BOREAL RESEARCH INSTITUTE

BOREAL RECLAMATION PROGRAM

SOIL BIOENGINEERING FOR SITE RESTORATION[1]

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November, 2013

INTRODUCTION

Increasing use and/or degradation of ecosystems requires development of effective strategies for restoration. Urban developments, industrial uses, including mining, oil and gas and forestry, as well as agricultural expansion impact ecosystems, either directly through habitat loss or indirectly by changing ecological conditions. Mining, oil and gas developments and forestry activities can result in significant ecological degradation. Soil bioengineering treatments can be used to treat drastically disturbed sites and return lost ecosystem functions and processes.

Soil bioengineering is the use of living plant materials to perform some engineering function (Schiechtl 1980). Various soil bioengineering systems can be used to address degraded ecosystems. Treatments using soil bioengineering systems can range from simple live staking to complex systems designed to stabilize steep, eroding or unstable slopes (Schiechtl and Stern 1997). The plant materials, usually dormant cuttings, used in soil bioengineering systems sprout and take root. The plants used in soil bioengineering are typically pioneering species so the vegetation established with soil bioengineering treatments is early seral and ideal for treatment of damaged or degraded sites (Polster 1989). By using early seral species the restored site is re-aligned with the natural successional trajectory for the area.

Labour for soil bioengineering projects can come from trained crews or from untrained community stewardship groups. Since the techniques are simple and the materials can be collected locally, soil bioengineering treatments are ideally suited to the treatment of small, local problems with local people. However, soil bioengineering can also be used to treat large sites. The basic premise with soil bioengineering treatments is that there is strength in numbers. Where a large eroding slope is causing a problem, rather than building some large structure such as a large retaining wall at the bottom, the soil bioengineering solution would involve a whole series of small retaining walls all the way up the slope (see wattle fences below). Similarly, when erosion problems threaten a streambank rather than building a large rip-rap slope, a soil bioengineering treatment would apply hundreds or even thousands of cuttings (see live gravel bar staking below) that would slow the near surface flood flows and thus prevent the substrate from being eroded and in some cases even allow suspended sediments to be deposited.

This technical note presents the use of soil bioengineering systems for treatment of sites that have been damaged, degraded or destroyed by the activities of humans. Soil bioengineering systems can help to re-establish the natural successional trajectory of ecosystems that have been negatively impacted by humans. As ways in which humans can live lightly on the landscape are sought, soil bioengineering offers treatments that can be applied by local stewardship groups as well as municipal workers. In industrial settings, soil bioengineering offers alternatives to the traditional hard engineering that is applied for slope failures and degraded sites. The soil bioengineering systems discussed in this technical note are more fully described in Polster (2011).

PLANT MATERIALS

Soil bioengineering methods use living plant materials to build structures to stabilize the problem site. As such, the construction materials must be strong enough to withstand the forces acting on them. In addition, since the intention of building the structures of living materials is that these materials will sprout and grow, the materials must be in a condition that will promote their subsequent growth. The plant materials are typically stem cuttings and must therefore be capable of forming new roots and shoots without special mist tents and bottom heat used in nurseries for plant propagation. Willows (*Salix* spp.), cottonwood (*Populus balsamifera* L.) and red-osier dogwood (*Cornus stolonifera* Michx.) are the most abundant woody native western Canadian species that have been found to reliably root from stem cuttings.

Willows and cottonwood are most commonly used for soil bioengineering projects. These species are used due to their aggressive growth on disturbed sites. The nomenclature of willows is notoriously difficult and the exact identification of the willows used in a soil bioengineering project is not necessary. Typically common willows such as Scouler's willow (*Salix scouleriana* Barratt in Hooker), Pacific willow (*Salix lucida* Muhlenberg), pussy willow (*Salix discolor* Muhlenberg) and glaucous willow (*Salix glauca* L.) are used. Although the nomenclature of the willows that are used is not important, it is essential that species be selected from habitats that approximate those found on the reclamation site. For instance, treatment of a dry raveling slope composed of sandy gravel would not be very effective with willows that were collected from around a marsh. Red-osier dogwood is particularly useful where the treatment site is under the canopy of other vegetation and not in direct sun.

