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Cultivation of Soils for Forestry

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Front cover: A view over the Findlay's Seat reserve at Teindland Forest near Elgin in North Scotland. The old trees in the foreground are about 150 years old and are the survivors from planting carried out after limited site preparation. This involved superficial drainage and the removal of vegetation around the planting position. Contrast the growth of the old trees with the taller trees in the background that are 45 years old from experiment Teindland 81 and which were established with cultivation techniques which disturbed the upper soil horizons and provided initial weed control.

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Cultivation of Soils for Forestry

Summary

This Bulletin describes how foresters can use cultivation to provide a favourable site for tree survival and growth. A guiding principle is to work within the limitations of the site and to appreciate the effects of cultivation upon the microsite and the wider forest environment. The wide range of cultivation techniques now available means that there can be no universal prescription and cultivation will not be appropriate in all circumstances. The forest manager can use this guide to formulate prescriptions and select techniques appropriate to different site types and environmental considerations. In outlining options, the recommendations favour those techniques that present the least risk of damage and which best promote rooting patterns favourable to the stability of trees and stands. Understanding the usefulness of different types of cultivation is critical to the efficient and sustainable management of the forest estate in Britain.

Section 1 covers the impacts of cultivation on site conditions (soil and air temperature, soil moisture, bulk density and nutrients). It also considers effects on the environment (landscape, archaeology, soil, flora, fauna, etc.), and discusses the effects of cultivation on tree survival, growth, yield and stability.

Section 2 considers a range of factors that influence the choice of an appropriate cultivation technique. Site characteristics and proposed woodland type are discussed. Cultivation recommendations for the major soil groups are given. The advantages and disadvantages of various cultivation techniques are discussed and guidance given on the selection of appropriate machinery. Finally, an economic evaluation of the benefits of cultivation is presented.

La Culture des Sols à des Fins Forestières

Résumé

Ce bulletin décrit la façon dont les forestiers peuvent avoir recours àla culture pour fournir un site favorable à la survie et à la croissance des arbres. Le principe directeur est de travailler dans les limites du site et d'avoir conscience des effets qu'aura la culture sur le microsite et l'environnement plus vaste de la forêt. Le vaste éventail des techniques de culture qui existe maintenant signifie qu'on ne saurait préconiser de méthode universelle, de plus la culture n'est pas appropriée dans tous les cas. Le gestionnaire de la forêt pourra se servir de ce guide pour formuler des instructions et sélectionner des techniques appropriées à différents types de sites et à des considérations écologiques variées. En passant en revue les options, les recommandations privilégient les techniques qui présentent les risques de dégâts les moins élevés et encouragent le mieux la formation de systémes de racines favorables à la stabilité des arbres et des bouquets. La compréhension de l'utilité des différents types de culture est cruciale pour la gestion efficace et durable des ressources forestières en Grande-Bretagne.

La section 1 couvre les conséquences de la culture sur l'état des sites (température du sol et de l'air, humidité du sol, densité apparente et substances nutritives). Elle rend également compte des effets sur l'environnement (paysage, archéologie, sol, flore, faune, etc.) et examine les effets de la culture sur la survie, la croissance, le rendement et la stabilité des arbres.

La section 2 examine une variété de facteurs influençant le choix d'une technique de culture appropriée. Les caractéristiques des sites et le type de bois suggéré y sont examinés. Des recommandations de culture s'appliquant aux prinicpaux groupes de sols sont données. Les avantages et inconvénients des différentes techniques de culture sont traités et des conseils sont donnés pour la sélection d'équipment approprié. Pour finir, l'évaluation économique des bénéfices apportés par la culture est présentée.

Bodenkultivierung in der Forstwirtschaft

Zusammenfassung

Dieses Bulletin beschreibt wie Forstwirte Kultivierung, zur Schaffung eines günstigen Standortes zum Überleben und Wachstum der Bäume, benutzen können. Es ist wichtig, innerhalb der Einschränkungen des Standortes zu arbeiten und die Auswirkungen der Kultivierung, auf den Mikrostandort und die weitere Forstumwelt, zu beachten. Aufgrund der verschiedenen Kultivierungsverfahren, die uns heute zur Verfügung stehen, gibt es keine Universalanordnung und Kultivierung ist nicht in allen Fällen angebracht. Der Forstwirt kann diesen Ratgeber benutzen, um Anordnungen zu formulieren und die passenden Verfahren, für die verschiedenen Standorttypen und Umwelterwägungen, zu wählen. Die beschriebenen Empfehlungen bevorzugen jene Verfahren, die das geringste Schadensrisiko darstellen und welche das beste Bewurzelungsmuster zur Baum- und Bestandstabilität fördern. Es ist wichtig, die Nützlichkeit der verschiedenen Kultivierungstypen zu verstehen, um den Waldbesitz in Britannien rationell und nachhaltig zu bewirtschaften.

