THE IMPORTANCE OF VESICULAR-ARBUSCULAR MYCORRHIZAE IN THE HECLAMATION OF MINE SPOILS[1]

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Vesicular-arbuscular mycorrhizae have been shown to benefit a plant through increased nutrient uptake and greater drought tolerance. Reclamation programs need to consider the short and long term effects of current practices on the establishment and maintenance of this symbiotic association.

INTRODUCTION

The tailings and spoils produced by mining activity are generally poor habitats for plant growth and survival. These disturbed soils are infertile, low in organic matter, have low soil moisture holding capacity, and may exhibit other adverse characteristica, such as low pH (Jurgensen 1978). Vegetation that is either planted on this material or establishes naturally may have to also overcome high soil temperatures and erosion. Although considerable research has been conducted on ways of ameleorating the effects of the adverse chemical and physical characteristics of mine spoils to increase plant growth and survival, there has only recently been attempts to understand the importance of soil microorganisms in the reclamation of these disturbed systems (Cundell 1977; Lawrey 1977; Fresequez and Lindemann 1982; Visser et al. 1983a). Vogel (1981) has emphasized that the biological properties of a mine spoil, along with the abiotic characteristics of this material, must be considered in any reclamation strategy.

Soil microorganisms have been shown to be responsible for the decomposition of organic matter, the mineralization of essential plant nutrients, the accumulation of soil organic matter, and changes in soil texture and water holding capacity (Swift et al. 1979). Parkinson (1979) has emphasized that, for reclamation of mine spoils to be effective, attention should be given to the restoration of belowground organisms and associated processes. Studies of the impact of mining activity on soil microorganisms and processes have shown that microbial numbers, diversity and activity is generally lower in spoil material than in undisturbed habitats (eg. Wilson 1965; Stroo and Jencks 1982; Visser et al. 1983).

One group of soil organisms that is recognized as important to the mineral nutrition of higher plants are those fungi which form symbiotic associations referred to as mycorrhizae. Of the three major types of mycorrhizal associations that exist (Harley and Smith 1983), vesicular-arbuscular (VA) mycorrhizae are the most common. This mutualistic relationship is ubiquitous in nature and is formed by a specific group of phycomycetous fungi. Rather than indicate those plant families which form VA mycorrhizae, it is easier to list those which do not, or in which only a few species may be mycorrhizal. Families of plants which do not usually form VA mycorrhizae include the Amaranthaceae, Chenopodiaceae, Cruciferae and Proteaceae (Mosse et al. 1981; Trappe 1981). The VA relationship has been shown to benefit the plant in several ways (table 1). For plants growing on mine spoils or in other highly disturbed habitats the ability of VA mycorrhizae to increase nutrient uptake and a plants ability to tolerate drought stress would certainly be crucial for growth and survival.

CHARACTERISTICS OF VA MYCORRHIZAE

Roots which are infected by VA fungi and develop functional mycorrhizae do not exhibit a change in gross root morphology. The symbiosis can not be recognized unless the roots are cleared and stained (Phillips and Hayman 1971; Kormanik and McGraw 1982). The fungus may gain entry into a root either via a root hair or by penetration through the epidermis (fig. 1). VA mycorrhizal infections are characterized by the

