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Use of mycorrhizae for land rehabilitation

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Introduction

There is an increasing demand by society for the reclamation of lands disturbed by human activities. The disturbances are most evident and protracted in areas subjected to moisture deficiency where the recovery efficiency of natural vegetation is limited. Such lands include not only arid deserts but also semi-arid and sub-humid rangelands and other economically valuable areas, extending from tropical zones to the temperate and boreal regions. The primary visible evidence of disturbance is the loss of vegetation and the effects have been most pronounced in subtropical and Mediterranean climate type areas; a term 'desertification' is commonly used for the process. The United Nations Conference on Desertification, 1977, used a generalized definition: desertification is the diminution or destruction of the biological potential of the land, ultimately leading to desert-like conditions. It is a human-impact-oriented definition, based on the premises that over-exploitation of land degrades vegetation and soil and diminishes water availability. The major human activities which cause desertification are the non-planned and non-regulated overgrazing, cultivation (tillage agriculture), deforestation, mining disturbances and excessive use of off-road vehicles, the latter becoming an important factor in developed countries. The perturbations associated with desertification include denudation, erosion, drought, nutrient deficiencies, increased heavy metal concentration, salinization, diminution of below-ground microbiota with associated decrease in nutrient cycling, and ecosystem energy budget changes. Human activities, leading to desertification, may be viewed as cyclic processes, especially in developing countries (Fig. 1).

Considering the world-wide social and economical impact of expanding desertification, the United Nations Conference on Desertification was convened as an intergovernmental meeting in 1977. In response to the recommendations by the Conference, the Workshop on Uses of Microbiological Proceses in Arid Lands for Desertification Control and Increased Productivity was organized by the United Nations Environment Programme jointly with International Symposia on Environmental Biogeochemistry, Inc., and held in New Mexico in October 1983. The Workshop panel addressed problems of utilization and management of organic matter resources, nitrogen input and management, utilization of micro-organisms in revegetation efforts, and actions for training and international cooperation

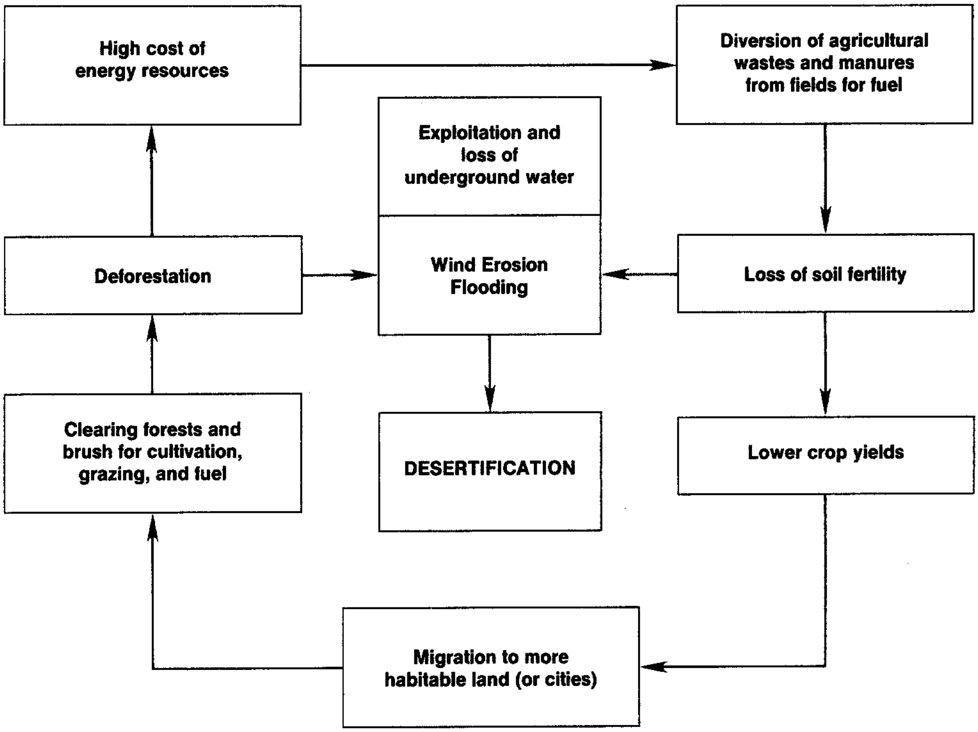

Fig. 1 Process leading to desertification in pastoral, low-intensity sustenance areas (revised from Nnadi 1986).

(Skujiņš & El-Tayeb 1986). It was recognized that mycorrhizae played an important part for a successful implementaton of re-vegetation efforts and the approriate utilization of presently available knowledge and needs for further research in this field were strongly emphasized. It was evident that the application of manipulative technologies involving mycorrhizae in arid, semi-arid and sub-humid areas would be highly rewarding and more important than in other climatic zones.

