PREVENTION OF DESERT SOIL EROSION AND ENHANCING SOIL STABILIZATION BY MYCORRHIZAL FUNGI AND BY CACTUS PLANTS INOCULATED WITH *AZOSPIRILLUM BRASILENSE*

Bashan, Y., Carrillo, A. E., Bethlenfalvay, G. J., Rojas, A., and Puente, M. E.
Environmental Microbiology, The Center for Biological Research of the Northwest (CIB), La Paz, B.C.S., 23000, Mexico

Introduction

When naturally vegetated deserts are cleared either to produce marginal agricultural land that is later abandoned or to build urban neighborhoods lacking paved roads, the natural, organic safeguards that hold the topsoil against erosion are destroyed. The result is a severe loss of soil and subsequent dust pollution. The latter significantly increases chronic respiratory illnesses. This phenomenon is on the increase throughout the developing world. In North America, it predominates in the semiarid region of the Mexican Northwest, where abandoned fields quickly become barren ("desertify"). Re-establishment of a plant cover in these areas cannot occur naturally, since the nurse plants (like the legume, mesquite) on whose canopies many of the climax-vegetation plants (cacti) depend for successful establishment, have been removed.

Many desert plants, especially cacti, are excellent top-soil stabilizers. These plants may be used to prevent soil erosion and reduce dust pollution in urban areas, but their low rate of establishment and slow development when transferred from natural habitats or from nurseries to eroded urban soil limit their use. Cacti (as all plants), however, not only benefit from, but actually depend on, the presence of soil microbes for early establishment and subsequent growth. Inoculation with soil organisms is therefore common practice of agriculture and forestry in developed countries. We contend that microorganisms, such as plant-growth-promoting bacteria (PGPB) and mycorrhizal fungi (MF), are integral parts of the revegetation process and can be used as a biotechnological tool to reduce soil erosion and dust pollution.

Results

The MF status of perennial plants in disturbed and undisturbed large field plots was studied in the Sonoran desert near La Paz, Baja California Sur, Mexico, to determine if MF contribute to the stability of "resource islands", (soils of improved plant-growth characteristics) under mesquite trees and to the establishment of cactus plants as understory plants. The roots of all 46 species of perennial plants tested were colonized by MF, but the extent of colonization varied widely (<10 to > 70%). Cactus species with low MF colonization established preferentially in association with nurse trees. Of the nine species of trees and arborescent shrubs in the area, the mature (>20 yr) nurse legumes *Prosopis articulata* (mesquite) and *Olneya tesota* (ironwood) supported the largest number of understory plants. The MF inoculum potentials of bare areas and areas under mesquite canopies were similar. However, propagule density under the canopy was 7-fold higher. These studies show that in the natural revegetation of disturbed desert areas MF help to stabilize windborne soil that settles under dense plant canopies, and later these mounds are colonized by cactus seedlings (3,7).

Seedlings of the giant cardon cactus (*Pachycereus pringlei*) were inoculated with the PGPB *A. brasilense* in pot cultures in different soils ranging from rich, resource-island soil under the mesquite canopy to poor bare-area soil. In rich soil, *A. brasilense* had no effect on cardon development. However, in bare-area soil, inoculation increased plant dry mass by 60% and root length by over 100%. The effect was not due to N_2 fixation as no acetylene-reduction activity was detected in the roots (6).

Survival and development of cactus transplants in urban, disturbed areas of the Sonoran desert in Baja California Sur, Mexico, was monitored. Young plants of three species of columnar pachycereid cacti (*P. pringlei*, *Stenocereus thurberi*, and *Lophocereus schottii*) inoculated with *A. brasilense* in an eroded area (a dirt road) had a high survival rate and developed more rapidly than uninoculated control plants during 3.5 yr after transplantation. Soil erosion in the inoculated experimental area diminished, and soil accumulation associated with the penetration of cactus roots of wind-deposited dust was significant (5).

Discussion

The mechanisms involved in the above phenomena encompass interdependent plant and microbial activities.