Cuttings used in soil bioengineering projects should follow the "rule of thumb" that is, if it is not as big in diameter as your thumb it is too small. Minimum diameter of the cuttings at the tip end should be at least 2.5 cm, and larger cuttings tend to work better than smaller ones as long as they are not old and decadent. In terms of length, cuttings should be at least 40 cm long and where structures such as wattle fences are being built, the cuttings should be as long as possible. Cuttings that are 6 or 7 m in length can be used to make very strong structures. Trim all of the small branches and twigs from the cutting before using it in a structure. Where live pole drains are being built, trim smaller twigs but pencil sized twigs can be left on the cutting as long as they do not have leaf or twig buds on them.

The cuttings that are collected for soil bioengineering projects need to be handled in such as way that they will retain their viability. Keeping the cuttings cool and moist and avoiding excessive damage to the cambium will help to retain viability. In addition, soaking the cuttings in water for up to 10 days has been found (Becker 2002) to stimulate root development in un-rooted cuttings. Cuttings should be collected during the dormant period for the plant (late fall to early spring) and where timing does not permit immediate use of the cuttings, they can be stored in a cold storage facility (0 to 1 degree C) for several months as long as they are kept moist. Storage of collected cuttings in snow banks has been found to be very effective.

TECHNIQUES AND DISCUSSION

Wattle Fences

Wattle fences are short retaining walls built of living cuttings. Figure 1 shows the typical design for wattle fences. Wattle fences are used on sites where over-steepened slopes are preventing growth of vegetation. As the cuttings are fairly well exposed, wattle fences work best where there is ample moisture available to sustain the growth of the cuttings. Other techniques such as modified brush layers can be used where sites are drier. Wattle fences can be very effective on streambanks where the moist conditions supports the growth of the cuttings and the stepped back design allows flood flows to pass without damage. In addition, the water flows against the cuttings that provide a resistance to erosion, thus protecting the bank from erosion. Wattle fences can be used on very steep slopes as long as the slope itself is globally stable. At the University of British Columbia wattle fences have been effective at revegetating the sand cliffs with an average slope of the in-situ materials of 70 degrees (Photographs 1 and 2). Wattle fences can be particularly useful where moisture sensitive soils are sliding down the slope as they will hold the soil and allow the moisture to drain, improving the stability of the soil.

Photographs 1 (left) and 2 (right). Wattle fences were used to treat the sand cliffs at the University of British Columbia. Red arrows show an untreated buttress in the background.

The support for wattle fences can be either stout cuttings as shown in Figure 1 or 15 mm steel concrete reinforcing bars (rebar). Where rebar is used care must be taken to avoid the hazard created with steel bars protruding from the slope. Where cuttings are used, care must be taken while installing the cuttings to ensure they are not damaged too much. Creation of pilot holes and the use of short tapping strokes to drive the cuttings in can prevent excessive damage. When cuttings are used, the cuttings as well as the cross pieces grow and contribute to the vegetation on the slope.

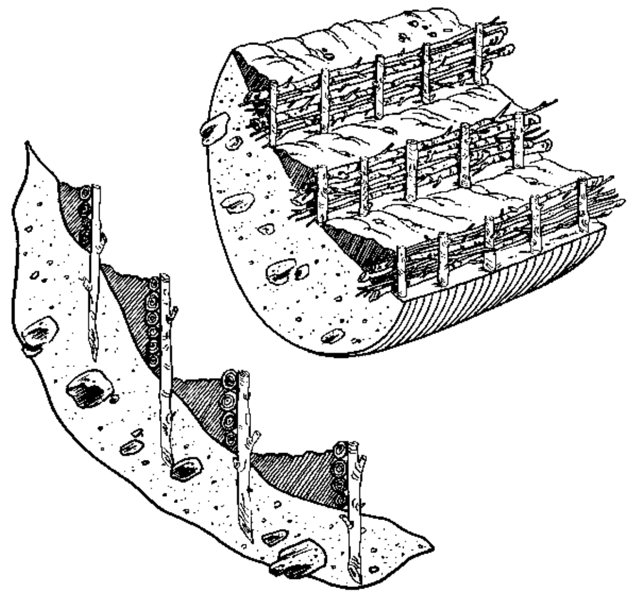

Figure 1. Wattle fences can be used to treat over-steepened slopes. The terracing created by the wattle fences reduces erosion while the growth of the cuttings provides a dense cover of pioneering woody species on the slope.

