14 THE ESTABLISHMENT AND CARE OF VEGETATION

Chapter contents

continued...

14 THE ESTABLISHMENT AND CARE OF VEGETATION

14.1 Introduction

The most successful revegetation schemes are those where the establishment of vegetation matches the needs of the intended land use.

The vegetation found on any area of land will either contribute to or detract from the use of that land. For vegetation to contribute to land use, clear definition of the proposed uses is needed. This definition of uses will enable the appropriate vegetation to be selected, established and maintained. In a reclamation scheme where no particular land use is intended the objectives of reclamation will define the vegetation types needed (see Box 14.1).

Figure 14.1 gives examples of the wide range of uses to which land may be put and the vegetation types which are appropriate to these uses. The figure clearly shows why it is important that the vegetation process is guided by well-defined objectives. Vegetation performs an important engineering function through its influence on the soil and soil moisture regime. These 'bioengineering' functions are summarised in Figure 13.4.

A temporary vegetation cover has been established on some reclaimed sites to enhance their appearance to potential developers (see Box 14.2).

The establishment and care of vegetation is a long-term operation. Almost all vegetation needs some continuing care and on reclamation sites this care may be intensive over five, ten or more years. It is therefore important that the requirements for vegetation care are understood and accepted when objectives are agreed, or that the objectives are set according to the resources which will be available in the future. Many reclamation schemes have deteriorated because the objectives and resources for long-term care were not properly matched.

New use / Vegetation type	Individual trees	Forest tree species	Native tree species	Mixed woodland	Shrubs	Pasture grasses	Mown grass	Rough grass	Wildflower mixture	Wetland species	Aquatic species
Productive grazing						⊠					
Marginal grazing						○		○			
Commercial forestry		⊠									
Marginal forestry		○	○	○							
Sport							⊠	○			
Caravan and campsites	○		○	○	○			○			
Car parks	○				○			○			
Picnic sites	○		○	○	○		○	○	○		
Walking	○	○	○	○	○	○	○	○	○		
Ball games							○	○			
Childrens play	○			○	○		○	○			
Wildlife	○	○	○	○	○	○	○	○	○	○	○
Landscape improvement	○			○	○				○		

⊠ : Essential ○ : Possible

Figure 14.1: Vegetation types for new uses of reclaimed land (from Robinson Jones Partnership, 1987[209])

Box 14.1: Vegetation in reclamation

The nature of the vegetation required will be determined by the objectives of reclamation.

Land use objectives

Vegetation may be fundamental to the intended use of land which has been reclaimed; *e.g.* agriculture, forestry, sport, wildlife conservation. In these cases it is essential that the intended use of the land is decided before reclamation begins so that ground preparation, fertility, species selection and plant establishment can be designed correctly.

Environmental improvement objectives

In some circumstances there may be no particular use to which land will be put after reclamation; *e.g.* where the objectives of reclamation are to improve the environment by controlling erosion, absorbing dust and noise, reducing wind speeds and improving the landscape. In these circumstances it is essential that the nature of the required improvement is known so that this objective may guide the revegetation process.

The design of a scheme of vegetation establishment is therefore a process of balance between what is desirable to fulfil the objectives set for the site, and what is practical within the limitations presented by the site, its substrate and the resources available. This chapter describes the approaches and techniques which can enable desirable vegetation to be established and developed on sites where coal mining and iron and steel-making have ceased.

Box 14.2: The benefits of temporary revegetation

Many former coal mining or steel making sites have the potential for new development uses, but lie temporarily derelict awaiting the economic or other circumstances which will trigger development. Other sites are reclaimed and prepared for development but remain empty for many years before being built on. These sites can revert to a semi-derelict state which makes them unattractive to developers.

Simple, economical techniques for revegetation can be applied to these sites to create a temporary vegetation cover which will improve their attractiveness and possibly facilitate a temporary use. Vegetation types which can be used for this purpose include:

- grass/clover swards;
- flowering legumes;
- fast-growing, flowering shrubs;
- low maintenance grass/flower swards;
- fast-growing trees such as Alder and Willow.

Where substrate conditions permit areas of a site may also be left to vegetate naturally and increase in ecological value.

The benefits of temporary revegetation are that it:

- gives rapid visual improvement, ahead of major long-term work programmes;
- demonstrates that land is owned and cared for, discouraging vandalism or dumping;
- allows temporary uses at minimal initial cost;
- improves marketability of development land without impeding that development;
- is inexpensive and can be abandoned for development;
- provides maturity if some vegetation is retained in the ultimate development;
- provides ecological value.

14.2 Approaches to vegetation design

14.2.1 Integration with landform design

The design of revegetation works is a key step in the process of reclamation scheme design, and should be integrated with the design of the landform since together these aspects govern the future appearance and use of the site. Box 14.3 shows how the process of vegetation design should include much more than simply the selection of species.

Box 14.3: The process of vegetation design

Objectives of reclamation	e.g. provision of recreation facilities and improvement of the landscape
Roles of vegetation	e.g. creation of scale and enclosure, visual interest
Survey of vegetation	e.g. shapes and sizes of masses and spaces, types of woodland, hedgerow, individual trees and grassland
Analysis of surroundings and proposed uses	e.g. likely site users, access routes, viewpoints
Outline landscape design	e.g. proposed distribution of main vegetation types
Detailed design	e.g. refinement of distribution, selection of species, implementation methods

14.2.2 Natural approach to revegetation

Some sites which are to be reclaimed may already have a substantial vegetation cover which has enabled informal new uses to be developed by local residents. These sites and uses can be formalised, for example by additional vegetation works and new accesses. This natural vegetation development provides a model for a natural approach to vegetation design (see Box 14.4 and Photographs 14.1 and 14.2).

Box 14.4: Natural colonisation : a model for vegetation design

Nature and time have combined to produce a vegetation cover on some derelict sites which are now used by the community for recreation. These sites have begun to blend into their surroundings. By studying and copying these natural processes it is possible to achieve similar results in a shorter time scale at relatively little cost. Vegetation types and species which are able to grow on derelict sites are those best suited to the harsh conditions. By working mainly with these vegetation types, the amount of site improvement required for success can be reduced, thus reducing costs. The long-term maintenance requirements of vegetation selected and established in this way will also be reduced since the objective will be to maintain a semi-natural state, not a highly artificial one.

The natural approach to revegetation seeks to establish a vegetation cover appropriate to the selected after-use using simple methods. By a careful process of surveying and conserving naturally developed vegetation, assessing the characteristics of the site and selecting plants which will grow satisfactorily with the minimum of site amendment, a naturalistic vegetation can be developed with limited expenditure. The natural approach makes use of on-site materials, readily available inexpensive amendments and natural colonisation to achieve a diverse and robust vegetation cover which has the added attraction of being relatively low in cost.

Natural colonisation can be used and manipulated to produce a diverse plant cover on sites, or parts of sites, where the substrate has been suitably prepared and a rapid cover is not essential for surface stabilisation. The process of colonisation and succession can be monitored and manipulated by carefully planned inputs of seed, plants and nutrients.

Photograph 14.1: This former mineral railway has developed naturally to become a well-used path (source: Richards, Moorehead and Laing Ltd)

Photograph 14.2: An attractive mixture of mountain grasses and heather has developed naturally on this old colliery spoil heap (source: Welsh Development Agency)

14.3 The implications of substrate characteristics for revegetation

14.3.1 The principal characteristics

The waste materials from the coal and steel industries present a range of physical and chemical characteristics which may restrict plant growth. The principal characteristics which have major implications for revegetation are:

- extremes of pH;
- toxicity;
- lack of plant nutrients;
- low organic matter content;
- coarse-grained material;
- compaction or consolidation.

14.3.2 Extremes of pH

Substrate pH influences plant growth mainly through its effect on the solubility of chemical elements, including those which are directly toxic to plants and those which are required as nutrients. Figure 14.2 shows the relationship between pH and the availability of the major plant nutrients. Most productive agriculture requires a soil pH of between 5.5 and 7.5 for satisfactory crop growth, and a pH of 6.5 is often quoted as optimal.[153] At this pH nutrient availability to plants is at a maximum and toxicity at a minimum. Soils of lower pH are commonly found supporting commercial forestry, extensive grazing or semi-natural vegetation, and a limited range of plant species will colonise very acidic substrates of pH 3.5 or lower. Few leguminous plants are well-adapted to acidic soils and nutrient availability may be limited by immobilisation in such soils. The production of self-sustaining swards therefore requires the correction of excessive acidity, or the selection of vegetation tolerant of the acid conditions which exist.

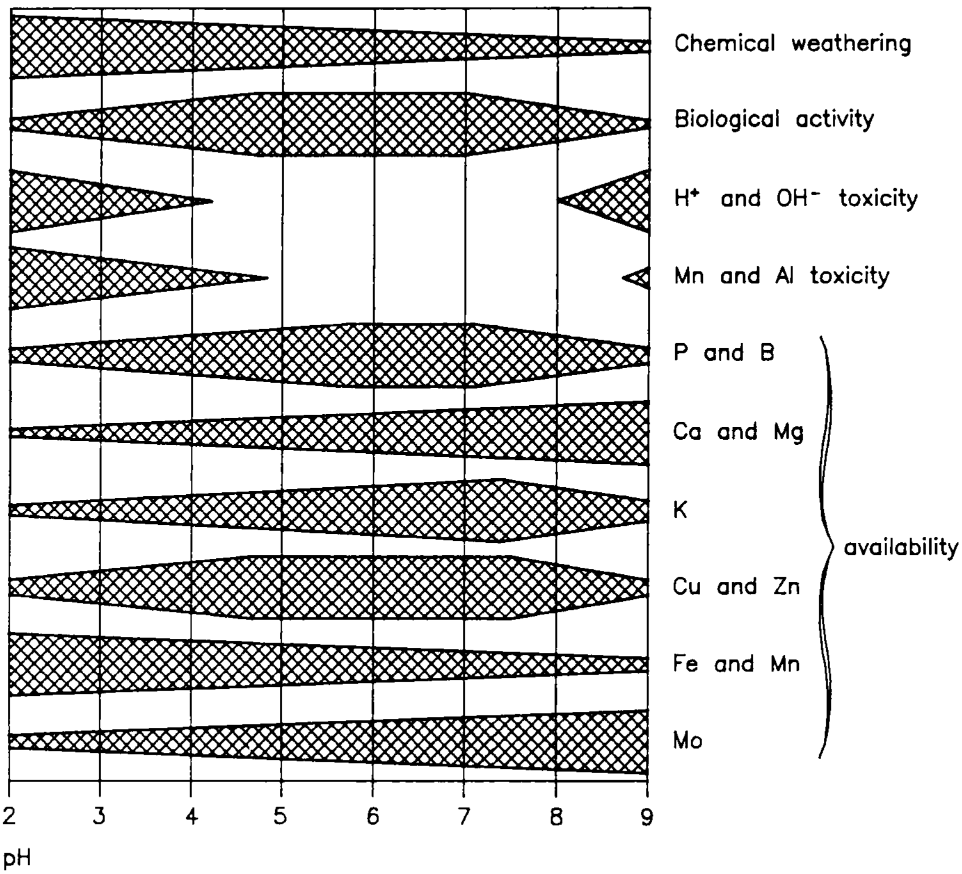


Figure 14.2: The influence of pH on nutrient availability

Highly alkaline substrates such as blast furnace slag are also inhospitable to productive agricultural species, but swards of *Festuca rubra*, *Dactylis glomerata*, *Phleum pratense* and *Lolium perenne* have been established and maintained experimentally on weathered slag to which sewage sludge and annual NPK fertiliser dressings were applied.[99] Weathered slag has a pH of 7.5-8.5, which is similar to that of naturally calcareous soils and chalks. The species of these nutrient-poor, calcareous habitats sometimes colonise weathered slags to produce a diverse grassland flora (see Box 9.5). Diverse grasslands have also been established experimentally on weathered slag substrates using controlled fertiliser additions.[14]