1. *Soil stabilization by MF - formation of resource-islands under nurse-plant canopies*. Cactus nurslings grow preferably under nurse-plant canopies, and, in the Sonoran Desert, mesquite is the most effective nurse plant (1). They are growing in the fine-textured soil accumulated from windborne dust captured under dense plant canopies. Such patches of soil are known as "resource islands" (8) because they contain more organic matter and nutrients than the surrounding desert sand, have higher water holding capacity and moisture content and lower pH, and maintain sub-canopy soil temperatures significantly lower than in the surrounding desert where seedlings of cardon cacti are not likely to survive. Other desert plants, like *Agave*, also take advantage of the improved growth conditions of the resource island and proliferate there. Our studies also showed that the soil microbes (in addition to the nurse tree) are a major contributors, facilitating establishment of nurslings under the canopy. The MF contribute to the binding of windborne soil particles that settle out under the canopy. The dense mats of MF mycelia that enmesh the soil particles in the top layer of the resource-island soil is a key factor for soil- aggregation and soil-stabilization processes, counteracting soil erosion (Fig 1).

The PGPR of the genus *Azospirillum* affect the development of cardon seedlings in vitro (10). Our current studies show that bacterial inoculation also significantly increased cardon growth in desert soil. The effect was more marked in poor soils collected from nearby bare areas (6).

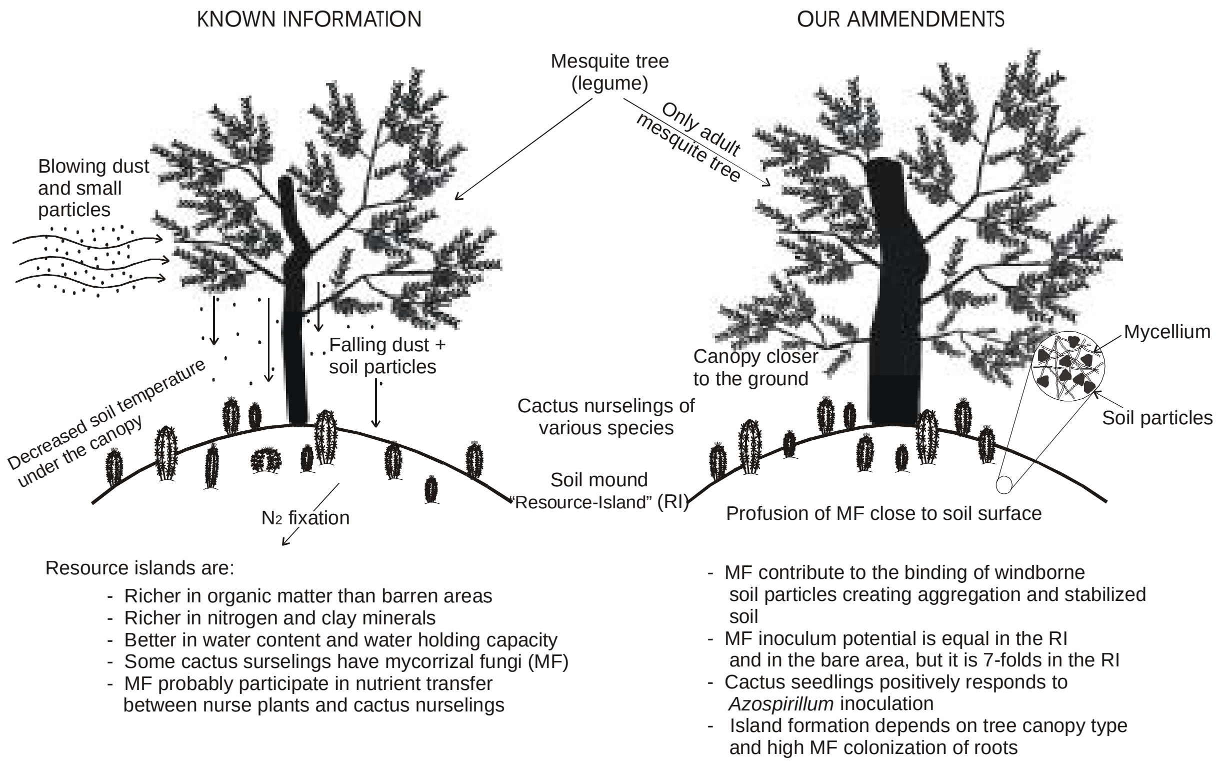

Fig. 1. Role of "Resource Island" in re-vegetation of disturbed arid environment (Sonoran desert, Mexico)

2. *Dust stabilization by inoculated plants*. One mechanism for the stabilization of dust by cactus roots with *A. brasilense* is the development of "rain roots" (ephemeral rootlets developed quickly by some cacti in response to transient rain episodes; 9) during the brief rainy season. Some of these roots survive after the rainy season and are instrumental in stabilizing dust. This root-stabilized dust enhances the formation of newly-deposited dust layers in the next dry season. In the rainy season that follows, the original dust layer is further colonized by permanent roots and the newer dust layer by the new "rain roots", thus continuing the cycle. Ultimately, the experimental plots were elevated above the surrounding, continuously eroding area (Fig 2).