Live Bank Protection

Live bank protection consist of wattle fences along the bank of the stream to create a woody buffer against further erosion. The construction of the live bank protection must be sufficiently dense so that erosion is avoided. Sometimes twigs and trimmings from the cuttings can be used to fill in gaps between the cuttings and thus avoid erosion. Once the cuttings used in the live bank protection sprout and grow, the resulting vegetation provides good protection against erosion. Live bank protection can be particularly effective along the edges of newly constructed ditches. Brush mats (see Schiechtl and Stern 1997) can be used with live bank protection where erosion is excessive.

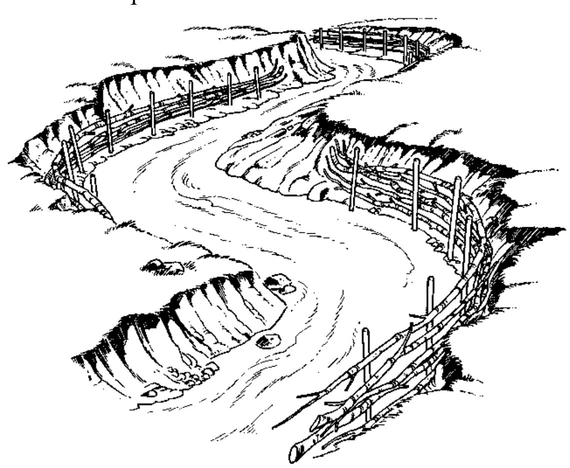

Figure 2. Live bank protection shown here without backfill. Note that the ends of the structures are carefully placed to avoid areas where the current is actively eroding the bank.

Live Pole Drains

Live pole drains are constructed of bundles of living cuttings and are used to provide a preferred flow path for soil moisture and therefore add stability to sites where excess soil moisture is resulting in soil instabilities (Figure 3). The bundles of cuttings are placed in shallow trenches in such a manner that they intersect and collect the moisture. The bundles are then lightly buried with local materials, taking care to avoid over-burial. Careful trimming of the cuttings is not required, although the bundles should be as tight as possible. The plants used to form the bundles sprout and grow, with the moisture continuing to drain from the lower end. Sites where excess soil moisture results in site instability can be treated with live pole drains. Traditional engineering solutions often entail the installation of "French drains" or loading the face of the slope with rock. However, live pole drains can be used to drain excess moisture from the site and provide a cover of woody vegetation. The growth from the live pole drains forms the initial cover on the seepage site, allowing other species to invade. As with other soil bioengineering techniques, live pole drains must be designed to suit the specific conditions of the site.

Live pole drains act to provide a preferred flow path for soil moisture. The moisture moves into the drain bundle and runs down the cuttings to the end of the drain. Numerous bundles can be fitted together to make long drains. The drains immediately start to drain the slope. The drains shown in Photograph 6.4-5, installed in 1985 continue to drain moisture from this slope. As the roots of cuttings used to construct the drain grow out from the bundle into the surrounding soils, the cavity provided by the drain is preserved even when the original cuttings have been lost over the years (Photograph 6.4-6 and 6.4-7).

Figure 3. Live pole drains can be used to stabilize slumping soils. This view shows the layout of live pole drains in a slump with the covering soils removed for clarity. The section shows a typical covering (1 - 2cm). Some twigs from the bundles should be left above ground.

