

Mycorrhizae in Agriculture and in Resource Islands in the Sonoran Desert

Gabor J. Bethlenfalvai¹ and Yoav Bashan²

¹U.S. Department of Agriculture, Agricultural Research Service, Corvallis, Oregon (emeritus)
Present address: 255 Hermosa Way, San Luis Obispo, California 93405, bethleng@charter.net

²MicrobiologPa Ambiental, Centro de Investigaciones Biológicas del Noroeste, La Paz, Baja California Sur, Mexico

Arbuscular-mycorrhizal fungi (AM) are commonly associated with plants in arid and semiarid regions (Stutz et al., 2000), where soils generally have high AM fungal diversity (Stutz and Morton, 1996). Under harsh conditions, such as in deserts, failure to form AM associations is a leading cause of plant failure (St. John, 2000). Attention has therefore focused mainly on plant responses to AM fungi in the past (Bethlenfalvai, 1992). With the progressive conversion of natural plant communities to disturbed ones, however, it is becoming ever more important to understand the mechanisms that operate in the entire plant-soil system, since this knowledge may be the key to the proper management or restoration of the environment (Warren et al., 1996).

The main factors that contribute to the fragility of arid lands are limiting water, nutrient, and temperature conditions (Nobel, 1996). Their effects are well known, while the contributions of factors that may stabilize the system, like soil microbes are little known, although their role in plant-community structure has been recognized (Callaway, 1995). Some members of plant communities can modify their harsh habitats by a process called habitat engineering (Jones et al., 1997), and by doing so, facilitate the establishment of other plants (nurslings). Associations of leguminous trees and desert succulents are an example of such nurse plant-nursling relationships whose effects include some influence over soil temperatures, nutrients, and soil water contents under the nurse plant's canopy (Callaway, 1995).

These zones around some perennial plants within the reach of their roots and branches, where the harsh conditions of the surrounding desert are less limiting, are called resource islands (Carrillo-Garcia et al., 1999, 2000). The islands themselves are shallow mounds formed when wind speed drops within the dense canopy of a plant, depositing windborne dust (Armbrust and Bilbro, 1997). The deposition is then stabilized and the resulting fine-textured soil of low bulk density, high water-holding capacity, stable aggregate structure and high nutrient levels becomes a habitat that supports communities of soil organisms (Aguilera et al., 1999).

While all members of such communities probably play an important role in nature's design, AM fungi are well known to alleviate stress in limiting environments (Sylvia and Williams, 1992). They are especially important for soil stabilization since their mycelia represent a dominant component of soil microbial biomass (Miller and Jastrow, 1995): their soil hyphae link and enmesh particles into stable aggregates (Miller and Jastrow, 1999; Wright and Upadhyaya, 1998). The hyphae also interconnect the roots of adjacent plants, facilitating an exchange of nutrients between them and with the soil (Schreiner et al., 1997). AM fungi are therefore an essential component of plant-soil systems of arid and semiarid lands (Bethlenfalvai et al., 1984; Cui and Nobel, 1992).

Changes in the soil habitat are not engineered by the plant alone; they are the result of concerted action by the canopy and of the AM root system. The establishment of an AM-hyphal network enhances not only plant development but results in soil-building interactions between the biotic and abiotic components of the soil (Bethlenfalvai and Schüepp, 1994). The dense mats of AM mycelia that enmesh the soil particles of resource islands may be a key to an aggregating

and stabilizing process (Miller & Jastrow 1999), counteracting erosion by increased soil deposition (Coppinger et al. 1991).

In arid ecosystems characterized by plant microhabitats centered on nurse plants, an early integration of mycotrophic seedlings into the community through a pre-established common AM mycelium may increase their survival rate, while nonmycotrophic plants would benefit from the improved growth conditions provided by the resource islands (Bashan et al. 2000) The profusion of AM mycelia often found in the top layers of resource-island soils suggests that they contribute to the binding of windborne soil particles that settle under plant canopies. Thus, they form a link in an autocatalytic cycle of plant-soil interrelationships: the fungi improve plant growth through enhanced nutrient uptake, the more vigorous plant intercepts more windborne soil, this soil is bound by the mycorrhiza into a growing mound, and the mound provides more nutrients to the plant and a growth substrate for the fungus, thus closing the cycle. Much further work is needed to integrate the role of AM fungi with the plant-soil system in deserts.

Aguilera L.O., J.R. Gutierrez and P.L. Meserve. 1999. Variation in soil micro-organisms and nutrients underneath and outside the canopy of *Adesmia bedwellii* shrubs in arid coastal Chile following drought and above average rainfall. *Journal of Arid Environments* 42:61-70.

