ORGANIC SOIL AMENDMENTS AND FIBER WATTLES FOR ENHANCED REVEGETATION AND EROSION CONTROL

by

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Abstract. Disturbed sites at surface mines that typically require special attention to erosion control include cut and fill soil slopes, runoff-diversion swales or ditches, and other similar areas where revegetation is hampered by the surface exposure of sterile subsoils and by the lack of topsoil. Recent field work in the western U.S. has demonstrated that organic soil amendments and biostimulants can significantly enhance sustainable revegetation at such sites. These additives help restore healthy microbial activity in the soil to encourage plant growth and decomposition, as well as to promote the recovery of mycorrhizae in the soil, a critical component for successful revegetation. When soft structural controls are needed to slow runoff and protect new vegetation, the use of fiber wattles has proven to be economical and effective.

Additional Key Words: reclamation, soil biostimulants, mycorrhizae, WEPP

Introduction

In many places of the semiarid Western U.S., revegetation of severely disturbed surface mining sites can be exceedingly difficult due to dry climates and the damage to topsoil regimes. Furthermore, most native plant species rely on mycorrhizal fungi associations within their root systems to survive the stresses induced by infertile soils, drought, and seasonal climate extremes. Mycorrhizae and their strands of hyphae (network of organic threads) form a critical symbiotic relationship with many types of plants, acquiring nutrient resources and moisture from the soil in exchange for photosynthates (e.g., sugars) supplied by the plant (Wicklow-Howard 1994; Marx 1996).

The two common types of mycorrhizal fungi are vesicular-arbuscular (VA) endomycorrhizae (typical to many rangeland grasses, forbs, and herbaceous plants) and ectomycorrhizae (typical to woody species, shrubs, and trees). The symbiotic process is highly energy efficient, because a plant would need to have 100 times more photosynthate to produce roots to cover the same volume as that occupied by the mycorrhizal hyphae (Rosseau 1994). At sites disturbed by excavation, stripping, or mine-waste storage, the topsoil that contains essential mycorrhizae colonies and microflora is removed or degraded, and successful revegetation for erosion control and land reclamation will require reintroduction of the local fungi (via spores and propagules) and the proper plant species, as well as organic soil amendments to encourage reestablishment of those colonies. This often is a difficult task in mountainous and arid regions of the West where the rich zone of microlife is usually less than 150 mm thick at the ground surface and has been damaged by disturbance activities related to mining.

If the reclamation site is expected to experience significant runoff from storm water or snow melt, then temporary erosion and sediment control (ESC) practices should be implemented while the revegetation program takes hold. Chemical and organic soil binders, erosion control blankets, mulches, and fiber wattles can be effective treatments on slopes and in runoff conveyance channels, where vegetation establishment is critical to a successful reclamation program.

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When rehabilitating a disturbed site, treatments that combine revegetation and surface amendments have been shown to be more effective in controlling erosion than either revegetation or surface amendments alone (Megahan and others 1992). Selection of an appropriate treatment(s) depends on factors such as local soil and climate conditions, topography, runoff controls, product availability, economic factors, and proposed follow-up management plans for the site. For example, over larger areas that exceed a half hectare, the practicality (irregular ground surface and rocky soil) and expenses (roughly $1.00 to $2.50 per square meter) of installing erosion control blankets on slopes will tend to favor alternative applications, such as hydroseeding with mulch and a high-quality soil binder (roughly $0.60 to $0.90 per square meter). In contrast, for runoff conveyance channels, soil binders and mulches likely will be inadequate to withstand water flows, and properly selected erosion control blankets to protect the seeded channels (or swales), along with fiber wattles used as sediment check dams, will be the preferred treatment.

Selection of Plant Species

Although there often is an emphasis on reestablishing only native plant species on reclamation projects, recent experience with revegetation of difficult sites in the semiarid West has indicated the importance of using both native and introduced, well adapted species that encourage the reestablishment of mycor-rhizal colonies and that are able to grow in a low-nutrient, low-organic environment. Such species naturally invade disturbed sites with little or no topsoil and set up prerequisite conditions for effective, long-term revegetation and erosion control. In many cases, the most desirable of these first-succession species are not the nonmycorrhizal weedy annuals, but rather the facultative mycotrophs (species that can be mycorrhizal and nonmycorrhizal, but initially may have low dependency on mycorrhizae), such as lamb's quarters - *Chenopodium album,* western wheatgrass - *Agropyron smithii,* and fourwing saltbush - *Atriplex canescens* (Trappe 1981; Pfleger and others 1994). Our experience has shown that rabbitbrushes - *Chrysothamnus* and some sagebrushes - *Artemesia* are important early stage plants. Also, studies have shown the importance in revegetation programs of using mycorrhizal legumes, such as flatpea - *Lathyrus sylvestris,* birdsfoot trefoil - *Lotus americanus,* and crown vetch - *Coromilla varia* (Lambert and Cole 1980). Knowing the types of plants commonly found in association with species like these is critical to establishing healthy successions and sustainable plant communities. Caution must be exercised when selecting species that are preferred forage by wildlife; for example, elk have been known to demolish revegetation sites when certain vetches are present.