Mycorrhizal responses to stress

Two predominant types of mycorrhizae are recognized; ectomycorrhizae where the fungi remain external to the cell wall, and endomycorrhizae where the fungi enter the cells (Harley & Smith 1983). Endomycorrhizae exhibit several distinctive morphological types but the most common is the vesicular–arbuscular mycorrhiza (VAM). The VAM type is the most common in diverse plant species excepting only a few families such as Amaranthaceae, Apiaceae, Brassicaceae, Chenopodiaceae, and Zygophillaceae (Trappe 1981) where only isolated species have been found mycorrhizal (Davidson & Christensen 1977; M. Allen 1983). The ectomycorrhizal associations are formed with woody species, mostly from the Fagaceae, Myrtaceae, Pinaceae, Rosaceae and Salicaceae. Representative species of these families usually have less importance in rehabilitation efforts in arid areas.

A major feature of lands in arid zones is the low precipitation. In addition they are characterized by widespread diurnal mean values of temperature, diversity of soils, variability in climatic regimes and extreme patchiness of soils characterized by clumping of vegetation. It is apparent that the phenology of VAM is tightly coupled to seasonality (M. Allen 1983) and that the functioning of VAM in arid communities is based on several interacting physiological mechanisms to override the extreme variability of localized environmental conditions (M. Allen 1984).

The importance of VAM for the increased phosphate uptake by plants in P-deficiency soils is well recognized. The primary mechanism is considered to be the hyphal transport of available soil P to plant (Hayman 1982). Additional proposed mechanisms include utilization of organic phosphates (Allen *et al.* 1981a), increased affinity by fungal hyphae for P (Cress *et al.* 1979), and increased phosphate requirement generated by increased photosynthesis-driven sink of VAM infected plants (Allen *et al.* 1981a,b).

Studies on the role of VAM in nitrogen assimilation are scarce. Limitations to productivity caused by N deficiencies in arid and semi-arid soils (West & Skujiņš 1978, Skujiņš 1981) suggest that the examination of VAM participation in N transport might yield fruitful results. Several typical VAM fungi, such as *Glomus mosseae* and *G. macrocarpum* have the capacity for reducing nitrate (Ho & Trappe 1975) and Ames *et al.* (1983) have reported hyphal transport of N from soil to a host plant. The interactions between mycorrhizae and symbiotic N_2-fixers are reported by Mikola (1985) and by Hayman (1985) at this conference.

The major limiting factor for both nutrient uptake and productivity is drought. VAM infection has been shown to increase water uptake and to increase drought tolerance of several plant species (Safir & Nelsen 1985). Several mechanisms for enhanced water uptake are hypothesized. It has been suggested that the effect is P mediated: increased uptake of phosphate by plants results in an increased water uptake and transpiration (Safir & Nelsen 1985). Hyphal transport of water to plants has also been suggested (M. Allen 1982; Hardie & Leyton 1981) and VAM infection may directly regulate leaf physiology, possibly by altering stomatal control (Levy & Krikun 1980; Allen *et al.* 1981b; Levy *et al.* 1983). Hormonal changes in leaves and roots may acount, in part, for the observed stomatal responses (Allen 1985). Two species of VAM fungi, *G. fasciculatum* and *G. mosseae*, had differing effects on the water relations of wheat during drought stress. Both species increased stomatal conductivity but *G. fasciculatum* infection resulted in reduced osmotic potentials whereas *G. mosseae* did not. Thus, plants infected with *G. fasciculatum* maintained open stomatas and positive turgor pressure under greater drought than *G. mosseae*-infected and nonmycorrhizal plants (Allen & Boosalis 1983). Additionally *Bouteloua gracilis* and *Agropyron smithii* inoculated with the same VAM fungus (*Glomus fasciculatum*) and having the same intensity of infection had different degrees of responses to drought and survival (Allen *et al.* 1984a) (Fig. 2). These results indicated that the intensity and type of response of plants to VAM formation was dependent on host plant, fungal species, and prevailing environmental conditions (Allen 1986).