A variety of different shapes can be used for the drains depending on the site conditions. A "Y" pattern of the drains can be used to collect moisture from a diffuse seepage zone (Photograph 3) while a linear pattern can be used where a discrete seepage site exists. The objective in design of the drains is to collect all of the moisture and to drain it away as quickly as possible. The drains grow into a dense stand of hydrophytic vegetation, which is exactly what nature would produce given enough time. This technique fits into the successional restoration scheme better than conventional "French" drains would. In addition, live pole drains can be installed without machine access and at fraction of the cost of traditional hard engineering solutions. Soil slumps such as those that occur the first spring after road construction or deconstruction operations can be stabilized using live pole drains.

Live pole drains are constructed by excavating a shallow trench from the site of seepage down the slope and away from the problem area. A bundle of cuttings is placed in the trench and lightly backfilled with local materials. The bundle is composed of cuttings with tips and butts alternating. The bundle is tied with bailing twine or mechanics wire as tightly as possible. Twigs and branches down to pencil sized twigs should be kept on the cuttings where possible as long as this does not result in too loose a bundle. Avoid retaining any twigs with buds on them as these will produce shoots before the roots have a chance to grow. Sites that are particularly wet may require rocks to hold the bundles down in the trench. In these cases, it may not be possible to actually excavate the trench, and the bundles can be inserted by standing on them and pushing them down into the mud. The key to live pole drain construction is to establish the drains in the area of seepage so that the drains provide a controlled alternative for the moisture to escape from the bank.

Photograph 3. Live pole drains can be used to treat moisture-related slumping sites.

<u>Modified Brush Layers</u>

Modified brush layers (Figure 4) are essentially a brush layer (Gray and Leiser 1982) supported on a short, small log or board. The use of a log or board for support of the brush layer provides the initial added advantage that the small terrace that is created can serve to "catch" rolling rocks rather than allowing them to roll down the slope, gathering speed and damaging vegetation. Although the log will eventually rot, the cuttings will by that time have grown to the point where they are stabilizing the slope. As the cuttings that are used in the brush layer grow, the wall of plants will also serve to trap rocks and soil and prevent movement of materials down the slope, thus further protecting vegetation on the slopes. Modified brush layers can be used on sites that would be too dry for effective wattle fence growth but where some form of additional support is needed for stabilization of the slopes (Photograph 4).