Oftentimes, successful plant communities tend to be site specific and may vary considerably due to changes in soil conditions (e.g., composition, texture, degree of compaction), slope steepness and aspect, elevation, micro-climates, and competition from other nearby plant communities. Prudent selection of seed mixes and planting programs requires careful observations of these conditions and factors. Nearby native plant communities provide important information, and seed selections should rely on such sources or on sites with similar climate and soil conditions. If possible, a reclamation project should use seed harvested within 150km of the project site, and within a range of 160m elevation. The ecospecific nature of many indigenous species is a critical factor in designing successful revegetation programs.

For most applications in the semiarid West, dormant seeding is essential. That is, the seed should be applied in the late fall or during the winter. In addition, careful supervision is recommended to ensure that seeding and treatment specifications are followed by the contractor. All seed tags should be verified and all treatment quantities monitored; mixing and application instructions should be followed. No substitutions or change orders should be allowed without prior approval of the specifier.

Soil Amendments

In rangeland conditions, VA mycorrhizal fungi produce fruit as single spores in the soil, which then can be transported via wind-blown dust, small mammals, birds, and insects (Trappe 1981). To encourage more timely and effective recovery of disturbed sites, they can be inoculated with locally borrowed and stockpiled topsoil, which contains plant seeds and fungi spores whose viability greatly decreases with storage time. Thus, stockpiling of topsoil (especially when done in thick accumulations) is most beneficial when storage time is limited to a few months. For longer storage periods, while topsoil texture and composition are preserved, the microlife and biological activity of the soil deteriorate significantly.

Laboratory propagated generic mycorrhizal inoculates also can be used to reintroduce fungi to disturbed sites, but they have shown limited effectiveness in the semiarid West due to site specific adaptations of fungi and widely variable characteristics of this region. Microflora, micro-organisms, and mycorrhizae associations have been observed to be highly adaptive and oftentimes unique to the specific attributes of individual sites. Even if commercial inoculates were successful, they could not be economically applied over wide areas and would be restricted to local "islands" of treatment.

Sometimes, the reintroduction of topsoil is not adequate to initiate proper plant succession or may not be economically feasible due to handling costs or the lack of locally available topsoil. The importation of topsoil to sites that have slopes steeper than 2.5:1 (horizontal to vertical) may cause potential slope stability problems, because usually the new soil is not tilled or mixed in with the underlying materials, forming a loose top dressing that is prone to sliding and debris flows during heavy rains or rapid snow melts. Track compacting with heavy equipment can help stabilize this surface layer of topsoil if there is a rough substrate, but if the substrate is fairly impermeable and resistant to water infiltration, then potential subsequent slippage may not be alleviated by such compaction. Thus, it may be necessary to use soil amendments that facilitate soil microbial development and succession. Some researchers have identified the importance of reintroducing to a disturbed mine site all components of a soil microbial community to bolster mycorrhizal colonization, including such things as enzymes, organic matter, carbon, and nutrient sources to help buildup the soil microflora and microfauna (Pfleger and others 1994). Others have indicated that ectomycorrhizal fungi associations prefer a soil environment where a greater proportion of soil nitrogen is present in organic form (Smith and Read 1997), which can be added via soil amendments that contain non-water-soluble nitrogen in the form of seed-meal components.

Recent field trials and full-scale project applications conducted by the authors have indicated that such organic, protein-rich, seed-meal products that also contain composted poultry manure and humates can significantly enhance the revegetation of disturbed sites, especially when used in conjunction with soil biostimulants and microbial enzymes. Organic fiber bulk and other soil-building amendments encourage healthy soil ecology and sustainable plant growth in contrast to the "thrive-and-crash" revegetation attempts often associated with chemical fertilizer ("nitrogen pulsing") or low-potency bovine manure compost applications on disturbed sites (McKell and others 1991).