14.3.3 Low nutrient status

Nitrogen and phosphorus are available to plants at extremely low concentrations in most colliery spoils and steel slags. Both nutrients are essential for the growth of plants and when supplies are inadequate young plants will fail to establish whilst established plants will become moribund

Box 14.5: Consequences of inadequate nutrient supply

Inadequate nutrient supply

⇓

Slow growth of roots

⇓

Small, shallow root system

⇓

Roots confined to small volume,
unable to exploit deeper reserves
of moisture, exposed to high temperatures
and desiccation

⇓

Nutrient supplies exhausted
Plant dies through drought or
becomes moribund

and decline (see Box 14.5). Legumes are particularly sensitive to a lack of available phosphate and the fixation of atmospheric nitrogen in the absence of adequate phosphate supplies will be poor.[185] Figure 14.3 shows the marked response of agricultural grass swards to treatment with fertilisers, and indicates the need to ensure that all major nutrients are in adequate supply. Although many non-agricultural species of herbaceous and woody plants will grow satisfactorily at much lower spoil nutrient concentrations the consequences of inadequate nutrient supply are the same - poor growth and susceptibility to drought.

14.3.4 Low organic matter content

Most of the nitrogen reserve in soils is in the form of organic matter containing typically 5% nitrogen which is mineralised at about 2% per year.[206] If organic matter is lacking it follows that the reserve of nitrogen is also poor. Organic matter contributes to the structuring of soils, particularly those with a high clay content, by stabilising aggregates of these fine particles as described in Section 5.3.3. Poorly structured soils, such as colliery spoil, will consolidate as they weather and the clay content increases. Slags, however, will weather very slowly and remain coarse-grained with large pore spaces. Consolidation of colliery spoil leads to impeded drainage, poor available water capacity and the restricted root extension of plants. As a result, extremes of summer drought and winter waterlogging are common on colliery spoils.[109, 205] Organic matter also absorbs moisture and so directly improves the available water capacity of the spoil. Colliery spoils and the wastes from iron or steel production are usually devoid of organic matter whereas a typical arable soil contains 0.5-2.5% organic matter. Soils under permanent pasture may contain much more organic matter than arable soils.

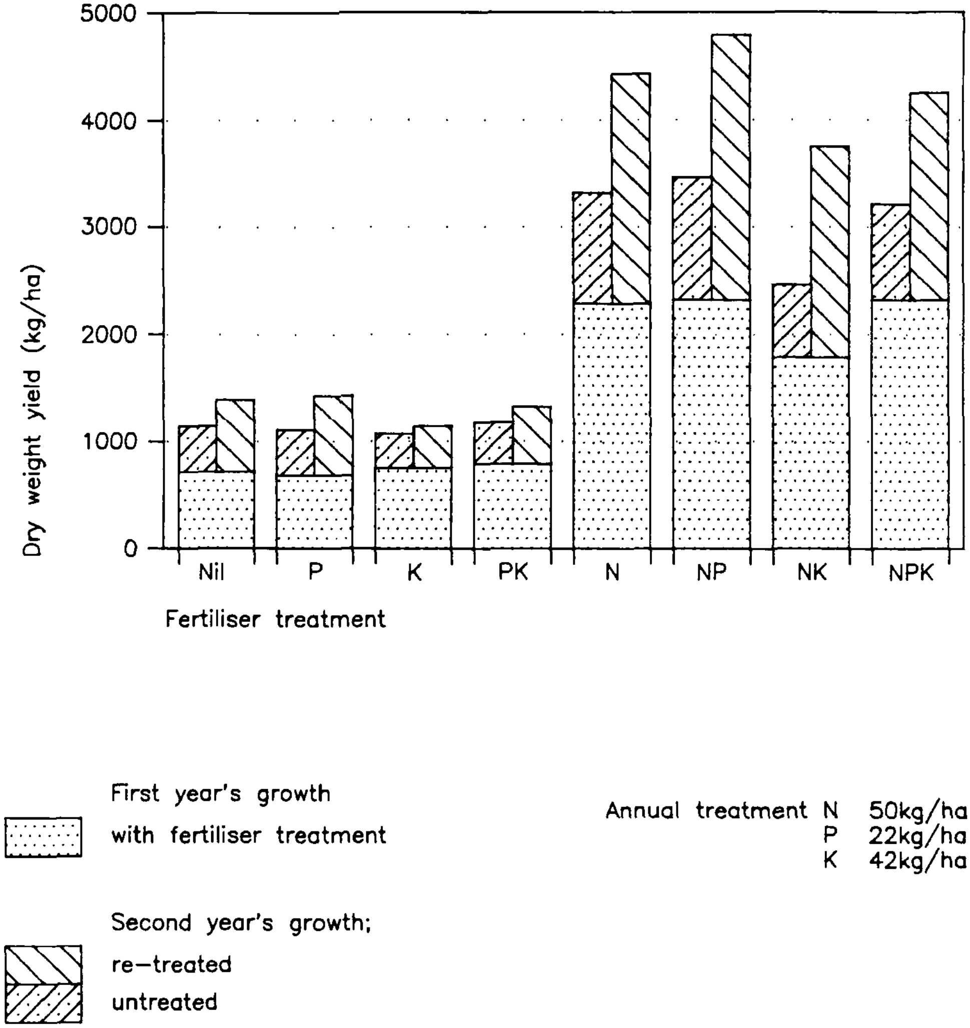


Figure 14.3: The response of an established grass sward to fertiliser treatment (from Bradshaw and Chadwick, 1980[40])

14.3.5 Coarse-grained materials and compaction

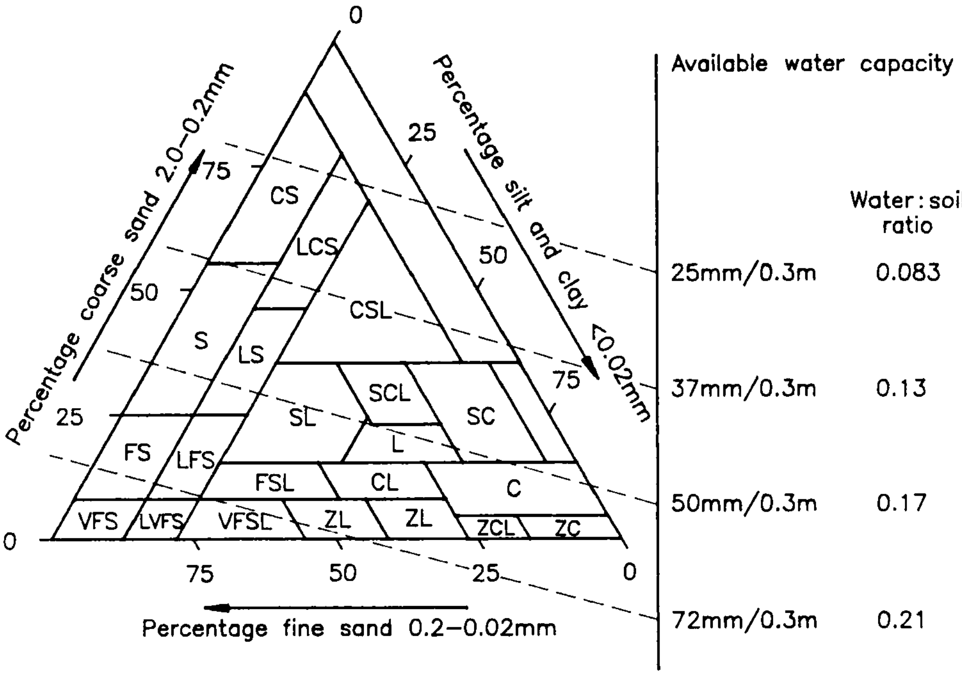
Substrate particles larger than 2mm retain very little water and where these are abundant they can significantly dilute the finer-grained soil. Figure 14.4 shows how the available water capacity of soil is related to its texture. Very coarse-grained spoils and slags, and severely compacted or consolidated spoils, have few soil pores of the size needed to hold water against gravity drainage. Coarse-grained materials will therefore be excessively free draining and plants with roots confined to the upper layers will be subject to extreme water stress. However, once deep-rooting plants, particularly trees, become established, and their roots extend below the zone of greatest soil-drying, even very coarse-grained materials can support a vegetation cover.

Spoil compaction is a common result of the use of mining or engineering machinery to place or regrade spoils (see Section 5.3). Compaction causes poor drainage and waterlogging during wet weather, and creates a lack of soil pores able to store water for use by plants in dry conditions (see Photograph 14.3). Plants growing in compacted spoils produce very shallow root systems due to:

- the physical impenetrability of compacted spoil;
- the seasonal death of roots in the saturated zone above the compacted layer.

As a result, the root system:

- provides poor physical anchorage for the plant;
- is confined to the zone of greatest temperature fluctuation;
- is confined to the zone of greatest moisture stress;
- is unable to exploit nutrients beyond the surface layer;
- is unable to exploit nutrients in the surface layers during drought or waterlogged periods.



Prefixes: C – coarse
F – fine
VF – very fine
L – loamy

Symbols: S – sand
Z – silt
C – clay
L – loam
CL – clay–loam
SL – sandy–loam
ZL – silty–loam

Figure 14.4: The soil texture triangle showing available water capacity (after Winter, 1974[264])

Photograph 14.3: Waterlogging of the root zone, caused by excessive compaction, has killed the roots of this tree (source: Richards, Moorehead and Laing Ltd)

14.3.6 Invasive and persistent weeds

Many derelict sites contain stands of weeds which, if spread during reclamation works, will become extensive, detrimental to the desired land use, and very expensive to control. Particular problems have been experienced with:

- Japanese knotweed *(Fallopia japonica)* - spread predominantly by rhizomes;
- Himalayan balsam *(Impatiens glandulifera)* - spread by seed;
- Bracken *(Pteridium aquilinum)* - spread by rhizomes and spores;
- Horsetail *(Equisetum* spp.) - spread by rhizomes and spores.

The assessment of potential reclamation sites in order to identify invasive weeds before any ground disturbance commences will enable a weed control strategy to be developed (see Box 2.2). Guidance on Japanese Knotweed identification and control has been developed for the Welsh Development Agency[201, 203] (see Photograph 14.4).

