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# Desert Plants and Mycorrhizae (A mini-review)

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**In natural ecosystems, roots of most plants have mycorrhizae as a major part of the rhizosphere. Although desert ecosystems are characterized by low density of vegetation cover, mycorrhizae are common as a necessity for the existence of the ecosystem. This mini-review includes sample reports of the last decades of the past century up till now reporting the presence of fungi in soils in most world deserts, presumably mycorrhizae. Moreover, the physiological role and the suggested role in the establishment of plants in disturbed land of these mycorrhizae have been explored. The overall summary is that desert ecosystems are not different from other ecosystem in the presence of mycorrhizae. These mycorrhizae might affect nutrient acquisition such as P, N, Fe, Zn, K and others. They also increase plant adaptation to drought and some other stresses.**

**Keywords**: Desert, Arid and Semi-arid lands, Mycorrhizae, Water relations, Nutrients, Drought.

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Desert (semi- and arid lands) covers about 40% of land surface.[1] This land stretches in areas of high pressure around the longitude 30º north and south of the Equator. Desert land is characterized by little precipitation (about 245 mm), hence a limited moisture, and high temperature at day time at least part of the year, and moreover high incidence of light are prevailing. In many areas of the desert, the soil is sandy and poor in organic nutrients and subjected to erosion due to unexpected rainy storms that are sometimes, accompanied by high wind velocity[2].

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These environmental as well as other biotic factors are reflected on the scattered vegetation type dominating in deserts. Succulent plants, where some have the crassulation acid metabolism pathway (CAM), but $C_4$ plants pathway are more common, do exist in desert ecosystem. On the other hand, annuals flourish in the desert when water supply is adequate. Due to the sparse coverage of vegetation, heat radiates quickly at night creating large differences in temperature between day and night[3].

Fungi forming mycorrhizal relationship with plants are a special group of the kingdom Fungi where this relationship is supposed to be symbiotic. This group can be classified into several types, but the arbiscular form [Arbuscular mycorrhizal fungi,(AMF)] forms 80% of this group. These fungi were classified in the order Glomales of Zygomycota, but in more recent classification, they were classified as a different Phylum Glomeromycota[4]. The Phylum contained four orders with 8 families and 10 Genera[5].

After that two Genera were included[6]. Historically, the name of this group of fungi was endomycorrhizae that has been changed into vesicular-arbuscular mycorrhizae (VAM), then arbuscular mycorrhizae (AM), but many scientists prefer the name arbuscular mycorrhizal fungi (AMF)[7]. This nomenclature will be followed in this text.

Fungi are principle component of the flora of rhizosphere in natural ecosystems,[8] but as a group, they are influenced by biotic- and abiotic factors.[9] The diversification of AMF depends on the ecosystem itself, [10] agricultural practices and soil environment (e.g. disturbance), the density of spores, length of mycelia, the number of species and other factors[11]. As mentioned in a previous review,[12] the plant response to mycorhizal fungi is different, and possibly weak or transient response by the plant, so that it allows the association. This association starts with the recognition of the partner, and for more details about the start and recognition see specific references.[13-14] As for the diversity of fungi associated with plant root, it was reported that 49 species of fungi were isolated and identified from the roots of one grass *Arrhenatherum elatius* only.[15] In samples of soil supporting wheat plant, 40 kinds of spores were found , of which 28 kinds belonging to the genus *Glomus*[16]. In general, it was estimated that 90% of higher plants form some mycorrhizal association,[17] but as mentioned about 80% form AMF. This review deals with what has been published about the presence and association of mycorrhizae with desert plants mainly the Arabian Desert that is part of the largest area of land deserts (i.e. Sahara). This review is not a comprehensive to all works published in this subject, but relevant papers about mycorrhizae presence in other desert areas are mentioned. Most of these papers are descriptive but molecular studies are also mentioned when relevant.

**Occurrence and diversity of Mycorrhizae in deserts and desert plants**

Observations of scientists as well as papers before 1968 about soil fungi, mainly mycorrhizae of desert plants have been reviewed.[18] Many reports indicated the presence of fungi that form mycorrhizae in desert plants and their activities which is very important to these plant. The role of these fungi in desert ecosystem, logically should be the same as in other ecosystems, but the difference is the mosaic and harsh environment of desert ecosystem. Now it is known that most families of desert plants form mutual association with fungi[19].

One of the earliest observations about the presence of AMF in some grown plants such as date palm (*Phoenix dactylifera* L.) and "Nabg" plant (*Zizyphus spina-christi* Willd) in the Crescent Desert near Baghdad (Iraq) has been reported, where it seemed to contribute in the plant mineral nutrition.[20] The report also mentioned the presence of AMF in some desert plants, with the most common plant *Peganum harmala* L. that flourish in summer months. Another report mentioned the presence of root nodules (Bacteria) on some wild leguminous desert plants such as *Alhagi maurorum* Medic. and *Prosopis stephaniana* Wild.[21], so the general conclusion of these tow reports was that all those microorganisms contribute in recycling the nutrients and help locating the water for these plants during the summer season, but the experimental evidence is lacking. Similar observation for date palm growing in oasis of Qassim area of Saudi Arabia was published indicating the presence of mycorrhizae.[22] The outcome of these observations in regard to the presence of mycorrhizae in date palm could be a general case for this fruiting tree in other areas and hence, this association speculatively increases the tolerance of this species to continental and harsh environment.