Armbrust D.V. and J.D. Bilbro. 1997. Relating plant canopy characteristics to soil transport capacity by wind. *Agronomy Journal* 89:157-162.

Bashan Y., E.A. Davis, A. Carrillo-Garcia and R.G. Linderman. 2000. 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* 14:165-176.

Bethlenfalvay G.J., S. Dakessian and R.S. Pacovsky. 1984. Mycorrhizae in a southern California desert: ecological implications. *Canadian Journal of Botany* 62:519-524.

Bethlenfalvay G.J. 1992. Mycorrhizae in crop productivity. In: Bethlenfalvay G.J. and Linderman R.G. Eds. *Mycorrhizae in sustainable agriculture*. Special Publication No. 54, American Society of Agronomy, Madison, Wisconsin, 1-27.

Bethlenfalvay G.J. and H. Schüepp. 1994. Arbuscular mycorrhizas and agrosystem stability. In: Gianinazzi S. and Schüepp H. Eds. *Impact of arbuscular mycorrhizas on sustainable agriculture and natural ecosystems*. Birkhäuser Verlag, Basel, 117-131.

Callaway R.M. 1995. Positive interactions between plants. *Botanical Review* 61:306-349.

Carrillo-Garcia Á., J.L. León de la Luz, Y. Bashan and G.J. Bethlenfalvay. 1999. Nurse plants, mycorrhizae, and plant establishment in a disturbed area of the Sonoran Desert. *Restoration Ecology* 7:321-335.

Carrillo-Garcia Á., Y. Bashan and G.J. Bethlenfalvay. 2000. Resource-island soils and the survival of the giant cactus, cardon, of Baja California Sur. *Plant and Soil* 218:207-214.

Coppinger K.D., W.A. Reiners I.C. Burke and R.K. Olson. 1991. Net erosion on a sagebrush steppe landscape as determined by Cesium-137 distribution. *Soil Science Society of America Journal* 55:254-258.

Cui M. and P.S. Nobel. 1992. Nutrient status, water uptake and gas exchange for three desert succulents infected with mycorrhizal fungi. *New Phytologist* 122:643-649.

Jones C.G., J.H. Lawton and M. Shachak. 1997. Positive and negative effects of organisms as physical ecosystem engineers. *Ecology* 78:1946-1957.

Miller R.M. and J.D. Jastrow. 1999. Mycorrhizal fungi influence soil structure. In: Kapulnik Y. and Douds D.D. Eds. *Arbuscular mycorrhizae: Molecular biology and physiology*. Kluwer Academic Press.

Miller R.M., D.R. Reinhardt and J.D. Jastrow. 1995. External hyphal production of vesicular-arbuscular mycorrhizal fungi in pasture and tallgrass prairie communities. *Oecologia* 103:17-23.

Miller R.M. and J.D. Jastrow. 1999. Mycorrhizal fungi influence soil structure. In: Kapulnik Y. and Doude D.D. Eds. *Arbuscular mycorrhizae: Molecular biology and physiology*. Kluwer Academic Press.

Nobel P.S. 1996. Ecophysiology of roots of desert plants, with special emphasis on agaves and cacti. In: Waisel Y., Eshel A. and Kafkafi U., Eds. *Plant roots, the hidden half*. 2nd Edition, Marcel Dekker, Inc. New York.

Schreiner R.P., K.L. Mihara H. McDaniel and G.J. Bethlenfalvay. 1997. Mycorrhizal fungi influence plant and soil functions and interactions. *Plant and Soil* 188:199-209.

St. John T. 2000. Mycorrhizae on the job: the experience of experts. *Land and Water*, September-October:49-52.

Stutz J.C. and J.B. Morton. 1996. Successive pot cultures reveal high species richness of arbuscular endomycorrhizal fungi in arid ecosystems. *Canadian Journal of Botany* 74:1883-1889.

Stutz J.C., R. Copeman, C.A. Martin and J.B. Morton. 2000. Patterns of species composition and distribution of arbuscular mycorrhizal fungi in arid regions of southwestern North America and Namibia, Africa. *Canadian Journal of Botany* 78:237-245.

Sylvia D.M. and S.E. Williams. 1992. Vesicular-arbuscular mycorrhizae and environmental stress. In: Bethlenfalvay G.J. and Linderman R.G. Eds. *Mycorrhizae in sustainable agriculture*. Special Publication No. 54, American Society of Agronomy, Madison, Wisconsin, 101-124.

Warren A., Y.C. Sud and the late B. Rozanov. 1996. The future of deserts. *Journal of Arid Environments* 32:75-89.

Wright S.F. and A. Upadhyaya. 1998. A survey of soils for aggregate stability and glomalin, a glycoprotein produced by hyphae of arbuscular mycorrhizal fungi. *Plant and Soil* 198:97-107.