14.4 The treatment of substrate characteristics

14.4.1 Introduction

The characteristics of the substrates found on abandoned coal mining and iron and steel making sites vary greatly from site to site and within individual sites. It is therefore essential that the different substrates are assessed carefully so that:

- the materials most suitable for plant growth are identified;
- the characteristics of each material are known;
- appropriate substrate treatments can be implemented;
- plant selection takes account of the substrate characteristics.

Two approaches may be considered once the substrate characteristics are known:

- selecting plants which will succeed in the substrates present. This approach is expanded in Section 14.5;
- treating the substrates to make them suitable for the plants which are desired.

Figure 14.5 summarises the techniques which are applicable to the treatment of common problems associated with colliery spoils and iron and steel-making slags. Many are standard practices in agriculture, forestry or civil engineering. Those techniques which have particular application to reclamation are described in the following sections.

Photograph 14.4: Japanese knotweed will spread rapidly if introduced to a site (source: Richards Moorehead and Laing Ltd)

14.4.2 Deep cultivation or ripping

Compaction and consolidation can be overcome by cultivation, but only if the spoil is loosened to create drainage pathways. The cultivation must therefore extend through the layer of impeded drainage to reach unconsolidated material beneath, or must be combined with the installation of a drainage system. Deep cultivation over an impermeable substrate will create a saturated marshy layer. This can be avoided if a minimum gradient of 1 in 10 is created during regrading or landforming operations,[32] with open ditches or other outlets for the drainage water (see Figure 14.6 and Photograph 14.5).

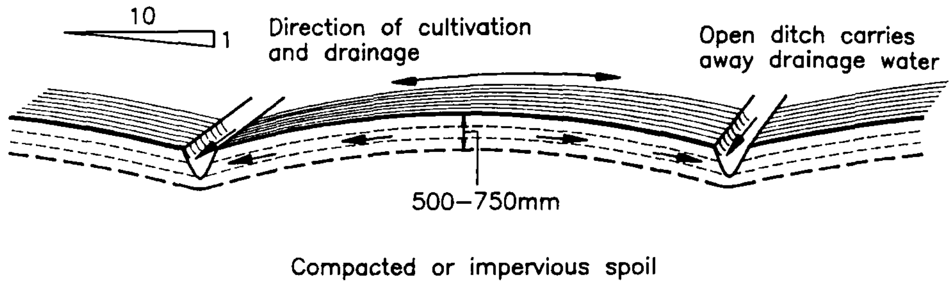
Deep cultivation within the restricted space available at developed sites can be difficult to achieve effectively. Main planting areas must be identified in the masterplan before reclamation, and these areas protected

Derelict land categories / Problems	Instability/erosion	Water shortage	Water–excess	Texture–coarse	Texture–fine	Compaction	Nutrient deficiency	Low ion exchange capacity	Alkalinity	Acidity–actual	Acidity–potential	Toxic–metals	Toxic–other	Salinity
Colliery spoil: opencast	●	☒	○	○		☒	●	○		○	○			○
deep mine	●	●	○	○		○	●	○		○	○			○
washeries	●	☒	○	○	●		●	○						
Iron and steel: disused plant			●	○		☒						○		
slag and spoil	●	●		●	○	○	●		●			○	●	
Coal carbonisation sites	○					○			○	○		○	☒	
Railway land				●	●	○	●					○	○	
Demolition rubble			○	●		●	●					○	○	
Treatment														
Weathering				◆		◆	◆*		◆*	◆*		◆*	◆*	◆
Grading	◆	◆*	◆*											
Ripping	◆/◇*	◆	◇*		◆	◆								
Compacting	◆	◇	◆*	◆	◇									
Liming							◆*		◇*	◆	◆*	◆*	◆*	
Fertilising							◆					◆*	◆*	◇*
Fine inorganic material		◆	◇	◆	◇			◆*						
Coarse inorganic material	◆	◇	◆	◇	◆									
Bulky organic material	◆*	◆		◆	◆	◆	◆*	◆*	◆			◆	◆*	◆
Drainage	◆		◆											
Irrigation		◆					◆/◇*					◆*	◆*	◆
Establish vegetation	◆		◆*			◆	◆	◆*						

○ : Present in some cases ☒ : Serious problem in most cases ◆ : Beneficial

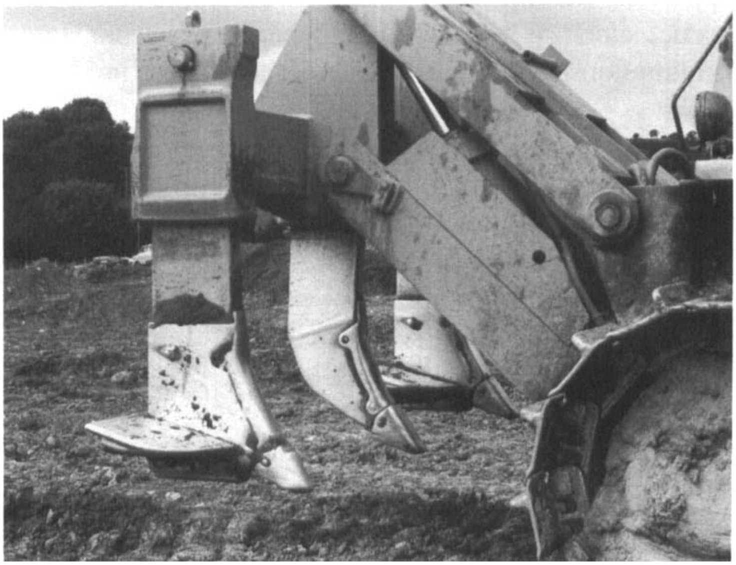
● : Present in most cases * : In some cases ◇ : Harmful

Figure 14.5: The treatment of substrate characteristics for revegetation (after Robinson Jones Partnership, 1987[209])



Deep cultivation of dry spoil coupled with an adequate gradient (*e.g.* 1:10) can provide a deep zone of well drained substrate in which roots can exploit the available water. Winged tines improve the shattering of compacted spoil between the tines. A 300hp (224kW) tracked tractor is needed to cultivate compacted spoil.

Figure 14.6: Deep cultivation to create substrate drainage



Photograph 14.5: Winged-tine ripper suitable for heavily compacted colliery spoil (source: the Forest Authority)

from compaction. Areas affected by building construction will require deep cultivation if ripping is impractical in confined areas.

Grass and planted areas should only be designed as soakaways for surface water runoff if adequate drainage capacity can be ensured, otherwise ponding will occur, resulting in the death of vegetation.

14.4.3 Use of topsoil and subsoil

Topsoil and subsoil are extremely valuable materials within reclamation sites, and should be conserved wherever practicable. The conservation and replacement of soils is a standard and critical practice in the restoration of most opencast mining sites, but very few abandoned deep-mine sites contain appreciable areas of undisturbed topsoil. The importation of soil to cover less suitable substrates is an attractive option which can overcome many obstacles to revegetation, but it is rarely adopted on a large scale since good quality topsoil is usually in short supply, is expensive to transport and can leave the source area in a derelict state. When soil is available locally from, for example, road or building construction sites, its use should be considered carefully:[34]

- topsoil is susceptible to a loss of structure, particularly if moved when wet (see Box 13.6);
- topsoil may contain a large number of weed seeds and fragments of pernicious weeds which will compete with young trees or shrubs in the placed material (see Section 14.3.6);
- topsoil may have a poor balance of nutrients, or may be too fertile for the establishment of low-maintenance swards or wild flowers;
- subsoil may be suitable for use if nutrients and organic matter are added;
- plant roots may not extend from the soil layer into the underlying substrate, leading to poor anchorage and the risk of drought.

14.4.4 Use of colliery spoil as a cover material

The fused slags from iron and steel-making are particularly inhospitable for plant growth. In some areas of Europe, coal mining and iron or steel making took place in close proximity and so the wastes from these activities occur together. Since colliery spoil is generally less difficult to make suitable for plant growth than slags, one option is to place a deep layer, 1m or more, of colliery spoil over the slag during reclamation, and to prepare this as the growing medium. This approach was successfully used in the preparation of the site for Garden Festival Wales 1992 at Ebbw Vale, South Wales. The site previously contained disused coal mines and a steelworks. Colliery spoil has also been used as a cover to reclaim other wastes (see Box 14.6).

Box 14.6: The use of colliery spoil as a cover material

Colliery spoil may be used to improve or cover other wastes during a reclamation scheme. This has been achieved at sites where colliery spoil heaps have been in close proximity to other wastes. Where the colliery spoil layer is used to cover a material such as unweathered slag which will not be exploited by plant roots, it is essential that the colliery spoil is sufficiently deep, and sufficiently improved and maintained to provide all the resources (water, nutrients, anchorage) needed by the developing vegetation. The substrate water regime may be predicted with the aid of spoil texture (see Figure 14.4) and climatic data.

At one site in Wales, a burning colliery spoil heap was removed and cooled and the material spread over metalliferous mine waste sealed with a polyethylene membrane. A 500mm deep layer of colliery spoil was used and vegetation was established directly onto the colliery spoil. Long-term trials had been established to test the method. In these trials, slag had also been used as a treatment, but vegetation failed because of the poor water holding capacity of the slag.

At a former steelworks site, colliery spoil from nearby tips was used to cover slag in order to establish vegetation. The slag was regraded to form benches to retain the colliery spoil. A depth of 1m was placed for tree planting; 450mm depth in areas prepared for grass (see Photograph 14.6).

Photograph 14.6: Placing colliery spoil over slag as a growing medium for trees and grass (source: Welsh Development Agency)

The physical and chemical characteristics of spoil heap materials can vary significantly with depth (see Section 5.3). The surface layer of a spoil heap may be much more suitable for plant growth than the bulk of the material, due to:

- weathering which improves texture;
- leaching which reduces acidity/alkalinity/salinity;
- microbial activity and plant colonisation which add organic matter and nitrogen.

Where it is proposed to use spoil materials as a substrate for plant growth the surface layer should be assessed separately and, if it is suitable, stripped, stored and replaced as a surface layer. If the spoil materials are mixed or used indiscriminately the benefits of the weathered surface layer will be lost.

Many other natural materials can be made into suitable substrates for plant growth, if the essential characteristics of available water capacity, nutrient supply, pH and soil aeration are provided. Soil-forming materials which have been used in land reclamation or restoration projects include shales, overburden, freshwater and marine silts, tailings from mineral processing, crushed brick and concrete, and a variety of organic residues.

14.4.5 Lime to correct acidity

The processes leading to spoil acidity are described in Section 5.3. Box 14.7 shows a method for calculating how much lime is required to bring the pH to the desired value and maintain it. The quantity of lime can be over 100t/ha if the spoil is highly pyritic, and so an accurate assessment of the requirement can also be economically important. Photograph 14.7 shows how pyritic acidity affects grassland.

The material most commonly used to raise the pH of colliery spoils is lime, in the form of ground limestone (calcium carbonate, $CaCO_3$). Magnesian limestone ($MgCO_3$) is avoided on sites where spoil salinity is high as the magnesium content contributes to the salinity.