Mycorrhizae could facilitate nutrient uptake in sand dune and play a key role in sand stabilization[23]. In Arabian Desert and in two sites near Riyadh, S.A. analysis of soil and roots of dominant plants such as *Anisosciadium lanatum*, *Horwoodia dicksoniae*, *Tripleurospermum auriculatum*, *Anthemis deserti*, *Rhazya stricta* and *Panicum turgidum*, showed the presence of AMF belonging to tow species, *Glomus fasciculatum* and *G. mosseeae*[24]. It was observed that the second fungus species, i.e. *G. mosseeae* was dominant in sand dunes near Riyadh, due probably to the alkalinity of the soil. This is in accordance with what have been reported about the preference of soil by the species of the mycorrhizae[25]. A survey of fungi present in the soil of some areas in the northeast of Saudi Arabia where truffles are native, indicated the isolation of 34 species of fungi that belong to 20 genera[26]. Most species were isolated from soil underneath or around the truffle ascocarps. The survey indicated the isolation of 30 species of fungi from the soil under the truffle fruit of *Tirmania nivea* and 24 species from the soil of *Terfezia boudieri*. For comparative view and due to the suspected connection of the truffle with *Helianthemum* species, 24 fungal species were isolated from the soil of *Helianthemum lippi*, while only 14 species of fungi were found in soil without vegetation.

In the great desert of north Africa "Sahara" and in four site in Algeria, one report mentioned the presence of mutualistic relationship between fungi and 20 plant species (*Quercus illex, Pinus halepensis, Pinus maritima, Juniperus phoenica, Cedrus atlantica, Peganum harmala* and *Globularia alypum*) as ectomycorrhizae and other species or genus (*Stipa tenacissima, Rosmarinus Tournefortii, Helianthemum Lippii, Tamarix* sp., *Eryobotria japonica, Casuarina equisetifolia, Herniaria Fontanesii, Noaea mucronata* and *Pistacia lentiscus*) as endomycorrhizae, while in *Eucalyptus* genus both types were found[27].

There is a group of hypogenous truffles of the genera *Picoa*, *Terfezia* and *Tirmania*, (collectively called desert truffles) that are mainly endemic to semiarid areas around the Mediterranean sea.[28] This group have mutualistic connection with some species of the family Cistaceae, mainly with the genus *Helianthemum*[29,30]. In general, some researchers argued that plants and the associated fungi have a principle role in such areas and may limit soil erosion and hence desertification.[31] However, Some other scientists declared that some published studies about the mycorrhizal state of desert truffles with *Helianthemum* species are doubtful as a result of their critiques in their publication with their final conclusion that reliable documentation of the anatomy of mycorrhizae was rare[29]. Studies of molecular phylogeny of mycorhizal desert truffle for host specificity might support these doubt.[32] One of these studies of the molecular phonology stated clearly that these fungi (desert truffles) were difficult to identify at the species level and the use of morphological features was problematic. In this study of phylogeny, the sequence analysis with distance and parsimony methods indicated a close generic relationship between *Tirmania* and *Terfezia*. Both genera developed the hypogenous habit as an adaptation to heat and drought prevailing in the ecosystem[32].

Temporal and spatial dynamics of AMF under the canopy of *Zygophyllum dumosum* Boiss. in the Negev Desert in Siena peninsula (a stretch of Sahara in Asia) has been published[33]. The study indicated another factor in the diversity of fungi. Following the presence of mycorrhizae under the canopy of that plant seasonally, there were a variations in the density of spores where the highest were in November and December months as the moisture of the soil was high and coupled with more soluble total nitrogen. The authors believed that the spore density and how many mycorrhizal associations were present could be used as an indicator for evaluating changes in soil ecology of desert ecosystem. However, an earlier study used three cycles of successive trap culture of soil within the desert plant *Prosopis glandulosa* var. *glandulosa* Torr. growing in Sonora and Chihuahua deserts of Arizona (USA), where the spore density at the beginning was in the range of what is normally published[34]. After three cycles of culturing, the number of spores has increased whith 75% of the total spores was not detected in the first cycle. This result suggested that a high percentage of AMF in arid habitat might be nonsporulating, a conclusion that reduces the importance of using the spore density as an indicator of changes in soil ecology of desert ecosystem.

Pande and colleagues reported that AMF associated with most of the plants is common in the arid soil of Thar Desert of India[35]. In support of this generalization, a more newer work with some medicinal plant in the same desert, where these plants were believed to be endangered of extinction, it was reported a richness of AMF[2]. This work also reported that spore density was not dependent on species, but positively with the pH of the soil and negatively with organic content of the soil. The types of AMF association and mycorrhizal population in the rhizosphere of Marwar Teak [*Tecomella undulata* (Smith) Seeman] in the arid zone of Rajasthan, India was investigated[36]. All soil samples contained the spores of *Glomus*, *Gigaspora* and *Sclerocystis*, but the most dominant fungus was *Glomus faciculatum*. In Cholistan desert of Pakistan, it was reported that mycorrhizae were found in 11 species of grasses that are very important for grazing.[37] The dominant species of fungi harboring these plants belong to the genus *Glomus* where the highest percentage were found in the roots of the grass *Panicum antidotale*.

In Junggar desert basin of the northwest of China, five common and typical of desert communities [*Eremopyrum orientale* (L.) Jaub. et Spach., *Gagea sacculifera* Regel., *Plantago minuta* Pall, *Tragopogon kasahstanicus* S. Nikit and *Trigonella arcuata* C. A.] were found to have AMF.[38] This study reported the isolation and identification of 54 species of fungi from the soil belonging to the genera *Acaulospora, Archaeospora, Entrophospora, Glomus and Paraglomus*, but the dominant species was *Glomus*. In addition, the study added that the proportion of root length colonized by the fungus was from 2 to 85% and the density of spores was from 1 to 120 spores per 20 ml soil.

