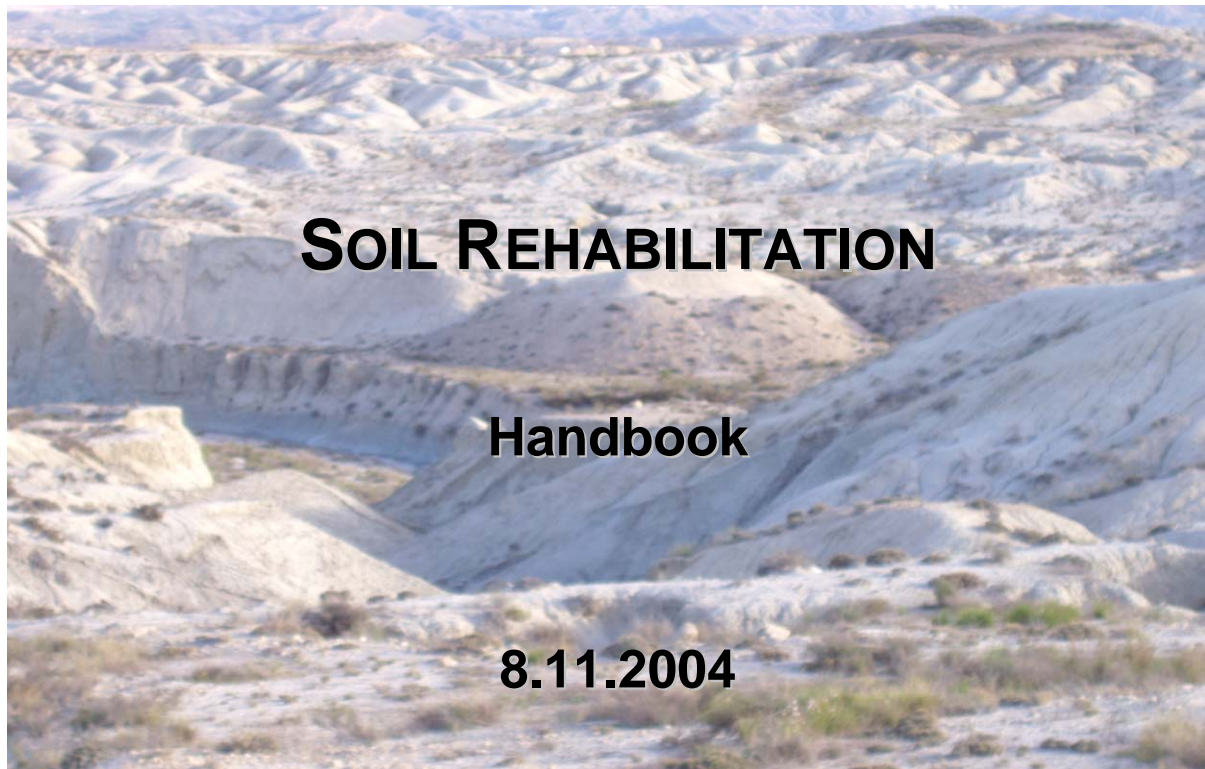




Indicators and Thresholds for Desertification, Soil Quality, and Remediation

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SOIL REHABILITATION

THE IMPORTANCE OF SOIL IN EUROPE

Preservation of soil resource is an important issue at the local, national and global levels. Soil is not only the basis for 90% of all human food, livestock feed, fibre and fuel but also provides more than productive functions. Europe's soils form the spatial structure for the development of human settlements: the building of houses and infrastructures, recreation facilities and waste disposal. It forms an essential part of the landscape, conserves the remains of our past and is itself a relevant part of our cultural heritage. At the European level, the diversity and multi-functionality of soils contribute to Europe's cultural and natural diversity.

Under natural conditions, soils tend to maintain equilibrium between pedogenetic properties and the natural vegetation. However, this equilibrium can be easily disturbed, especially by human intervention. Agricultural activity, for example, may in certain circumstances seriously damage a soil and decrease considerably its natural quality. In many European countries, inappropriate agricultural practices are compounded by the adverse environmental and climatic factors: climate, relief, lithological substrate and inappropriate plant cover. Both intensive agricultural practices and the agricultural use of marginal lands, which are very susceptible to environmental degradation and unsuitable for crop production, have led to unsuitable land management techniques. This, in turn, has led to a loss of soil quality and fertility and the subsequent abandonment of the land (giving rise to soil degradation and desertification).

A key factor in degradation of these soils is the loss of natural plant cover, allowing increased water erosion processes to occur. Another problem, especially for European soils because of the high population density, is the introduction of contaminants. The principles of soil conservation have been known for centuries and in many countries recognition of the dangers of soil degradation has prompted national soil conservation programmes.

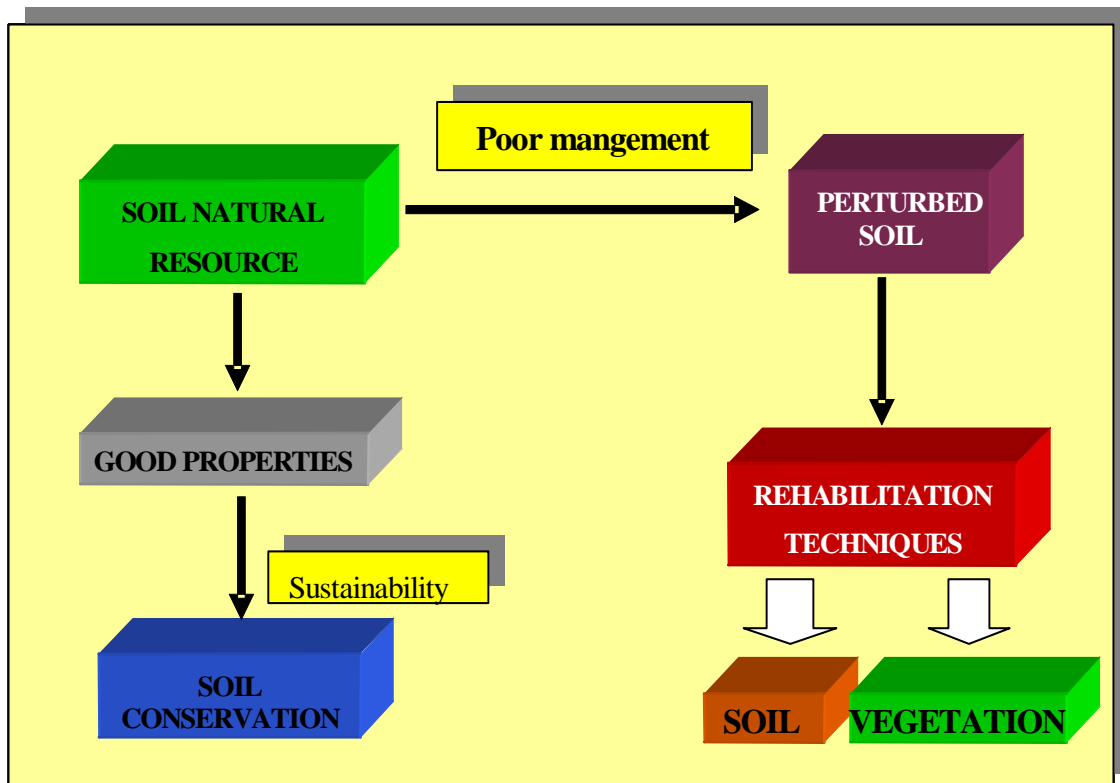
The soils of many European regions are exposed to contamination and also to erosion and desertification processes. For this reason, many soils (particularly, those of the Mediterranean countries) are in poor condition, e.g. having low organic matter contents. Intensive cultivation and continual ploughing, in combination with years of unsuitable agricultural practices, have had

an important effect on humification processes and have resulted in states associated with degradation. There is a significant reduction of vegetal remains entering the soil, while at the same time the humus is undergoing a process of accelerated mineralization as a result of tillage. The inevitable product is an accelerated decrease of the organic matter content and its related consequences.

In ecosystems with degraded areas as described above (scarce vegetation, exposure to adverse climatic conditions, contamination processes, and a very low content of organic matter), the microbial populations capable of surviving are scarce, and those, which manage to, have a very precarious hold. Under such conditions, the carrying out of programs for soil rehabilitation should be a **PRORITARY OBJETIVE**, in order to conserve a natural resource: **THE SOIL**. The addition of organic amendments has been proposed as a method to improve soil quality (Soil Rehabilitation), especially when the material contains a large amount of easily biodegradable organic carbon. But soil rehabilitation is something more than only the addition of organic matter to the soil. For carrying out an appropriate program of soil rehabilitation, it is necessary to have sufficient high quality information about the problem, and to know what has to be done.

SOIL REHABILITATION

At the global level, combating soil degradation (SOIL REHABILITATION) will help offset greenhouses gas emissions, provide a better environment, guarantee more food to an increasing population, and contribute to the economic progress of future generations. Protecting soil helps to preserve Europe’s identity. However, soil is a limited and not renewable resource, and a damage of the soil is not easily reversible. The multi-functionality of soils is closely linked to the soil paradox. On the one hand the importance of soils to a wide range of human activities make them more vulnerable to damage and depletion from many sides. On the other hand its buffering capacity, its resilience, and its capability to filter and absorb contaminants result in the fact that damage is rarely perceived until it is far advanced. Now, after many years of misuse, *warning signs are appearing more clearly and both soil rehabilitation and preventive responses are required, in order to prevent us from transferring problems to future generations.*

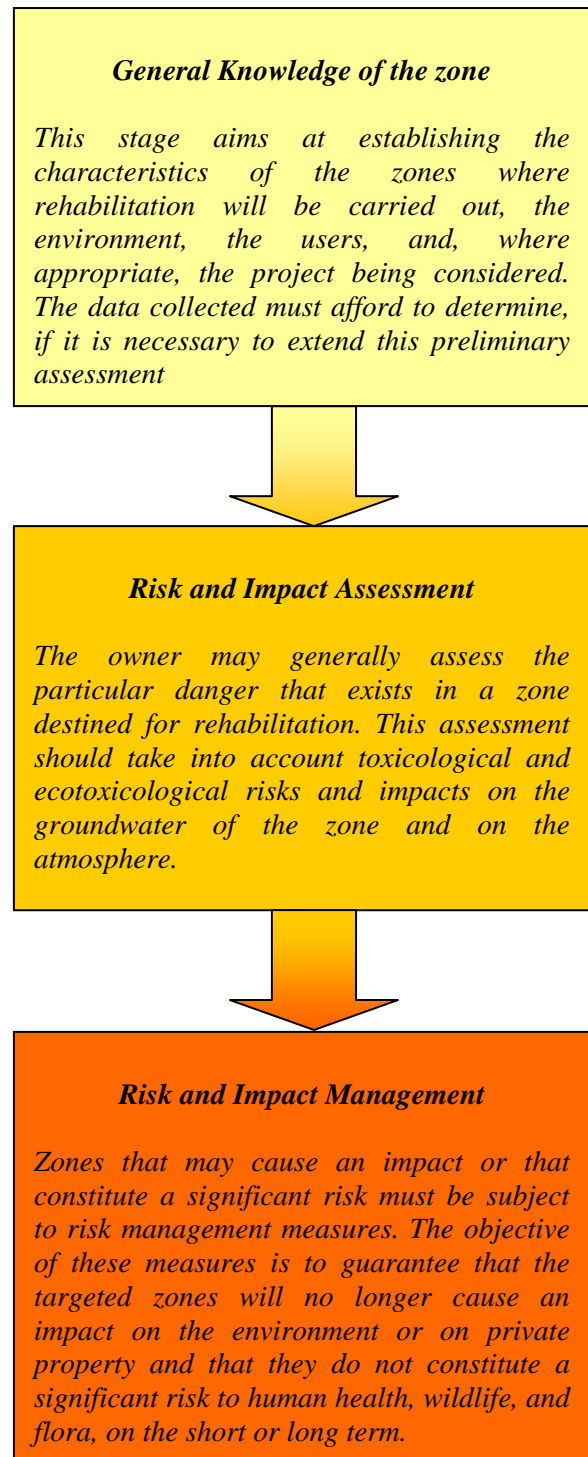


The Rehabilitation Principle

It is the responsibility of present-day society to repair as much as possible the damage resulting from past errors rather than to pass it on to future generations. Even if it has no impact or does not constitute a significant danger in its present state, a degraded or contaminated zone remains a site risk. Poorly planned modifications (change in use, drainage or excavation work carried out at the site, etc.) can make this risk serious. Sites affected by the consequences of unsustainable production and consumption cannot simply be abandoned and forgotten.