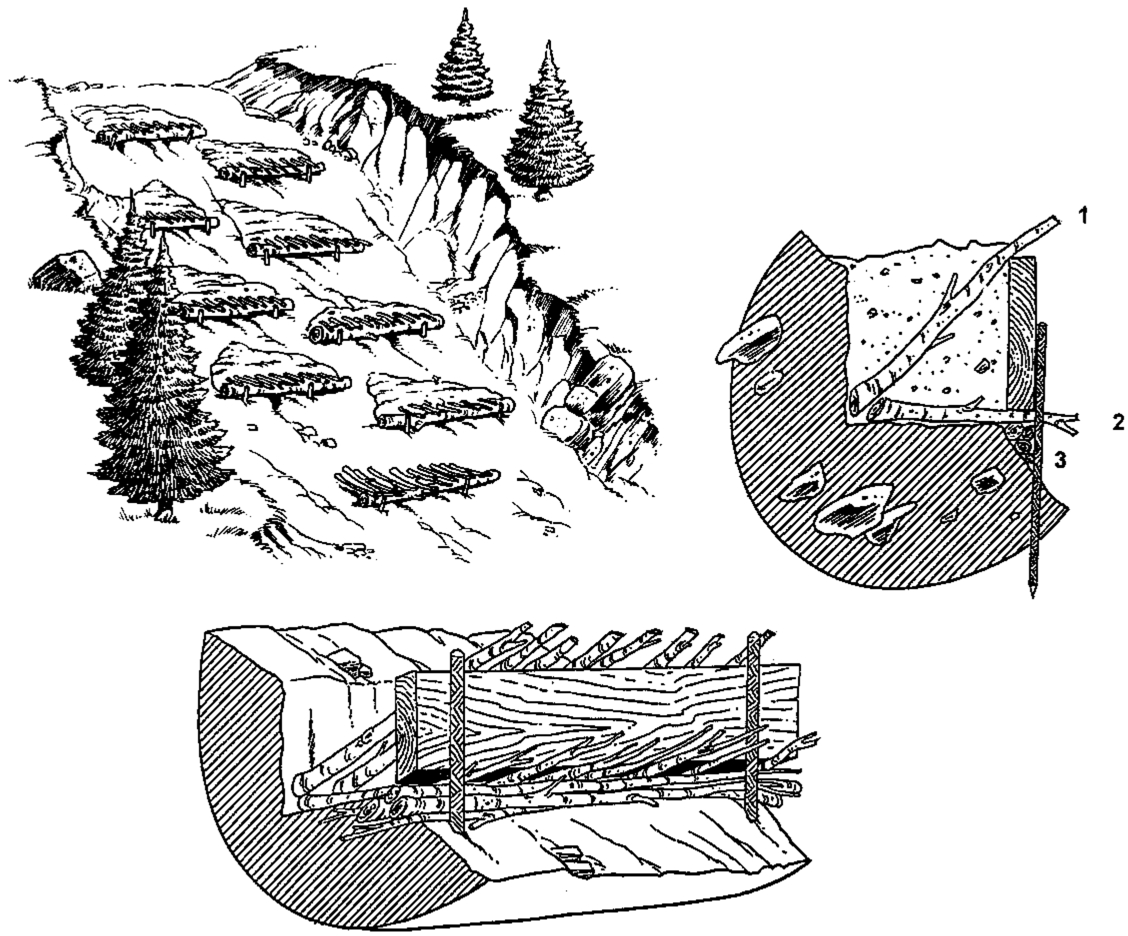

Figure 4. Modified brush layers should be staggered across the slope (left). Three different positions for placement of cuttings are shown in the diagram on the right. Boards or logs can be used for support. On mesic sites, modified brush layers should be built with the cuttings above the board or log ("1"). On dry sites, the cuttings should go below the board or log (2), while on very moist sites a small wattle fence can be installed below the board or log (3) to provide drainage.

Logs or boards (5 cm by 20 cm (2" by 8")) approximately 2 m in length are used for the modified brush layers. This allows a large number of modified brush layers to be established on the slope rather than one or several long ones. This has the advantage of providing separate, independent structures so that if a very large rock comes down and destroys one of the modified brush layers, there are still others to do the work. Many soil bioengineering systems use this "strength in numbers" concept.

Live cuttings or reinforcing steel bar (rebar) is used to hold the modified brush layers in place. Stakes that are about 1.2 m long have been found to be best for support of modified brush layers. Willow cuttings for the modified brush layers are collected locally. Logs, if selected, can often be collected from the cut blocks adjacent to the slides or from slash piles in the local area. In many cases however, the costs associated with collection of local logs is significantly greater than the cost of buying a comparable cedar board (5 cm by 15 cm or 5 cm by 20 cm rough cut).

The modified brush layers are constructed by initially establishing the stakes in the ground. The stakes should be placed one-quarter of the way in from the ends of the board as this provides the position of least stress (zero moment). The log or board is then placed above the stakes on the slope, and an initial bench is created by back filling behind the log or board. The cuttings are then placed on the bench and backfill is pulled down to cover the cuttings. Stakes can be driven into holes that have been created using large steel bars with pointed tips. On most slopes, the modified brush layers are established in a staggered pattern about 2 to 3 meters apart. However, on steeper slopes, the distance between the structures should be reduced. Like wattle fences, modified brush layers should be built from the bottom of the slopes to the tops thus proving places for the workers to stand as they construct additional structures.

Variations of the modified brush layer designs, as shown above, have been used successfully in a variety of locations. Cuttings can be placed below the board or log, poking out from under the wood ("2" in Figure 6.4-3). This is useful where moisture may be limiting. In places where there is ample moisture, a few willow cuttings can be laid below the board against the supporting stakes, much like in a wattle fence ("3" above). Cuttings can also be place out the ends of the structure and in the backfill behind the structure. The key is to provide the bench to control movement of material on the slope and to provide living plants to take over the function of catching falling material once the board or log rots away. As with most soil bioengineering systems, once there is an understanding of the principles associated with the system, a wide variety of specific designs can be used.