Twelve species of fungi that form mycorrhizae were isolated and identified from soil and roots of plants in three arid areas of southern Namibia[39]. The dominant spore type was of *Glomus aggregatum*, and it appeared that the species composition of fungi could be influenced by geographic distance of the study area, rather than land utilization. This study indicated, on the other hand, that mycorrhization varied with different land utilization regimes. A survey study of the plants of Gurbantunggut desert in Xinjiang in China indicated that after examining the root of 23 of annual and perennial plant species for mycorrhizal colonization, it was found that 61% of plants form mycorrhizal association, but 4 plant species did not form[40]. This survey identified 14 genera with *Glomus* as the most dominant followed by *Acaulospora* then the genus *Archaeospora*.

Earlier study of Baja desert in California USA indicated the association of AMF with eight endemic plants.[41] A survey of 38 species belonging to 19 families of perennial plants in four sites of the State Park in Anza-Borrego desert in southern California was conducted.[25] The survey results were that all have mycorrhizal association by six species of fungi. The survey also, indicated that the distribution of fungi was not random but there was an interaction with soil factors prevailing in this desert. It was found that the perennial plants have bigger roots and more dense mycorrhizae in Chihuahua desert than annual plants[42].

Seasonal dynamic of AMF community in four sites in southeastern Arizona along the side of San Pedro river and their colonization of the tall grass *Sporobolus wrightii* was studied.[43] The study revealed the presence of 15 species of 5 genera namely *Glomus*, *Acaulospora*, *Paraglomus* and *Archaeospora*; and their association was coordinated with the growth/ reproductive stages; the highest association in all the three site was from February till May which is the vegetative stage and the lowest was in September till December, the stage of reproduction.

The assessment of the roots of 15 plant species (in spring and autumn) from one site, and 19 plant species (in autumn only) in Mojave desert for AMF colonization were performed during the tow seasons[44]. The result was that the level of AMF hyphae decreased in dry year from spring to autumn in most species but a few increased. The results of this study also indicated that perennial plant showed mycorrhizal association whereas the annual plants showed low level of AMF hyphae or without association during the seasons of tow years. The mycorrhizal inoculation potential (MIP) was assessed in the soil where all samples have the potential, but the values of MIP were not correlated with AMF colonization. Supporting these findings, are the results of another study in the *Larrea tridentata-Ambrosia dumosa* community where AMF varied with varied precipitation and the season[45].

Most of these studies examining the seasonality collected the samples in no more than four times per year, hence consecutive seasonal patterns were not clear enough. In another community of a grass site in southwest China, the seasonality was investigated monthly over one year.[46] It was reported that AMF colonization fluctuated significantly throughout the year and their seasonal patterns were different in each species. Moreover the results showed that AMF colonization correlated significantly with environmental factors such as rainfall, sunlight hours, soil phosphorus content, etc.

Another interesting area of research in arid land is the disturbed soil due to mining or other activities. It was tackled in the red desert of Wyoming state where some species from Zygophyllaceae were dominant in natural soil and formed association with mycorrhizae but on disturbed soil they did not[47].

Some Plants growing in Simpson Desert of Australia seemed to beadapted to sever drought in poor soil[48]. A survey of these plants (52 species) for AMF association indicated that 73% of these plants formed mycorrhizal association. The survey also, indicated that there were tow species of the family Chenopodiaceae (*Salsola kali* L and *Sclerolaena diacantha* (Nees.) Benth), that formed an association, finding that contradicted the common believe that members of this family did not have mycorrhizal association[48].

**Role of mycorrhizae**

Since AMF could form an enormous hypha network system in the rhizosphere, it could enhance the stability of soil aggregates, fix dune, and improve soil conditions physically and chemically.[49] Some scientists explained the role of AMF as enhancement of establishing plants in soil by increasing the plant resistance to environmental stresses, enhancement of nutrients uptake and improving soil quality.[50, 51] On the other hand, others viewed the importance of AMF participation in the re-establishment of endangered species in desertified areas in arid land.[52] However, it was clearly indicated by other studies that microorganisms including fungi (i.e. AMF) have the potential of enhancing the plant growth through facilitating the absorption of water and some nutrients, increasing the yield of the plant and changing the expression of chemicals directed to plant defense[53,54,55].

**Establishment studies**

Due to drought and misuse of natural habitats in the past few decades, desertification especially in coastal regions of west Africa (Senegal and other neighboring countries) has been announced, although, the phenomenon of desertification, as seen by some scientists [56] is very difficult to evaluate as there is no reference situation to compare with to reach real values of desertification. Studies of re-establishing these areas by plants that were tolerant to prevailing natural environment (such as nutrient deficiency and pathogens) were active in spite of the lack of reference situation. There were some efforts to re-establish the natural habitat in these areas[57].

One of the selected genera for establishment was the genus *Acacia*, where the relationship between the tow fungi, *Scleroderma dictyosporum* and *Pisolithus* sp. and the tow species of plants, *Acacia mangium,* Willd and *Acacia holosericea*, A. Cunn. ex G. Don. was investigated. The results of this study indicated that mycorrhizae increased the formation of root nodules and decreased the community of parasitic nematodes especially *Hoplolaimus pararobustus* with the plant *A. holosericea*.[57] Another important trial for establishment of *Acacia* in the desert of pre-Sahara Savanna, where the plant is subjected to extinction due to drought, seed pest invasion and over-exploitation by humans for wood and fodder, was the use of compost (of *Acacia cyanophylla* leaves) as surface fertilizer to increase AFM of *Acacia tortilis* ssp. *raddiana* in its natural habitat.[58] The results showed an increase in mycelia production which could be an indication that this approach might be one way of improving the survival of planted seedlings in arid regions.