Rehabilitation must not only readjust the situation by decreasing the negative impact but must also aim at upgrading, which means, restore a maximum of possible uses to the zone and reintegrate it into the cycle of sustainable development. If we cannot immediately rehabilitate some zones, the present generation has the duty, as a responsible society, to promote the general concept of Rehabilitation, elaborate a strategy to make the concept reality and to apply this strategy immediately in cases of high priority.

Stages for approaching soil rehabilitation



Soil rehabilitation and planning requirements

Soil rehabilitation should finally attain a state where the soil is able to sustain “stable vegetation”. For this reason, a revegetation of the degraded zones in Europe is the main criteria for soil rehabilitation. This revegetation will be different in semiarid zones than in other zones with a non-arid climate. In any case the establishment of a good program for soil revegetation is needed.

Sometimes the need for soil rehabilitation can be anticipated, but usually this is not the case. Where rehabilitation need can be anticipated, mechanical techniques can be applied. Topsoil can be stockpiled, for example, to improve the success and reduce the costs of subsequent rehabilitation work. In cases of an unanticipated rehabilitation need, such mechanical measures are usually not feasible. For example, side cast topsoil may not be recoverable.

Although almost any disturbance can be reversed with sufficient effort, there is usually some limit to what is achievable and desirable. Some disturbances are very difficult to handle because of concerns about worker safety, short periods with acceptable site conditions, exposed bedrock, widely dispersed disturbance, unfavourable subsoil, excessively steep slopes, risk of damaging other resources, or other factors. Subsequent sections of this handbook provide examples of how soil and site conditions affect the practicability of rehabilitation projects.

Preparing the rehabilitation plan: format and content requirements

Preparing the rehabilitation plan

For a stand-alone rehabilitation plan, much of the soil and site data required should be detailed on the field cards used for preparing revegetation prescriptions. The parts of this prescription that are especially relevant to the rehabilitation plan include those on ecology and resource information, soil conservation, visual landscape, range, etc.

In cases of anticipated harvesting-related rehabilitation, the critical site factors, rehabilitation objectives and general actions will be presented within the soil conservation section of the revegetation prescription.

For unanticipated rehabilitation, it is good policy to show the location and extent of areas to be rehabilitated on a base map that generally meets the revegetation prescription mapping criteria. The main purpose of the map is to show where the rehabilitation will take place and where different techniques will be used.

Guidelines on information, which should be included in each section of the rehabilitation plan, are presented below.

Problem analysis and critical site factors for rehabilitation

The problem analysis provides background information on the nature of the soil disturbance, outlines the existing limitations to soil productivity and discusses any site or soil factors that will influence the selection of an appropriate series of treatments.

The problem analysis should give a realistic overview of the limiting critical site factors associated with the proposed rehabilitation.



Discuss, for example, whether ...

- ***soil texture or moisture regime*** will limit the use of certain treatments (e.g., cultivating wet, fine-textured soils is usually ineffective)
- ***topsoil or forest floor displacement*** will result in serious ***nutrient depletion*** or other effects such as drier soil or loss of rooting medium
- ***intense burning*** will result in nutrient loss
- ***ruts*** will hold water and restrict the extension of plant roots
- ***unfavourable subsoil*** (compact, clay rich, calcareous or saline) will be exposed or mixed with surface soils as a result of the disturbance or proposed rehabilitation
- ***the risk of erosion or mass wasting*** will increase, or mass wasting already initiated will need to be stabilized
- ***construction, disturbance or rehabilitation*** will disrupt or intercept surface and subsurface drainage
- ***stones or stumps*** will limit the use of implements such as a winged subsoiler
- ***safety considerations*** will limit access to unstable slopes or other situations
- ***the risk of wildlife or cattle*** entering the site, which requires special procedures to protect seedlings.

Detailed treatment objectives

Detailed treatment objectives are required to define what the rehabilitation proposes to achieve. Sufficient information must be included so that an expert can judge the usefulness of the proposed treatments for dealing with the challenges identified in the problem analysis.

Rehabilitation always implies the overall objective to return a site to an acceptable level of productivity or stability in such a manner that it will no longer require human intervention. Detailed treatment objectives, however, are equally needed to define measurable targets that will enable the attainment of the overall project objectives. Such targets are a prerequisite for the evaluation of the rehabilitation project.

Examples:

- ***To control erosion*** by establishing a ***vegetative cover*** that has *x* per cent cover or stocking after one season
- ***To control erosion and moderate soil temperature and moisture*** by spreading a ***mulch*** of fine organic debris on the surface
- ***To decompact soil*** by ***tilling*** to a depth of *x* cm and to restore soil structure by establishing specified cultivars of densely rooted grasses
- ***To reduce the likelihood of future nutrient deficiencies*** by ***conserving and respreading topsoil***
- ***To restore soil organic matter levels*** by incorporating organic amendments at a rate of *x* kg/ha, to a depth of *x* cm
- ***To re-establish a plant community*** with specified species and defined proportions (per cent) of hardwoods, softwoods, shrubs or grasses.

Rehabilitation treatments

This section contains details on equipment, materials and procedures. It has to provide sufficient details to demonstrate that there is a reasonable probability that the work will be done correctly. Unless justification is otherwise given, the plan should contain the following information about the proposed treatments:

Drainage and erosion control

- techniques for restoration of above- and below-ground water movement (shown on sketch maps if necessary)
- techniques for stabilizing slopes and reducing surface soil erosion (including bioengineering techniques if necessary).
-

Restoring soil productivity

- methods and sequence of operations for topsoil conservation and its respreading
- type of equipment and cultivators used (e.g., ripper, discer, winged subsoiler, excavator, rottiller) along with specifications for the tillage such as depth and clod size
- soil moisture at the time of cultivation (e.g., dry enough to shatter, but not so dry that the soil turns to powder, to the full depth of cultivation)
- formulation of fertilizer, application rates, timing and techniques
- type and source of mulch that will be used and rate and method of application
- contingency plans, if weather conditions remain unsuitable for extended periods.
-

Vegetation

- proposed revegetation procedures, including seed mixture, rates, and application techniques, along with procedures for establishing shrubs, hardwoods or softwoods, including seed source, stock type and planting densities.

Schedule

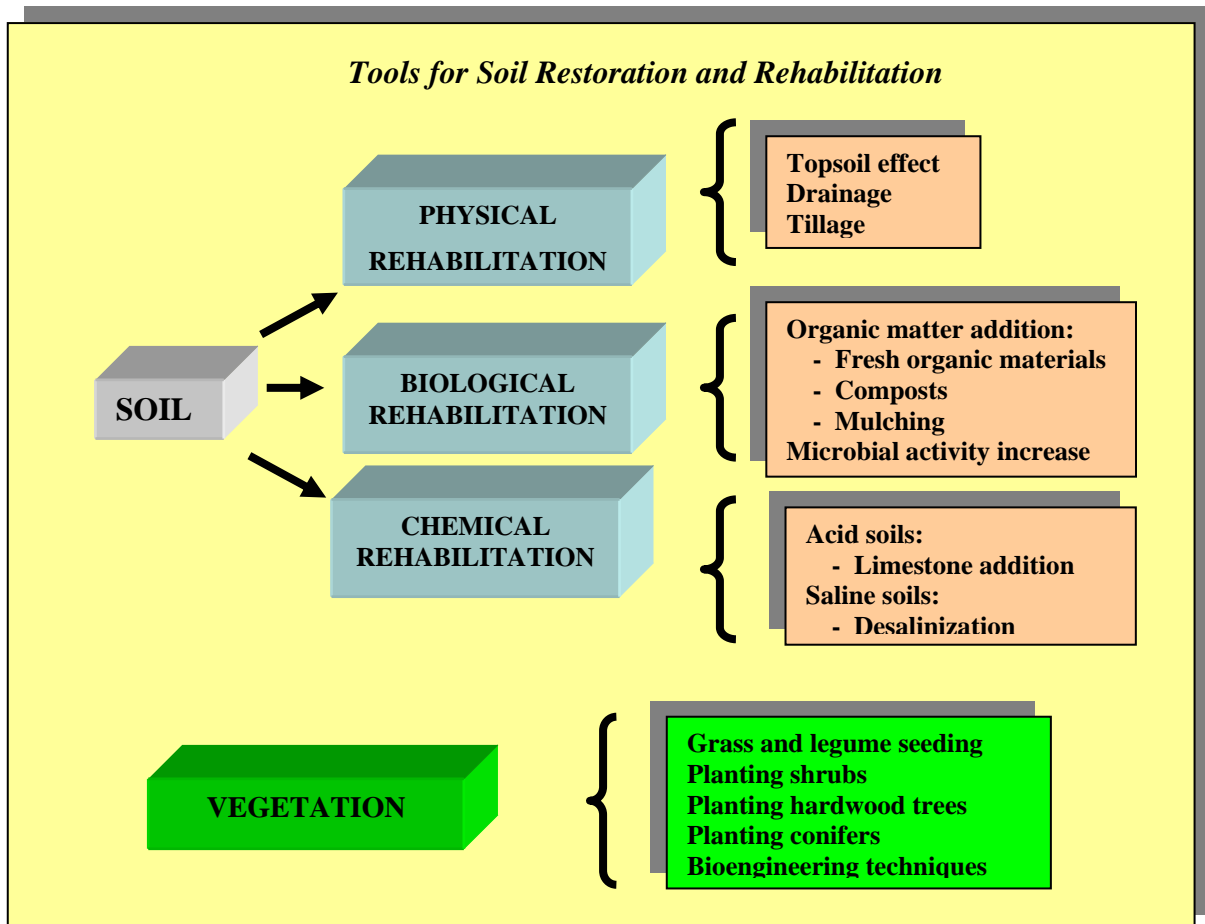
The schedule should specify the timing of operations, as well as an estimated completion date. Certain types of work (e.g., tillage) can only proceed when conditions are appropriate, even though other constraints, such as schedules for seedling delivery, may create a pressure to proceed inappropriately. A good schedule recognizes logistical requirements for sequential treatments and is also flexible enough to allow for delays.