Degradation of land is often accompanied by salinization following improper changes in water regime. Although germination of fungi associated with cultivated plants was inhibited by the presence of moderate salt concentrations (Hirrel 1981), VAM infection could overcome some detrimental effects caused low concentration salt additions in another case (Hirrel & Gerdeman 1980). Buwalda *et al.* (1983) reported that VAM-infected wheat and barley assimilated higher concentrations of Br and Cl than non-mycorrhizal plants, concluding that these responses may be necessary for proper cation–anion balance due to carbon loss to the fungus. Allen &

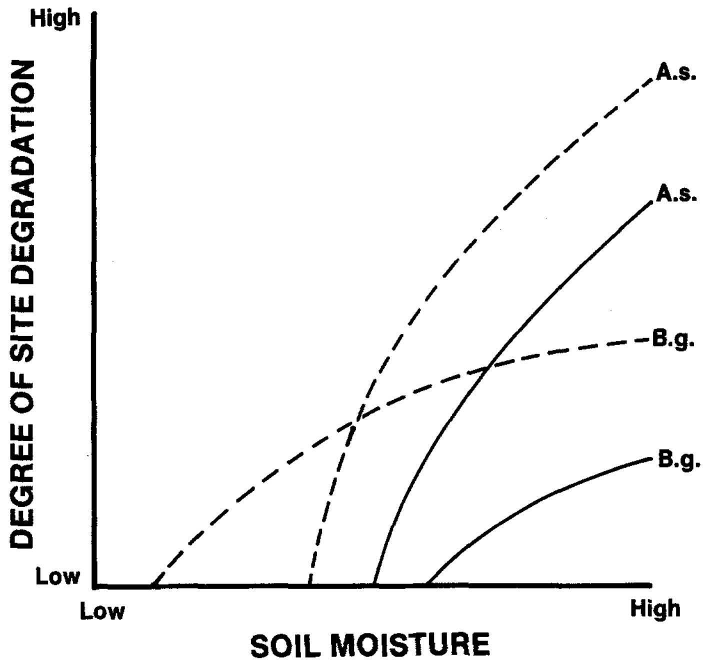

Fig. 2 Plant-VAM ecological response to soil moisture and the degree of site degradation comparing nonmycorrhizal (——) and mycorrhizal (----) *Agropyron smithii* (A.s.) and *Bouteloua gracilis* (B.g.) (redrawn from Allen 1986).

Cunningham (1983) demonstrated that, although mycorrhizal *Distichlis spicata*, a halophyte, took up more NaCl than non-mycorrhizal plants, VAM plants also assimilated more K, maintaining a constant Na : K ratio, and increased P uptake. The fungus used for this study was of *G. fasciculatum* from a highly saline soil, capable of establishing itself on root systems at markedly higher salt concentrations than the *G. fasciculatum* used by Hirrel & Gerdemann (1980) obtained from cultivated plants. These results indicated a possibility for using salt-tolerant VAM strains for revegetating saline areas.

Effects of land disturbances on VAM fungi

In a mycorrhizal association with plants the fungus is considered as the obligate symbiont. Any perturbation affecting the plant will result in a fungal response. The process of desertification results in reductions of plant production, and in changes of plant species distribution at the affected sites in response to a variety of interacting changes in soils, climate and land management. In addition, there are changes in the diversity and numbers of microbiota, with relatively unknown consequences to community processes (Allen & MacMahon 1985).

Cultivation of soil tends to reduce VA fungal densities and alter their diversity, ultimately resulting in a lowered resilience of an agroecosystem. The VAM spores located near the surface of a tilled and well aerated soil appear to decompose more rapidly, although when buried they may survive for longer periods of time in both mesic and arid habitats (Christensen & Allen 1980; Allen *et al.* 1984b; Allen &

MacMahon 1985). In arid regions land is often fallowed with no green cover crop to facilitate soil water recharge. In Nebraska during the alternate years with no plant cover present, the numbers of the small-spored, drought tolerant *G. fasciculatum* decreased from wheat lands to be replaced by the large spored *G. mosseae* (Fig. 3). High rates of inorganic fertilizer (especially P) and fungicide applications inhibit VAM persistence (Hayman 1982; Menge 1982) as well as over-irrigation, apparently due to lowered pO_2 (Saif 1981). Even moderate salinity can inhibit establishment of some VAM fungi (Hirrel & Gerdeman 1980; Hirrel 1981). Consequently, irrigation can lead to salinization and reduce infection in crop plants. A combination of agricultural practices often change the germination and proliferation of VAM and result in lowered productivity of arid sites (Trappe 1981; M. Allen 1984).