3. *Increased metabolic activity of cactus roots by inoculation with PGPB.* Extrusion of protons from roots, with a concomitant lowering of the rhizosphere pH, is a well-known function of plant metabolism. This activity can be influenced through nitrogen fertilization (4) or through inoculation with *A. brasilense* of wheat, soybean and cowpea (2). Acidification the rhizosphere changes, and can improve, the availability of plant nutrients, such as phosphorus. Little is known about proton extrusion by noncrop plant roots, and about cactus roots in particular. Our study showed that proton extrusion by intact cactus seedlings (growing under hydroponic conditions in vitro) is minimal. However, similar to some crop plants, cactus seedlings responded to nitrogen; ammonium ions increased proton extrusion while nitrate blocked it (Fig. 3). Inoculation with *A. brasilense* partially decrease nitrate inhibition. These findings, if shown to occur also in desert soil, will be relevant to vegetation processes, as some desert soils are relatively rich in unavailable (poorly soluble) P and poor in N. We suggest that inoculation with *A. brasilense,* known to fix N_2 and to enhance P solubilization by rhizosphere acidification, may be an

important subject for study in desert revegetation. This may have been the reason why inoculated transplants survived better than noninoculated ones in eroded areas.

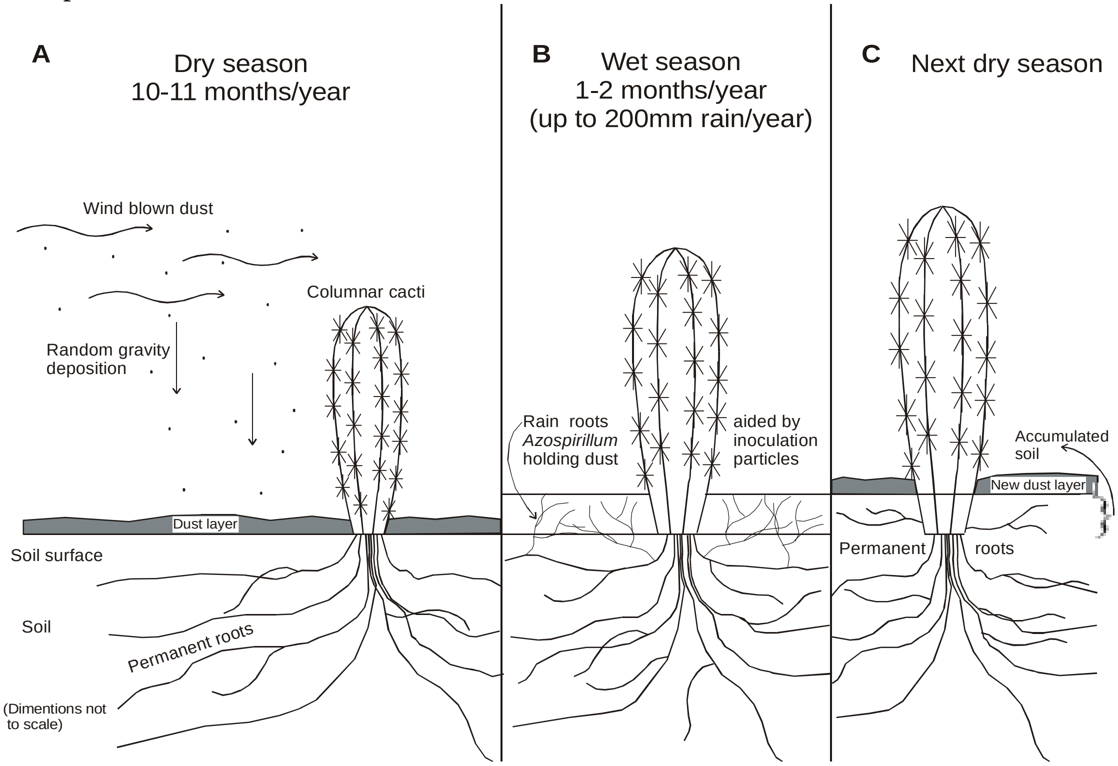

Fig. 2. Soil accumulation in cactus vegetation under arid environments (Sonoran desert, Mexico)

These studies demonstrated that (i) natural revegetation processes in the desert can be valuable guides for revegetation programs, (ii) mycorrhizal fungi are indispensable in desert soil stabilization, and (iii) the use of bacterial inocula with cacti to enhance plant establishment in disturbed areas is feasible, and has the potential to stabilize soil and prevent soil erosion.