Guidelines for planning

- *Try to proceed with the rehabilitation **as quickly as possible** after or concurrently with harvesting. Note, however, that although some types of work need to proceed very quickly to prevent hazards other types should not proceed at all if, for example, slopes are unstable.*
- ***Avoid leaving bare soil** exposed for long periods, especially where there is a significant risk of erosion or on sites with fine-textured soils.*
- ***Schedule fertilizer** applications so that losses are minimized and risk of "burning" due to excessive application is avoided. For best results, apply fertilizer just before or during periods of rapid plant growth.*

TOOLS AND TECHNIQUES FOR SOIL REHABILITATION

This section provides information on rehabilitation methods used to restore soil and vegetation along with some ideas for managing cattle on rehabilitated areas.



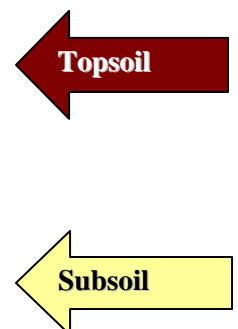
SOIL PHYSICAL REHABILITATION

Topsoil handling

"Topsoil" is defined here as the uppermost soil layer, usually including the top 20–25 cm of mineral soil, where the bulk of the rooting zone is located. The topsoil as well as the forest floor contain large reserves of plant nutrients and the organisms that influence soil nutrient cycling. The best way to establish productive nutrient cycles on rehabilitated sites is to conserve and respread the topsoil and forest floor in the case of silviculture.

Guidelines to ensure successful topsoil handling

- Consider the **thickness** of both useful and unfavourable soil materials. Rooting depths in undisturbed soils can be a useful guide for determining the thickness of soil materials worth salvaging. Where forest floors are too thin to be easily separated, keep these materials with salvaged topsoil. Do not include deeper soil layers with adverse chemical and physical properties (e.g., Bt horizons with a high clay content, cemented horizons, or subsoil with high concentrations of salts or carbonates).
- In case of silviculture, ensure that contractors are informed on the rehabilitation requirements in regard to logging plans. Pre-work site visits are valuable to acquaint the equipment supervisor and operators with the identification of the soil layers that will need to be handled and especially the



depth to unfavourable subsoil.

- Develop a consistent method for locating separate piles of topsoil and less desirable fill materials (on level or gently sloping ground, topsoil and excavated subsoil can simply be placed in the most convenient locations for respreading).
- Use excavators for cut and fill construction because of their greater flexibility in removing and placing soil materials. Front-mounted blade equipment is particularly unsuitable for construction on slopes because of its uncontrolled side casting.
- For cut and fill construction, always use the same sequence for positioning different layers of material within fills. The correct sequence is topsoil, then

remaining developed soil (i.e., B horizon) with a final covering with subsoil material. The unweathered subsoil material forms the outer track of the running surface and will protect the underlying topsoil. To facilitate side cast and topsoil recovery on slopes, utilize stumps and woody debris to create barriers against which these materials can be piled on the down slope side.

Also remember:

- **Minimize inclusion of stumps and woody debris with topsoil.**
- **Avoid handling topsoil during wet conditions.**
- **Ensure that topsoil piles are protected from traffic and water erosion, and are not buried by slash.**
- **When respreading topsoil, avoid creating a smooth-graded or coarse, cloddy surface. Ensure that the roughness of the final surface is suitable for the subsequent seeding and fertilization treatments.**
- **Scatter slash on the soil surface to provide some protection from erosion until vegetation is established.**
- **Where rehabilitation treatments will include both tillage and topsoil respreading, plan the sequence of operations to avoid recompacting tilled areas. Winged subsoilers can till under respread topsoil with a minimum of mixing. Excavators can respread topsoil and decompact in one operation by tilling a strip just ahead of a windrow of recovered topsoil, which is progressively spread across the tilled surface.**
- **In some cases, topsoil piling is not warranted. For example, it may be too difficult to separate and stockpile topsoil on very rocky sites. Wet sites where the landings are continuously saturated are also unsuitable for topsoil respreading.**

- Some special considerations apply for handling topsoil under winter conditions:
 - For excavated trail construction, remove snow from the inner track area and compact it where the fill will be placed. Put salvaged topsoil on this area, and cover it with more snow to form the running surface. When rehabilitation is carried out, the equipment operator will easily recognize the base of the fill when the bottom layer of snow is encountered.
 - For construction of temporary winter access on gentle ground, avoid blading soil materials more deeply than the minimum needed to enhance freezing of the running surface.

Soil Drainage

Good soil drainage is essential for successful crop production. Soil microorganisms as well as plant roots require oxygen. When a soil is poorly drained, it remains saturated or nearly saturated with water for fairly long periods, thus limiting the supply of oxygen and restricting crop growth. In northern maritime areas, poor soil drainage also results in cold, wet soils in spring, and poor trafficability for spring and fall tillage, seeding, and harvesting operations. This leads to serious delays in seeding, germination, and harvesting of spring seeded crops, with increases in crop disease, maturity related problems, soil compaction, and higher equipment operating costs. Poor soil drainage also contributes to poor winter survival of perennial legume and winter cereal crops.

Moisture moves through the soil at different rates depending on the size and distribution of pore spaces between soil particles. The greater the volume of large pore spaces, e.g. in sandy and gravely soils, the faster water will drain out of a soil. In a fine textured (clayey) soil, the total pore space volume is small and the movement of moisture is slower than in sandy soils.

Soil particles have a natural tendency to cling together to form soil aggregates, a condition known as soil structure. Soil structure can be improved by judicious use of limestone, manures, fertilizer, crop sequence, and tillage practices. Development of an improved soil structure will increase the pore volume distribution in the soil and permit more rapid removal of surplus water.

In most cases, soil management practices alone are not sufficient to control excess of soil moisture adequately. In such cases, use one or a combination of the following Rehabilitation measures:

- ***Open ditches*** to collect surface water or to intercept water flowing onto land from a high point.
- ***Tile drains*** to remove surplus water from within the soil and thus control the level of the water table in the soil. This is the most effective method of artificial drainage.
- ***Subsoiling*** is beneficial, if an impervious layer exists in the soil at a reasonable depth. The impervious layer (hard-pan or clay-pan) is broken up by a deep tillage machine to permit more rapid movement of surplus water. Subsoiling will only be effective, if carried out when the soil is fairly dry down to the depth of the subsoil tillage. This corrective measure is usually of a temporary nature.

Tillage

In many cases, the productivity of disturbed soils is limited by their physical properties. The upper mineral soil horizons of productive soils are characterized by an open structure in which large pores allow excess water to drain away. This allows the soil to warm more quickly in the spring. In addition, oxygen flow to respiring plant roots is enhanced in soils with open structure. The depth of surface soil with a favourable physical condition is often a good indicator of expected site productivity. Tillage is used primarily to decompact the soil and re-establish soil porosity, allowing plant roots to penetrate deeper into the soil.

Decompaction on degraded soil by tillage for Soil Rehabilitation



Determining tillage depth

It has been commonly accepted that the deeper the tillage the better, up to some practical physical limit of the equipment – usually around 50 cm. Increasing the rooting depth has been considered advantageous even though the natural vegetation may have grown on shallower soils. Deep tillage has the possible benefit of breaking up impermeable layers such as dense Bt horizons, and increasing rooting depth beyond that of the original soil. Increased rooting depth may also mitigate some of the adverse effects of the initial disturbance on surface soils.

Deep tillage can have a number of negative effects, such as increased costs, added stress on equipment, and transfer of unfavourable subsoils or rocks to the surface. Some types of equipment capable of reaching 50 cm depths (e.g., crawler tractors with ripper teeth) are not very effective for decompaction. The usual effect of tilling with rock rippers is to create large clods, leave deep furrows, and bring rocks to the surface. Furthermore, unless the ripping is done repeatedly, much of the area remains in a compact condition. Shallower tillage or the use of more appropriate equipment is usually more cost-effective and may provide superior results. Examples of more appropriate tilling implements include winged subsoilers designed specifically for this purpose and hoes with long ripping tines.

When determining the appropriate decompaction depth, evaluate:

- ***Unfavourable subsoil:*** These should not be mixed with the surface soil.
- ***Moisture content at depth:*** Soils that are too wet at depth to achieve proper shatter should not be deep-tilled.
- ***Stoniness:*** In stony soils, make sure that uniform cultivation is achievable, and if large stones are brought to the surface, ensure that they will not hinder subsequent treatments such as seeding or planting.
- ***Natural rooting depth:*** Evaluate the reasons for a shallow rooting depth in undisturbed soils adjacent to the area. Where rooting depth is controlled by soil temperature or nutrient imbalances in the subsoil (e.g., calcium carbonate or salinity), deep tillage will not result in deeper root penetration. Ensure that surface horizons are rehabilitated correctly before considering deep tillage as a means to increase site productivity.
- ***Depth of compaction:*** It is often difficult to determine the depth to which soils have been compacted by equipment traffic. The bulk density of undisturbed soils increases with depth, while the effects of compaction decrease with depth because of (1) the dissipation of energy within the upper layers of the surface soil and (2) the increased bearing strength of naturally dense soils below. Well-built winter roads may have only very shallow surface compaction or puddling. Skid trails may have severely puddled surfaces, but compaction may not extend very far below the surface. In such cases, deep tillage would not be as effective as shallow tillage. Subsoils that were relatively unaffected by the disturbance may even suffer degradation of soil structure as a result of deep tillage. Select treatments appropriate to the nature and depth of the disturbance.

Maintaining soil structure after tillage

Good tillage loosens the soil, breaks massive soil materials into small clods and encourages the formation of more porous aggregates. The long-term stability of aggregates and pore spaces depends on soil texture, soil organic matter and soil biological activity.

In coarse-textured soils, tillage alone may be sufficient to restore soil structure and maintain productivity, provided organic matter and nutrients have not been lost. Good tillage of medium- and fine-textured subsoils can create a reasonable soil structure, but the effect will be short-lived unless aggregate stability is also restored. Without organic matter and biological activity, aggregates created by tillage will fall apart when the soil gets wet, the large pores will disappear because of structural collapse, and the smaller pores will become clogged with silt and clay particles.

- *To rehabilitate severely disturbed medium- and fine-textured soils that have low levels of organic matter content or biological activity; a **vigorous plant community** should be quickly established after tillage.*
- *In soils low in organic matter, consider incorporating additional **organic matter** in the form of **amendments** to help maintain the pore structure.*

Tillage and soil moisture

The goal of tillage is to shatter the soil. Tillage will be ineffective and may degrade rather than improve soil structure, if it is conducted when the soil contains enough moisture to make it plastic, in which case it will tend to mould rather than shatter when a force is applied to it. The actual water content at which a soil will shatter varies according to soil texture.

Moisture content needs to be determined prior to tilling medium- and fine-textured soils. Ideally, they should be friable, which means they should be dry enough to crumble when worked (rather than smear), but not so dry that they turn to powder. If the soil is too wet, tillage equipment can mould the soil into large chunks that do not improve soil structure. Wet soil can be puddled, resulting in destruction of soil aggregates and their associated pores. If a medium- or fine-textured soil is too dry, the equipment will have difficulty penetrating to sufficient depths, and may pulverize the soil rather than shatter it. Pulverized soil will quickly recompact when it gets wet.