Temporary Surface Treatments

Temporary surface treatments are needed to protect slopes from erosion while the newly seeded vegetation is becoming established. These treatments can be divided into several categories, including mulches, soil binders/tackifiers, and surface structures that restrict and slow overland flows. Mulches generally are thought of as organic products (straw, wood fibers, cellulose, tree bark), but they also may consist of clean gravel or crushed rock up to 300-mm size (rock mulch), which provides a more permanent, but less aesthetic, slope protection than the temporary organic materials. Often, hydro-application is the most cost-effective way to spread organic mulch on a slope, but when antecedent wet soil conditions make it difficult to apply more water to the slope due to the increased erosion potential, the mulch should be spread by hand or by dry choppers/blowers. Application rates of about 2.24 tonnes/ha (1 ton/acre) for organic mulch are common. Mulch coverings also can be applied via erosion control blankets, which are unrolled and stapled on the slope, or via a bonded-fiber-matrix mulch that resembles a thick, blown-in-place "blanket" of tackified mulch (applied with a hydromulching machine). Helicopter application of mulch slurries also is an option for large areas or remote sites.

Most of the organic-based or clay-based tackifiers used in hydroseeding or hydromulching are designed to "stick" the mulch down to the ground surface, not to bind the soil particles together. Therefore, a heavier-duty soil binder may be needed for temporary erosion control on steeper slopes; when revegetation is the goal, salt-based or hydrocarbon-based binders (such as the type used for dust control) should be bypassed in favor of emulsions or biodegradable polymer products that can penetrate the ground surface to form a thin cohesive layer. One such product specifically formulated for this purpose, Henkel Terra Control™ (known as Atlas SoilLok™ in North America) forms a biodegradable, elastic, permeable, lattice-like network structure that binds together the upper few millimeters of soil and consequently helps prevent erosion during germination and vegetation establishment.

In addition to the surface treatments described above, slopes that are long and fairly steep also may require temporary structures to disperse the energy of overland runoff; chisel grooves, mini-terraces, fascines (bundles of branches), and fiber wattles can be used on the slope. Wattles are long (typically 8m in length), flexible, sausage-like bundles of straw or flax fibers that are staked down on the ground to provide runoff barriers. They can be used effectively along contours on large slopes undergoing revegetation and reclamation, as well as in drainage swales or ditches as check dams that form small sediment traps. Installed costs typically range from $6.50 to $8.00 per lineal meter ($2.00 - $2.40 per linear foot). During installation, they must be properly trenched in place (to prevent undercutting by runoff), laid along contour, and have proper end protection (ends turned uphill or the use of small earthen dikes) to help prevent lateral end-around runoff erosion. It is preferable to leave these materials permanently on the slope to become part of the landscape, and thus, avoid having to re-access the slope to remove them after vegetation is established.

Case Studies

High Altitude Mine Reclamation

A major revegetation program was conducted in 1995-96 on steep (2:1 and greater), erodible slopes at the Beartrack Mine in the mountains of Central Idaho, near the town of Salmon. Organic soil amendments selected for the project included Quattro Fertil-Fibers™ (a seed-meal and composted poultry-waste product with carbon and humates and an N-P-K ratio of 6-4-1) applied at 1 ton/ac. (2.24 tonne/ha) and Quattro Kiwi Power™ (a concentrated liquid complex with microbial stimulants, enzymes, cytokinins, and sarsapogenin, all necessary for developing and sustaining plant life in sterile soil conditions) applied at 7 gals./ac. (65.5 liter/ha). In prior experience, the authors have seen this latter product promote the health of plant species that are mycorrhizal dependent, indicating that it may accelerate the microlife rebuilding process in disturbed soils. In addition, higher-than-recommended levels of Quattro Cliffhanger™ tackifier, as much as 150 lb./ac. (168 kg/ha), were used in the hydroseeding application to help hold the soil treatments on the slopes.

Care was taken to select only locally adapted seed for the revegetation program. Chemical analyses of exposed subsoils showed deficiencies in elemental sulfur, so some was included as part of the treatment. Primary target areas were road cuts within the active mining area and those that accessed the mine facilities. Wetland areas downslope from the mine also were treated. Application of the seed and soil amendments was restricted to the late fall season, and was carefully monitored on site to ensure that design specifications were met by the contractor. The hydroseeded treatments survived the runoff from a 25-yr storm soon after they were applied. A very successful revegetation program resulted during the first full growing season, even in areas where previous seeding efforts had failed. The project received an environmental restoration award from the Idaho Mining Association.

Arid Mine Land Reclamation

A similar treatment of organic soil amendments was used in a recent revegetation program at the Black Pine Mine in the semiarid high desert of Southern Idaho. The growth media consisted of sterile subsoils, and many sites were steeply sloping at near the angle of repose (1.3:1, H:V). Target areas also showed high pH (>7.3) and a high calcium carbonate content.