There were some attempts to restore the woody vegetation in their natural habitats in the northern Mediterranean that have been destroyed by clearing the plots for agriculture then abandonment of fields, fire and overgrazing[59]. These attempts were limited because the transferred seedling did not form deep roots rapidly after planting.[60] In an attempt to modify the root morphology in the nursery to increase the ability of roots to capture and transport water efficiently, tow treatments of *Pistacia lentiscus* L. seedlings were examined. These treatments were inoculation with AMF and subjecting the seedling to drought periods[61]. The results indicated the potentiality of this treatment but the researchers doubted that this will achieve the final goal of restoration of plants in their natural habitat (Lesvos, Greece and Valencia, Spain).

In the arid and semiarid land of Sonora desert of Baja peninsula in California, mycorrhizae were used to study their role in the establishment of cactus seedlings (*Pachycereus* *pringlei*) under the canopy of the plant *Prosopis articulata*.[62] in disturbed soil. The result reported that AMF inoculum potential appeared not to be the main factor in the establishment.

Earlier, Allsopp and Stock[63] suggested that the establishment of plants with small seeds such as those of grasses may strongly depends on AMF association, but that was questioned by a new study [64] in the Chihuahua Desert as the pioneer species of grasses were independent on mycorrhizae and if associated with AMF, the interaction showed a negative responsiveness for their seedlings stage. However, few AMF were found to be associated with the roots of the dominant $C_4$ perennial grass *Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths in semiarid land of New Mexico, but the abundance of endophytic fungi group called dark septated fungi (DSF), reported also in this study could be the one responsible for the establishment[65].

**Physiological role**

From the studies of the role of mycorrhizae in the establishment, it could be seen that the establishment was aided by AMF by increasing the efficiency with which the soil volume was exploited by host seedlings, and this could inhibit other non-mycorrhizal seedlings[66]. In general, AMF enhanced nutrient uptake for both native and cultivated species[17].

Assimilates, on the other hand, has been reported to flow from mature plant (source) to the seedlings (sink) growing in the vicinity of mycorrhizal network of mature plant, where the heavily shaded seedling accumulated up to six times more labeled carbon (fed to mature plant) than that accumulated by the half shaded seedlings[67]. It could be concluded that transport of assimilates might reduce the asymmetrical competition and increase seedlings survival. In another study of transporting labeled phosphorus from the mature plant to its seedlings, the results indicated that this transport could not be predicted on the bases of proximity to mature plant, neither on the size nor taxon. Moreover, the pattern of transport could be different in a mixture of established plants, growth form and phenology[68]. In general, the competitive interactions among seedlings of native plants and the invasive ones and among plants of different size still in need for further studies[66].

Spore germination of AMF (*Glomus epigaeus*) was reported to be enhanced by charcoal as it could remove the inhibitory substances from the spore coat[69]. Another study of the initial stages of mycorrhizae formation between *Helianthemum sessliflorum* (Defs.) Pers. and *Terfezia leonis* Tul. using charcoal in agar medium reasoned the enhancement of spore germination by charcoal to the adsorption of nutrients by charcoal, so the only continuous source of nutrients was the roots, creating a constant gradient of nutrients that attracted the growth of the fungus towards the roots[70].

Mycorrhizal association between fungi and plants enhanced the uptake of nutrients such as phosphorus[71], water, nitrogen, magnesium and iron[72] by the host plant. Reviewing older literature, the AMF were reported to help plants in uptake of P, N, Zn, K, Cu, Sr, S and other minerals[73]. AMF also, participated in improving the tolerance of acidity, salinity, heavy metal toxicity and resistance to drought.[72] They also, ameliorated the composition of the soil, by dissolving soil nutrients to be available for absorption.[74] In a more recent study on the role of three local AMF communities and the host benefit (mineral acquisition) in tow sites in Kalahari-desert in Botswana, it was reported that all the three communities increased significantly the size of the seedlings of the indigenous tree *Vangueria infausta* Burch. and the highest level of AMF was in the soil with intermediate P concentration.[75] The results also, indicated that tow communities response was highest in their soils of origin, and the presence of AMF lead to a significant depletion of P from the soil, while these communities differed in their potential of enhancement of P, Ca and N uptake. The overall conclusion of this studies was that the significant interaction between AMF communities and soil type in terms of Ca and N concentration in the shoot- indicated a local adaptation of fungal species.

Under drought stress, six species of AMF (*Gigaspora margarita*, *Glomus constrictum*, *G. fasciculatum*, *G. mosseae*, *Sclerocystis rubiformis* and *Scutellospora calospora*) increased the accumulation of amino acids, protein, chlorophyll and sugar content in *Ziziphus mauritiana* Lam. compared with non mycorrhizal plants, hence, this plant depended on AMF under drought conditions[76]. Earlier, it was reported that under repeated drought exposure, AMF participated in pepper plant tolerance and extra radical hyphae development regardless the plant size and nutrient content[77].

Studying the nutrition status, water acquisition and gas exchange of three desert succulent plant, namely *Agave deserti* Engelm., *Ferocactus acanthodes* (Lem.) Britton and Rose and *Opuntia ficus-indica* (L.) Miller under growth chamber conditions and inoculation by AMF isolated from field was reported[78]. The results showed an increase of P content in roots and P and Zn in the shoot and an increase in some other parameters such as hydraulic connectivity of roots, daily uptake of $CO_2$. The conclusion of this study was that AMF increased water and nutrient uptake in arid land of these three species. In support of this conclusion, the results of another study of the mycorrhizal associations with some plant species in a soil strip of different successional stages in Egypt[79]. It was found in this study that the increase in mycorrhizal colonization resulting in an increased content of chlorophyll, soluble sugars, and protein significantly and improved the water status of most studied plant species.