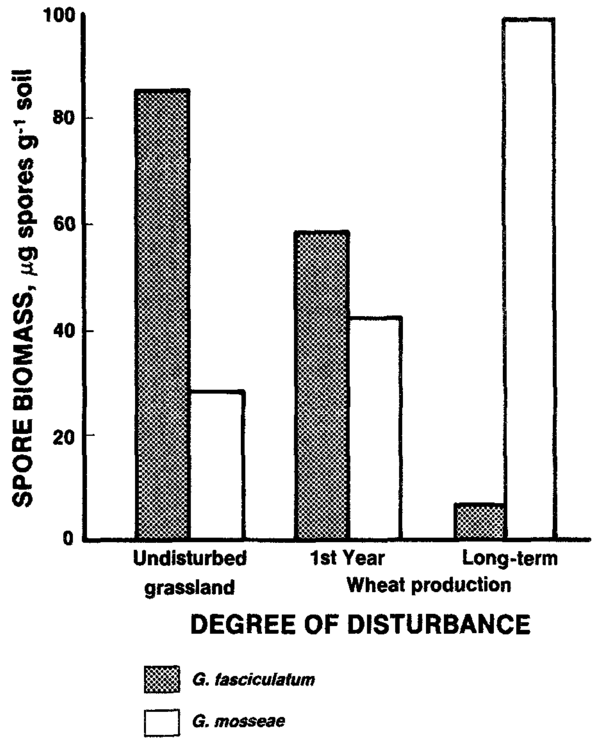

Fig. 3 Changes in spore biomass of *Glomus fasciculatum* and *Glomus mosseae* with increasing time of wheat production in Western Nebraska grasslands (adapted from Allen & Boosalis 1983).

Overgrazing can seriously reduce the presence and persistence of VA fungi, although the effect is probably indirect. Assuming that the major fraction of the carbon source for growth of VA fungi is derived from the plant, any factor reducing the amount of C fixed by the plant reduces fungal growth (Johnson 1976; Ferguson & Menge 1982). Evidence has shown that overgrazing significantly reduced VAM infection frequency, spore density and species composition (Bethlenfalvay & Dakessian 1984; Wallace 1981). When carbon availabilty becomes a major limiting factor, the fungus might act temporarily more as a pathogen than as a mutualist (Bethlenfalvay *et al.* 1982). High grazing intensity can reduce VAM inoculum due to soil erosion (Powell 1980) and by soil compaction due to trampling which reduces soil pore size necessary for the induction of sporulation (Griffin 1972).

During the coal and mineral mining activities not only are plants physically removed, but upon soil replacement the changes in soil texture and deposition of salts and heavy metals cause a dilution or complete elimination of VA fungi from the soil (Williams & Allen 1984). The observed low sporulation in a heavy clay soil, used as a topsoil replacement (Allen & Allen 1980), might be a response to the small pore sizes. Although certain VAM ecotypes tolerate heavy metals and high salinity (Gildon & Tinker 1981; Allen & Cunningham 1983), many VAM fungi are sensitive to high salt content or heavy metals often present in soils following mining disturbances (Gildon & Tinker 1981; Hirrel 1981).

A secondary consequence, often resulting from site disturbances and affecting re-establishment of desirable plants and VAM fungi is the invasion by weeds (E. Allen 1984a). Non-mycotrophic weeds, such as *Salsola kali*, can invade disturbed sites rapidly and compete with desired grasses or forbs for water and nutrients (Allen & Allen 1984; Allen & Knight 1984). Since many of the invading weed species are non-mycorrhizal (E. Allen 1984a), without host plants the VAM fungi may not be able to persist. Allen & Allen (1980) have reported existence of disturbed sites up to 10 years old without the presence of VAM fungi dominated by *S. kali* and *Halogeton glomeratus*.

Most of the reported studies on VAM fungal responses to various stresses, simulating conditions at disturbed sites,have been performed by laboratories or are based on pot cultures in greenhouses. Few direct or correlative experimental field studies on the effects of VAM on plant growth, especially from arid regions, have been reported. The available information, however, suggests a highly positive effect of VAM for restoring vegetation in disturbed lands. VAM-inoculated *Atriplex canescens* had higher rates of survival and greater productivity than non-mycorrhizal plants after eight years in a disturbed mine spoil (Aldon 1975). Call & McKell (1985) reported that mycorrhizal shrubs performed better on oil shale spoils than non-mycorrhizal shrubs. In field experiments a lowered productivity in wheat coincided with a reduced VAM infection and a fungal species shift from one promoting tolerance to drought (*G. fasciculatum*) to another not promoting such tolerance (*G. mosseae*) (Allen & Boosalis 1983). By comparing phenology and water relations of VAM-inoculated and non-mycorrhizal *Agropyron spp.* in overburden spoil material containing no inoculum in western Wyombing, mycorrhizal grasses had significantly lower stomatal resistance and lowered xylem stress than adjacent non-mycorrhizal plants in soils of equal water-stress status (Allen & Allen 1985). Mycorrhizal plants also extended their growing season in response to increasing drought. Apparently, in the presence of VAM the carbon gain was increased due to the increased CO_2 conduction facility, resulting in a longer growing season, thus enhancing the survival potential of these grasses.