Designing the seed mix was based on identifying local, well-adapted plant communities and selecting appropriate species. Hydroseeding was done in the late fall to ensure a dormant seeding process. Sites with difficult access were seeded and mulched using a slurry delivered aerially by helicopter. As with similar projects based on the Quattro soil amendments, a one-pass application was used to lay down the seed, amendments, and mulch. Treated sites showed well-established vegetation during the first growing season. Even sites which initially had resisted reclamation efforts appeared to be on their way toward sustainable plant communities and long-term erosion control.

Use of Fiber Wattles

Fiber wattles installed along contours on revegetated slopes or in drainage ditches can provide significant erosion and sediment control by dispersing the runoff laterally and trapping sediment on their upslope sides. If exposed slopes have poor soils and organic amendments are needed, the small mini-terraces formed by wattles encourage those amendments to stay in place and not be washed away. Also, past studies in roaded forest terrain have shown that "slope obstruction index" is the field characteristic most related to sediment transport distance (Haupt 1959), and wattles directly provide effective slope obstruction features.

The parallel spacing of fiber wattles installed along contours on a slope typically is specified by manufacturers in the range from 2.5 to 8 m, but we could find no design guidelines or specifications based on slope steepness and soil type. Therefore, we investigated the feasibility of applying the WEPP (Water Erosion Prediction Project) model (Flanagan and Livingston 1995) to help with designing the spacing layout. The results from one study of a constructed fill slope comprised of silty subsoils are summarized below.

Assuming an average wattle diameter of 240 mm and a typical burial (trenching) depth of 90 mm, the effective sediment-trapping height of a given wattle is 150 mm as measured normal to the slope surface. Then, the sediment-storage capacity of the wattle can be calculated as the triangular wedge directly upslope of the wattle (Figure 1). We assumed that the upper 30 mm of this wedge should not be included in the sediment-storage capacity, but rather should be reserved in the design as a temporary ponding area for runoff water (this allows for some water storage before the runoff spills over the wattle and flows downslope). The design volume for sediment storage upslope of the wattle then was calculated for various slope angles (see Table 1). The mass of sediment storage was obtained by multiplying the storage volume times an assumed density of 1,300 kg/m^3 for uncompacted, hydraulically deposited sediment. The WEPP computer model was used to predict sediment yield due to a given local design storm that might occur in the early spring immediately following a seeding program, but prior to the establishment of significant vegetation on the slope.

Thus, using physical characteristics of the local soil and simple, planar slope elements of bare soil, WEPP provided estimates of sediment yield (in kg per running meter of slope) for various upslope lengths (i.e., assumed spacing distance for wattles up the slope). This procedure assumed that each wattle would retain the runoff and sediment from the slope element directly above it, extending either to the top of the slope or up to the next wattle installed upslope. Table 2 contains example output from these computer analyses for the constructed fill slope (embankment).

Designing the layout of the flax-fiber wattles then was based on a comparison of the sediment yields with the wattle capacities given in the third column of

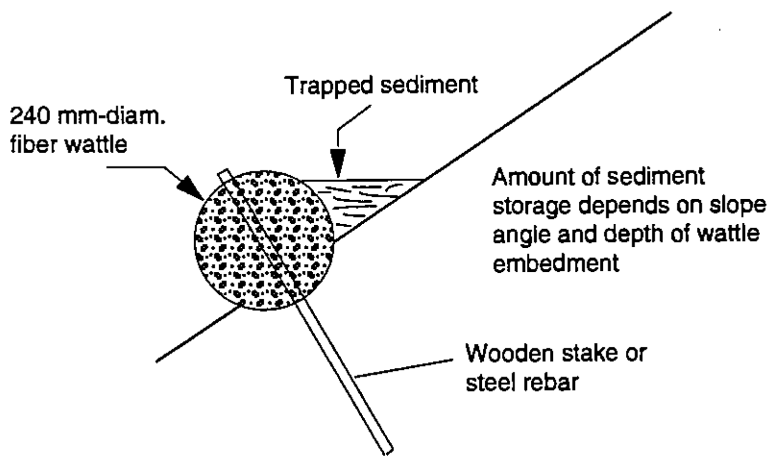

Figure 1. Sediment Captured by a Fiber Wattle Installed on a Moderately Steep Slope

Table 1. Estimated Design Storage Capacities for Sediment Trapped Upslope of a Fiber Wattle

Slope Angle	Storage Volume (m^3 per m of run)	Storage Mass* (kg per m of run)
3:1 (18.4°)	0.0169	21.97
2.5:1 (21.8°)	0.0140	18.20
2:1 (26.6°)	0.0112	14.56
1.5:1 (33.7°)	0.0084	10.92

*Based on a dry unit mass of 1,300 kg/m^3 for the hydraulically deposited sediment.