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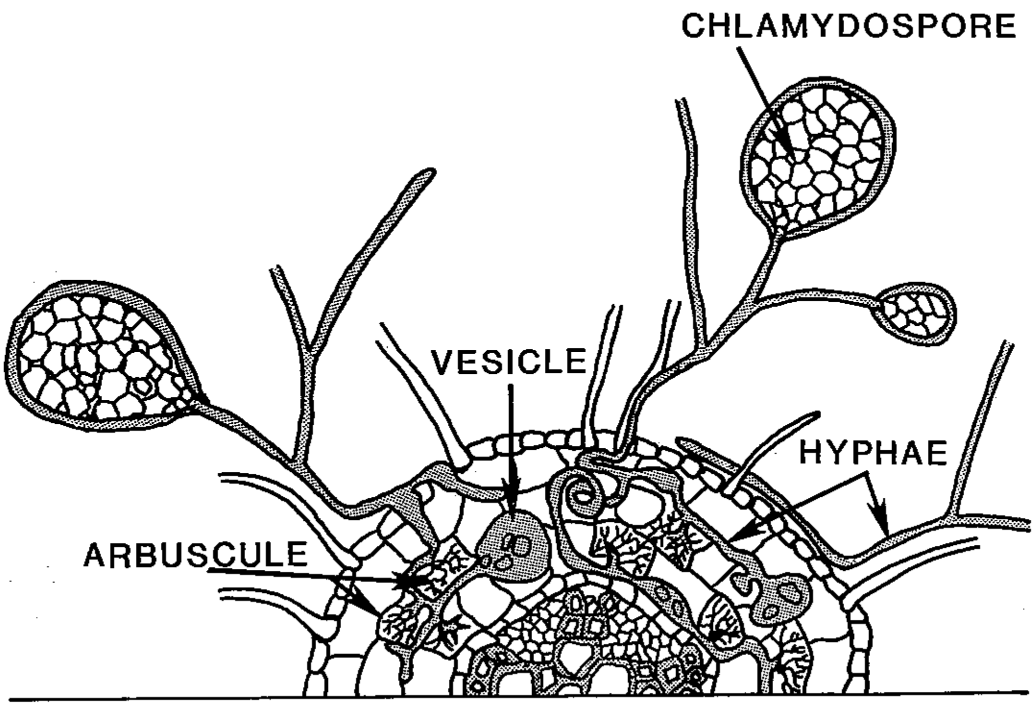

Figure 1. Diagramatic representation of a cross section through a VA mycorrhizal root.

occurrence of nonseptate hyphae solely within the cortex of the root (fig. 1), the formation of very finely branched intracellular structures called arbuscules, and the production of thick-walled inter or intracellular vesicles. The arbuscule is considered to be the primary site of nutrient transfer between fungus and host (Schoknecht and Hattingh 1976). Externally there can be an extensive mycelial system growing along the root and extending outward into the soil. The increase in phosphorus uptake by VA mycorrhizal plants is due to the ability of VA fungi to explore a larger soil volume than plant roots.

Table 1. Benefits derived from the VA mycorrhizal association.

Benefits	References
Increased phosphorus uptake	Smith (1982)
Increased nitrogen availability	Ames et al. (1984)
Increased uptake of minor elements	Cooper & Tinker (1978)
Increased plant growth	Sparling & Tinker (1978) Bryan & Komanik (1977)
Greater drought tolerance	Allen et al. (1981)

Some VA fungi also produce large soil-borne chlamydospores either singularly (fig. 1) or in clusters (sporocarps). Species occurrence and taxonomy of this group of fungi is based on presence and morphology of the chlamydospore (Trappe and Schenck 1982). Various methods have been developed to collect and concentrate VA fungal spores or other propagules from soils; the methods usually developed for a particular soil type (Daniels and Skipper 1982).

OCCURRENCE OF VA MYCORRHIZAE IN MINE SPOILS

Surveys of revegetated mine spoils have generally shown that most plants established on this material as a result of either a reclamation program or that have colonized naturally, are frequently mycorrhizal (eg. Daft and Nicolson 1974; Khan 1978; Reeves et al. 1979; Call and McKell 1982; Kierman et al. 1983). However, nonmycorrhizal species can also become successfully established on these disturbed soils (Doerr et al. 1984). These nonmycorrhizal species are characterized as possessing a weedy growth habit or ruderal strategy (Miller 1979).

Growth increases and greater survival of VA mycorrhizal plants on mine spoils as compared with nonmycorrbizal species have been demonstrated (eg. Daft and Hacskaylo 1977; Aldon 1978; Khan 1981). Results from a study by Lambert and Cole (1980) on the effects of VA mycorrhizae on the growth and establishment of legumes on a strip-mine spoil in Pennsylvania are presented in table 2. They found significant increases in legume growth and survival over a 3 year period.

Although plants growing on mine spoils may form VA mycorrhizae over time, reclamation programs need to consider the length of time until adequate and effective VA associations are established and the possibility that VA fungal inoculum may have to be introduced. Following mining, propagule numbers and occurrence of VA fungi may be significantly reduced if they are present at all. Allen and Allen (1980) reported that spore counts and percent mycorrhizal infection were significantly reduced in a strip-mine spoil as compared with the undisturbed prairie up to 3 yrs after reclamation. Zak and Parkinson (1982) found that an extracted oil sands tailing contained no VA fungal inoculum. Slender wheatgrass plants growing in this material were not observed to be mycorrhizal until the 2nd growing season; at which time infection was light and sporadic (Zak and Parkinson 1983).