The possibility that VAM infection could simultaneously affect plant response to several types of stresses was deduced from field observations of environmental variability (Allen 1983). Precipitation was markedly seasonal and the VAM infection in shrubs appeared to be coupled to periods of adequate soil moisture. Soil patches with various combinations of N deficiencies, high P, and high salinities were found throughout the site, but there was little variability in plant infection and spore counts among individual locations (Allen, unpublished). VAM fungal hyphae were concentrated near the edge of the canopy where also the maximum decomposer activity was occurring (Allen & MacMahon 1985). It was evident that VAM fungi were the necessary component for increasing water uptake and increasing salinity tolerance of plants while maximizing nutrient uptake in optimized root locations and during optimum periods of nutrient availability.

Restoration of VAM fungi in the field

A number of tested and experimental methods have been proposed for re-establishing VAM to promote recovery of desired plant communities. In this section the currently applicable methods for plant communities in precipitation deficient regions are described, namely, inoculation and land management including application of succession theory.

Inoculation

Inoculation of plants with mycorrhizae has been a common practice for ectomycorrhizal trees where techniques for growing masses of axenic fungal mycelia have been used. Techniques do not yet exist, unfortunately, for growing VAM fungi without a host (Allen & St John 1982). Attempts at field inoculation in mesic habitats have indicated that various selected procedures might be effective, nevertheless. Hattingh & Gerdemann (1975) successfully used a sieved inoculum coating citrus seeds and enhanced VAM reformation in fumigated fields. Hall (1980) applied pellets of *G. fasciculatum* inoculum to eroded New Zealand soils. Alternatively, Kormanik *et al.* (1980) added a small amount of VAM inoculum to a fumigated plot, increased the density of the added fungi with an annual cover crop which stimulated high fungal sporulation and followed by the introduction of desired plants. Direct placement of topsoil containing VAM inoculum also can be effective (E. Allen 1984b).

Atriplex canescens shrubs have been individually inoculated and successfully planted in disturbed arid soil (Aldon 1975); similarly, various inoculated shrub species have been successfully planted onto oil shale spoil material (Call & McKell 1985). The potential for inoculating shrubs in nurseries and planting them in disturbed sites has been discussed and reviewed by Wood (1984). The limiting factor for large scale inoculations is the lack of techniques for the mass culture of inocula. Until a technique is available for growing VAM fungal inocula in mass for extensive usages, inoculation will remain only as a potentially effective tool for small-scale efforts.

Land management

In cases where land is to be disturbed and degradation has not yet occurred, proper land management is the most effective means to preserve VAM and to protect plant growth. Soil organic matter retention is a critical factor for the maintenance of nutrient supply and for the reduction of erosion (Paul 1976). Moderate to high levels of organic matter promote VAM establishment and persistence (Christensen & Allen 1980; St John & Coleman 1983). A relatively continuous vegetational cover may be essential for the supply and maintenance of an adequate carbon source for fungal survival (Allen & Boosalis 1983). It is not known yet and it should be tested if low-water use crop or grass cover would not be preferable to a 'bare-soil' treatment during a fallow year for a more successful maintenance of VAM fungi, eventually leading to higher yields. As an example, alternate cropping of wheat (a water-demanding species) and pearl millet might allow spring water recharge and minimal use of water during the alternate years while retaining the carbon input for VAM fungi (Allen 1986). It is possible, that the success of minimum tillage (no-till) practices, expanded during the last decade may be ascribed in part to the maintenance of VAM in soils (Yocum *et al.* 1985). Intensive use of inorganic fertilizers, especially superphosphate, apparently drastically inhibits VAM formation (Hayman 1982). Careful fertilizer management is essential for the retention of VAM fungi.

In mining situations, retention and respreading of topsoil on mine overburden material has been shown to re-establish VAM and desirable plant species effectively. Allen & Allen (1980) reported that infection frequency and spore counts were recovered to within 50% of undisturbed sites in three years after topsoil was re-spread on disturbed sites, whereas in a site where topsoil was not retained no VAM fungi were observed and non-VAM weeds, such as *S. kali* and *H. glomeratus* still predominated 10 years after reclamation efforts began. Even the addition of relatively small amounts of fresh topsoil (2–4 cm in depth) to a site resulted in 60% of the Poaceae roots being infected in the first growing season, where no infection was observed in adjacent non-covered overburdened soil (E. Allen 1984b). Piled and stored topsoil loses many of its biological components rapidly (Miller *et al.* 1979; Fresquez & Lindemann 1982). The longevity of VAM fungal propagules in stored topsoil needs further study but some data has suggested that in both mesic and arid soils spores persisted for up to five to eight years (Christensen & Allen 1980; Allen *et al.* 1984b; Allen & MacMahon 1985). The persistence of VAM may also be related to moisture content of the stored topsoil (Miller *et al.* 1985).

Application of succession theory

For an alternative approach to the reconstruction of disturbed arid ecosystems, at the Utah State University we have initiated several projects testing the use of succession theory as a guide for managing disturbed lands. Rather than attempting to override normal successional processes and environmental variables, an attempt is made to prime natural processes in order to re-establish a desirable community more rapidly.