14.4.6 Sources of nutrients and organic matter

The types and sources of chemical fertilisers are well known, but many cheap or waste materials can be used in their place as sources of nutrients and organic matter. The characteristics of some soil amendments are given in Table 14.1. Other materials which could be used may be available on a local basis. Small-scale trials of novel materials would help to identify of short-term toxicity or nutrient imbalance.

Box 14.7: The calculation of lime requirement in colliery spoil

Acidity in colliery spoil can be conveniently divided into:

- active acidity: the free hydrogen ion content which determines substrate pH;
- reserve acidity: the exchangeable hydrogen ion content which determines resistance to change in pH by buffering action;
- potential acidity: the acid generating power of the spoil.

Active and reserve acidity may be determined by standard soil science methods and a lime requirement calculated.

Should the spoil contain pyrite then the potential to produce acidity in the future could be considerable. An estimate of this potential and hence a lime requirement can be determined by analysis.[66, 96] The steps are:

(i) determination of pyritic sulphur;

(ii) calculation of the amount of lime the pyritic sulphur in the spoil would consume if it was all to be oxidised. 1% sulphur = 34.45 tonnes $CaCO_3$ equivalent per 1000 tonnes of material;

(iii) determination of the acid neutralising capacity of the spoil, in tonnes $CaCO_3$ per 1000 tonnes material;

(iv) subtraction of (iii) from (ii) to produce a lime requirement in tonnes $CaCO_3$/1000 tonnes spoil.

Figure 5.2 shows the levels of pyrite and acid neutralising capacity found in some colliery spoils and Figure 14.7 shows the effect of repeated additions of lime to a very pyritic colliery spoil when the lime added did not neutralise all the potential acidity.

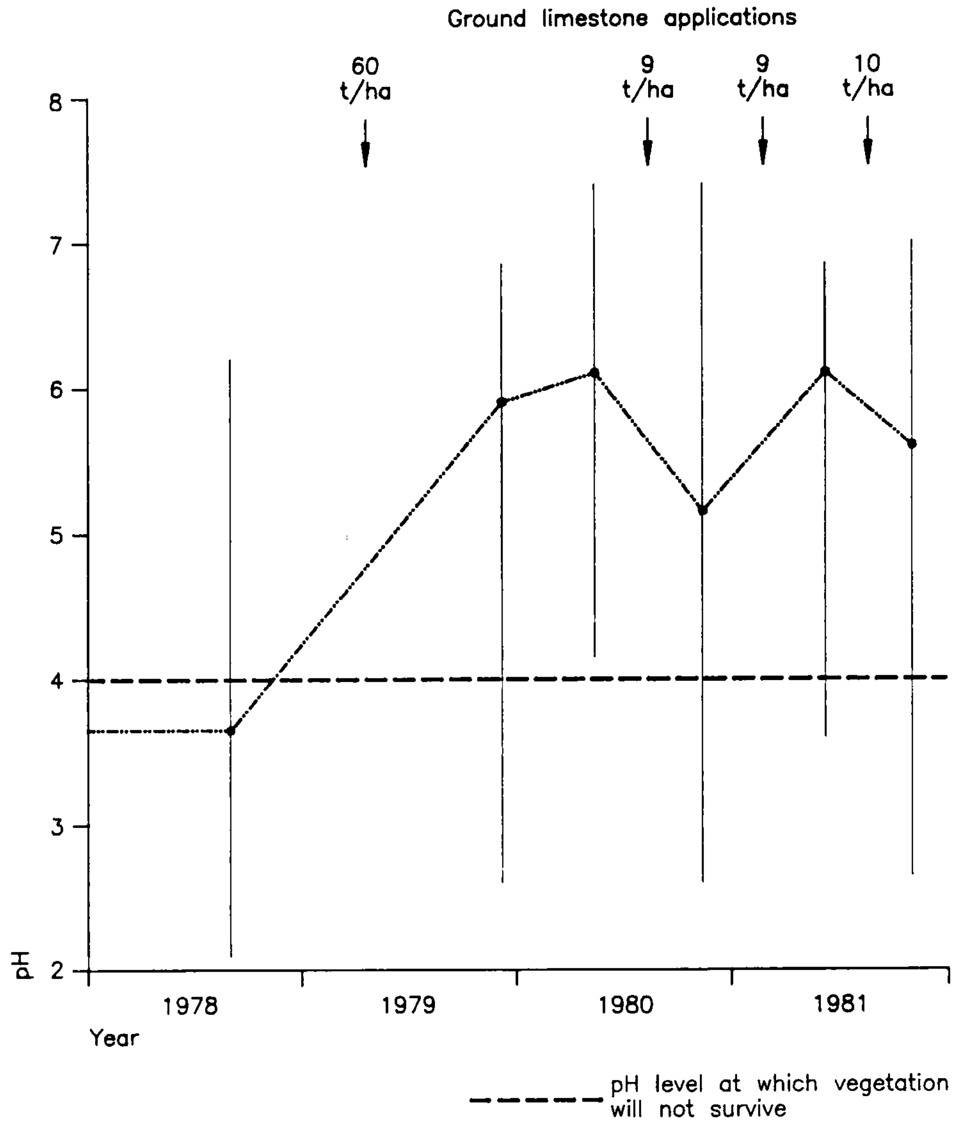


Figure 14.7: The effect of liming on mean pH and range on a pyritic colliery spoil heap. Even with repeated lime applications, the pH of parts of the site is too low to support plant growth

Photograph 14.7: Acidity from pyrite oxidation has completely killed the grass sward allowing erosion to begin (source: Welsh Development Agency)

14.4.7 The role of legumes

The use of legumes such as clover (*Trifolium* spp.) to provide a long-term supply of nitrogen is a traditional agricultural practice which is the subject of renewed interest due to the rising monetary and energy cost of fertiliser manufacture. These legumes, if provided with sufficient phosphate, moisture and temperatures for optimum growth, can fix 100kg or more of nitrogen per hectare per year.[67, 185] Much of this nitrogen is contained within organic matter in the soil where it contributes to the 'nitrogen capital' and is slowly mineralised for uptake by other plants. Figure 14.8 shows that although colliery spoil contains much nitrogen, very little of this is available to plants. If nitrogen fertiliser is applied to swards on colliery spoil the accumulation of nitrogen in organic matter is increased. However, the use of a legume in place of nitrogen

Table 14.1: Organic soil amendments (after Coppin and Bradshaw, 1982[56])

Material	Usual composition (% dry solids) N	P	K	Organic matter	Usual application rates (dry t/ha)	Special problems or advantages
Farmyard manure	0.6-2.5	0.1	0.5	24-50	5-40	Variable
Pig slurry	0.2-4.0	0.1	0.2	3	5-20	High water content, possibly high Cu
Poultry manure, broiler	1.5	0.9-2.5	1.6-2.5	60-80	2-10	High levels of ammonia, odours
Poultry manure, battery	2.0-4.0	0.5	0.6	35	2-10	
Sewage sludge, digested	2.0-4.0	0.3-1.5	0.2	45	5-50	Possibly toxic metals and pathogens, odours
Sewage sludge, raw	2.4	1.3	0.2	50	5-50	
Mushroom compost	2.8	0.2	0.9	95	5-20	High lime content
Domestic refuse, composted	0.5	0.2	0.3	65	20-70	Contains miscellaneous objects
Brewery sludge, digested	1.5	0.9	0.3		5-20	Uncommon
Peat	0.1	0.005	0.002	50	5-10	Variable, high carbon to nitrogen ratio. Production may cause destruction of wetland habitats
Straw	0.5	0.1	0.8	95	5-20	Decomposition uses soil nitrogen
Sawdust	0.2	0.02	0.15	90	10-30	High carbon to nitrogen ratio, requires pulverising, maturing or composting
Woodchips	0.2	0.02	0.1	90	10-30	
Bark	0.3	0.09	0.7	90	10-30	
Lignite, ground	1	0	0	0		High cation exchange capacity