Ensure that rehabilitation plans involving tillage are scheduled only for soils that can be expected to reach appropriate moisture content in most years. Plans must allow for early start-up, if appropriate soil moisture conditions occur early and for delays, if conditions are not appropriate. Local experience with site conditions, pre-work soil moisture monitoring, and post-treatment evaluation of tillage effectiveness are essential for developing good tillage prescriptions.

Equipment used for decompaction

Winged subsoiler

Winged subsoilers can be effective and efficient tools for decompacting soils in rehabilitation work, if they are used by an experienced operator under suitable soil conditions. The winged subsoiler, with the wings set at the proper angle, lifts the soil and then allows it to fall back in place as the machine passes, resulting in shatter without burying the forest floor, topsoil, or bringing unfavourable subsoil to the surface. A good subsoiling operation can leave vegetation sufficiently intact so that it will continue to grow.



On the better models of winged subsoilers, the wings can be adjusted to match soil conditions, particularly if the soil is dry, high in clay content, or extremely dense. When adjusted properly, the implement lifts the soil slightly above it without causing extensive smearing or compaction below the wings. The trench created around the shanks should be narrow, and the soil should not be pulled up into furrows. Furrows indicate that the subsoiler is not penetrating deep enough, or that the angle of the wings is set too steep.

The shank spacing can usually be adjusted to accommodate landing sizes or different road and trail widths. Because the entire soil layer is lifted and dropped, soil between the wings is shattered, and adequate tillage can be

Trench of a subsoiler



achieved in one pass. Even though the wings are independently mounted to prevent hang-ups, the subsoiler is ineffective on sites with large amounts of large rocks (>50%) or buried logs.

The winged subsoiler is the most effective implement for decompacting large areas with relatively uniform conditions.

Excavator

Hydraulic excavators are more flexible tools than winged subsoilers in many situations. Excavators are readily available, and a number of attachments are available to achieve different soil rehabilitation objectives including, mixing, mounding, tilling, manipulating slash, spreading mulches, etc. A conventional bucket is suitable for a limited amount of tillage; soil with the correct moisture content can be lifted and dropped to achieve good shatter. A mounding rake or similar toothed implement is probably more efficient for decompaction. When equipped with a thumb, an excavator easily handles coarse woody debris that needs to be moved. Various other attachments are available for excavators, including mounders, mulchers, and rototillers.

Excavators are well suited for the following types of operations:

- ***rehabilitating areas*** where access is limited to low ground pressure equipment
- ***building and rehabilitating excavated trails on steep slopes***
- ***continuous topsoil replacement and tillage***, especially on sloping sites where material must be retrieved from sidecast piles or berms
- ***loosening and filling in ruts***
- ***mixing forest floor and organic amendments*** with surface mineral soils
- ***creating mixed mounds*** or individual planting spots to achieve rehabilitation objectives
- ***achieving effective tillage*** where buried wood, stumps or stones prevent the use of implements such as the winged subsoiler.

Other equipment

Several different types of mechanical site preparation equipment are available that could be used for soil rehabilitation. Most implements, however, are designed to create favourable microsites for planting, rather than to decompact extensive areas in a homogeneous fashion. Experience with the use of specific site preparation implements for soil rehabilitation is limited, but many possibilities exist for applying mounding, scalping and disc trenching, mixing, or ripping/ploughing equipment in order to attain the desired goal

Examples:

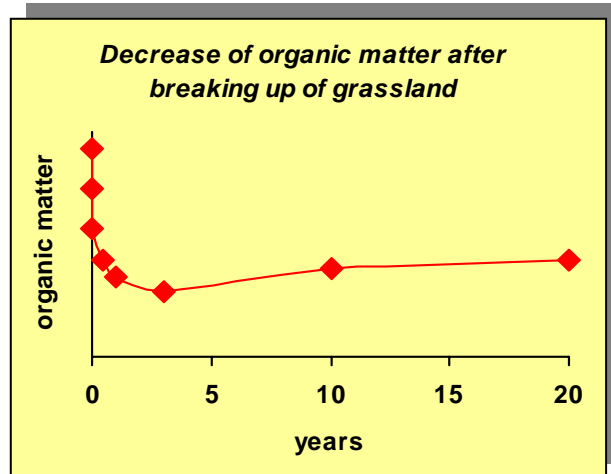
- *Roadside work areas that have shallow compaction might be **disc-trenched** to improve early seedling performance and survival, especially if the areas are not sufficiently compacted to warrant subsoiling or, if the subsoiler cannot be used effectively on the site.*
- ***Mounding** may be a suitable treatment on heavily disturbed wet sites.*

In all cases where the use of site preparation equipment is proposed, the rehabilitation plan must include a clear statement of the productivity objectives, the proposed methods for restoring productivity and sufficient detail to allow the evaluation of the likelihood that the proposed rehabilitation work will achieve stated objectives. The plan should also serve as a basis for assessing whether the rehabilitation has been adequately performed.

SOIL BIOLOGY REHABILITATION

Effects of organic matter decline

Soil degradation is becoming a major concern in several countries. Loss of organic matter is often identified as one of the main factors contributing to declining soil productivity, but it is misleading to equate a loss in soil organic matter with a loss in soil productivity. Soil organic matter contributes to soil productivity in several ways, but there is no direct quantitative relationship between soil productivity and total soil organic matter. In fact, it has been the decline in organic matter that has contributed to the productivity of the crop-fallow system.



Insofar as organic matter contributes to improved soil physical properties (e.g., tilth, aggregation, moisture holding capacity and resistance to erosion) increasing soil organic matter will generally result in increased soil productivity. However on many soils, suitable soil physical properties occur at relatively low levels of organic matter (2-4 per cent).

A level of organic matter higher than required to produce suitable physical properties is beneficial in that the soil has a greater buffering and nutrient holding capacity, but it does not contribute directly to soil productivity. If soils are managed in a way that organic matter is not declining (steady-state), soils higher in organic matter (e.g., 8 per cent) are not inherently more productive or fertile than those that have less organic matter (e.g., < 5 per cent).

To equate the ability to supply nutrients with total soil organic matter is not valid. The "active" fraction of organic matter is a more reliable indicator of soil fertility than is total soil organic matter. In cultivated soil, the "active" fraction is influenced mainly by previous management. Soil organic matter cannot be increased quickly even when management practices that conserve soil organic matter are adopted. The increased addition of organic matter associated with continuous cropping, and the production of higher crop yields, are accompanied

by an increase in the rate of decomposition. Moreover, only a small fraction of crop residues added to soil remains as soil organic matter. After an extended period of time, the return of all crop residues and the use of forages in rotations with cereals and oilseeds may significantly increase soil organic matter, particularly in the "active" fraction.

Managing soil organic matter

There have been vast changes in the nature of agricultural production. In the past, farms were small, and much of what was produced was consumed on the farm. This system resulted in a limited removal of soil nutrients, since most of the nutrients were returned back to the land.

The advent of the internal combustion engine, migration from rural to urban communities, increasing farm size, and specialization in production have resulted in a system of production where there is greater removal of plant nutrients from the soil and less opportunity for nutrient cycling. Maintenance of organic matter for the sake of maintenance alone is not a practical approach to farming. It is more realistic to use a management system that will give sustained profitable production.

The greatest source of soil organic matter is the residue contributed by current crops. Consequently, crop yield and type, method of handling residues, and frequency of fallow are all-important factors. Ultimately, soil organic matter must be maintained at a level necessary to maintain soil tilth.

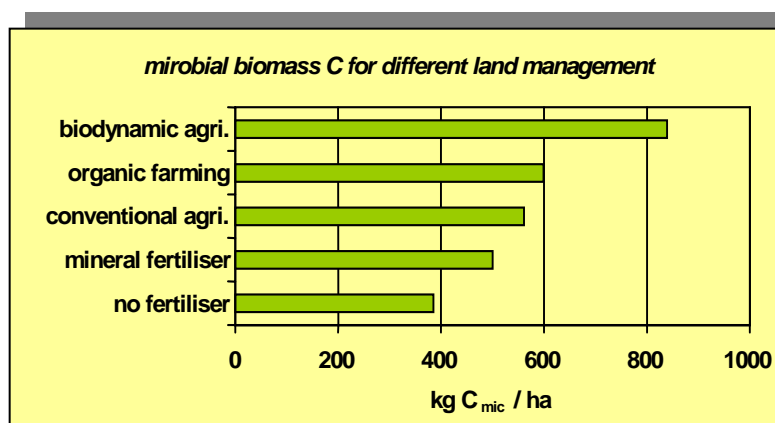


As has already been stated, the loss of organic matter and the degradation of a soils structure are closely related with the loss of its agricultural potential and with an increasing risk of erosion. This phenomenon has been defined as a diminution or destruction of the soil's biological potential, leading in extreme conditions to desertification.

One important characteristic of the soils of the Mediterranean region is that they are indeed submitted to erosion and desertification processes and that they have a low organic matter content. Intensive cultivation, continual ploughing, and forest fires, allied to years of unsuitable agricultural practices, have had an important effect on humification processes and on properties associated with degradation. All of the above has led to a great diminution in the quantity of vegetal remains contributed to the soil, while the humus is undergoing a process of accelerated mineralization as a result of tilling. The inevitable result is a progressive diminution of the soil's organic matter content and the negative consequences entailed. The organic matter improves soil aggregate stability and structure and increases its porosity and water holding capacity, thus favouring gas and water exchange and the exploratory capacity of plant roots. The cationic exchange capacity is increased which favours nutrient fixation. Nutrients are maintained longer at the soil's disposition, and this increases the development of its microbial flora.



One way of improving the fertility of degraded soils and particularly of improving their microbial activity, is to add “young” exogenous organic matter. By this term we mean that the amendment must contribute to providing labile organic matter in sufficient



quantities to stimulate the life of the microorganisms, which exist in the soil. The characteristics of such amendments must be that they behave well from a physical point of view (e.g. increasing soil sponginess). They must also contribute to improving the nutritional quality of the soil and, most importantly, the labile organic fraction, which is beneficial in that it acts as a catalyst for

the microorganisms. In this way the soils potential fertility and biogeochemical cycles of the most important elements are improved.

In ecosystems as degraded as have been described (soils with no vegetation, exposed to adverse climatic conditions, and with a very low content of organic matter), the microbial populations capable of surviving are few and those, which manage, have a very precarious hold. Among the principal factors, which affect the development of the organisms, are the high temperatures and low rainfall, which leads to extremely high evapotranspiration and a water deficit in the soil. The organisms, which best adapt to these conditions show a common behaviour pattern: their period of activity is confined to the times when water is available, and they have developed resistance mechanisms during unfavourable times. In such conditions the addition of organic materials has been proposed as a method to improve soil quality, especially when the material contains a large amount of easily biodegradable organic carbon. This is why such materials may be described as bioamendments because of their capacity to improve the soils' biological and biochemical fertility, which are closely related to microorganisms.

Soil amendments, fertilizers and mulches

Soil amendments are materials that are mixed into the soil to restore soil organic matter, long-term nutrient status, or soil structure. Chemical fertilizers provide an efficient means of improving short-term nutrient status. Mulches protect the soil from erosion; conserve moisture, and moderate soil temperature. Except for chemical fertilizers, soil amendments are bulky and expensive to transport, so local availability is a key factor determining their suitability for soil remediation.