Odum (1969) listed a number of characteristics distinguishing an early versus a mature ecosystem, developing from an abiotically regulated, 'leaky' system to a biotically regulated, nutrient conservative system. Major distinguishing characteristics attributed to a mature ecosystem include spatial integrity and a high degree of symbiosis. Mycorrhizae are mutualistic associations between below-ground parts of plants and fungi, and evidently is one of the components essential to restoring biotic regulation to a disturbed ('young') ecosystem. In addition, Walker *et al.* (1981) suggested that if nutrients are retained, progressive succession should occur, resulting in a long term productive system. Where nutrients are lost by erosion or leaching, however, retrogressive succession would occur leading to low productivity (Fig. 4). Disturbed lands in water-deficient regions (semiarid and arid zones) provide excellent situations for testing these hypotheses for the benefit of their restoration for improved economic use.

In arid soils shrubs establish themselves in clumps, forming 'fertile islands', as reviewed by Skujiņš (1981) and further supported by Phillips & MacMahon (1981). We have demonstrated that these islands are also sites of highest VAM activity and that disturbance results in a loss of spatial integrity (Allen & MacMahon 1985). Reconstructon of a 'young' disturbed ecosystem to a self-perpetuating desirable community may depend on the ability to reconstruct the spatial nature of the site.

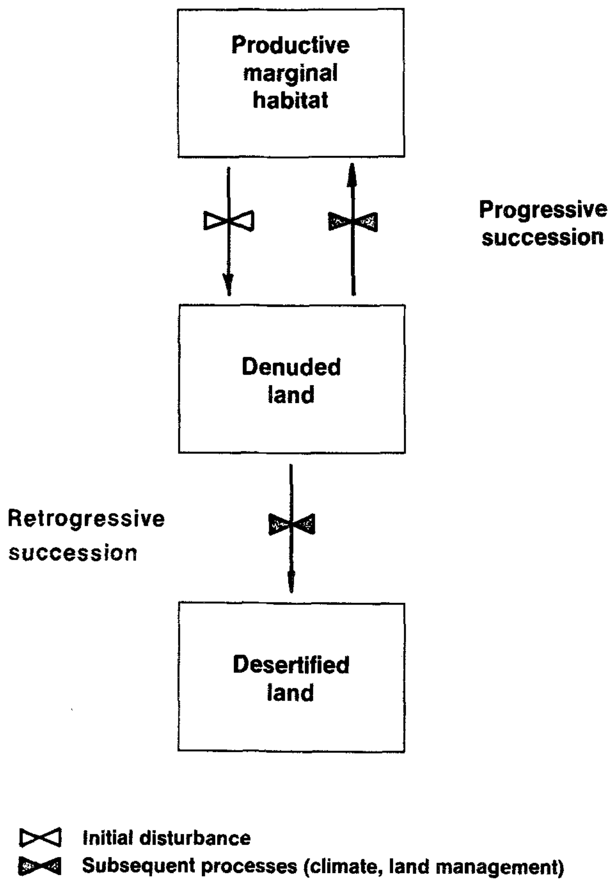

Fig. 4 Pathways of progressive and retrogressive succession during desertification process (adopted from Allen 1986).

The general successional model proposed by Clements (1916) has been described by MacMahon (1981) as a succinct categorization of successional processes, useful for understanding the dynamics of community establishment. They also represent processes applicable to management activities for the enhancement of succession rates. Consequently, planting appropriate shrubs in patterns and densities reflecting natural processes has successfully retained some viable VAM propagules remaining in the topsoil and some infection was evident during the first year (Allen, unpublished results). Current approaches to the problem have emphasized also the role of vectors of VAM transport (MacMahon & Warner 1984). Both abiotic (wind, snow) and biotic vectors (mammals such as mice, rabbits, deer, etc.) for dispersal of VAM spores have been identified as participating factors. The vertebrates spread spores by defecating ingested plant material. Participation of invertebrates in spreading spores may also be important, although only grasshoppers to date have been shown to be a significant vector using the same mechanism (Warner 1985). By planting shrubs in clumps, changes in turbulence patterns may result in increased deposition of wind-and snow-borne spores (Allen & Hipps 1985). Shrubs also ameliorate the harsh environmental conditions of the site (Parmenter & MacMahon 1983) potentially resulting in enhanced deposition of spores and mycelial fragments by animals (Maser *et al.* 1978; McMahon & Warner 1984).