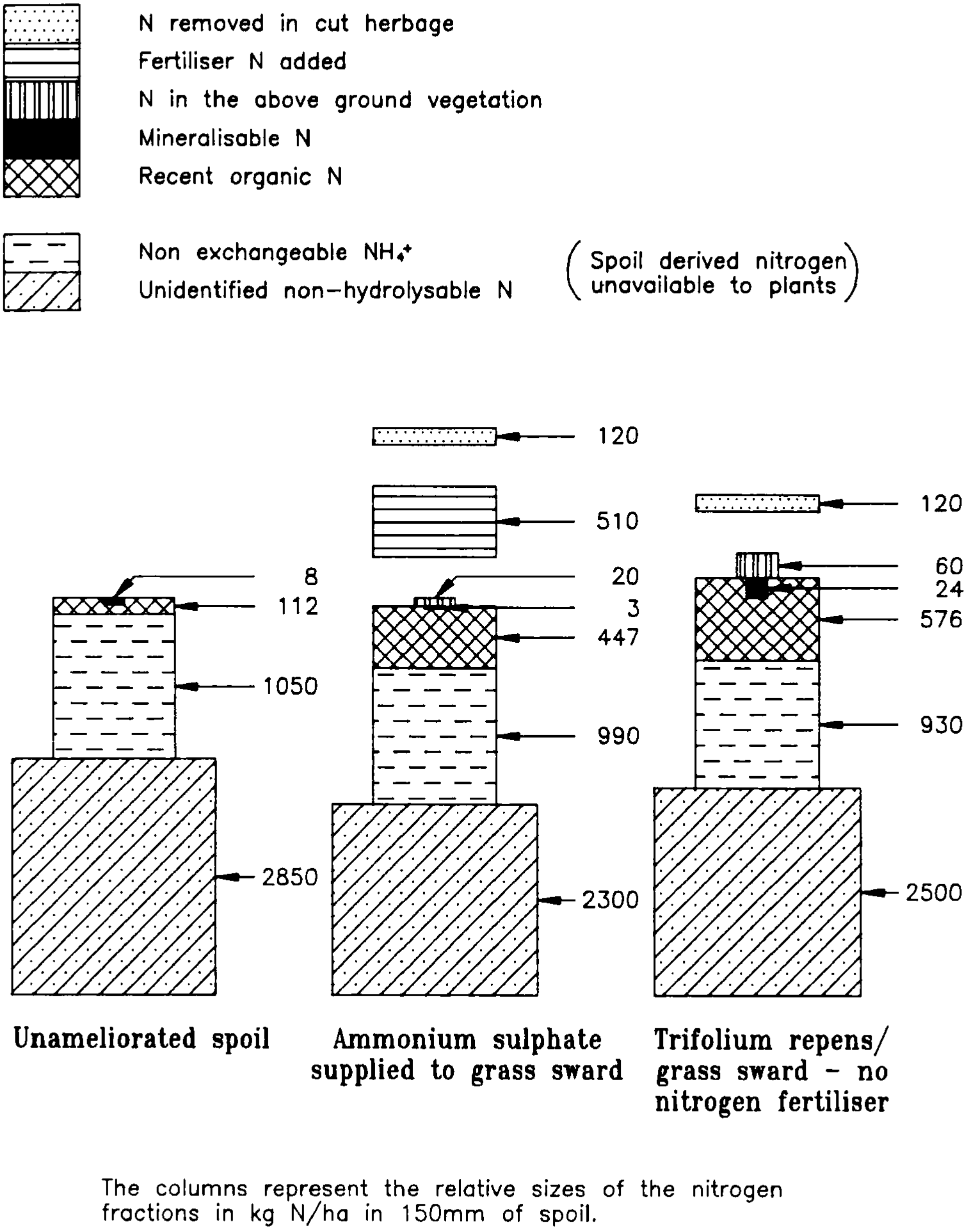


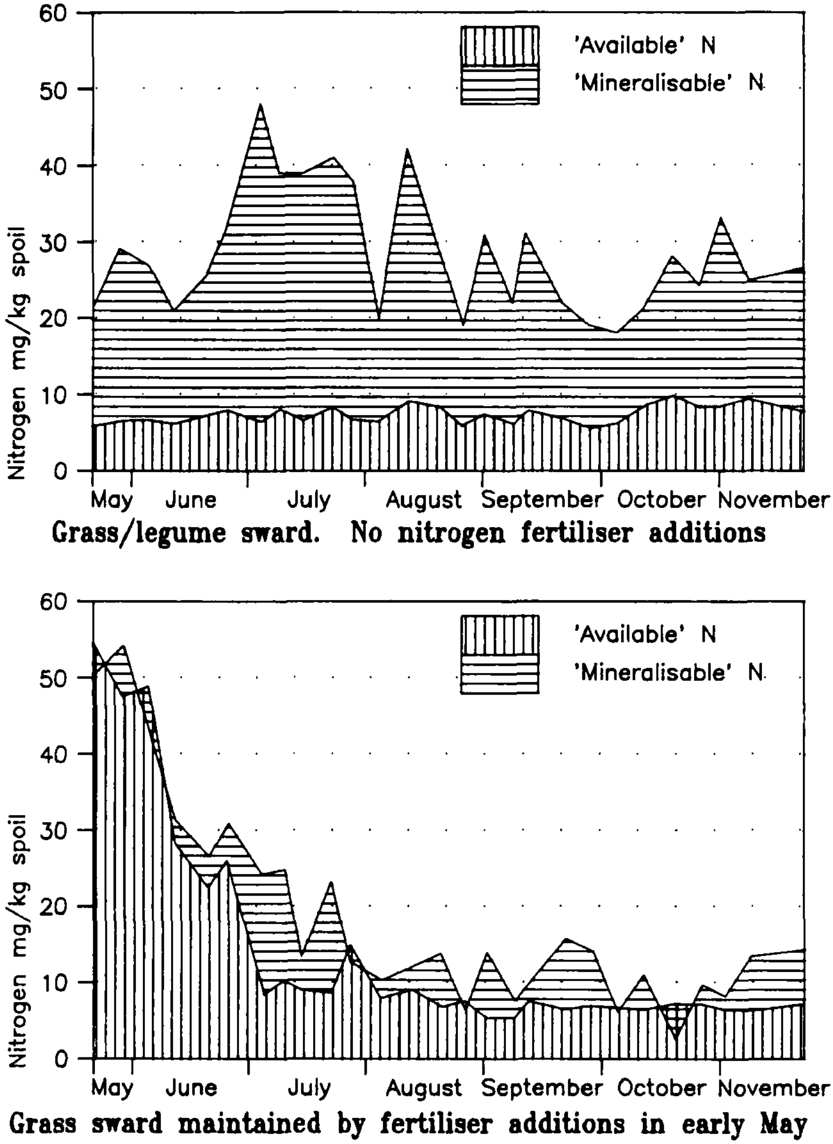
Figure 14.8: The accumulation of nitrogen in colliery spoil seven years after revegetation (after Palmer, 1984[184])

additions, over the same period, results in greater accumulation of organic nitrogen and more mineralisable nitrogen. Figure 14.9 shows that colliery spoils which are vegetated with legumes are able to supply nitrogen to the sward continuously throughout the season whereas colliery spoils which receive nitrogen only from fertiliser inputs quickly lose their power to supply nitrogen to the sward.

The legumes used in colliery spoil reclamation include agricultural herbaceous species; perennial shrubs such as lupin (*Lupinus arboreus*), gorse (*Ulex europaeus*, *U. gallii*) and broom (*Cytisus scoparius*); and trees such as black locust (*Robinia pseudoacacia*). alder (*Alnus glutinosa, A. incana, A. cordata*) although not a legume, also fixes nitrogen and is perhaps the most important tree used in land reclamation in Britain. Legumes will only fix nitrogen if inoculated with the correct strain of *Rhizobium* bacteria. As *Rhizobium* is likely to be absent from the substrates of derelict land, it is essential to inoculate the seed before sowing (see Section 14.6). *Alnus* and *Robinia* should become inoculated in the tree nursery, but if this has not occurred the soil from beneath established stands of these trees can be applied to the root zone at planting, to encourage inoculation.

14.4.8 Mycorrhizae

Mycorrhizae are naturally-occurring associations between the plant roots and symbiotic fungi, which have the effect of increasing the intensity and surface area of the root system within the rooting zone and therefore increasing the extraction of nutrients from a volume of nutrient-poor soil (see Box 5.2). Mycorrhizae are of particular benefit to species which typically grow on coarse-grained, impoverished and base-poor soils such as heathland and mountain soils. Pines and birches are frequently reported to benefit from mycorrhizae in such situations.[190] As many colliery spoils share the characteristics of these substrates there is considerable potential for the deliberate introduction of the appropriate fungi to trees planted on reclamation sites.



'Available' nitrogen is that immediately available in a mineral form (NH_4^+, NO_3 or NO_2^-). 'Mineralisable' nitrogen is that capable of being mineralised from spoil organic matter and is an indication of spoil fertility.

Figure 14.9: The short term effect of fertiliser nitrogen applied to vegetation on colliery spoil (from Palmer, 1984[183])

14.4.9 Water-storing polymers

The available water capacity of substrates can be increased by the use of polymers such as polyacrylamide gels. The use of these products has been reviewed.[128] The products were developed principally for use in arid zones, but offer a means to improve the water supply in individual tree pits or within the rooting zone. The gels absorb typically 100-400 grammes of water per gramme of dry granule when excess water is present. This water is then released as the substrate dries. The gels have a life of between 1 and 4 years in most substrates under temperate conditions, and can therefore buffer vegetation against drought periods.

14.5 Species selection

14.5.1 Site improvement with pioneer crops

The most commonly used procedure for the revegetation of derelict land has been to select the vegetation appropriate to the proposed land use and to establish it immediately after earthworks have been completed. This has entailed considerable efforts to modify the substrates to suit the vegetation. By contrast, those concerned with the restoration of opencast mined land, with afforestation and with agriculture frequently establish a pioneer crop of a short duration as part of a programme of soil improvement, before the final long-term crop or vegetation is established. Pioneer crops can provide:

- organic matter;
- improved soil structure;
- nitrogen (if legumes are used);
- shelter for exposure-intolerant plants (nurse-crop).

Nurse-crops should be selected with care to avoid excessive competition with the intended final vegetation. Annual grasses such as 'Westerwolds' rye grass have been used to protect trees and shrubs sown directly into colliery spoil. Short lived shrubs, particularly the legumes lupin, gorse and broom, have been used to protect seedling trees and to provide additional nitrogen.[151, 196] Vigorous, exposure tolerant pioneer trees such as alder and birch can produce a young woodland environment suitable for the growth of ecologically or commercially attractive canopy species such as oak (*Quercus robur, Q. petraea*) ash (*Fraxinus excelsior*) and beech (*Fagus sylvatica*).

It has become common practice to plant mixtures of woodland species regarded as pioneer, canopy and understorey species in order to create naturalistic woodlands. The practice is based on the expectation that the shade-tolerant canopy species will eventually emerge from the protection provided by the fast-growing, light-demanding pioneer species to form the eventual woodland canopy. Considerable success has been achieved by this means, when ground improvement and climate have been satisfactory.[105] This practice compresses the traditional succession pattern, by planting all three groups of plants at the same time. Significant management effort can be required if the pioneer species become too dense or if the canopy and understorey species are unable to survive exposed conditions until sufficient protection is provided by the pioneers. Where the work of vegetation establishment can be implemented in phases over say, 5-20 years, a system of site improvement by pioneer and nurse crops into which less robust but more desirable species are added when conditions are suitable, offers the potential for lower costs and more successful plant establishment. The creation of a diverse range of habitats is a common objective of many reclamation schemes (see Box 14.8). Diversity of species and structure can also be achieved by creative management over the medium term, as discussed in Chapter 15.

14.5.2 The performance of vegetation

Once the objectives of revegetation have been defined, the process of species selection and refinement is one of seeking to bridge the gaps between the required performance of the vegetation and the ability of each

Box 14.8: Habitat creation

Reclamation schemes offer an excellent opportunity for the creation of wildlife habitats to replace those which are being lost through Man's activities. Developing techniques for the establishment of diverse flowering grasslands, wetlands and waterbodies, woodlands and scrub continue to widen the range of possibilities.

In the majority of cases there will be no overriding reason for a single habitat type to be created over a whole site. More commonly, habitat creation will seek to produce a diversity of:

- vegetation types e.g. woodland, scrub, grassland, wetland;
- shapes and sizes of habitat;
- edges and transitions (ecotones);
- species within each habitat.