Organic soil amendments

Logging residues

The most readily available organic materials in forests are usually the residues of logging: branches, tops, and non-merchandisable stems. Accumulations of these materials adjacent to roads and landings are often burned, providing ash that could serve as a soil amendment.

Fine branches, tops, and especially foliage contain significant quantities of nutrients, and can be mixed directly as a soil amendment to improve soil physical properties, enhance nutrient status, and increase mineral soil organic matter content.

This type of treatment may be particularly useful where topsoil and the forest floor were not conserved before construction, or on cold, dense subsoils that are deficient in organic matter. Depending on the size and shape of the materials, it may be useful to chip fine residues where equipment is available.

When using logging residues:

- *Assess **nutrient status** before incorporating logging residues. Residues that consist primarily of large woody material have high C:N ratios. This material can be chipped and incorporated but doing so will tie up large amounts of nitrogen in decomposition, reducing nutrient availability for the vegetation.*
- *Before incorporating large amounts of predominantly woody material, **consult with a soil expert** to assess the nutrient content of the amendment, the rate at which it is expected to decompose, bind nitrogen, and the amount of fertilizer needed to prevent nutrient deficiencies. Debris made largely of needles and finer branches will not pose the same problems.*

Other materials

Organic materials from a variety of sources can be used as soil amendments, including topsoil salvaged from nearby construction sites, manure, hay, straw, pulp mill sludge, sewage sludge, or municipal compost. Good rehabilitation projects take advantage of these materials as their availability arises. Consider the following guidelines in using these materials:

- **Topsoil and forest floor:**

This material, salvaged from other construction projects (e.g., permanent roads or landings) can be used to supplement materials present on the site.

- **Manure, hay and straw:** Little planning is required to use these materials. Manure provides a good source of organic matter and includes nutrients such as nitrogen, phosphorus and potassium.

Hay from local meadows is a particularly good resource, since it is unlikely to introduce any unwanted species. Sometimes mouldy hay can be obtained very economically. Straw is usually free of weed seeds and has an intermediate C:N ratio that is higher than hay but lower than woody residues.

Addition of organic matter to soil in experimental plots for Soil Rehabilitation



Spreading manure



- **Pulp mill sludge:** This material has a high C:N ratio and small particle size. It decomposes more rapidly than woody residues when used as a soil amendment, and fertilization is likely necessary to prevent nutrient deficiencies. Consult with a soil expert.

Stabilized sewage sludge ready for spreading



- **Sewage sludge:** Sewage sludge has a high nutrient content, but is only available near population centres. High water content increases transportation costs, but specialized pumping and sprayer equipment allows

application as slurry at some distance from roads. Preferable, however, is to extract excess water in a press and to stabilize the sludge with lime, polymers or through composting. To protect ground and surface waters, consult with an expert to determine

application rates based on the nutrient and trace metal content of the sludge. Quite often national ministries regulate the location and rates of sludge application, and permits must be obtained before its transport and use.

Municipal waste compost



- **Compost:** Municipal and other composts may be available near populated

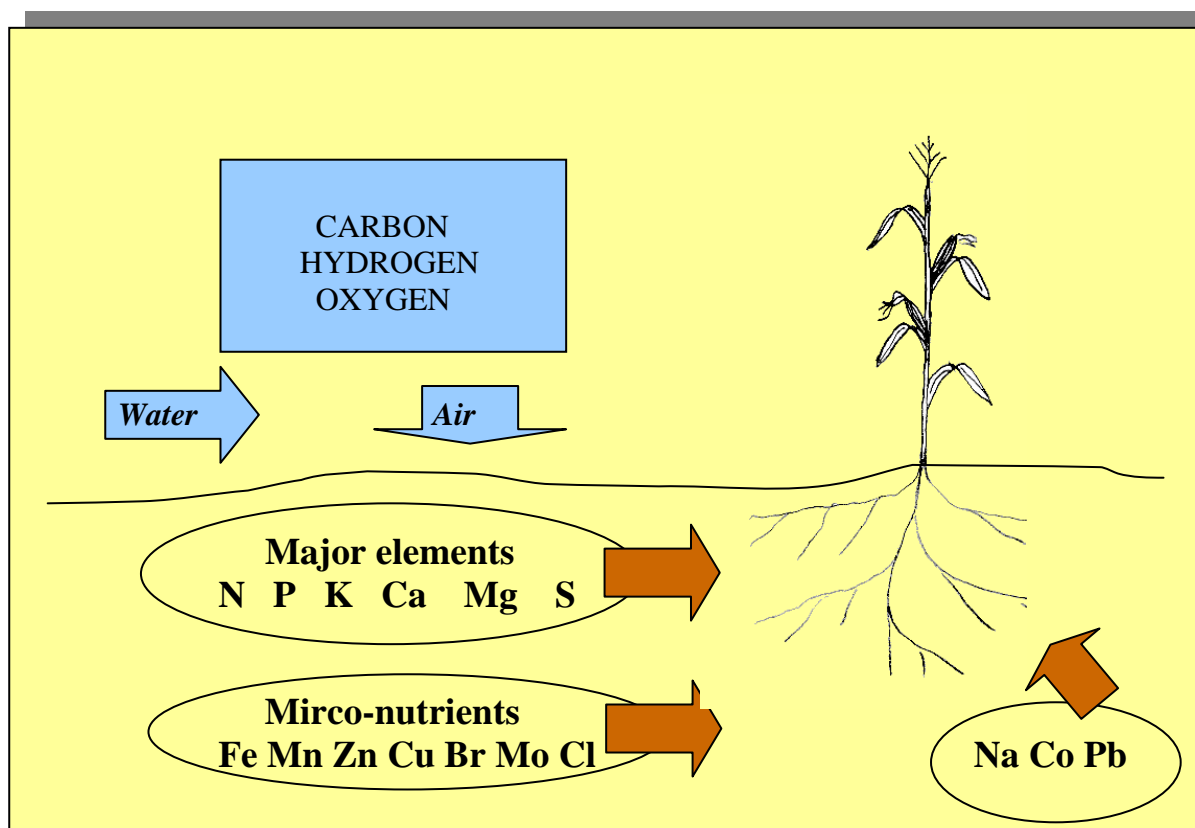
areas. Their nutrient concentrations are usually lower than those in sewage sludge but higher than in logging residues or pulp mill sludge. Consider compost primarily as a source of organic matter as opposed to a source of nutrients.

- ***Food industry wastes:*** The food industry in many industries produce suitable organic matter, which could be used before or after composting. Many of these such as olive oil and wine production are also fortuitously located in European areas, which are more prone to desertification. Another example is coffee grounds, which are produced in large quantities in the Mediterranean region.

Chemical fertilizers

Fertility of a soil is "the quality that enables it to provide nutrients, in adequate amounts and in proper balance for the growth of specified plants, when other growth factors such as light, moisture, temperature, and the physical condition of the soil are favourable." For optimum crop production, adequate and balanced supply of plant nutrients is essential.

Erosion, leaching, and cropping are all responsible for the removal of plant nutrients from soils. Obviously, the relative amounts removed in each of these ways will vary from soil to soil and will also depend on rainfall, soil texture (i.e. proportions of sand, silt, and clay), nature and amounts of nutrients present, and the cropping practices followed. Erosion losses are appreciable on steep slopes whereas removal by leaching occurs in level areas. Some nutrients such as N in the nitrate form are readily removed by leaching. Others, such as P are much more resistant to loss by leaching. Since water moves through coarse textured (sandy) soils more readily than through fine textured clayey soils, leaching losses are usually greater in the former. Since different crops have different nutrient requirements, removal by cropping will vary according to the crop removed.



The essential elements may be classified as follows: Major elements or macro nutrients are required in relatively large amounts, i.e., (i) *carbon, hydrogen and oxygen*, which are supplied by air and water, (ii) *nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur*, which come from the soil. Trace elements or micro-nutrients are required in relatively small amounts, i.e., *iron, manganese, zinc, copper, boron, molybdenum, and chlorine*, all of which come from the soil. A number of other elements such as *sodium, cobalt and lead* are also taken up by plants from the soil. Although a few of these have been found beneficial under some circumstances, plants will generally grow and develop normally without them.

Chemical fertilizer and Soil Rehabilitation

A single large application of chemical fertilizer is usually insufficient to restore the nutrient supply of a degraded soil. If soil organic matter has been displaced or destroyed, and if only limited vegetation cover is present, most of the nutrients added in a large application may be lost from the site. Instead, fertilization should be used primarily to enhance the early establishment and growth of vegetation, which will restore soil structure and organic matter content. Modest repeated applications may be needed until the internal nutrient cycle of the site is re-established and can meet the needs of the vegetation. However a site should not be

considered adequately rehabilitated if the survival of the vegetative cover depends on continued fertilization.

While natural, temperate forests commonly respond to nitrogen fertilization and only rarely to phosphorus, potassium, or sulphur, any of these nutrients may be deficient in disturbed and rehabilitated soils. Soil tests can be obtained from commercial laboratories to help determine fertilizer requirements for grasses and legumes, but recommendations based on fertilizer response trials are not available for most tree species and forest soils. In any case, such recommendations are based on annual growth rather than on long-term requirements. Fertilizer tends to be a small portion of total rehabilitation costs, so if nutrient deficiencies are anticipated, complete formulations are usually used at rates that approach safe maximums.

Maximum fertilizer rates are set to reduce the risks of (1) damaging vegetation from over-fertilization and (2) losing fertilizer through runoff or leaching. Damage to young seedlings has been reported at application rates around 100 kg N/ha. The risk of fertilizer damage increases greatly with decreasing moisture and increasing temperature. Therefore higher fertilization rates can be used without damaging seedlings in climates with higher precipitation. However, in wet environments, large amounts of fertilizer can be lost from recently disturbed sites that are low in organic matter and have limited vegetation cover.

Three general formulations can be considered for rehabilitation work

N alone	<i>This may be adequate for light disturbance.</i>
N plus high P ₂ O ₅	<i>Can be used to enhance establishment of grasses. Consider banding for grasses, or other approaches (including spot application) to get P₂O₅ close to the plant roots in critical situations.</i>
N, P ₂ O ₅ , K ₂ O plus low S	<i>This should be sufficient to supply all the major nutrients that are likely to be deficient. This is an economical and effective choice</i>

High analysis granular fertilizers are preferred because of their lower transport and handling costs. A complete fertilizer with approximately equal concentrations of the macronutrients (such as 19-18-18, containing 19% N, 18% P₂O₅, and 18% K₂O) is desirable because of the low fertility of severely disturbed soils. Many possible formulations are available,

and for most situations it is difficult to identify a clear advantage for any one recipe. Cost and availability will usually dictate the best formulation to use.

Application rates for initial fertilization will usually range between 30 and 100 kg N/ha, depending on the severity of nutrient depletion at the site, the risk of runoff, the amount and composition of seeded cover, and the



rehabilitation objectives. If 19-18-18 were used, the range of application rates would be 160 to 525 kg of fertilizer product per hectare. Application rates in the lower part of the range (30–50 kg N/ha) are suitable for erosion control situations where legumes make up a large proportion of the seed mix. For largely grass mixtures where short-term erosion control is the primary objective, use application rates in the middle of the range (50–80 kg N/ha). To restore soil structure and long-term productivity for tree growth, application rates in the higher part of the range (up to 100 kg N/ha) are appropriate but be aware that high rates of fertilization can lead to loss of fertilizer due to leaching. Repeated applications at lower rates are probably better than one large application, but transport and setup costs are usually lower for a single large application. Consult with an expert in your area for more information on typical fertilizer application rates.