Exploring the partitioning of nutrients between root and shoot as affected by AMF, it was reported that P content of both roots and shoot of date palm seedlings (*Phoenix dactylifera* L. cv. Khedhri) increased significantly in the seedlings inoculated by AMF (*Glomus deserticola* Trappe, Bioss & Menge) regardless the other treatment by Mg[80].

Drought stress effect on the growth, water relations and mineral nutrition of the mycorrhizal association *Helianthemum almeriense*-*Terfezia claveryi* under the growth chamber conditions was reported.[81] The study results indicated that after subjecting the plants to drought conditions (sustaining the matric potential of the soil at -0.5 MPa) there were no effect of drought on the level of mycorrhizal colonization of the host plant. The results also, indicated that the rate of survival of inoculated plants was higher compared to the non mycorrhizal association. The water potential was 26% higher under drought and 14% under irrigation regime. Moreover, the net photosynthesis, transpiration and stomatal conductance were higher in inoculated plants compared to the plants that were not inoculated. The same trend of nutrient content (N, P and K) was found in this study. These findings suggested that AMF could participate in plant adaptation to arid climates. These results were within the notion that AMF can affect the water balance of the host plant, a general conclusion drawn by reviewing the water relations, drought and AMF.[82] One study investigating seasonally dynamics of AMF for tow desert shrub species, *Larrea tridentata* and *Ambrosia dumosa* reported that AMF varied seasonally, and drought negatively affects AMF root colonization[83].

A laboratory experiment of the effect of NaCl-salinity on the growth of one of AMF namely *Cenococcum graniforme* (Sow.) Ferd. in Mclin Narkrans liquid medium was reported.[84] The results showed that the highest tolerance of the fungus reached 11 gm of NaCl/L, and the growth stopped at 13 $gm.L^{-1}$. The level of NaCl in most saline soils in arid regions is generally, less than 6-8 $gm.L^{-1}$.

## CONCLUSIONS

By reviewing the published observations and research papers dealing with AMF and desert ecosystem, it could be concluded that AMF-Plant association do exist in desert ecosystem like other ecosystems although annual plants do not have this association, possibly due to their short life. AMF colonization of desert plants needs more experimental work for the descriptive observation of the relationship reviewed so far here.

AMF could enhance the stability of soil aggregates, fix dune, and improve soil conditions physically and chemically. There is some evidence of the importance of AMF participation in the re-establishment of plant species in desertified areas in arid land. This participation could be through increasing the plant resistance to environmental stresses and enhancing plant acquisition of water and nutrients.

## REFERENCES

1. Deichmann, U., Eklundh, L., Global Digital Datasets for Land Degradation Studies: A GIS Approach. GRID Case Study Series 1991; 4.

