenix dactylifera* L. (date palm) in Morocco. Afr. J. Biotech. 5(6):510-516.

Bouhired, L., S. Gianinazzi and V. Gianinazzi-Pearson. 1992. Influence of endomycorrhizal inoculation on the growth of *Phoenix dactylifera*. In: Micropropagation, root regeneration and mycorrhizas. Joint meeting between Cost 87 and Cost 8.10, Dijon, France; 53.

Chao, C. C. T. and R. R. Krueger. 2007. The date palm: Overview of biology, uses and cultivation. Hort Sci. 42(5):1077-1082.

Downer, J. 2004. Palm tree management. Part I: Selecting the right palms. Landscape Notes 18(4):4.

Eissa, M. F. M, M. A. El-Sharief, M. M. Abdel-Gawad, A. E. Ismail and W. M. A. El-Nagdi, 1998. Histological response of susceptible andresistant date-palm cultivars to Meloidogyne incognita infection. Pak. Nematol. 16:103-109.

El Hadrami, A. and J. M. Al-Khayri. 2012. Socioeconomic and traditional importance of date palm. Emir. J. Food Agric. 24:371-385.

Ezawa, T., K.Yamamoto and S. Yoshida. 2000. Species composition and spore density of indigenous vesicular-arbuscular mycorrhizal fungi under different conditions of P-fertility asrevealed by soybean trap culture. Soil Sci. Plant Nutr. 46:291-297.

FAO. 2007. Agro-Statistics Database. http://faostat.fao.org/site/339/default.aspx

Fries, L. L. M., R. S. Pacovsky, G. R. Safir and J. Kaminski. 1998. Phosphorus effect on phosphatase activity in endomycorrhizal maize. Physiol. Plant. 103:162-171.

Gavito, M. E. and M. Miller. 1998. Changes in mycorrhiza development in maize induced by crop management practices. Plant Soil 198:185-192.

Harrison, M. J. 1997. The arbuscular mycorrhizal symbiosis. In: G. Stancey and N. T. Keen (Eds.), pp. 1-34. Plant-Microbe Interactions, Vol. 3. Chapman and Hall, New York.

Hodge, A., C. D. Campbell and A. H. Fitter. 2001. An arbuscular mycorrhizal fungus accelerates decomposition and acquires nitrogen directly from organic material. Nature 413(6853):297-299.

Jaiti, F. A., A. Meddich and I. El Hadrami. 2007. Effectiveness of arbuscular mycorrhizal fungi in the protection of date palm (*Phoenix dactylifera* L.) against bayoud disease. Physiol. Mol. Plant Pathol. 71:166-173.

Janos, D. P. 2007. Plant responsiveness to mycorrhizas differs from dependence upon mycorrhizas. Mycorrhiza 17:75–91.

Jeffries, P. and J. M. Barea. 2000. Arbuscular mycorrhiza—a key component of sustainable plant–soil ecosystems. In: B. Hock (Ed.), pp. 95–113. The Mycota, Vol. IX. Fungal Associations. Springer-Verlag, The Netherlands.

Jeffries, P., S. Gianinazzi, S. Perotto, K. Turnauand J. M. Barea. 2003. The contribution of arbuscular mycorrhizal fungi in sustainable maintenance of plant health and soil fertility. Biol. Fertil. Soil. 37:1–16.

Khaliel, A. S. and A. N. Abou-Hailah. 1985. Formation of vesicular-arbuscular mycorrhiza in *Phoenix dactylifera* L. cultivated in Qassim region, Saudi Arabia. Pak. J. Bot. 17:267-270.

Khudairi, A. K. 1969. Mycorrhiza in Desert Soils. BioSci. 19(7):598-599.

Ministry of Environment and Water (MEW). 2005. Yearly Agricultural Statistics. Dubai United Arab Emirates.

Morandi, D. 1996. Occurrence of phytoalexins and phenolic compounds in endomycorrhizal interactions, and their potential role in biological control. Plant Soil 185:241-251.

Mozafar, A., T. Anken, R. Ruh, and E. Frossard. 2000. Tillage intensity, mycorrhizal and non mycorrhizal fungi, and nutrient concentrations in maize, wheat, and canola. Agron. J. 92:1117-1124.

Plenchette, C., J. A. Fortin and V. Furlan. 1983. Growth responses of several plant species to mycorrhizae in a soil of moderate P-fertility. I. Mycorrhizal dependency under field conditions. Plant Soil 110:199-209.

Quarles, W. 1999. Plant disease biocontrol and VAM fungi. IPM Pract. 21:1-9.

Shabbir, G., A. J. Dakheel, G. Brown, M. C. Rillig. 2011. Potential of arbuscular mycorrhizal technology in date palm production. In: S. M. Jain, J. M. Al-Khayri and D. V. Johnson (Eds.), pp. 449-476. Date Palm Biotechnology, Springer, Dordrecht.

Schultz, C. 2001. Effect of (vesicular-) arbuscular mycorrhiza on survival and post vitro development of micropropagated oil palms (*Elaeis guineensis* Jacq.). Ph.D. thesis. Universität Göttingen, Germany.

Sieverding, E. 2008. Mycorrhizae and water management in crops, lawn and turf. Landscape 8:14-16.

Smith, S. E. and D. J. Read. 1997. Mycorrhizal Symbiosis. Academic Press, London.

Stribley, D. P., P. B. Tinker and R. C. Snellgrove. 1980. Effect of vesicular arbuscular mycorrhizal fungi on the relations of plant growth, internal phosphorus concentration and soil phosphate analyses. J. Soil Sci. 31:655–672.

Tawaraya, L. and M. Saito. 1994. Effect of vesicular-arbuscular mycorrhizal infection on amino acid composition in roots of onion and white clover. Soil Sci. Plant Nutr. 40:339-343.

Vigo, C., J. R. Norman and J. E. Hooker. 2000. Biocontrol of the pathogen *Phytophthora parasitica* by arbuscular mycorrhizal fungi is a consequence of effects on infection loci. Plant Path. 49:509-514.

Zaid, A. and P. F. deWet. 1999. Date palm propagation. In: A. Zaid and E. J. Arias (Eds.), pp. 74-106. Date Palm Cultivation. FAO Plant Production and Protection Paper No. 156.

Zaid, A., P. F. deWet and A. Oihabi. 2002. Diseases and pests of date palm. In: A. Zaid (Ed.). pp. 227-281. Date palm cultivation. FAO paper No. 156, Rome, Italy.