It is apparent that the successionally oriented manipulation of plant invasion enhances natural mycorrhizal re-establishment by increasing residual VAM survival through reduction of the denudation intensity and by concentrating VAM fungal migration into more habitable sites. The shrub units serve as islands for re-inoculation of the surrounding area.The successional recovery processes affect not only mycorrhizae but the total soil microbiota by inreasing their numbers and activities, leading to the enhancement of nutrient turnover rates (Skujiņš 1984). Thus, the restorative successional process might be adaptable for both restoring natural vegetation by appropriate planting of shrub islands and for enhancing cultivation areas following the evaluation of the dynamics of planted wind breaks.

Conclusions and recommendations

It is apparent that vesicular–arbuscular mycorrhizal fungi are essential components of both agricultural and native vegetation communities. Inoculation techniques for rehabilitation may be used, but until improved inocula production methods are developed, the best alternative is an appropriate management of a site, preventing loss of VAM and plant cover. Rehabilitation of disturbed sites should include techniques designed to stimulate reformation of VAM symbioses. When factors preventing nutrient loss, and others enhancing plant production and retention can be spatially integrated, then the progressive succession for the increase of agricultural potential or for native community reconstruction should be achievable even in arid lands. The alternative is a retrogressive succession leading to desertification and creation of derelict lands incapable of sustaining resources necessary for fostering human communities.

The panel of the UNEP–ISEB Workshop on Uses of Microbiological Processes in Arid Lands for Desertification Control and Increased Productivity, 1983, submitted to the UNEP the following *Recommendations* for action (as published in Skujiņš & El-Tayeb 1986), directed to the appropriate international and national agencies for implementation on national and local levels. It was recognized that considering the current state of available information on mycorrhizae and of available technologies, implementation of most of the recommendations require further development and further basic studies.

1. Encourage and expand inoculation of degraded soils during revegetation with soil pellets containing spores and hyphae of appropriate mycorrhizal fungi. Implementation: technological development needed locally for the production of inocula.
2. Plant or seed disturbed lands with plant species having low mycorrhizal dependencies followed by seasonally dependent planting of species with high dependencies in discrete patches. Select plant species with low water-use requirements and control grazing for maintenance of stands. Implementation: adapt and use methods which have been found successful for reclaiming areas; floristic and fungal characteristics of soils should be evaluated first.
3. In view of the increasingly high costs of fertilizers, studies should be conducted to increase yields of arid area crops by utilizing mycorrhizal fungi. Studies should seek to improve inoculation techniques and to address factors leading to improved mutual

plant–fungi physiological responses. Implementation: further development and testing required.

4. Use successional introduction of plant species to prime early establishment events during rehabilitation of severely degraded lands. Specifically, there is a need to develop optimal planting patterns and densities for a natural increase of mycorrhizal fungi, organic matter and cycling of nutrients. Implementation: development needed.

5. Creation of a mycorrhizal fungal species bank for arid zones should be expedited. Implementation: such mycorrhizal species collection would be most appropriately located and associated with existing international culture collections, such as listed by MIRCEN.

6. Identify the dependency of plant species on mycorrhizae for each area and ecosystem to achieve the goals noted in Recommendations above. Implementation: extensive studies are required.

7. Studies of mycorrhizal effects on plant nutrition have been in evidence only for the last decade. Consequently, a basic understanding of plant–mycorrhizal interactions are still unknown. Knowledge in the following study areas is needed for improved utilization of mycorrhizae in arid zones: (a) genetic potential of the various fungal species; this includes knowledge of the potential for genetic manipulation of fungal gene pools for use of known genetic characters for specific habitats; (b) ecological interactions in the mycorrhizosphere; (c) physiological and biochemical mechanisms of mycorrhizal effects; (d) basic ecology of mycorrhizae to better formulate uses of mycorrhizae for specific, localized applications; (e) utilization of the systems approach to link mycorrhizal processes with other microbial and plant-regulated processes, especially in legumes. Implementation: extended basic studies required.

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Summary

Utilization of vesicular–arbuscular mycorrhizae (VAM) markedly increases the success of rehabilitation of disturbed and degraded lands, either in mesic or in moisture-deficient zones. It has been demonstrated that the presence of VAM is critical for the regeneration of natural ecosystems in arid lands. Inoculation techniques for rehabilitation have been tested and are considered highly valuable for the purpose, but until improved inocula production methods are developed, the best alternative is a proper management of a site, preventing loss and assuring maintenance of an appropriate plant cover, where the roots serve as an energy source and medium for VAM proliferation. Re-establishment of plant cover on denuded lands has been tested by using succession theory by priming natural processes and thereby enhancing the rate of succession. The introduction and appropriate management of VAM in these tests has shown highly positive effects on the results. The international concern and support for such activities has been expressed by the UNEP–ISEB Workshop, 1983, recommending immediate applications of available VAM technologies in rehabilitation, and extensive further research efforts for the utilization of VA mycorrhizae.