Fertilizers can be broadcast on the surface, included in a hydroseeding slurry, or incorporated, if shallow mixing (<20 cm) is part of the rehabilitation plan. Fertilizer is usually applied at the time of seeding, ideally immediately after the seedbed is prepared. Higher losses of seed and fertilizer occur after the freshly prepared surface has been subjected to rainfall. Where vegetation is already established, apply fertilizer when growth is most rapid. In interior temporal areas, fertilizer can also be applied in the fall or winter, though higher losses may result. Fall and winter applications are not recommended in coastal regions with high amounts of rainfall because of high leaching losses.

Other Points to remember:

- To avoid burning seed, do **not mix** seed and fertilizer together in the same bin for dry seed application.
- Where a large amount of a nutrient-poor material such as wood chips or sawdust has been applied, **extra nitrogen will be needed** to counteract the nitrogen-immobilizing tendency of the added organic material. Consult with an expert to determine rates. Urea (45-0-0) is suitable for use in combination with nitrogen-poor amendments.
- Where there is a **risk of drought**, reduce single application rates or incorporate the fertilizer.
- If fertilizer supplies are limited, apply the fertilizer to **critical locations** such as large fills and cut banks.
- Schedule a **second fertilizer application** within three to five years after seeding to maintain the vigour of grasses and legumes at critical erosion control locations, and for severely degraded soils.
- **Slow-release fertilizers** like sulphur-coated urea should not be applied within 3 m of watercourses.

Mulches

Mulches are non-living materials spread over the soil surface to reduce erosion and aid plant establishment by conserving moisture and moderating soil temperatures. Several types of mulches can be used, including relatively thick layers of organic material, manufactured mulch mats of various types, and thin layers of mulch primarily applied during hydroseeding.



Thick mulches: Materials suitable for thick mulches include logging residues (either fine slash or chipped debris), forest floor material, straw or hay. As a rough guideline, 5–10 cm should be a sufficient depth for most sites. Decomposition occurs slowly because the mulched layer dries out repeatedly, but the materials will eventually contribute to the restoration of soil organic matter.

Thick mulches imitate the ecological functions of a forest floor. They are recommended primarily for drought-prone sites, but may also be appropriate where soils are wet or cold as long as trees are planted on elevated microsites or the mulch provides a suitable rooting medium for seedlings. The mulch will keep fine-textured soils moist and soft, and tree roots may explore the interface between the mulch and mineral soil. Thick mulches will prevent the growth of grass and many weedy species. They are best used in combination with planted shrubs and trees.

Manufactured mulch mats: Various types of manufactured mulch mats are available, including plastic and fibre matting or netting materials. Some of these products can also aid in germination and vegetation establishment. Mats must be in close contact with the soil surface to be effective, and this may limit their suitability for mechanical slope protection of forest roads, where slopes often have rough surfaces. Their ability to trap sediment and biomass is useful in building soil, improving surface soil conditions, and restoring soil organic matter. Because of cost, the use of manufactured mats is limited to small, critical areas such as ditch lining and bridge crossings.

Thin mulches: Thin mulches are useful to aid the germination and establishment of grasses and legumes on drought-prone sites, highly erodible soils, unconsolidated (sandy) surface soils, and slopes with southerly or westerly exposures. The mulches can be applied over the top of seed to protect it from desiccation and wind, water, or gravity movement. Some types of light mulches need a tackifier applied to or with them to prevent them from blowing or washing away.

The most common mulching technique for use in combination with grasses and legumes is wood fibre applied with a hydraulic seeder with mechanical agitation. Products consist of ground wood fibres mixed with a green dye to improve visibility during application. Although it can be combined with seed and fertilizer, this type of mulch is best applied in a second pass over the top of seeded areas. In this way, seed is in contact with soil and covered by mulch. Recommended rates are 1000–2000 kg/ha. Application at these rates takes 6 to 12 loads with a seeder for every load of seed application. It is important to note, however, that while rates at the upper end of this range improve erosion control, they may also reduce plant establishment.

Thin straw mulches offer excellent soil protection. Straw can be applied by hand, or with a straw blower (available through farm equipment suppliers). A blower speeds application and ensures more even coverage. Recommended rates range from a minimum of 2000 kg/ha to over 5000 kg/ha. For maximum effectiveness, a tackifier should be sprayed over the surface straw to hold it in place. Mechanical means of anchoring straw, such as disking, rolling, or covering it with netting, are generally impractical for forest soil rehabilitation.

SOIL CHEMICAL REHABILITATION: ACID SOILS

The major causes of acidity are the type of material from which the soils were formed and very high precipitation. In areas where annual precipitation is quite low, nutrients are not leached; soils are neutral to alkaline in reaction and are naturally quite fertile. In other areas the soils are developed from calcareous (limestone) materials and are naturally alkaline as well. In the Atlantic area, high precipitation of approximately 1000 mm results in severe leaching of elements such as calcium, magnesium, and potassium from the surface soil leaving it strongly acid and relatively infertile.

In strongly acid soils, aluminium and manganese are more soluble and can be present in toxic amounts in the solution, which surrounds the soil particles and roots. Fertilizer efficiency is reduced in such soils and the activity of soil bacteria is drastically limited. Soil acidity is, therefore, a major limitation to crop production.

When soil samples are analysed in the laboratory, the degree of soil "acidity" or "alkalinity" is expressed in terms of "pH values". It is important to understand the meaning of this term.

While the pH of a soil refers to the concentration of hydrogen ions in that soil, it is the effect of the pH on the solubility and availability of many of the elements in the soil that is important rather than the actual concentration of hydrogen ions. Since the concentration of soluble salts in soil can affect pH measurements, 0.01 M CaCl₂ is used to eliminate this effect. Therefore in some laboratories, pH is determined using this dilute CaCl₂ solution. This results in more consistent pH values, which are about 0.5 of a unit less than those determined in water.

What is pH?

- *The pH scale is divided into **14 divisions** or pH units ranging from 0, which is extremely acid, to 14, which is extremely alkaline.*
- *Soil "pH" refers to the concentration or **activity of hydrogen ions** in the soil solution surrounding soil particles and plant roots.*
- *A pH of **7.0** means that the soil is **neutral in reaction**. Soils with a pH below 7.0 are acid and soils with a pH above 7.0 are alkaline.*
- *The pH of most **cultivated** mineral soils of the European Union falls in the range between **4.6 and 6.6**.*

Importance of Limestone in Crop Production

The addition of limestone is essential for the successful production of many crops in European soils. Although the overall effect of liming is to increase yields, there are 5 major functions which lime fulfils in the soil:

What Kind of Limestone and How Much?

There are two types of agricultural limestone generally available: calcitic which contains calcium carbonate, and dolomitic which contains both calcium and magnesium carbonates. The type and amount of limestone required depends on the calcium and magnesium level within the soil and the requirements for the crops to be grown. Both will correct soil acidity.

5 major functions of lime in soil

1. It **reduces toxic levels** of soluble aluminium and manganese.
2. It **increases the efficiency** of applied **fertilizers**.
3. It **encourages the activity of soil bacteria** thus releasing valuable nutrients such as nitrogen, phosphorus, and sulphur from organic components within the soil. In the case of legumes, it also stimulates the nitrogen-fixing bacteria in the root nodules.
4. Through several processes, it **stabilizes soil aggregates** and renders the soil more resistant to erosion.
5. It supplies **calcium and magnesium for crops**.

In addition to the type of limestone to be applied, there are two other important considerations regarding the use of limestone:

- **Neutralizing Value** - This refers to the effectiveness of limestone as compared to pure calcium carbonate. The higher the neutralizing value, the more soil acidity it will neutralize. In theory, the neutralizing value is 100 for calcitic limestone and 109 for dolomitic limestone. Due to some impurities, however, the values for commercially available limestone will be slightly less.
- **Rate of Reaction** - Limestone reacts slowly with the soil and the rate at which it reacts depends mainly on the fineness to which it is ground, although calcitic limestones are somewhat more soluble than dolomitic limestones. Finely ground material begins to react immediately whereas very coarse material may react slowly over 2-3 years. Very coarse limestone, such as fertilizer filler or "grits", will take many years and are of no value in attempts to change soil acidity.

Usually legislation requires that agricultural limestone must be labelled to indicate its calcium and magnesium content, neutralizing value, and its physical state (sieve size).

The rate of limestone application required to achieve a given soil pH will depend on three main factors: (1) the initial soil pH, (2) the texture of the soil, and (3) the organic matter content of the soil. The only reliable way to determine the rate of limestone required is by a soil test, which is highly recommended.

In general, it is not advisable to lime to pH 7.0. Unnecessarily high liming rates may have adverse effects on the availability of phosphorus and certain trace elements.

How and When to Apply Limestone

Limestone can be applied whenever field conditions are suitable. For immediate response and maximum yields, limestone should be thoroughly mixed with the soil before the crop is seeded. Part of the needed amount may be ploughed down, and the balance worked into the surface, or it may all be applied on the surface as on permanent-type pastures. Liming sod is an ineffective manner of raising pH of the plough layer. Limestone applied on the surface of sod penetrates very slowly (up to 1.5 cm per year) and requires many years to correct the acidity throughout the plough depth. Frequent light applications are preferable to heavy rates on sod, since the heavier rates result in localized areas of extremely high pH and may cause some depression in the yields of sod crops.

Applying moderate rates to large areas rather than using the same quantity to supply the full limestone requirements over smaller areas obtains maximum benefit from limestone. Subsequent applications may be made during the next cycle of the rotation to bring the pH to the desired level.

In humid areas affected by the Atlantic, leaching, acid rains, and crop removal of calcium and magnesium will slowly but steadily lower the soil pH and "maintenance applications" of lime are required. While maintenance applications should be based on periodic checks of soil pH, a general recommendation for sandy or silt loams is 500-600 kg ha⁻¹ per year. Heavy fertilization with acid forming fertilizers such as ammonium nitrate or diammonium phosphate will increase this requirement.

VEGETATION

Factors affecting plant growth

Many factors influence plant growth, some of the most important ones are:

Climate

The daily and seasonal supply and distribution of moisture, heat, sunlight, wind, and frost provide varieties of regional and local climatic environments. Such environments directly influence the growth, quality, and maturity of crops. Also, indirectly they may affect the severity of many plant diseases and pest infestations.



At present, sufficiently accurate definition and delineation of local specific crop geoclimatic environments is difficult and incomplete. There is, however, much that can be done to take advantage of favourable elements of the climate. Successful farmers can select plant species and varieties within species to suit the local climate. They can, at least to a degree, modify local field and soil climates by protective hedges, land drainage, tillage practices, and the use of crop residues or snow barriers to reduce the severity of winters to biennial and perennial plants. The application of many fertilizers, fungicides, and pesticide treatments can be adjusted to weather conditions.

Soil

Crop production capacity is greatly influenced by soil quality. Soil quality is determined by physical and chemical characteristics, some of which may or may not be economically controlled. Many of the physical properties such as texture, slope, and soil depth, cannot be modified economically by the farmer. Yet, these factors determine the suitability of a soil for agricultural production. In general, for the cool moist climate of maritime regions, the most desirable soils are friable, well-drained sandy loam or loams on relatively level to gently rolling topography.