2. Panwar, J. and Tarafdar, J.C., Distribution of three endangered medicinal plant species and their colonization with arbuscular mycorrhizal fungi. *Journal of Arid Environments* 2006; **65**: 337-350.
3. Raven, P.H., Evert, R.F. and Eichhorn, S.E., *Biology of plants* 6th. E. W.H. Freeman and company, Worth Publishers. New York 1999.
4. Schüßler, A., Schwarzott, D. and Walker, C., A new fungal phylum, the Glomeromycota: phylogeny and evolution. *Mycological Research* 2001; **105**: 1413–1421.
5. Walker, C. and Schüßler, A., Nomenclatural clarifications and new taxa in the Glomeromycota. *Mycological Research* 2004; **108**: 981-982.
6. Sieverding, E. and Oehl, F., Revision of Entrophospora and description of *Kuklospora* and *Intraspora*, two new genera in the arbuscular mycorrhizal Glomeromycetes. *Journal of Applied Botany and Food Quality* 2006; **80**: 69-81.
7. Bharadwaj, D.P., The Plant–Arbuscular Mycorrhizal Fungi–Bacteria–Pathogen System: Multifunctional Role of AMF Spore-Associated Bacteria. Doctor's dissertation. Swedish University of Agricultural Sciences, Uppsala 2007, ISBN 978-91-576-7389-3, ISSN 1652-6880; 2007.
8. Peterson, R.I., Ashford, A.E., Allaway, W.G., Vesicular arbuscular mycorrhizal associations of vascular plants on Heron Island, a Great Barrier Reef coral cay. *Australian Journal of Botany* 1985; **33**: 669-676.
9. Mohammad, M.J., Hamad, S.R., Malkawi, H.I., Population of arbuscular mycorrhizal fungi in semi-arid environment of Jordan as influenced by biotic and abiotic factors. *Journal of Arid Environments* 2003; **53**: 409-417.
10. Helgason, T., Daniell, T., Husband, R., Fitter, A.H. and Young, J., Ploughing up the wood-wide web ? *Nature* 1998; **394**: 431.
11. Dodd, J.C., The role of arbuscular mycorrhizal fungi in agro-and natural ecosystems. *Out look on Agriculture* 2000; **29**: 55-62.
12. Al-Whaibi, M.H., Phytoalexins. *Saudi Biol. J.* **14**(1): 1-12 (a mini review, In Arabic) 2007.
13. Gianinazzi-Pearson, V., Dumas-Gaudot, E., Gollotte, A., Tahiri-Alaoui, A., and Gianinaui, S., Cellular and molecular defence-related root responses to invasion by arbuscular mycorrhizal fungi. *New Phytol*. 1996; **133**: 45-57.
14. Lambais, M.R., Ríos-Ruiz, W.F. and Andrade, R.M., Antioxidant responses in bean (*Phaseolus vulgris*) roots colonized by arbuscular mycorrhizal fungi. *New Phytologist* 2003; **160**: 421-428.
15. Van den koornhuyse, P., Baldauf, S.L., Leyval, C., Straczek, J., Young, J.P.W., Evolution: Extensive Fungal Diversity in Plant Roots. *Science* 2002; **295**: 2051.
16. Ghazala Nasim, R.B., Glomalean spores associated with major cereals I-wheat. *Caderno de Pesquisa Sér. Bio., Santa Cruz do Sul*, 2005; **17**(1): 137-1540.
17. Brundrett, M.C., Mycorrhizas in natural ecosystems. *Advances in Ecological Research,* 1991; **21**: 171-313.
18. Went, F.W. and Stark, N., The Biological and mechanichal role of soil fungi. *PROC. N.A.S*. 1968; **60**: 497-504.
19. Trappe, J.M., Mycorrhizae and productivity of arid and semiarid rangelands. In: Manassah, J.M., Briskey, E.J. (Eds.), Advances in Food-Producing Systems for Arid and Semiarid Lands. Academic Press, New York, 1981; 581-600.
20. Khudairi, A.K., Mycorrhiza in Desert Soils. *BioScience*, 1969; **19**(7): 598-599.
21. Khudairi, A.K., Root nodule bacteria of *Prosopis stephaniana. Science* 1957; **1925**: 399.
22. Khaleil, A.S. and Abu-Heilah, A.N, Formation of vesicular-arbuscular mycorrhizae in *Phoenix dactylifera.*L., cultivated in Qassim region Saudi Arabia. *Pak. J. Bot*. 1985; **17**: 267-270.
23. Koske, R.E., and Gemma, J.N., Mycorrhizae and succession in plantings of beach grass in sand dunes. *American Journal of Botany,* 1997; **84**: 118-130.
24. Khaleil, A.S., Mycorrhizal status of some desert plants and correlation with edaphic factors. *Trans. Mycol. Soc. Japan*, 1989; **30**: 231-237.
25. Bethlenfalvay, G.J., Dakessian, S., Pacovsky, R.S., Mycorrhizae in a southern California desert: ecological implications. *Canadian Journal of Botany* 1984; **62**: 519-524.
26. Bokhary, H.A. and Parvez, S., Soil mycoflora from trufflè native areas of Saudi Arabia. *Mycopathologia* 1992; **118**(2):103-107.
27. Mejstík, V.K. and Cudlín, P., Mycorrhiza in some plant desert species in Algeria. *Plant and Soil* 1983; **71**: 363-366.
28. Moreno, G., Díez, J. and Manjón, J.L., *Terfezia boudieri*, first records from Europe of a rare vernal hypogeous mycorrhizal fungus *Persoonia* 2002; **17**: 637-641.
29. Kovacs, G.M., Vagvolgyi, C. and Oberwinkler, F., In *Vitro* Interaction of the Truffle *Terfezia terfezioides* with Robinia pseudoacacia and *Helianthemum ovatum*. *Folia Microbiol*. 2003; **48**(3): 369-378.
30. Fortas, Z. and Chevalier, G., Effet des conditions de culture sur la mycorhization de l'*Helianthemum guttatum* par trois espèces de terfez des genres *Terfezia* et *Tirmania* d'Algérie *Can J Bot* 1992; **70**: 2453-2460.
31. Honrubia, M., Cano, A. and Molina-Niñirola, C., Hypogeous fungi from Southern Spanish semi-arid lands *Persoonia* 1992; **14**:647-653.
32. Díez, J., Manjón, J.L. and Martin, F., Molecular phylogeny of the mycorrhizal desert truffles (Terfezia and Tirmania), host specificity and edaphic tolerance. *Mycologia* 2002; **94**(2): 247-259.