Sektion 1 beschreibt die Auswirkungen der Kultivierung auf Bodenbedingungen (Boden- und Lufttemperatur, Bodenfeuchtigkeit, Trockenrohdichte und Nährstoffe). Einflüsse auf die Umwelt (Landschaft, Archäologie, Boden, Flora, Fauna usw.) werden ebenso betrachtet und die Auswirkungen von Kultivierung auf Baumanwuchs, Wuchs, Ertrag und Stabilität werden diskutiert.

Sektion 2 betrachtet eine Reihe von Faktoren, welche die Wahl des passenden Kultivierungsverfahrens beeinflussen. Standortmerkmale und gewünschte Waldtypen werden diskutiert. Für die Hauptbodengruppen werden Kultivierungsvorschläge gegeben. Die Vor- und Nachteile verschiedener Verfahren werden behandelt und es werden Ratschläge zur Wahl der richtigen Maschinen gegeben. Zuletzt wird eine ökonomische Bewertung der Vorteile von Kultivierung dargelegt.

Introduction

Foresters use cultivation to improve conditions for tree growth by changing soil and site features. Proper preparation of the site can be vital in ensuring successful and cost-effective establishment of young trees. However, successful use of cultivation demands an appreciation of other issues affecting establishment such as site type, plant quality, species requirement and herbicide regime. It also requires awareness of potential effects of cultivation upon the wider environment. The purpose of this Bulletin is to provide a guide to the selection of appropriate cultivation techniques as part of establishment systems on a wide range of forest sites in Britain.

Cultivation has played an important role in the expansion of forestry in Britain. The development of ploughing techniques for use on marginal upland soils underpinned the major afforestation programmes of the 1950s to the 1980s. An estimated 90 per cent of afforestation and 60 per cent of restocking sites in Britain are now cultivated in some way before planting or regeneration. Therefore, understanding the usefulness of different types of cultivation is critical to the efficient and sustainable management of the forest estate.

Our appreciation of the effects of cultivation upon tree root physiology, rooting patterns and soil properties has advanced considerably in the last 15 years as has our understanding of the potential impacts of cultivation on the wider environment. Long-term findings from cultivation experiments of the 1950s combined with interim results from experiments of the 1960s and 1970s, and early results from the latest series of experiments have all enhanced our knowledge. This extensive data set provides a much clearer picture of the short and long-term effects of various cultivation techniques on different sites and tree species. Our revised specifications for different soil groups are based on these findings.

Previous cultivation guides have only covered the use of ploughs. Major advances have taken place so that the range of cultivation equipment suitable for use in Britain now includes disc trench scarifiers, patch scarifiers, mounders and subsoilers*. The range of potential cultivation techniques now available combined with the variation of soil types in British forests means that there is no single universal prescription for site preparation.

The range of sites being planted has expanded to include improved grassland and arable land. These can present specific problems such as existing field drainage systems and a rich weed flora which can be stimulated by cultivation. Cultivation also has a potential role as a means of promoting more consistent natural regeneration in both conifer and broadleaved woodlands.

All these developments justify the comprehensive re-appraisal of previous cultivation recommendations, which is given in this Bulletin.

The reasons for using cultivation

Cultivation should be used where it is the most effective means of overcoming adverse site and soil conditions to provide a favourable environment for tree survival and early growth. The choice of an appropriate technique can also provide longer-term benefits such as improved root anchorage and tree stability. In upland Britain, cultivation can promote the return of a forest ecosystem to impoverished soils degraded by centuries of burning and grazing damage following deforestation. This process can be accomplished by sensitive choice of techniques while the efficiency of restocking

* A Glossary with a detailed definition of cultivation and other technical terms (marked in the text with an asterisk) can be found on pages 83–85.

Table 1.1 The effects of cultivation

Potential physical effects	*Potential biological changes*	*Potential environmental effects*
Altering the surface configuration of the site	Increase in rate of nutrient release from decomposing organic matter to the planted or regenerating trees	Greater sediment loss and altered patter of water flow, especially during and after storms
Removal of physical obstructions such as brash	Alteration to the amount of vegetation cover and the type of plant community	An increase in nutrient losses
Breaking up humus and mixing it with other soil horizons	Increase in activity of soil fauna, fungi, and microbes resulting from improved aeration	Alteration of the visual texture of the landscape
Increasing pore space and breaking breaking up compaction		Damage to archaeological remains
Changing soil and air temperatures near the soil surface		
Amending soil moisture conditions		

and natural regeneration can be similarly improved.