Photograph 4. Live pole drains can be used to treat moisture-related slumping sites.

Live Palisades

Live palisades are large cottonwood posts installed in trenches adjacent to the eroding stream or river where the natural riparian vegetation has been lost due to clearing or erosion. Figure 3 shows the typical design for live palisades. The key is to get the cottonwood posts down into the water table so that the trees will grow even during dry weather. Large cottonwood posts (15 to 20 cm diameter by 3 to 4 m long) are inserted into a trench dug by an excavator a few meters away from the actively eroding bank. The cottonwood post is expected to root along its entire below ground length and thus produce a dense cylinder of roots that will protect the bank from erosion as the steam encroaches on the palisade. The large cottonwood posts are placed about 50 cm apart so that the growth of the roots will overlap within one growing season. Cottonwood roots can grow as much a 1 cm per day during the growing season (Braatne and Rood 1998). Riparian cottonwood trees provide significant riparian benefit when they mature.

Care must be taken when establishing live palisades in gravelly alluvial materials that the excavation of the trench for the palisades does not cause an increase in bank instability. Setting the row of palisades well back can help reduce this problem. In some cases, two rows of palisades can be installed in a single trench by simply laying the posts in at an angle. Where fine silty materials are encountered, a tractor mounted post-hole auger with an extension to reach the water table can be an effective tool for inserting the poles. In addition to the cottonwood poles, cuttings of willow and red-osier dogwood can be added to increase the vegetation cover and enhance the diversity.

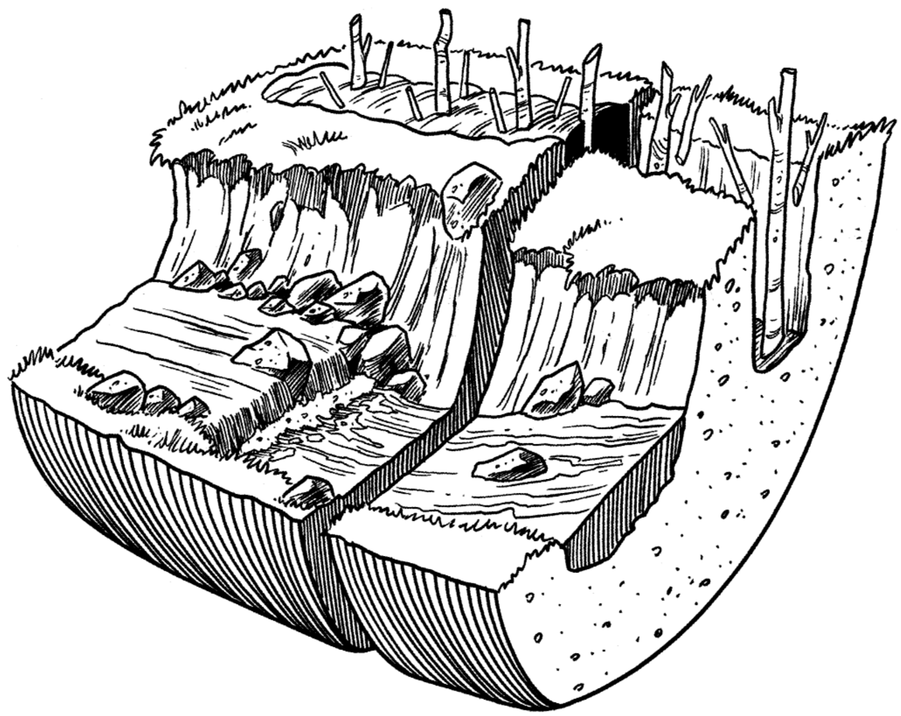

Figure 3. Live palisades consist of a row (or rows) of large cottonwood posts sunk into the water table. Smaller cuttings of willow and red-osier dogwood are inserted in the trench as it is backfilled to provide some diversity to the riparian stand as it develops.