Natural recolonization of disturbed sites by VA fungi appears to be very slow (Mosse et al. 1981) and there is some questions as to the means by which VA inoculum is dispersed (Trappe 1981). Movement of inoculum either as spores or root fragments can only be accomplished by the physical movement of soil particles (Gerdemann and Trappe 1974). While wind has been postulated as an agent of dispersal, there is little evidence that VA fungal spores are actually moved in this manner. Trappe (1981) stated that wind action may be an important mechanism for spore dispersal during dry periods in arid habitats. MacMahon and Warner (1984) did collect airborne VA spores, using sticky tape, at a strip mine in Kemmer, Wyoming. Dispersal of VA inoculum has also been observed to occur by the action of animals (McIllveen and Cole 1976; Masser et al. 1978; MacMahon and Warner 1984).

ESTABLISHMENT OF DESIRED PLANT SPECIES

The combination of a slow rate of natural recolonization and the low inoculum levels found in most mine spoils can significantly reduce the ability to establish VA mycorrhizal dependent plant species. Reeves et al. 1979 found that less than 1% of the plant cover on a disturbed area in the oil shale region of western Colorado was mycorrhizal. They suggested that the reduced numbers of VA propagules in disturbed sites prevented the successful establishment of mycorrhizal dependent species. Janos (1980) has also indicated that if VA mycorrhizae are not present or if inoculum levels are low, nonmycorrhizal species will predominate. Once nonmycorrhizal species are established at a site, they can effectively block the introduction of mycorrhizal dependent plants by not providing for the maintenance and increase of VA mycorrhizal inoculum. Allen and Allen (1980) found that Salsola kali, a nonmycorrhizal species, dominated a strip-mine spoil with less than one VA fungal spore per gram for 10 yrs, while this plant would normally occur for 2-3 yrs on undisturbed shortgrass prairie. In a study by Doerr et al. (1984) on the effects of disturbance on plant succession and levels of VA mycorrhizal inoculum in a sagebrush grassland, a high correlation was found between VA inoculum levels following disturbance and grass production. Their study indicated that the net effect of a reduction in mycorrhizal inoculum levels following disturbance was to increase the time until the establishment of mycorrhizal dependent species and thus the time necessary to reestablish a stable system. Allen (1984) has indicated that the rate of plant succession on a disturbed site may be regulated by the rate at which VA mycorrhizal inoculum increases with time. Considering that the majority of plant species used in revegetation programs both in temperate regions of the United States (eg. Kiernan et al. 1983) and in the semi-arid regions of North America (eg. Lindsey 1984) are mycorrhizal dependent species, it becomes important that reclamation methods be developed to (1) ensure the maintenance of naturally occurring VA inoculum in spoil material, and (2) in sites where VA inoculum has been significantly reduced, to provide for the rapid reestablishment of these symbionts in the system.

Table 2. Effect of VA mycorrhizae on the growth and survival of 3 legume species in a strip mine spoil (from Lambert and Cole 1980)[1]

Legume	VA Status	Dry wt (g)/m² 1975	Dry wt (g)/m² 1976	% Survival 1977
Birdsfoot	–	3	3	9
treefoil	+	16*	24*	54*
Crownvetch	–	2	2	7
	+	23*	41*	54*
Flatpea	–	4	2	3
	+	13*	15*	44*

[1]*values differ at $p = 0.05$.

EFFECTS OF AMENDMENTS ON VA MYCORRHIZAL DEVELOPMENT

In that mine spoils are low in available nutrients and organic matter, some form of nutrients and organic matter will have to be added to these sites in order to establish a vegetative cover. Parkinson (1979) has stated that the restoration of an active soil microflora and fauna in reclaimed spoil will also involve the addition of nutrients and organic matter and possibly the reintroduction of specific groups of decomposers and symbiotic microorganisms. Since plant growth and survival are intimately connected to the belowground processes of decomposition and nutrient cycling, reclamation procedures must ensure the establishment and maintenance of belowground communities and processes if reclamation is to be effective over the long term. The type and rate of application of an amendment to a mine spoil will depend in part upon the chemical and physical characteristics of the spoil, the availability of the amendment, and cost. The effects of the ameliarating material on the development of soil processes and the reestablishment of the necessary saprophytic and symbiotic microorganisms need also to be considered. Visser et al. (1984a) reported that an initial application of either fertilizer, peat, or sewage sludge to a subalpine coal mine spoil and an oil sands tailing from Alberta, Canada had significant effects on microbial development and plant growth in these spoils over a 4 yr period.