Site features such as a high density subsoil (e.g. clay soils), the effects of an ironpan, or the thermal insulation and water impedance of an organic layer can all produce adverse conditions for tree growth. Other limiting factors may include large accumulations of spruce brash, vigorous weed cover, allelopathic vegetation such as heather, or the compaction and rutting caused by harvesting machinery. Appropriate cultivation methods can alleviate these limiting factors and improve the success of planting or regeneration. The technique used must be carefully chosen in relation to other factors, such as soil, species, environmental constraints and vegetation type. The choice of technique should be based upon a sound understanding of the effects of cultivation (see Table 1.1). Cultivation should not be prescribed as a universal solution to establishment difficulties. On certain soil types or in particular conditions, no cultivation can be a preferable option.

The management objective is to find the **combination of options** which lowers establishment costs or provides higher revenues, such as longer rotations on wet soils. Cultivation is only one element in achieving cost-effective establishment systems.

The text which follows is divided into two main sections. The first section describes the known biological and other effects of cultivation on the microsite and on the general environment. The second part provides details of specifications and techniques, and guidelines which allow appropriate prescriptions to be formulated for different site and environmental conditions.

In presenting these options, we have favoured techniques which present least risk of damage to the environment and which best promote rooting patterns favourable to the stability of trees and stands. The general theme has been to encourage foresters to work with the site limitations rather than use aggressive site preparation techniques to overcome them.

Previous cultivation guides

The main references are Zehetmayr (1956); Taylor (1970); Thompson (1984). Ploughing and subsoiling equipment was described by Taylor (1970) and updated and codified by Thompson (1978). Other useful references for upland conditions include Tabbush (1984 and 1988) and Nelson and Quine (1990). The terrain classification referred to is described by Rowan (1977) and nutrient deficiency categories have been defined by Taylor and Tabbush (1990). More detail on cultivation of lowland soils for new planting can be found in Willoughby and Moffat (1996). Cultivation of man-made soils (e.g. colliery spoil heaps, old mineral workings) is described by Moffat and McNeill (1994). Detailed recommendations on drainage can be found in a forthcoming guide by Ray (in preparation).

The impacts of cultivation

Chapter 1

The impacts of cultivation on site conditions

Soil temperature

Soil temperature has a strong influence on root growth and uptake of water and nutrients. For example, root activity in Sitka spruce has been shown to commence at around 5°C and increase rapidly between 10°C and 25°C (Coutts and Philipson, 1987). Roots of well handled Douglas fir were inactive below the higher soil temperature of 8°C (Tabbush, 1986). In roots of Scots pine (*Pinus sylvestris* L.) nitrogen uptake was found to be slow until soil temperatures exceeded 15°C (Örlander *et al.*, 1990). In British Columbia, the best growth of white spruce (*Picea glauca* (Moench) Voss) was recorded at a soil temperature of 20°C (Dobbs and McMinn, 1973, 1977) and decreased sharply as soil temperature declined to 10°C.

Cultivation often results in an increase in the mean temperature of soil in the rooting zone within the 10–20°C range. Dobbs and McMinn (1973) found that blade scarification raised the average soil temperature at 5 cm depth in mid-summer from 14°C to 17°C. Large increases in soil temperature from the use of scarification and ploughing in restocking on morainic soils have also been recorded in Sweden (Örlander *et al.*, 1990) and Quebec (Prévost, 1992). These increases occur partly from the increase in radiation reaching the mineral soil surface after removal of vegetation and partly from improvement in thermal conductivity from mixing mineral soil and organic matter.

In upland Britain, soil temperature in the rooting zone is generally below 10°C for 2–3 months of the growing season. Raising soil temperature during stand establishment has long been recognised as desirable, especially on north-facing sites with reduced insolation. Surface organic layers such as mor or peat