<u>Live Gravel Bar Staking</u>

Excess gravel deposits in streams and rivers can occur in areas of resource development from erosion of upslope areas. These in turn cause disturbances in the stream flow that result in greater accumulations of sediments downstream (see Photographs 5 and 6). This cycle continues until the stream ends up as a broad expanse of bare gravel with a braided channel and no fish habitat. Live gravel bar staking is designed to establish the natural successional processes that would revegetate the gravel bars and eventually lead to a single channel with well-vegetated banks. The key to live gravel bar staking is to get the cuttings well into the substrate. Use of an excavator is essential (Figure 4). Cuttings should be a minimum of 1 m long and should not protrude from the gravel bar surface more than 20 cm. Large diameter cuttings (4 to 10 cm) appear to work better than smaller stock.

Figure 4. Live gravel bar staking is used to initiate natural succession on bare gravel bars. The sprouted cuttings trap small woody debris that in turn creates a flow disruption that results in deposition of sediment. Once the sediment builds to the point where the sprouts can no longer trap small woody debris there is no more sediment capture until the next year when growth of the sprout again traps woody debris.

Photographs 5 (left) and 6 (right). Live gravel bar staking installed in March 1998 as stabilized large quantities of sediment. Photograph 6 shows this site on June 19, 2011. The root infused sediment is very stable and will not be washed out with high water. Note how the cross sectional configuration of the gravel deposits has changed. Red arrow shows tree on opposite bank for location.

Live Staking

Live staking is perhaps the simplest form of soil bioengineering (Figure 5). Live staking is the use of living cuttings (willow, cottonwood, red-osier dogwood, etc.) to stabilize slumping materials or to "pin" sods to a slope. Live staking is particularly useful in silty materials that tend to flow down the slope in the spring. In these cases, the cuttings are inserted into the soft materials in the spring and as the cuttings grow over the summer, the roots serve to bind the unstable materials and to prevent further flows. Live staking can be used to establish riparian cover or to initiate successional processes on degraded sites.

The cuttings used in live staking should be inserted into the soil so that at least 3/4 of the length of the cutting is underground. On drier sites, 7/8 of the cutting should be inserted. Cuttings need not be planted vertically (as shown) but can be slipped into the soil diagonally, as 1ong as the cutting will remain moist over most of its length. A dibble or a "pinch bar" with a pointed tip can be used to provide a pilot hole for the cuttings as long as the soil is packed firmly around the cutting once the cutting is in the ground. Heavy gloves such as welder's gloves can be used to push cuttings into the soil. Rubber auto body mallets can also be used to drive in cuttings. Where difficulty is encountered, cuttings may be trimmed to maintain the 3/4 or 7/8 burial, as long as the cutting is at least 60 cm long.

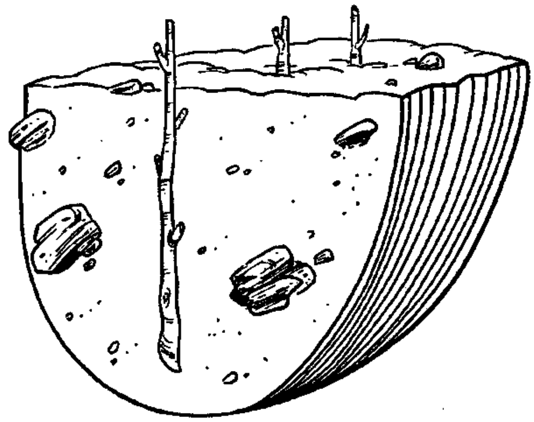

Figure 5 (left) Photograph 7 (right). Live staking is a simple method of establishing pioneering woody vegetation. It can be effectively used on "flowing" silts and to establish riparian vegetation along streams. Most (3/4 to 7/8) of the cutting should be underground to establish a balance between root and shoot growth.

CONCLUSIONS

Soil bioengineering techniques can be used to treat a variety of problems that may arise in the restoration of disturbed sites. These techniques can provide protection from erosion and effective pioneering vegetation that is congruent with the natural vegetation in the area. In most cases these techniques are easy to install and can be constructed by relatively untrained crews or volunteer groups. The diversity of techniques available allows soil bioengineering to address a wide array of problem sites. Soil bioengineering fits nicely between traditional engineering and normal revegetation programs.

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