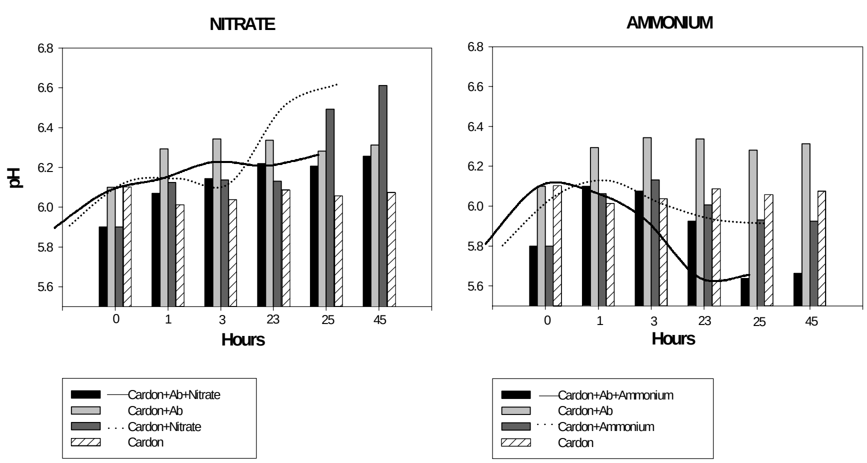

Fig. 3. Rhizosphere acidification by Pachycereus pringlein (cardon cactus) plantlets, exposed to different nitrogen sources, and inoculated with Azospirillum brasilense (Ab).

Acknowledments. This study is dedicated to the memory of the late Mr. Avner Bashan from Israel, and was supported by Consejo Nacional de Ciencia y Tecnologia (CONACyT) Mexico, contracts # 26262-B and # 28362-B and by the Bashan Foundation.

References

1. Arriaga, L., Maya, Y., Diaz, S., and Cancino, J. 1993. Association between cacti and nurse perennials in a heterogeneous tropical dry forest in northwestern Mexico. J. Veget. Sci. 4:349-356.
2. Bashan, Y. 1990. Short exposure to *Azospirillum brasilense* Cd inoculation enhanced proton efflux in intact wheat roots. Can. J. Microbiol. 36: 419-425.
3. Bashan, Y., Davis, E.A., Carrillo, A., and Linderman, R.G. 2000. Assessment of VA mycorrhizal inoculum potential in relation to the establishment of cactus seedlings under mesquite nurse-trees in the Sonoran desert. Appl. Soil Ecol. 14:165-176.
4. Bashan, H., and Levanony, H. 1989. Effect of root environment on proton efflux in wheat roots. Plant Soil 119: 191-197.
5. Bashan, Y., Rojas, A., and Puente, M.E. 1999. Improved establishment and development of three cacti species inoculated with *Azospirillum brasilense* transplanted into disturbed urban desert soil. Can. J. Microbiol. 45: 441-451
6. Carrillo-Garcia, A., Bashan, Y., Diaz-Rivera, E., and Bethlenfalvay, G.J. 2000. Effects of resource - island soils, competition, and inoculation with *Azospirillum* on survival and growth of *Pachycereus pringlei,* the giant cactus of the Sonoran Desert. Restor. Ecol. 8: 65-73
7. Carrillo-Garcia, A., Leon de la Luz, J.-L., Bashan, Y. and Bethlenfalvay, G.J. 1999. Nurse plants, mycorrhizae, and plant establishment in a disturbed area of the Sonoran desert. Restor. Ecol. 7**:** 321-335
8. Halvorson, J.J., Bolton, H. Jr., Smith, J.L., and Rossi, R.E. 1994. Geostatistical analysis of resource islands under *Artemisia tridentata* in the shrub-steppe. Great Basin Naturalist 54:313-328.
9. 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. pp 823-844. Marcel Dekker, Inc. New York.
10. Puente, M.-E., and Bashan, Y. 1993. Effect of inoculation with *Azospirillum brasilense* strains on the germination and seedlings growth of the giant columnar Cardon cactus (*Pachycereus pringlei*). Symbiosis 15: 49-60.