Such diversity is greatly assisted by appropriate landform design (Box 13.5) but can be achieved by :

- designing irregular shapes and mosaics to maximise the edges and transitions;
- designing species mixtures to create variety of light and shade;
- modification of the substrate pH and nutrient content.

candidate species to grow successfully on the site. Figure 14.10 summarises this process. As a general rule plants which can tolerate poor site conditions do not produce rapid growth or high crop yields. Where such performance is the objective and site conditions cannot practically be improved then a compromise must be found or the objective reviewed. A summary of the many criteria which contribute to the selection of species for a range of land uses is given in Table 14.2. Within each species the performance and characteristics of ecotypes, varieties or cultivated varieties (cultivars) may vary greatly. This is particularly true of plants used in agriculture, and of plants with a wide geographical range. The tolerance of climate and substrate, and the growth habits exhibited by different ecotypes, varieties and cultivars within one species

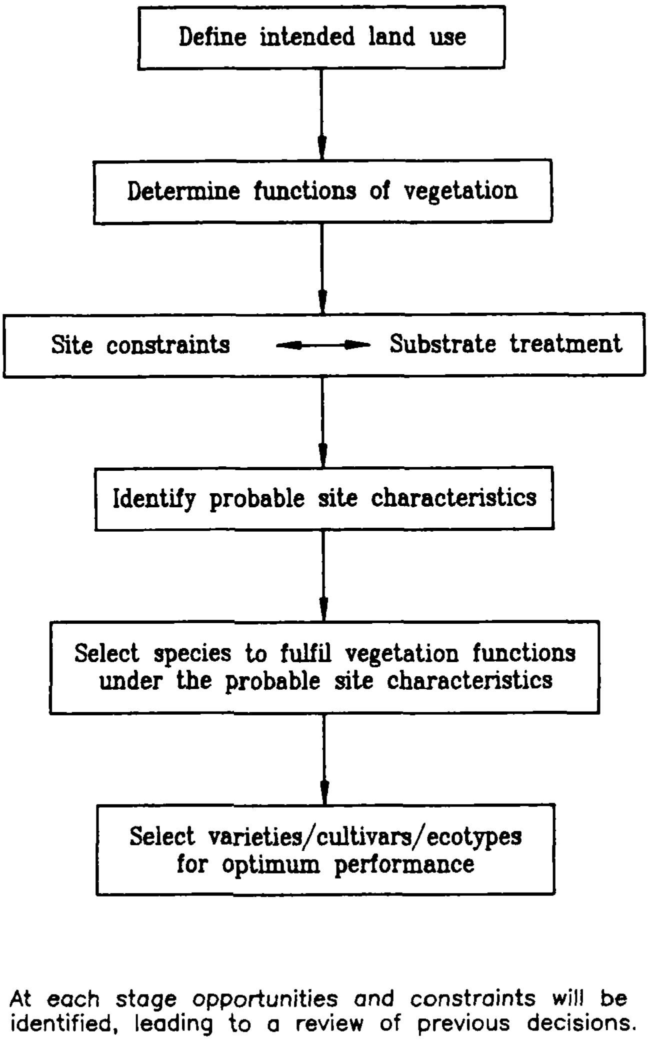


Figure 14.10: Species selection flowchart

Table 14.2: Criteria for the selection of plant species

Criterion	Agriculture	Ground cover: Sports & Amenity	Ground cover: Wild	Ground cover: Under trees	Ground cover: Erosion control	Trees and shrubs: Forestry	Trees and shrubs: Amenity	Trees and shrubs: Woodland (wild)	Trees and shrubs: Screening
Climate:									
Drought resistance		X	X	X		X		X	
Frost hardiness		X	X	X		X	X	X	X
Exposure (especially coastal)						X		X	
Cold (short growing season)	X	X	X	X		X		X	
Land use:									
Wildlife value			X	X		X		X	
Nativeness			X					X	
Palatability	X								
Productivity, high or low	X	X	X	X		X			
Screening value							X	X	X
Timber quality						X		(X)	
Soil:									
pH	X	X	X	X	X	X	X	X	X
Fertility, high or low	X	X	X	X	(X)	X	X	X	X
Texture	X	X	X	X		X	X	X	X
Soil depth						X	X	X	X
Moisture availability	X	X	X	X	X	X	X	X	X
Flooding tolerance							(X)	(X)	
Pollution tolerance							X		X
Role:									
Pioneer/nurse				X	X	X		X	X
Climax			X					X	
Soil builder	X	X	X	X	X	X	X	X	
Quick establishment		X		X					X
Ecotypes:									
Cultivar	X	X	X	X					
Provenance						X	X	X	
Locally collected ecotypes	X		X					X	X
Plant habit:									
Height			X	X			X		X
Growth rate	X	X	X	X	X	X			X
Rhizomes/stolons		X	X	X	X				X
Suckering habit		X	X	X			X	X	X
Rooting depth					X		X		
Competitiveness			X					X	
Disease resistance	X	X				X	X		

X - important factor, (X) - in some cases.
From Coppin & Bradshaw, 1982.[56]

can be sufficient to govern the success or failure of revegetation. When the objective of revegetation is to create naturalistic habitats or to conserve wildlife, it can be particularly important that only local ecotypes are used. Where natural colonisation of spoil materials has already occurred the plants may be better adapted to the site conditions than commercially available plant material and so the propagation of colonising plants (by seed or vegetative means) should be considered.

14.5.3 Tolerance

In Section 14.4 it was shown that the selection of species or varieties which will tolerate the conditions of the site offers a complementary or alternative approach to treating the anticipated problems which the site presents. The following problems may be overcome partially or completely by the selection of tolerant species or varieties:

- exposure and extremes of temperature;
- substrate wetness;
- substrate dryness;
- substrate acidity or alkalinity;
- low nutrient status;
- contamination by heavy metals *e.g.* from flue dusts;
- salinity.

The use of tolerant species is likely to restrict the range of vegetation functions available since species which possess tolerance of extreme conditions are generally specialised in their adaptation. This approach may therefore require a review of the scheme objectives. The approach is considered to be particularly suited to schemes intended to improve the landscape, provide wildlife habitats and low-key informal recreation facilities, rather than for schemes intended to provide highly productive agriculture or forestry uses of sites.[34] Guidance on the use of metal-tolerant species is given in Box 14.9.

Box 14.9: The use of metal-tolerant species in land reclamation

Species of grasses growing on metalliferous mine sites have been selected because of their tolerance to high concentrations of heavy metals and some of these species are commercially available. These grasses can be used for the direct revegetation of soils and spoils with high concentrations of metals provided that the grasses are tolerant of the specific metals in the soil and of the other substrate and climate conditions. The advantages of using metal tolerant species are:

- they are relatively cheap to establish;
- it is not necessary to import covering material;
- it is not necessary to remove contaminated material prior to vegetation establishment;
- site disturbance is minimal, reducing the risk of metal dispersal;
- the vegetation cover will provide some erosion control.

Disadvantages are:

- if grazing is intended this will need to be carefully controlled so that grazing animals do not ingest large quantities of metals;
- run-off will be contaminated with metals and so vegetation establishment alone may not be a suitable treatment near watercourses;
- use of the site will need to be restricted so that sensitive members of the population (e.g. children) do not have prolonged contact with spoil materials;
- erosion may occur on steep slopes if the spoil material vegetated is fine-grained and erosion control measures (such as the use of geotextiles) are not used.

Local experience and knowledge of plant performance under the conditions expected to be present is particularly valuable since great climatic and substrate variation exists between the sites on which individual species have been used. Where little experience of colliery spoil revegetation exists in a region, much can be learned by characterising the spoils and examining natural vegetation development on other substrates with similar characteristics, under similar climatic conditions.

14.5.4 The implications of management

The selection of species and varieties to fulfil the desired purpose of the vegetation may commit future managers of the site to a particular method and regime of maintenance work. The management requirements of the vegetation *e.g.* cutting, fertilising, liming, thinning are therefore a significant factor in the choice of plant species or variety. Plants which are invasive or excessively vigorous have proved costly to control or eradicate.

14.6 Sowing and planting methods

14.6.1 Introduction

The sowing and planting methods used in reclamation works have been adapted and developed from agriculture and forestry practice, to deal with the coarser-grained substrates and other physical difficulties found on colliery spoil and steel-making slags.

14.6.2 Sowing methods

In all methods of sowing the objective is to place the seed where it receives adequate moisture and protection from desiccation but is able to emerge before the reserves of the seed are exhausted. In situations where a coarse-grained substrate, lack of rainfall and desiccating sun or wind are prevalent it is common practice to protect the seed with mulches.

The most widely used sowing method is broadcast sowing, in which simple agricultural equipment, or hand methods, are used to distribute the seed on to the prepared surface. The seed is protected from desiccation by:

- allowing rainfall to wash the seed into a rough substrate surface;
- covering the seed by very shallow cultivation (harrowing);
- covering the seed with an application of mulch.

In areas of very intense rainfall, many reclamation schemes have involved mulching the seed with poultry house litter which adheres to the substrate, protecting the seed and surface against erosion by water run-off. Litter has been applied at 10t/ha and acted as the principal nutrient source for grass (see Table 14.1).

14.6.3 Specialised techniques

Hydraulic seeding (hydroseeding or hydraulic mulch seeding) is used particularly to apply seed, fertilisers and mulch to inaccessible areas such as steep slopes where ground preparation and mechanical sowing are impossible (see Box 14.10). Hydraulic seeding has a number of drawbacks which restrict its wider use:

- it is more expensive than traditional methods;
- it can aid germination and establishment but will not overcome fundamental substrate problems;
- separate fertiliser applications are required after seeding.

Techniques for the establishment of trees and shrubs by sowing directly into derelict land substrates continue to be developed (Box 14.11). Straw and similar long-fibred mulches are used to protect the seed of trees and

Box 14.10: The use of hydraulic seeding

Hydraulic seeding ('hydroseeding') is a technique for the rapid application of seeds and fertilisers onto an area where, for reasons of access, speed of application or ground conditions, conventional seed drilling or broadcasting techniques cannot be used. It is not an alternative to the proper preparation of the growing medium although the use of mulches can improve the initial establishment of seedlings in situations where full seedbed preparation is not practicable. Specialised hydraulic seeding machinery consists of a tank fitted with a slurry pump, agitator paddles, hoses and a demountable jet. This machinery is usually mounted on a lorry or trailer. The application typically consists of the following:

- seeds;
- legume inoculum - *Rhizobium* bacteria;
- soluble and/or slow-release fertiliser;
- mulch - a bulky material to act as a carrier, protect the seeds, reduce soil moisture loss and provide initial erosion protection;
- stabiliser/binder - to protect the soil surface, seeds and mulch from erosion.

These are mixed with water to form a slurry of 10-15% solids, applied at 2-4 litres/m^2. Where substantial mulch protection is required e.g. 2-4 t/ha this is applied as a second layer.

Hydraulic seeding cannot overcome unsuitable substrate characteristics such as excessive droughtiness or infertility. The use of soluble fertilisers can be directly harmful to the seed in the slurry or to the germinating seedling, since evaporation can produce high concentrations of salts. Legumes, which are often essential to the long-term provision of nitrogen, are particularly sensitive to fertiliser damage.

If hydraulic seeding is to be used to vegetate inaccessible slopes, the vegetation type and its long-term maintenance should be considered with care.

Hydraulic seeding is a valuable technique for special situations; it is not a panacea for all unfavourable sites.

Box 14.11: Direct seeding of trees and shrubs

The natural colonisation of colliery spoil heaps by trees and shrubs, and their development into woodland or scrub communities has prompted researchers to develop techniques which mimic this process but take a much shorter time. Success was achieved in landscape schemes on natural soils in the late 1970s. In the early 1980s attempts were made to establish trees and shrubs from seed on colliery spoil and oil-shale heaps ('bings') in Scotland. These were also successful, but the techniques have not yet been applied on a large scale to reclamation sites in Europe.

Successful establishment requires that the substrate and any applied mulch protect the seed from seasonal desiccation and freezing over a prolonged period until dormancy breaks and the germinated seed establishes a root system. Consequently most derelict land substrates require preparation works, and the use of mulches such as chopped straw. At present the techniques are widely considered to be insufficiently reliable for large scale adoption, particularly on the more exposed sites, although demonstration plots have been set up.

The seeding strategy is to produce a rapid annual herbaceous nurse cover, which is succeeded by a shrub layer and eventually by the pioneer and climax trees. Nitrogen-fixing herbs, shrubs and trees are usually included to produce a steady improvement in the substrate.