Chemical characteristics that affect soil quality are: acidity, organic matter content and supply of essential plant nutrients. In general, if physical properties are satisfactory, the chemical

properties can be modified by adequate use of agricultural limestone, manures, commercial fertilizers, green manure plough downs, and other organic additives.

Micro-organisms

Soil microorganisms (bacteria, yeasts, fungi, algae, protozoa, etc.) are present in soils; furnish them with food and water plus a suitable habitat. Their food is the energy of the material, which enters the soil in the form of plant and animal residues. As soil microorganisms decompose organic matter, they release its nitrogen, phosphorus, and other mineral nutrients in forms available to crops. In addition, the decomposing organic matter improves soil tilth, increases the moisture holding capacity, and lessens soil loss.



Crop Sequence

Traditionally, farmers have been encouraged to adopt and follow crop rotations designed for their specific type of farm operation. Crop production programs in the past were less intensive and only "key" crops in the rotation were fertilized. The main advantages claimed for crop rotations were better control of insects, diseases, and weeds, and better maintenance of soil structure.



Farmers are now encouraged to adopt different cropping systems on different soils for maximum production. Certain fields, which are particularly suited, may be used for cash crops. Other fields may need to be maintained in continuous forage production, and still others may be used in a rotation of several crops. This enables more flexibility in the cropping program from year to year, as warranted by changing feed requirements and changing cash crop opportunities. However, to successfully carry out such a program adequate fertilization of each crop is required, as well as plant disease, insect, and weed control measures. The cropping program should, over the long term, maintain or improve the productive capacity of the soil.

Lime and Fertilizer

Some soils are, by nature, very acid and low in available plant nutrients. Thus in planning a crop production program, agricultural limestone should be applied at the rate required to raise the soil pH to the optimum level for the crops which are to be grown, and the right kind and amounts of commercial fertilizers and/or farm manures must be applied to supplement the essential plant nutrients in the soil.



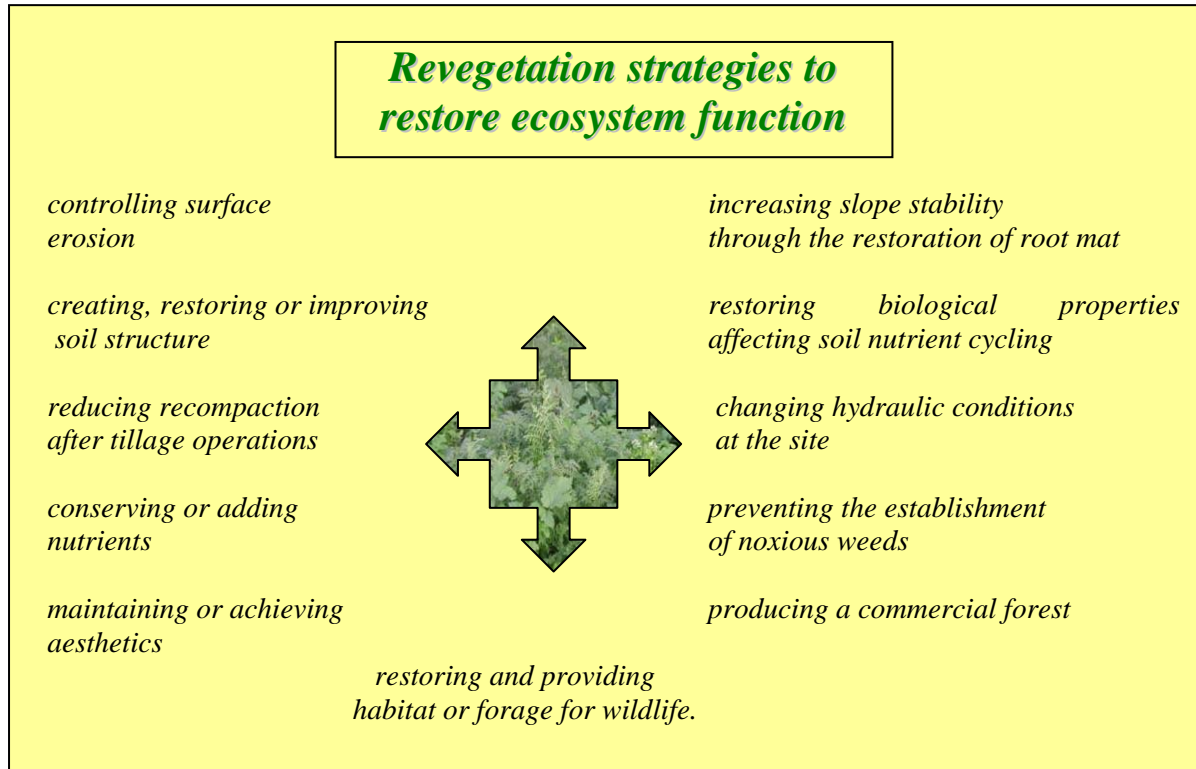
Crop Management

In addition to the foregoing, a successful crop production program is influenced by soil preparation, seeding date, tillage, weed and pest control, time and placement of fertilizer applications, grazing practices, harvesting dates, etc.



Revegetation strategies to restore ecosystem function

Revegetation is a fundamental part of all rehabilitation projects. The type of revegetation techniques used depend largely on the rehabilitation objectives, which may include:



Determining desired characteristics of vegetative cover

Revegetation of some kind is an essential part of every rehabilitation process. Bare soil will erode, recompact (if it has been recently tilled), lose soil structure, lose nutrients, and undergo invasion by weed species. A wide variety of approaches to revegetation are possible. Traditional approaches have usually involved seeding a mixture of agronomic grasses and legumes with erosion control as the primary objective. Modern rehabilitation projects have more demanding objectives, however, such as re-establishing a commercial forest. Sometimes, techniques required for one objective (such as developing complete ground cover to prevent erosion) may conflict with others (establishing a free growing crop of trees).

The guidelines below, and the discussion of various revegetation strategies that follow, show how different techniques might be used to achieve a variety of rehabilitation objectives.

- To control surface erosion, use grass and legume seed mixes as your first choice, then shrubs and hardwood species, then conifers. However, keep in mind that grass, particularly sod-forming species, may interfere with conifer establishment on some sites.
- Use vegetation with ecological characteristics that are compatible with your long-term objectives. Gain familiarity with the potential of native grasses and legumes by experimenting on sites with low erosion potential. Keep in mind that experience with native grasses and legumes is limited, and they may be more risky than agronomic seed mixes, where immediate erosion control is required. Consult with an agrologist in your area for help in selecting native plants for use in rehabilitation prescriptions.
- Use grasses and legumes to restore and maintain soil structure, especially in medium- and fine-textured soils.
- To enhance development of soil with a distinct forest floor, consider using native shrubs and hardwood species. They may be successfully inter-planted with conifers. Keep in mind, however, that native shrubs and hardwood trees are less effective than grasses and legumes for short-term erosion control and rapid improvement in soil structure.
- Develop or have an expert develop site-specific requirements for seeding rates, planting densities and species mixes. More intensive approaches are often required in rehabilitation work than in agriculture.
- Consider using bioengineering techniques in situations of high sensitivity or risk.
- When developing strategies for revegetation, consider other uses of the site and their possible effects on your plans. For example, where deer populations are large, plan to control browsing by creating barriers to deer access, delaying planting until other food sources are available, or by using other techniques. Also, in areas with cattle grazing, plan and implement measures to prevent cattle from congregating on the rehabilitated area, minimize grazing use until the tree seedlings become established, or try other techniques such as obstacle planting to protect seedlings. Local experience will often be the best source of innovative solutions to problems associated with shared use of rehabilitated areas by wildlife or cattle.
- Remain flexible. There are an unlimited number of possible approaches. Be guided by the ecological considerations of the site, an analysis of the risk, and your ultimate objectives.

Grass and legume seeding

Native plants, domesticated native plants, and introduced agronomic species may all be useful for rehabilitation. There is a very large selection of species to choose from, and seed mixes can be easily tailored to achieve particular effects (Fig. 6). Grass and legume seeding can also be used to meet many other revegetation objectives such as restoring soil structure, enhancing site nutrient status, hastening green-up, and producing forage.

Seeding grass for Soil Rehabilitation

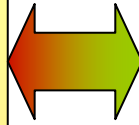


Native and domesticated grasses and legumes can be used in the same situations and applications as agronomic varieties, and in many cases, they will be better suited for use on a particular area. Many native plants may be well adapted to conditions of low nutrient status, and they will most likely reduce potential adverse effects on biodiversity that may arise from seeding introduced plant cultivars in forest and range ecosystems.

Choosing the proper species for a particular situation requires that the characteristics of the species be matched with the site conditions and rehabilitation objectives. Attributes such as root form, reproductive system, growth form, timing, and adaptability all affect the suitability of plants for a particular site and objective. For help in formulating seed mixes, consult experts, who are familiar with your area.

Disadvantages of seeding grasses and legumes for rehabilitation

- Seeded species may affect tree growth by **competing for moisture and nutrients**.
- Seeded species may increase the risk of **frost damage** and **snow** press damage to tree seedlings in some situations.
- Many species currently used are not native and may thus have adverse effects on **biodiversity** when used in forest and range ecosystems.
- Where emergency revegetation is required, the effect of uncontrollable factors such as **weather** or **seed predation** on the remediation plan need to be considered.
- Few nitrogen-fixing legumes can be grown on **acid soil** (common in forests) or at **high elevation**.



Advantages of seeding grass and legumes for rehabilitation

- Seeding is **inexpensive**, fast, and easy.
- Many **different varieties** are available for specific conditions or to meet a variety of objectives.
- Seeding promptly after a disturbance can provide an almost continuous **ground cover**.
- **Dense root mats** formed by some species are very favourable for stabilizing soil and developing soil structure.
- **Deep-rooted** species are highly suitable for reducing soil moisture levels where slope stability or site wetness is a problem.
- Some species establish rapidly and yet are **short-lived**, thereby **reducing competition** over the longer term.
- Many species of grasses and legumes are **widely adapted**.
- Some **native species** can be used in many situations and others (such as less palatable or slow-growing species) can be developed for special uses.

Planting shrubs

Revegetation with native shrubs can be a valuable rehabilitation tool (Fig. 7), particularly in highly sensitive areas such as recreation areas, alpine tundra, and grasslands. Native shrubs have not received a great deal of attention for rehabilitation of forest lands in the past, but the infrastructure necessary to allow routine use of shrubs has been rapidly developing in recent years. Commercial seed-pickers are available to collect material. Nurseries often also currently grow native species in a variety of container stock types.

Various methods can be used to establish native shrubs. Container stock can be hardy and, although it may be browsed in some areas, it can be planted in areas where seed retention and survival are problems. Many species such as alder, rose, soopolallie and juniper may be planted by direct seeding, if a source of seed can be found. Furthermore,

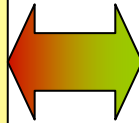
Autochthonous plant (Pistacia lentiscus) used for Soil Revegetation in semiarid zones



several species can be established as rooted cuttings –willow for example can be established as unrooted cuttings of stems – but mortality rates are high. For help in developing rehabilitation plans involving the use of shrubs, consult with ecology and soil specialists in your area.