33. He, X., Mouratov, S, and Steinberger. Y., Temporal and spatial dynamics of vesicular-arbuscular mycorrhizal fungi under the canopy of *Zygophyllum dumosum* Boiss. in the Negev Desert. *Journal of Arid Environments* 2002; **52**: 379-387.
34. Stutz, J.C., and Morton, J.B., Successive pot cultures reveal high species richness of arbuscular endomycorrhizal fungi in arid ecosystems. *Canadian Journal of Botany* 1996; **74**: 1883-1889.
35. Pande, M., Tarafdar, J.C., Gupta, G.N., Vesicular arbuscular mycorrhizal infection in arid zone trees of agroforestry systems. *Journal of Indian Society of Soil Science* 1999; **47**: 54-57.
36. Mohan, V. and Mishra, R.N., Studies on Vam association in Marwar Teak (*Tecomella undulata* (smith) Seeman) in siols of Rajasthan. *Mycorrhiza-News*, 1998; **10**(1): 16-18.
37. Chaudhry, M.S., Nasim, F.H. and Khan, A.G., Mycorrhizas in the perennial grasses od Cholistan desert, Pakistan. *Internat. J. Bot*., 2006; **2**(2): 210-218.
38. Shi, Z.Y., Zhang, L.Y., Li, X.L., Feng, G., Tian, C.Y. and Christie, P., Diversity of arbuscular mycorrhizal fungi associated with desert ephemerals in plant communities of Junggar Basin, northwest China. *Applied Soil Ecology* 2007; **35**: 10-20.
39. Uhlmann, E., Gorke, C., Petersen, A. and Oberwinkler, F., Arbuscular mycorrhizae from arid parts of Namibia. *Journal of Arid Environments* 2006; **64**: 221–237.
40. Tian Changyan, Shi Zhaoyong, Chen Zhichao and Feng Gu., Arbuscular mycorrhizal associations in the Gurbantunggut desert. Arbuscular mycorrhizal associations in the Gurbantunggut Desert.*Chinese Science Bulletin*.. 2006; **51**: 140-146.
41. Rose S.L., Vesicular-arbuscular mycorrhizal associations of some desert plants of Baja California. *Canadian Journal of Botany*. 1981; **59**: 1056-1060.
42. Collier, S.C. Yarnes, C.T., Herman, R.P., Mycorrhizal dependency of Chihuahuan Desert plants is influenced by life history strategy and root morphology. *Journal of Arid Environments* 2003; **55**: 223-229.
43. Kennedy, L.J., Tiller, R.L. and Stutz, J.C., Associations between arbuscular mycorrhizal fungi and *Sporobolus wrightii* in riparian habitats in arid South-western North America. *Journal of Arid Environments* 2002; **50**: 459-475.
44. Titus, J.H., Titus, P.J., Nowak, R.S. and Smith, S.D., Arbuscular mycorrhizae of Mojave desert plants. *Western North American Naturalist*, 2002; **62**(3): 327-334.
45. Apple, M.E., Thee, C.I., Smith-Longozo, V.L., Cogar, C.R., Wells, C.E. and Nowak, R.S., Arbuscular mycorrhizal colonization of Larrea tridentata and Ambrosia dumosa roots varies with precipitation and season in the Mojave Desert. *SYMBIOSIS* 39:xx–xx. ISSN 0334-5114. 2005.
46. Li, L., Yang, A. and Zhao, Z., Seasonality of arbuscular mycorrhizal symbiosis and dark septate endophytes in a grassland site in southwest China. *FEMS Microbiology Ecology*, 2005; **54**: 367–373
47. Miller, R.M., Some occurrences of vesicular–arbuscular mycorrhiza in natural and disturbed ecosystems of the Red Desert. *Canadian Journal of Botany*, 1979; **57**: 619-623.
48. O'Connor, P.J., Smith, S.E. and Smith, F.A., Arbuscular mycorrhizal associations in the southern Simpson Desert. *Australian Journal of Botany* 2001; **49**(4): 493-499.
49. Bearden, B.N. and Petersen, L., Influence of arbuscular mycorrhizal fungi on soil structure and aggregate stability of a vertisol. *Plant Soi*l 2000; **218**: 173-183.
50. Schreiner, R.P., Mihara, K.L., McDaniel, H., Bethlenfalvay, G.J., Mycorrhizal fungi influence plant and soil functions and interactions. *Plant Soil* 1997; **188**: 199-209.
51. Jeffries, P., Barea, J.M., Arbuscular mycorrhiza-A key component of sustainable plant–soil ecosystems. In: Hock, B. (Ed.), The Mycota. IX Fungal Associations. Springer–Verlag, Berlin, 2001; 95-113.
52. Panwar, J., Vyas, A., AM fungi: a biological approach towards conservation of endangered plants in Thar Desert, India. *Current Science* 2002; **82**: 576-578.
53. Bultman, T., Bell, G., Interaction between fungal endophytes and environmental stressors influences plant resistance to insects. *Oikos* 2003; **103**: 182-190.
54. Hildebrandt, U., Schmelzer, E., Bothe, H., Expression of nitrate transporter genes in tomato colonized by an arbuscular mycorrhizal fungus. *Physiologia Plantarum* 2002; 115, 125.
55. Mucciarelli, M., Scannerini, S., Bertea, C., Maffei, M., In vitro and in vivo peppermint (Mentha piperita) growth promotion by nonmycorrhizal fungal colonization. *New Phytologist* 2003; **158**: 579-591.
56. Veron, S.R., Paruelo, J.M. and Oesterheld, M., Assessing desertiûcation. *Journal of Arid Environments* 2006; **66**: 751-763.
57. Founoune, H., Duponnois, R. and Ba, A.M., Ectomycorrhization of *Acacia mangium,* Willd. and *Acacia holosericea*, A. Cunn. ex G. Don in Senegal. Impact on plant growth, populations of indigenous symbiotic microorganisms and plant parasitic nematodes. *Journal of Arid Environments* 2002; **50**: 325-332.
58. Labidi, S., Nasr, H., Zouaghi, M. and Wallander, H., Effects of compost addition on extra-radical growth of arbuscular mycorrhizal fungi in *Acacia tortilis* ssp. *raddiana* savanna in a pre-Saharan area. *Applied Soil Ecology* 2007; **35**: 184-192.
59. Brandt, C.J., Thornes, J., *Mediterranean*

*Desertification and Land Use*. Wiley, London 1996.