Since the establishment of VA mycorrhizae in mine spoils should be an important component of an overall reclamation strategy, attention should be given to the effects of reclamation practices on (1) the rates at which plants develop VA mycorrhizae following the application of surface amendments, and (2) the means of enhancing the mycorrhizal status of plants used in revegetation programs. Little information is available, however, on the effects of reclamation practices, such as the addition of inorganic or organic amendments, on VA mycorrhizal development. Studies in agricultural systems (eg. Hayman et al. 1975) have generally shown that additions of N or P fertilizer suppresses VA mycorrhizal development. In mine spoils, the effects of

Table 3. Initial VA mycorrhizal development of slender wheatgrass on amended oil sands tailings and subalpine mine spoils (from Zak and Parkinson 1982)[1]

		% Infection			
Spoil	Weeks	Control	Peat	Fertilizer	Sewage
Oil	2	0	0.6	0	0
Sands	6	0	4	0	0
	10	0.9[a]	23[b]	0	0
Sub-	2	0	5	0	0
alpine	6	4[a]	10[a]	0.5[a]	0
	10	23[a]	58[b]	44[b]	16[a]

[1]Within a row, means superscripted differently differ at $p = 0.05$.

Table 4. The VA mycorrhizal status of slender wheatgrass grown on an oil sands tailing and a subalpine coal mine spoil, 2 and 4 yrs after application of surface amendments (from Zak and Parkinson 1983)[1]

		% Infection			
Spoil	Years	Control	Peat	Fertilizer	Sewage
Oil	2	4[a]	46[b]	1[a]	0
Sands	4	36[a]	62[b]	43[c]	0.3[d]
Sub-	2	42[a]	41[a]	29[ab]	9[b]
alpine	4	70[a]	51[b]	70[a]	32[c]

[1]Within a row, means superscripted differently differ at $p = 0.05$.

fertilizer addition will be dependent on the nutrient status of the spoil and the amount lost through leaching. Sewage sludge has also been used to ameliorate the nutrient poor conditions of mine spoils (eg. Peterson et al. 1979, Pietz et al. 1982). However, very little research has been conducted on the effects of sewage sludge application on VA mycorrhizae. Spitko and Manning (1981) showed that VA mycorrhizal development of onion in an agricultural soil was inhibited by a single application of sewage sludge at rates of 4.7 or 9.4 t dry wt/ha.

The potential use of various inorganic and organic amendments in mine spoil reclamation warrants a critical examination of their short and long term effects on VA mycorrhizae. In a field study in Alberta, Canada, Zak and Parkinson (1982) found that initial rates of VA mycorrhizal development of slender wheatgrass (Agropyron trachycaulum) growing on an oil sands tailing and a subalpine coal mine spoil were significantly affected by the single application of either fertilizer, peat, or sewage sludge (table 3). Percent infection was highest during the first growing season in the peat treated spoils. A later investigation (Danielson et al. 1984) determined that the peat used in the field study did contain viable VA propagules. The occurrence of mycorrhizae at 2 wks only in the peat amended spoils was due to the higher VA inoculum levels and indicated the importance of specific amendments in the rapid reestablishment of VA relationships. Over the long term, Zak and Parkinson (1983) found that the original application of an amendment to the two mine spoils had significant effects on the VA mycorrhizal development of slender wheatgrass (table 4). Mycorrhizae were not detected in the fertilized oil sands tailing until the end of the second growing season. In the sewage-amended tailing, VA mycorrhizae were not observed until the end of the 4th year. In the subalpine soil, VA infection was significantly reduced in the sewage amended spoil during the 2nd and 4th years following the initial application as compared with the control. Zak et al. (1982) also reported that the addition of either fertilizer, peat or sewage sludge to the two mine spoils under investigation had significant effects on the occurrence of VA fungi and spore numbers 3 yrs. after intial application. Spore numbers of Glomus aggregatum were significantly lower in the fertilized and sewage-treated subalpine mine spoil as compared with the control. Spore production by a second fungus, Glomus mosseae was not affected by the amendments. These results suggested that the application of an amendment to a mine spoil could significantly lower VA inoculum production and alter the occurrence of VA fungi.