Disadvantages of planting shrubs for rehabilitation

- *Ground cover is discontinuous and it may take many years to develop a forest floor and continuous root mat. Planting shrubs is **not** the best choice for **short-term** erosion control.*
- *There is **no direct return** on the **cost** of planting, though there may be indirect returns.*
- *Shrubs will **compete** with **conifers**, but in well-designed plantings there may actually be a net growth benefit to conifers.*
- *Some shrub species may be severely checked by heavy **browsing**.*



Advantages of planting shrubs for rehabilitation

- *Shrubs have deep, woody root systems that give **mechanical support** to **slopes**. When planted with grass, they can help to prevent sloughing of the shallow sod layer. The woody top growth also helps to stabilize rehabilitated areas by **reducing surface wind velocity**.*
- *Shrubs **establish** more **quickly** and **easily** than trees, and often grow on sites not suitable for conifers.*
- *Available shrub species tend to be **indigenous** and better adapted than introduced grasses and legumes.*
- *Some species will **fix nitrogen** even in areas where legume success is unlikely.*
- *Shrubs may serve as nurse trees to a conifer crop by providing a **browsing source** to draw animals away from seedlings and by protecting seedlings from frost.*
- *Shrubs improve soil and **forest floors** by **drying** them out, adding **organic** matter, and, as mentioned above, some can even fix nitrogen. Compared to grasses and legumes, these objectives may be achieved with fewer negative effects on conifers.*
- *Shrubs provide a good source of food and protective cover for **wildlife**.*
- *In forested areas, shrubs may improve **visual quality** by screening disturbed areas from view, and by softening the harsh lines of disturbed areas.*

Planting hardwood trees

Much of the previous discussion on native shrubs applies to hardwood trees as well. Investigations in regards to mixed planting have indicated that, in certain situations, these techniques may possess some growth and performance advantages over the conifer component of a mixed planting.

Disadvantages of planting hardwood trees for rehabilitation

- *Returns on planting cost investment may be **lower** than for other species, though that may change. There continues to be psychological resistance to planting hardwoods.*
- *Planting material for hardwoods is **not as readily available** as for softwoods.*
- *At high densities in mixed planting, hardwood trees will **compete** with **conifers**.*
- *Hardwood trees may be **affected by herbicides** used on other parts of the block.*
- ***Birch** is often **browsed by wildlife**, which may reduce stocking success.*



Advantages of planting hardwood trees for rehabilitation

- *Hardwood species are often **natural pioneers** of disturbed sites. They can establish easily, produce large quantities of **leaf litter**, which helps rebuild the forest floor, stimulate plant and microbial activity, and re-establish soil ecosystem functions. Their **roots** help improve soil physical and chemical properties. Red alder has the additional benefit of being able to fix nitrogen.*
- *Hardwood trees **grow fast**, which helps "green up" disturbed areas and enhance visual quality.*
- *A hardwood cover on rehabilitated areas within a cutblock may contribute to the achievement of **biodiversity** and wildlife **habitat** objectives.*
- *Depending on the stocking levels, hardwoods may act as a **nurse crop** and improve conifer growth by moderating temperatures and protecting softwood regeneration from browsing and windthrow.*
- ***Shorter rotations** for most hardwood species allow more flexibility in the timing of rehabilitation. For example, on blocks requiring access for some time after planting, rehabilitation of roads and trails could be delayed without losing the opportunity to produce a merchantable hardwood crop.*

Planting conifers

Planting conifers for rehabilitation requires more flexibility and perhaps more stringent planting practices than would be used in planting most cutover areas (Fig. 8). For example, consider planting at higher than maximum stocking densities, where soil conservation or risk of increased seedling mor-

Use of conifer plants (pinus) for Soil Rehabilitation



tality are issues. In rutted areas take more care to select good microsites for planting; consider larger than normal stock, where the need for more robust seedlings is indicated, and species requirements may change as a result of disturbances.

Commercial planting densities are often too low to provide optimum rehabilitation effects such as erosion control or nutrient capture.

Disadvantages of planting conifers for rehabilitation

- Above- and below-ground **growth** is **slow** compared to that of some other types of vegetation.
- Forest floors and site-nutrient pools are **restored** more **slowly** than with other vegetation types.
- **Root** systems are **coarse** compared to those of some other types of vegetation and are therefore not the best for controlling erosion or restoring soil structure.
- Commercial planting **densities** are often **too low** to provide optimum rehabilitation effects such as erosion control or nutrient capture.

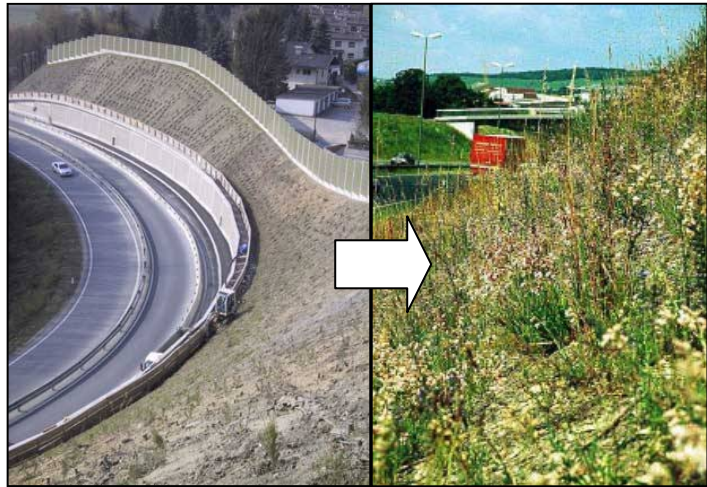


Advantages of planting conifers for rehabilitation

- Planting conifers offers the most direct route to a forest of anticipated **commercial value**.
- Stock and **seed** are readily **available**.
- Seed-rich debris may serve as both **seed source** and **mulch**.
- **Rapid growth** of conifers mitigates visual impacts associated with soil disturbances.
- Conifers have greater **root strength** for slope stabilization than grasses or legumes.

Bioengineering techniques

Bioengineering in rehabilitation refers to the use of living plants to create structures, usually to control erosion or stabilize slopes. Bioengineering techniques involve the very intensive use of relatively large pieces of living material. The living material is used in such quantity that it helps provide slope stability even before it begins to grow. As the living



material grows, the benefits of revegetation and slope stabilization are achieved in one action.

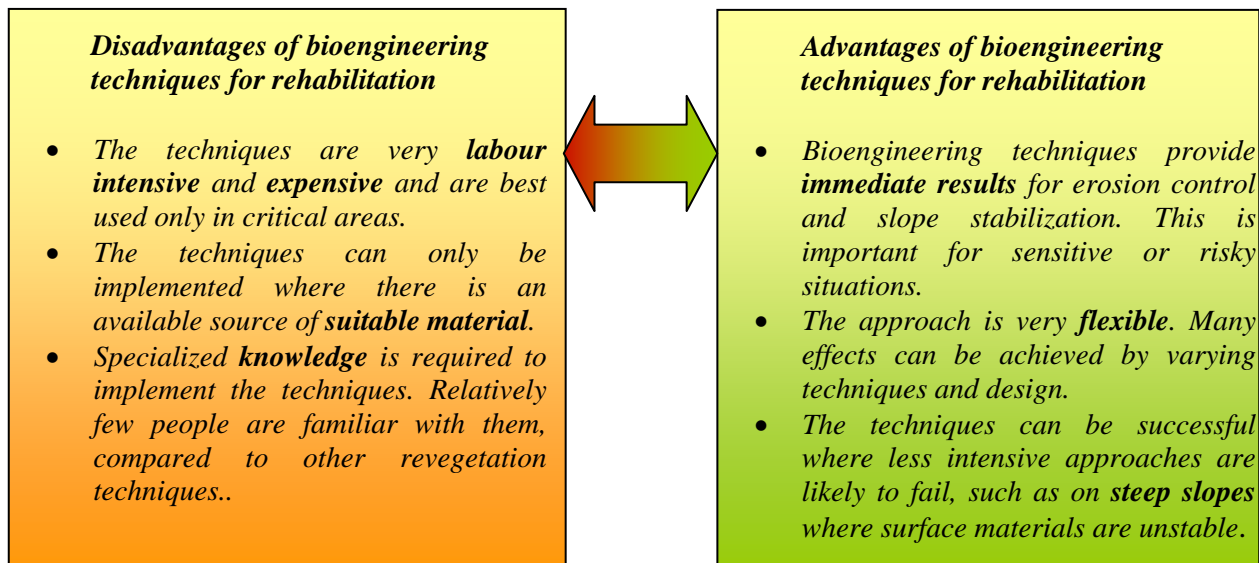
Bioengineering can be used to stabilize existing slopes or to help reshape slopes to more stable forms. Small terraces, for example, can be created to trap sediments and dissipate the energy of running water. Bioengineering techniques may be useful where:

- Slopes are very active and seed loss is likely or damage is imminent.
- There is high risk of damage and significant public concern.

The major categories of bioengineering techniques include:

- *Live staking*: Inserting, driving or burying individual cuttings in random, grid or linear patterns to immediately stabilize eroding or slumping slopes
- *Cordons, hedges and brush layers*: Constructing terraces or trenches, either parallel or diagonal to the slope contours, for hedge-like plantings of live cuttings or rooted trees or shrubs to stabilize loose slopes.
- *Wattles (sticks interwoven into fences) and fascines (bundles of sticks)*: Staking or burying fences or bundles of interwoven live branches in rows or shallow trenches, either parallel or diagonal to the slope contours to create relatively large structures to trap sediments, slow water movement and ultimately revegetated slopes

For help in applying these techniques, consult an expert in bioengineering.



Cattle grazing and rehabilitation

In some situations, cattle grazing may interfere with the prescribed goals of establishing conifer seedlings and maintaining vigorous vegetation cover. Agronomic seed mixes are often very palatable and may attract cattle to the rehabilitated area, resulting in trampling damage to planted tree seedlings. Since vigorous vegetation cover is required to rebuild soil



structure, high rates of vegetation removal by cattle may seriously reduce the effectiveness of this treatment. It is therefore important on blocks with grazing to consider how best to manage cattle.

Cattle management is carried out within the broad strategies established under a range use plan for the range agreement holder, usually a local rancher. Changes in cattle management and

the range use plan require the cooperation of the rancher and consultation with local agrologists. Rehabilitation plans must include provisions to ensure that the accumulated effect of cattle damage does not reduce conifer stocking to less than acceptable levels.

To prevent cattle from congregating on rehabilitated areas, consider such practices as:

- *deferring use until late in the season*
- *allowing for only **short periods** of grazing on blocks with rehabilitated areas*
- *locating **salt blocks** to encourage cattle to congregate away from rehabilitated areas*
- *leaving an **irregular ground surface**, pulling logging debris onto the roads or landings, or otherwise making it difficult for cattle to move around on the rehabilitated areas*
- *obstacle **planting***
- *portable **electric fencing***
- *using **seed mixes** or **native plants** that are low-growing or unpalatable to cattle*
- ***regular herding** of the cattle to improve grazing distribution*
- ***seed distribution** along **roads**, **landings** and **cutblocks** to disperse cattle into other areas*
- ***avoiding configurations** at the layout stage that concentrate cattle on landings and skid trails. For example, avoid coalescing disc-trenches, windrows, or debris piles that direct cattle onto the rehabilitated area.*