The strategy requires close monitoring of the vegetation over the course of its development so that imbalances in the density of each layer can be corrected. Excessive herbaceous growth will cause competition for water, nutrients and light. Insufficient growth will leave the tree seedlings exposed to frost and desiccating winds. Management inputs such as selective herbicides, fertilisers and thinning are likely to be required.

shrubs against desiccation. Special machinery has been developed to chop straw and apply it pneumatically to seeded areas. Bitumen emulsion is applied to stick the straw in place. An alternative method, used where very steep slopes are to be grassed, involves the application of a sheet or mat of material over the prepared slope. The seed mixture may be sown before the mat is laid, or incorporated within the mat. Erosion control can be achieved with a woven mesh of coconut fibre, wood fibre or synthetic material. Where seeds require protection from desiccation, composite mats of straw, coconut fibre, paper and synthetic mesh are used.

14.6.4 Tree planting

It is generally accepted that young trees are better able to withstand the stress of transplanting than are older, larger trees, and that young trees are more adaptable to the harsh substrate or climate conditions of newly reclaimed sites.[34] For this reason it is sensible to transplant 1-3 year old trees, approximately 300-900mm tall, when establishing dense or extensive woodland areas. Larger trees of height greater than 2m are used only where good ground conditions and significant visual benefits justify the higher cost of the tree stock and planting.

14.6.5 Tree shelters

Tree shelters are used to provide protection for tree species that are intolerant of exposure, where circumstances dictate that they should be planted on exposed sites. Shelters consist of translucent polypropylene tubes of 80-100mm diameter and up to 1.8m height. They raise the temperature and humidity of the micro-climate around each tree, promoting growth. Tree shelters have been in common use since the mid-1980s[90] but the ability of young trees to adapt to the transition from the sheltered microclimate to the exposure at the top of the shelter is not documented for the severely exposed sites on which most benefit might be expected. An alternative approach of phased planting was described in Section 14.5.1. Tree shelters also provide protection against damage by mammals, herbicides and mechanical disturbance.

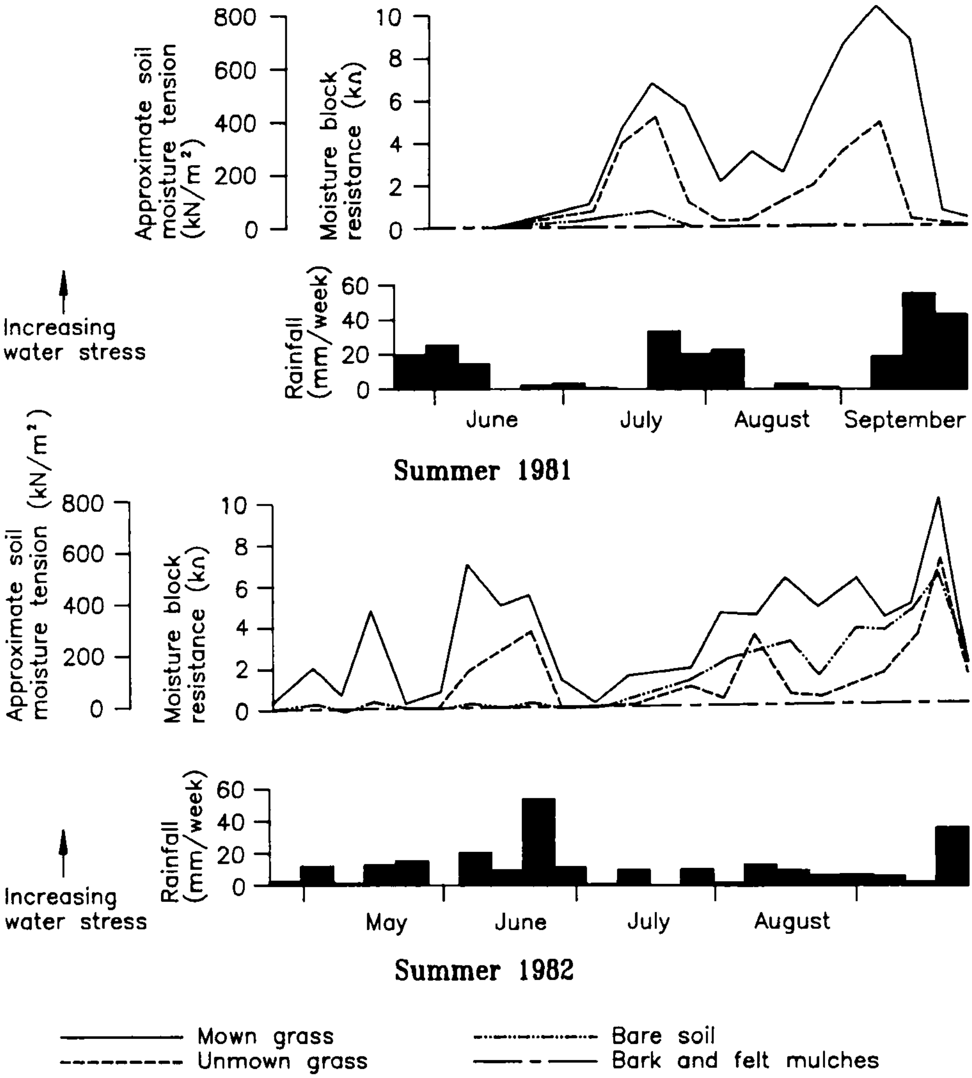
14.6.6 Weed control

Weed control is crucial to the successful establishment of transplanted trees and shrubs in many situations, and yet it is often neglected. Newly planted trees suffer significant root damage and can extract water from only a small volume of substrate. Grass and associated herbaceous vegetation is particularly efficient at extracting water from the soil, and can quickly create drought conditions which will kill or restrict the growth of the desired trees. It has been shown experimentally that most soil moisture is lost by transpiration through herbaceous vegetation, and that relatively little is lost by evaporation. A grass sward, whether mown or not, created soil moisture tensions sufficient to restrict water and nutrient uptake by the trees for most of the growing season (see Figure 14.11). This was reflected in the reduced survival and growth of the trees (see Table 14.3).

Infertile colliery spoil can provide a weed-free substrate for tree planting, but in many schemes a grass sward has been sown over the whole site immediately after regrading, in order to protect the surface against erosion. The vigorous varieties of grass used for this purpose are particularly detrimental to young trees (see Box 14.12 and Figure 14.12). Where erosion cannot be avoided by slope design or the use of mulch materials, the approach now adopted is to sow less vigorous grasses and to kill the sward in the planting area with a contact herbicide to produce a dead grass mat amongst which the young trees are planted. This approach requires sufficient time for sward establishment and thorough herbicidal control before planting. Dense planting which will rapidly produce a vegetation cover to protect the spoil surface is desirable. In some schemes the herbicide treatment has been confined to bands or spots so that much of the surface retains its grass cover. This practice reduces the risk of erosion but increases the need for subsequent weed control treatments around each tree. Weed control methods are described in Section 14.7.

14.6.7 Mulching

Mulching the spoil surface will aid the conservation of soil moisture, provided that grass and weeds have been removed. Mulches can also reduce the development of new weed growth but will have little effect on the growth of established or perennial weeds.



Initial wilting of annual crops has been recorded at a soil moisture tension of 500kN/m² (Winter 1974). Recently planted trees have severely damaged root systems and are particularly vulnerable to drying soil.

Figure 14.11: Moisture block resistances at 100mm depth under five ground covers in summer 1981 and 1982 (after Davies, 1987[68])

Table 14.3: The effect of grass competition on young trees

First year's growth and foliar analysis results for cherry (*Prunus avium*) at Alice Holt, UK, 1982 (after Davies, 1987[68]).

		Mown grass	Unmown grass	Bare soil
Height growth (cm)		9	31	80
Diameter growth (mm)		3	7	14
Leaf size index[(1)]		29	53	100
Foliar nutrient concentrations (% of dry weight)	N	2.6	2.5	3.4
	P	0.19	0.17	0.20
	K	1.1	1.1	1.6

[(1)] Leaf size index obtained by multiplying leaf lengths and widths.

Two types of mulch are commonly used in reclamation schemes:

- impermeable sheets *e.g.* polyethylene mats and strips;
- coarse granular materials *e.g.* bark, wood chips.

Granular mulches create a zone of still or slow-moving air at the soil surface. The humidity of this air rises so that the rate of evaporation from the soil is reduced. The mulch also intercepts solar radiation, thereby insulating the soil. Rainfall percolates rapidly to the soil surface where it is protected from rapid evaporation. Granular mulches only function if they are free-draining *i.e.* they are coarse-grained (free from particles of less than 5mm size) and relatively non-absorbent.

Box 14.12: Trees on colliery spoil (after Derelict Land Reclamation Research Unit, UK 1979[73])

The survival and growth of trees on colliery spoil are determined by tree species and site conditions. Figure 14.12 gives data on 12 tree species in a trial on colliery spoil established in 1971 in West Yorkshire. Some species (for example *Acer platanoides*) had high survival rates but did not grow whilst others exhibited both good survival and growth (*Betula pendula*, *Alnus* spp., *Salix caprea*, *Populus alba* and *Robinia pseudoacacia*). Survival and growth were particularly affected by competition from grass which itself was affected by fertiliser treatment as the following data shows.

Treatment	Average annual productivity (t/ha/year)		
	Betula pendula	*Alnus glutinosa*	*Salix caprea*
Grass removed, lime added	1	0.6	1.3
Grass removed, basic slag* added	0.7	0.3	0.8
Grass retained, lime added	0.4	0.9	0.5
Grass retained, basic slag* added	0.5	0	0.5

*Basic slag, a product of the steel industry, has a liming effect and is high in phosphate (Box 9.4).

The phosphate in the basic slag encouraged white clover (*Trifolium repens*) growth and the nitrogen fixed by the white clover caused vigorous grass growth. Where basic slag was applied grass growth was vigorous, even on those plots where grass had initially been removed. The result was that tree productivity was poorest where grass was sown and where basic slag was applied.

The results of this trial illustrate the need to match site conditions and treatment to ensure satisfactory growth of trees on colliery spoil.