STOCKPILING TOPSOIL: EFFECTS ON VA MYCORRHIZAE

In areas where sufficient topsoil occurs over an area to be surface mined, U.S. Federal law requires that the topsoil be selectively removed and replaced over the spoil following recontouring. Topsoil has been shown to be an effective amendment for improving the biological, chemical and physical properties of mine spoils; thereby increasing the success of a revegetative program (eg. Grandt 1978; McGinnies and Nicholas 1980). With current strip-mine methods, immediate application of stripped topsoil onto spoil does not occur. Rather, the topsoil is stockpiled until it is needed for reclamation, which can either be as short as several months or as long as several years. Visser et al. (1984a) have indicated that for topsoil to be an effective amendment of mine spoils, there should not be any loss in biological, chemical and physical properties during storage.

Several studies have demonstrated that VA mycorrhizal inoculum potential declines following the stockpiling of top soil (Gould and Liberta 1980; Reives et al. 1980). Although plants growing in stockpiled topsoil do develop VA mycorrhizae, the rate of mycorrhizal development is significantly less (table 5). Visser et al. (1984c) found that stockpiling of a prairie topsoil for 3 yrs resulted in lower

Table 5. Mycorrhizal inoculum potential (MIP) and % infection of corn plants grown in stockpiled topsoil (from Liberta 1981)[1]

Treatment	MIP	% infection
)ld Field	85[a]	68[a]
. yr - stored	57b	42[b]
! yr - stored	12[c]	7[c]

[1]Within a column, values followed by the ame letter are not significantly different at p 0.05.

mycorrhizal inoculum and a shift in VA fungal species. They suggested that the lag in VA development of slender wheatgrass in the stockpiled topsoil compared with the undisturbed soil may have been due to differences in VA species associated with the root systems rather than reduced VA inoculum levels. VA fungi have been shown to differ in their rates of infectivity (Sanders et al. 1977). If plants are more dependent on VA mycorrhizae during the seedling stage (Mosse et al. 1981) than at a later period of growth, a delay in VA mycorrhizal development in stockpiled topsoil could result in poor growth and survival if plants are stressed during the seedling stage. As stated earlier, factors which affect the rates at which plants used in revegetation develop VA mycorrhizae should be taken into consideration during the planning of a reclamation program.

Table 6. Role of VA mycorrhizae in ecosystem functioning.

1. Nutrient cycling
2. Soil stabilization
3. Regulation of plant species composition
4. Regulation of the rate of plant succession

CONCLUSIONS

VA mycorrhizal associations are recognized as important components of most terrestrial habitats and have been shown to effect several key ecosystem processes and characteristics (table 6). In recent years, there has been increased attention given to the importance of this symbiotic association in the growth and survival of plants used in the revegetation of mine spoils. VA mycorrhizae should not be seen as a panacea for the problems associated with mine spoil reclamation, but as a necessary component of an overall reclamation strategy.

If the rapid reestablishment of VA mycorrhizae with plants grown on mine spoils is to occur, attention should be given to determining initial VA inoculum densities in the spoil material and in developing reclamation procedures which promote both mycorrhizal development and optimum plant growth. Since some form of fertilizer and organic matter will have to be added to these sites, amendments should be chosen and applied at ratea which can achieve this goal. Reclamation programs will have to balance short-term needs, such as rapid vegetation development for erosion control, with the long-term goal of establishing a functional stable system.

In spoils where VA inoculum levels are low, it will be necessary to add inoculum to the site to ensure rapid mycorrhizal development. This may be accomplished either via an amendment such as topsoil or by outplanting VA mycorrhizal seedlings. The latter is only practical with shrubs and trees. Current technologies are not adequate for the wholesale production and incorporation of VA fungal inoculum into mine spoils. Wood (1984) has also commented that current demand by the reclamation market does not appear to be sufficient over the next decade to offset the cost of developing the technologies for large scale production of VA fungi. However, over the long-term, VA mycorrhizae may be more cost effective for the reclamation of mine spoils than continuous fertilization.

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