Table 2. WEPP-Predicted Sediment Yields (kg/m) for Planar Slope Elements Between Wattles (silty loam slope)

A. Design storm: 24-hour event with 71.1 mm (2.8 in.) of rain

Slope Angle	Upslope Length of Slope Element (spacing between wattles) 3 m	6 m	9 m	12 m
3:1 (18.4°)	5.73	12.71	20.76	29.80
2.5:1 (21.8°)	6.16	13.75	22.55	20.76
2:1 (26.6°)	6.65	14.92	24.59	35.52
1.5:1 (33.7°)	7.16	16.21	26.86	38.96

B. Design storm: 24-hour event with 50.8 mm (2.0 in.) of rain

Slope Angle	Upslope Length of Slope Element (spacing between wattles) 3 m	6 m	9 m	12 m
3:1 (18.4°)	2.81	6.51	10.97	16.14
2.5:1 (21.8°)	3.05	7.10	12.02	17.74
2:1 (26.6°)	3.31	7.78	13.25	19.62
1.5:1 (33.7°)	3.60	8.54	14.63	21.77

C. Design storm: 24-hour event with 30.5 mm (1.2 in.) of rain

Slope Angle	Upslope Length of Slope Element (spacing between wattles) 3 m	6 m	9 m	12 m
3:1 (18.4°)	0.83	2.10	3.78	5.83
2.5:1 (21.8°)	0.92	2.34	4.22	6.53
2:1 (26.6°)	1.02	2.62	4.76	7.37
1.5:1 (33.7°)	1.13	2.95	5.38	8.37

Table 1. Assuming the 71.1-mm precipitation event, the treated slope (which had a steepness of between 2:1 and 2.5:1) would require a wattle spacing of about 6 m (20 ft). Rather than basing the analysis on a single design storm, WEPP also could be used to simulate local climatic conditions over a period of time and then accumulate the sediment yields.

Wattles should be properly trenched in and then staked at regular intervals of about 1.2 m (i.e., use 6 to 7 stakes per each 7.6-m long wattle). The steeper the slope, the greater the overhang will be on the upslope side of the trench, and the more difficult the trenching operation will be. In fact, on steep slopes approaching 1.3:1 (37°), the trenches will look more like flat ledges. Examples of fiber wattle installations are shown in Figures 2 and 3.

Conclusions

Successful revegetation of disturbed mining sites requires an integrated approach based on restoring healthy soil ecology through the use of organic soil amendments, proper selection of plant species, and temporary protection of the ground surface against erosion. Our experience indicates that rebuilding soil microlife, including the important component of mycor-rhizal fungi, can be accelerated by the use of fiber bulk that contains organically-bound nitrogen in a protein-rich, seed-meal and poultry manure mixture and by the use of liquid organic complexes. Investigations are continuing into the "why" and "how" of this process. Though the bio-mechanics of this soil restoration activity is not fully understand, recent field experiences and case studies (similar to the ones presented above) continue to add convincing evidence that such organic soil amendments out-perform traditional chemical/ mineral fertilizer treatments on disturbed sites with sterile soils.

Proper assessment of physical conditions at the reclamation site and a characterization of nearby mature plant communities should be relied upon to select seed mixes for establishing early-stage plant

Figure 2. Fiber Wattles Installed on a Large Embankment Slope Prior to Hydroseeding and Application of Organic Soil Amendments

Figure 3. Fiber Wattle Installed as an Effective Check Dam and Sediment Trap in an Interceptor Ditch

species that will lead to accelerated development of long-term, stable plant communities. On severely disturbed sites, special attention should be given to those plant species that can invade sterile sites and help establish conditions for increased microbial and mycorrhizal activity, which are essential for long-term, sustainable vegetation and erosion control. In most cases, dormant seeding in the late fall or winter should be prescribed. Contractors should be monitored closely to ensure that project specifications are met.

Organic soil binders and tackifiers are useful for holding the seed, soil amendments, and mulch on slopes, and to protect the newly treated areas from erosion. Soft structural controls in the form of fiber wattles also provide protection against erosion during the critical early stages of revegetation on slopes. Wattles even can be used as effective sediment traps (small check-dams) in runoff conveyance channels or swales. Regardless of their field usage, fiber wattles provide effective obstructions to surface runoff, and they can be left on-site to become part of the permanent reclamation landscape.

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