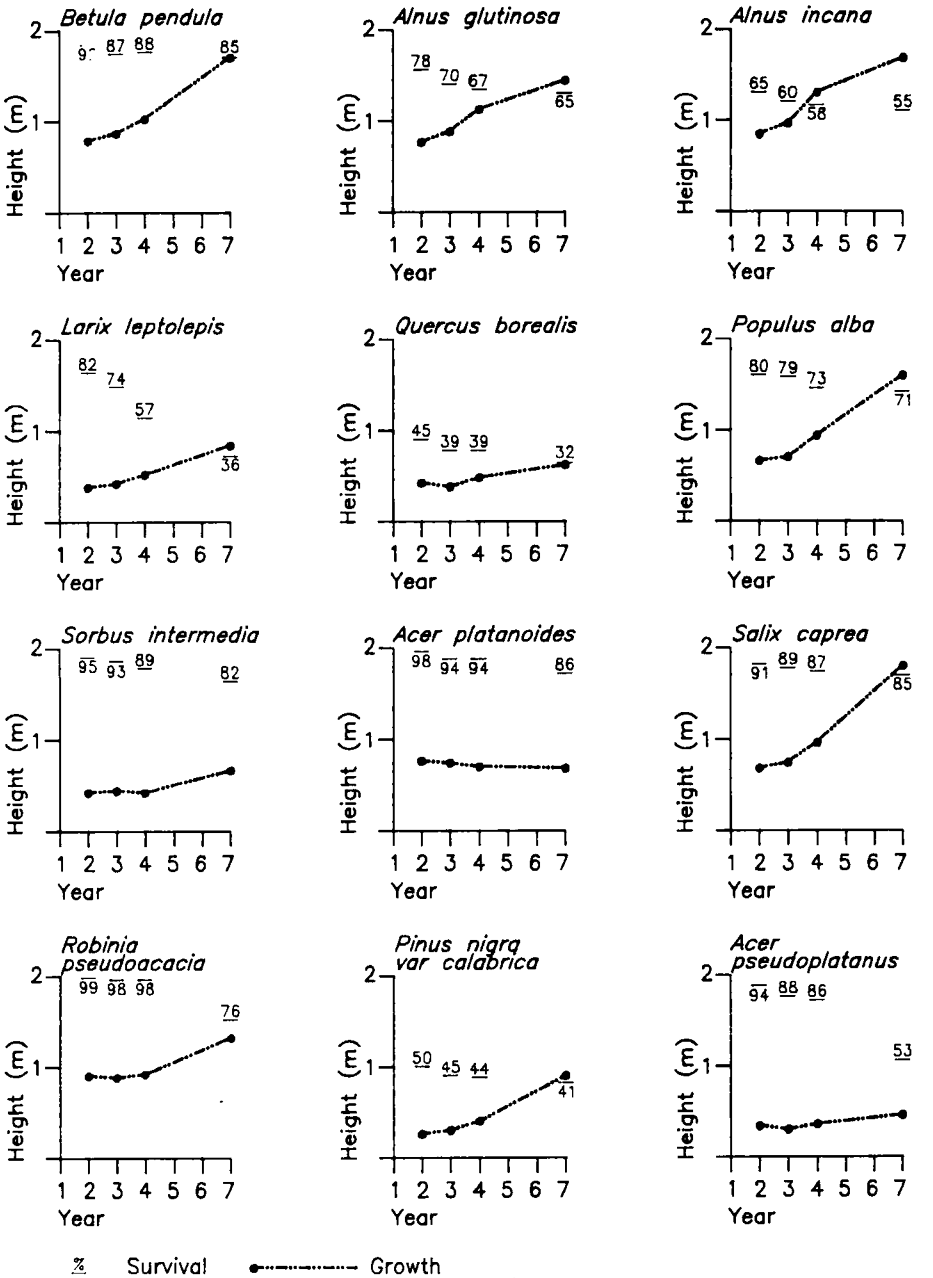


Figure 14.12: Growth and survival of trees on restored colliery spoil (after DLRRU 1979[73])

Tree bark is commonly used as a mulch. It should be prepared by chopping and screening to remove particles smaller than 5mm. Finely pulverised bark is not suitable as a water-conserving mulch since:

- it absorbs rainfall which then evaporates;
- in wet conditions it becomes saturated and anaerobic.

Many coarse-grained granular materials are produced as waste products from agriculture, horticulture or forestry. If they are non-absorbent and slow to degrade they can provide inexpensive mulch materials.

14.6.8 Irrigation

Irrigation water is commonly applied to transplanted trees during the first and sometimes the second, growing season. The primary purpose is to ensure survival during dry periods but effective irrigation will also increase the rate of root growth and therefore reduce the period during which the tree is unable to exploit reserves of water deeper in the substrate. Irrigation is generally used when water stress becomes apparent or the scheme manager believes that tree damage may occur, rather than in response to set rainfall or soil moisture deficit criteria.

Irrigation is routinely practised in agriculture and fruit growing. The equipment and techniques used locally in these industries can generally be applied to land reclamation schemes. Whatever techniques are used, irrigation achieves the best results when sufficient water is applied to wet the substrate thoroughly to the full rooting depth. Water at the substrate surface will encourage shallow rooting but is rapidly lost by evaporation. It is therefore largely ineffective.

14.7 The care of newly established vegetation

14.7.1 Establishment

Vegetation is usually described as established when it no longer requires special care to ensure that all parts of the plant are functioning normally and natural development will proceed. The requirement for works to care for vegetation is greater in the early stages of establishment and growth, and if sufficient inputs are not provided the establishment period will become extended (Figure 14.13). The principles and operations required to ensure the establishment and long-term development of vegetation on reclaimed land, including land which has been revegetated with a minimum of disturbance, are similar to the principles and operations applied to such vegetation on natural sites. The key difference is that vegetation on reclamation sites without a fully developed soil cover is particularly fragile and sensitive to any deterioration in substrate characteristics since nutrient supply, soil moisture and many other factors are poorly buffered by the substrate.

14.7.2 Weed control and trees

The critical importance of weed control, described in Section 14.6, extends through much of the establishment period, until the tree root systems develop sufficiently in zones of constant soil moisture. Weeds continue to reduce the uptake of nutrients by trees, by depleting soil moisture in the upper substrate where nutrient concentrations are highest. The early care of trees is usually directed towards achieving a closed canopy (*i.e.* touching branches) which will suppress weeds by shading (see Photograph 14.8). Contact herbicides are the most commonly used method of weed control in reclamation plantings. Residual herbicides such as simazine are not favoured since they bind poorly to the surface layer of spoil and can damage the tree. They are also susceptible to leaching and can contaminate watercourses. The use of herbicides is now closely controlled by legislation within the European Community. Mechanical vegetation control by mowing or strimming is effective

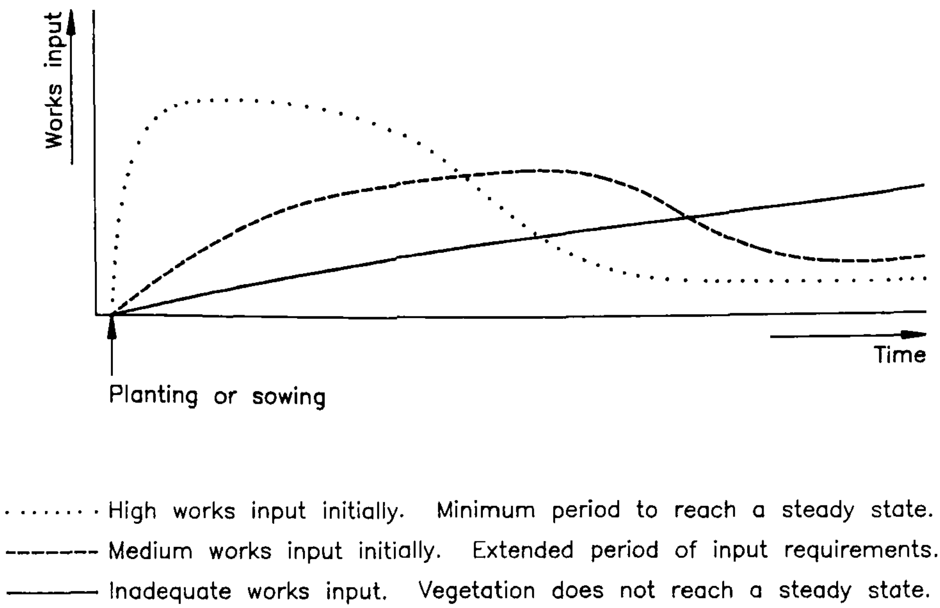


Figure 14.13: The care of new vegetation

against annual weeds but of little value in reducing competition from perennial weeds, particularly grass. Strimmers and mowing machinery have been found to cause considerable damage to young trees unless used with care.

14.7.3 Lime requirements

The pH of the substrate may fall progressively as shown in Chapter 5. Unless the substrate pH is monitored periodically and maintained within the range required for the vegetation, by the application of lime, the growth and development of the vegetation will be impaired. This process, termed regression, has led to established swards on reclaimed colliery spoil deteriorating to a moribund, patchy cover.

Photograph 14.8:
Rapid tree growth produces a dense, weed-suppressing canopy (source: Richards, Moorehead and Laing Ltd)

14.7.4 Nutrient applications

Colliery spoil and steelworks substrates lack reserves of nutrients, particularly nitrogen (Sections 5.4, 9.2.3). Applications of inorganic nitrogen fertilisers have only a temporary effect on the substrate nitrogen concentration and contribute very little to the nitrogen capital of the substrate. As a result vegetation, and in particular the vigorous, fast-growing species which demand high nutrient supplies, is particularly sensitive to inadequate nutrient additions. The application of organic nutrient sources can ensure a more consistent supply of available nitrogen than inorganic fertilisers. A programme of routine substrate sampling and analysis is valuable, particularly where nutrients are removed through agricultural cropping. In West Yorkshire all reclaimed colliery spoil sites used for agriculture are monitored annually.[215] Sewage sludge offers a cheap or free source of nutrients for maintenance purposes, but its use is restricted to sites:

- where odours are not a problem;
- where run-off can be avoided;
- where the heavy metal content of the sludge is within guideline concentrations;
- where there is no health risk.

14.7.5 Grazing

Perennial grasses sown on colliery spoil or slag may develop seed heads during the first growing season, as a response to moisture stress. This impedes their vegetative development towards a dense sward. Where rhizomatous or stoloniferous grasses have been sown to ensure the stabilisation of the substrate a dense, vegetative cover is particularly important. Mowing or grazing of the young grass is frequently practised. This encourages a vegetative response provided that the young plants are not damaged excessively. Grazing is a valuable tool for grassland management since it removes excessive growth and can recycle nutrients (see Section 15.5) but uncontrolled or excessive grazing has been a major cause of sward regression (see Photograph 14.9). Overgrazing causes regression through:

- damage to the growing point of grass plants;
- damage to the growing points of legumes, inhibiting nitrogen fixation;
- removal of nutrients.

Grazing also severely damages newly emerging grass plants which can be uprooted.

A key function of grassland management is the maintenance of a balance between nutrient inputs and removals, and a balance between the amount of grazing and the growth of the sward. This balance is also a vital part of the maintenance of nitrogen fixation by legumes (see Box 14.13).

Photograph 14.9: Severe sward regression caused by overgrazing (source: Richards, Moorehead and Laing Ltd)

Box 14.13: Key points in the maintenance of nitrogen fixation by legumes

- select legumes appropriate to the substrate and site use;
- inoculate with the correct *Rhizobium* strain;
- maintain near-neutral pH or select legumes adapted to the pH;
- maintain available phosphate concentrations;
- ensure adequate available water capacity in the substrate;
- avoid excessive salinity or soluble fertiliser applications;
- balance the growth of legumes and grasses by carefully monitored nitrogen applications;
- graze or cut to control grass growth;
- avoid overgrazing of legume swards.