60. Vallejo, V.R., Serrasolses, I., Cortina, J., Seva, J.P., Valdecantos, A., Vilagrosa, A., Restoration strategies and actions in Mediterranean degraded lands. In: Enne, G., Zanolla, C., Peter, D. (Eds.), Desertification in Europe: Mitigation Strategies and Land-Use Planning. European Commission, Luxembourg, 2000; 221-233.
61. Green, J.J., Baddeley, J.A., Cortina, J. and Watson, C.A., Root development in the Mediterranean shrub *Pistacia lentiscus* as affected by nursery treatments. *Journal of Arid Environments* 2005; **61**: 1-12.
62. Bashan, Y., Davis, E.A., Carrillo-Garcia, A., and Linderman, R.G., Assessment of VA mycorrhizal inoculum potential in relation to the establishment of cactus seedlings under mesquite nurse-trees in the Sonoran Desert. *Applied Soil Ecology* 2000; **14**: 165-175.
63. Allsopp, N., Stock, W.D., Mycorrhizas, seed size and seedling establishment in a low nutrient environment. In: Read, D.J., Lewis, D.H., Fitter, A.H., Alexander, I.J. (eds), Mycorrhizas in ecosystems. Cab International, Wallingford, 1992; 59-64.
64. Pezzani, F., Montana, C. and Guevara, R., Associations between arbuscular mycorrhizal fungi and grasses in the successional context of a two-phase mosaic in the Chihuahuan Desert. *Mycorrhiza*, 2006; **16**: 285-295.
65. Porras-Alfaro, A., Herrera, J., Sinsabaugh, R. L. and Natvig, D. O., Effect of long-term nitrogen fertilization on mycorrhizal fungi associated with a dominant grass in a semiarid grassland. *Plant Soil.* 2007; **296**: 65-75.
66. Goodwin, J., The role of mycorrhizal fungi in competitive interactions among native bunchgrasses and alien weeds: A review and synthesis. *Northwest Science*, 1992; **66**(4): 251-260.
67. Francis, R. and Read, D.J., Direct transfer of carbon between plants connected by vesicular-arbuscular mycorrhizal mycelium. *Nature* 1984; **307**: 53-56.
68. Chiariello, N., Hickmann, J.C. and Mooney, H.A., Endomycorrhizal role for interspcific transfer of phosphorus in a community of annual plants. *Science*, 1982; **21**: 941-943.
69. Daniels, B.A. and Trappe, J.M., Factores affecting spore germination of the vesicular-arbuscular mycorrhizal fungus, *Glomus epigaeus*. *Mycologia*, 1980; **72**: 457-470.
70. Roth-Bejerano, N., Livine, D. and Kagan-zur, V., *Helianthemum* - *Terfezia* relations in different growth media. *New Phytol*., 1990; **114**: 235-238.
71. Titus, J.H., Leps, J.,, The response of arbuscular mycorrhizae to fertilization, mowing, and removal of dominant species in a diverse oligotrophic wet meadow. *American Journal of Botany* 2000; **87**: 392-401.
72. Barea, J.M., Jeffries, P., Arbuscular mycorrhzae in sustainable soil–plant systems. In: Varma, A., Hock, B. (Eds.), Mycorrhiza-Structure, Function, *Molecular Biology and Biotechnology*. Springer, Berlin, 1995; 875.
73. Powel, C.L. and Bagyaraj, D.J., VA mycorrhizae. CRC Press. Florida; USA. 1984; 121.
74. Berthelin, J., Leyval, C., Laheurte, F., De-Giudici, P., Involvement of roots and Involvement of roots and rhizosphere microflora in the chemical weathering of soil minerals. In: Atkinson, D. (Ed.), Plant Root Growth, An Ecological Perspective. British Ecological Society Special Publication, London, 1991; 547.
75. Bohrera, G., Kagan-Zurb, V., Roth-Bejeranoc, N., Wardd, D. Beckc, G. and Bonifacioe, E., Effects of different Kalahari-desert VA mycorrhizal communities on mineral acquisition and depletion from the soil by host plants. *Journal of Arid Environments* 2003; **55**: 193-208.
76. Mathur, N. and Vyas, A., Influence of arbuscular mycorrhizae on biomass production, nutrient uptake and physiological changes in *Ziziphus mauritiana* Lam. under water stress. 2000. *Journal of Arid Environments*, 2000 **45**: 191-195.
77. Davies, E.T., Potter, J.R. and Linderman, R.G., Mycorrhiza and repeated drought exposure affect drought resistance and extra radical hyphae development of pepper plants independent of plant size and nutrient content. *Journal of Plant Physiology*, 1992; **139**: 289-294.
78. Cui, M. and Nobel P.S., Nutrient status, water uptake and gas exchange for three desert succulents infected with mycorrhizal fungi. *New Phytol* 1992; **122**: 643-649
79. Ramadan, T. and Omar, S.A., Mycorrhizal associations with some plant species in a soil strip of different successional stages in Egypt. *Journal of Plant Nutrition,* 2000; **23**(8): 1153-1166.
80. Al-Whaibi, M.H. and Khaleil, A.S., The effect of Mg on Ca, K and P content of date palm seedlings under mycorrhizal and non-mycorrhizal condtions. *Mycoscience* 1994; **35**: 213-217.
81. Morte, A., Lovisolo, C. and Schubert, A., Effect of drought stress on growth and water relations of the mycorrhizal association *Helianthemum almeriense-Terfezia claveryi*. *Mycorrhiza*, 2000; **10**(3): 115-119.
82. Auge, R.M.,, Water relation, drought and vesicular-arbuscular mycorrhizal symbiosis. *Mycorrhiza*, 2001; **11**: 3-42.
83. Clark, N.M., Rillig, M.C and Nowak, R.S., Arbuscular mycorrhizal fungal abundance in the Mojave Desert: Seasonal dynamics and impacts of elevated CO2. *Journal of Arid Environments*, 2009; **73**: 834-843.
84. Saleh-Rastin, N., Salt tolerance of the mycorrhizal fungus *Cenococcum graniforme* (Sow.) Ferd. *Forest Pathology* 1976; **6**(3): 184-187.