Résumé

Utilisation des mycorhizes pour améliorer la réhabilitation du sol

L'utilisation des mycorhizes vésiculaires et arbusculaires (VAM) améliore de façon importante la réhabilitation des sols bouleversés et dégradés, et cela aussi bien dans les régions moyennement humides que dans celles où l'humidité est déficiente. Il a été démontré que la présence de VAM est essentielle pour la régénération des éco-systèmes naturels dans les sols arides. Des techniques d'inoculation ont été testées et leur valeur pour la réhabilitation des sols a été démontrée, mais, en attendant qu'on ait mis au point des méthodes améliorées pour la production d'inoculums, la meilleure manière de procéder est d'aménager le site de façon à éviter la disparition et assurer le maintien d'une couverture végétale appropriée, dont les racines servent aux VAM de source d'énergie et de milieu de développement. On s'est efforcé de rétablir la couverture sur les sols dénudés d'après une théorie dynamique comportant un amorçage des processus naturels et une accélération du taux de succession. L'introduction de VAM dans ces tests et leur emploi judicieux ont donné des résultats très positifs. L'intérêt et le soutien de ces activités sur le plan international se sont exprimés lors du séminaire UNEP-ISEB de 1983 où il a été recommandé d'appliquer immédiatement à la réhabilitation des sols les techniques de VAM disponibles, et d'intensifier les efforts de recherche sur l'utilisation des VAM.

Resumen

Uso de micorrizas para la recuperación de terrenos baldíos

Entre las recomendaciones promulgadas por la reunión de trabajo organizada por UNEP-ISEB sobre la Utilización de Procesos Microbiológicos para Controlar la Desertificación y Mejorar la Productividad de Suelos Aridos, 1983, se cita con especial énfasis la utilización de micorrizas vesículo-arbusculares (MVA) para dichos propósitos. Se reconoce actualmente que entre los efectos beneficiosos de esta asociación hongo-planta, presente en la mayoría de las plantas vasculares, se incluye una mejora en la absorción de P y N y una mayor tolerancia a la sequía. Los mecanismos que regulan estas actividades necesitan, sin embargo, ser elucidados; por ejemplo, la mayor resistencia a la sequía puede deberse a una respuesta fisiológica de la planta a la presencia de la micorriza o bien al aumento de superficie del sistema radical debido a las hifas del hongo, que permite un mejor acceso al agua del suelo. Observaciones de campo muestran que plantas micorrizadas pueden producir mayores cosechas, sobrevivir mejor en condiciones adversas y tener periodos de crecimiento mas largos que las no micorrizadas. La alteración de la superficie del suelo conduce a una perdida de vegetación con la subsiguiente erosión y perdida de la actividad biológica del suelo. Esto puede ser debido a un excesivo pastoreo (especialmente en regiones áridas y semi-áridas), a una labranza inadecuada, o a la destrucción total de la cobertura vegetal debido a una explotación minera. Estas actividades pueden disminuir significativamente e incluso eliminar los hongos VA de los suelos en cuestión. Hasta el momento, se ha demostrado que los esfuerzos para restaurar la vegetación tienen mayores probabilidades de éxito cuando los respectivos hongos VA estan presentes. Los métodos para la restauración de MVA en la vegetación de suelos en proceso de recuperación incluyen la inoculación artificial. El uso de inóculo en forma de pellets, de suelo infectado o de plántulas inoculadas ha sido un éxito en ensayos a pequeña escala. La utilización mas amplia de estos

métodos esta limitada por la falta de técnicas que permitan obtener cultivos masivos de MVA. La mejor solución hasta ahora parece consistir en desarrollar los esfuerzos de restauración siguiendo la sucesión natural de los ecosistemas respectivos. Por ejemplo, en zonas semiáridas los esfuerzos de revegetación basados en el concepto de las 'islas de fertilidad', parecen ofrecer buenas posibilidades. Varias especies de plantas apropiadas localizadas en zonas concretas pueden llegar a ser fuentes de inóculo de hongos VA (y otros componentes biológicos del suelo) para una cierta zona circundante. Un incremento en la fertilización fosforada limita la proliferación de MVA. En las situaciones producidas como consecuencia de una explotación minera se ha utilizado en muchos casos la capa superficial del suelo para facilitar la recuperación de la zona, pero hay que tener en cuenta que un almacenamiento prolongado del suelo puede conducir a perdidas de una gran parte de sus componentes biológicos, incluyendo los propágulos de los hongos VA. Los mejores métodos de uso y administracion del suelo para mantener e incrementar la proliferación de las MVA incluyen prácticas que mantienen y aumentan la materia orgánica del suelo, incluyendo el aporte de una cubierta vegetal relativamente continua que provea las fuentes de C necesarias para el crecimiento de los hongos VA.