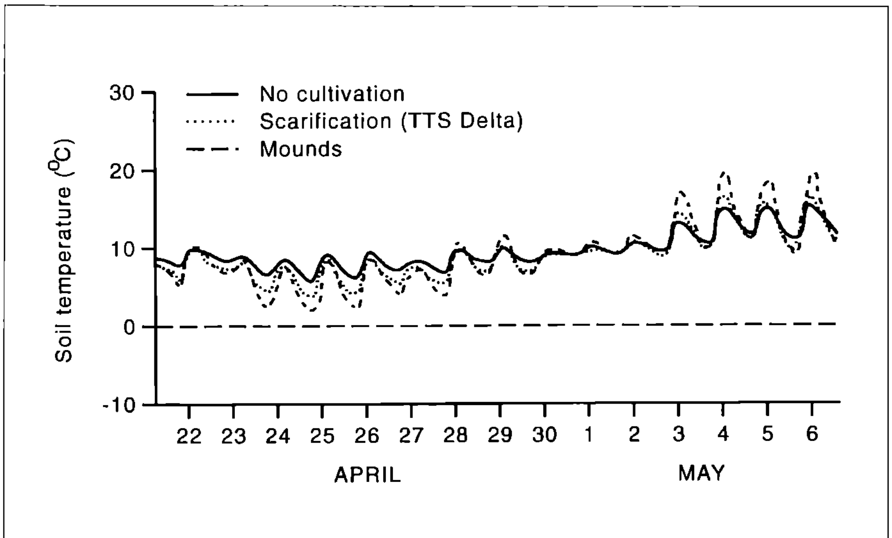

Figure 1.1 Soil temperature at 10 cm depth over a 14-day period in April-May showing the contrast between no cultivation, scarification and mounding. Brown earth soil at Corris, Wales. [Source: Anderson, unpublished]

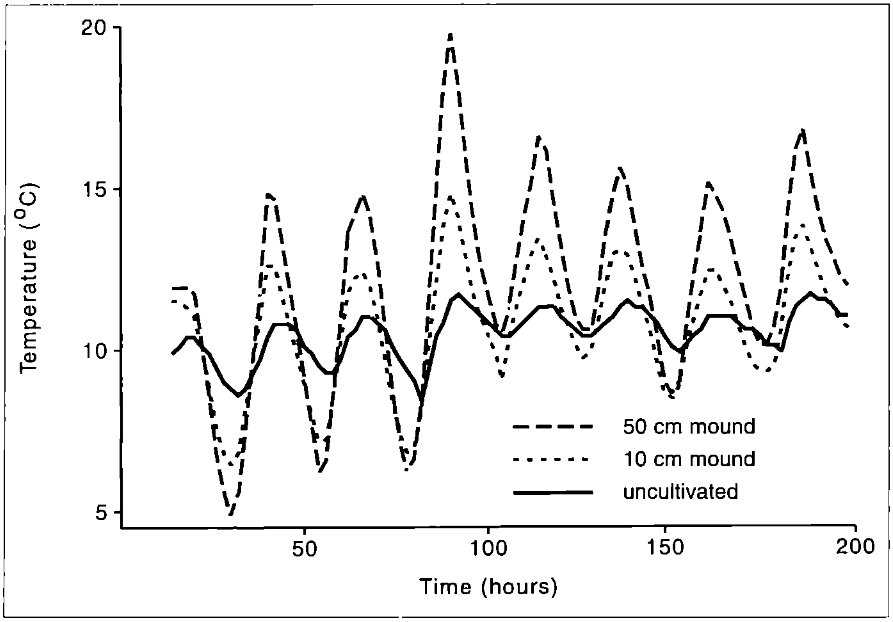

Figure 1.2 Soil temperature at 15 cm depth over a 7-day period in June on a restocking site on a surface water gley soil in Kielder. Three treatments were contrasted: uncultivated, 10 cm mounds, 50 cm mounds. [Source: Ray and Anderson, 1990]

which have large heat capacity or low thermal conductivity tend to keep the underlying soil cool by insulating it from incoming radiation. A similar effect is caused by conifer litter or brash on restocking sites (Smith, 1988).

In the eastern Southern Uplands on a heathland ironpan soil, Ross and Malcolm (1982) observed that maximum diurnal temperature ranges from late July to mid-August were greatest on complete cultivation compared with the uncultivated soil and were two to three times greater at 10 cm depth in cultivated than in undisturbed soil. These differences were still evident at 60 cm depth where mean temperature over the period was 0.5°C higher in ploughed than in undisturbed soil.

Figure 1.1 shows soil temperatures in April and early May at 10 cm below the soil surface on a brown earth soil on a restocking site in Wales. Four treatments were compared: disc trench scarification with the TTS Delta; mineral mounding; and two uncultivated controls, one of which had complete control of weeds by herbicides. In cool overcast periods in April, the lowest soil temperatures were recorded in the mounds but in sunny periods in early May, mounded sites had significantly higher daytime temperature than controls. Disc trenching had an intermediate effect. There were no appreciable differences between the controls.

On restocking sites on three soil types (brown gley, surface-water gley and ironpan soils) there was a much greater diurnal range of soil temperature on large mounds (50 cm) compared with the untreated surface; up to 6°C higher in mid afternoon in summer (Nelson and Ray, 1990; Ray and Anderson, 1990; Figure 1.2).

The maximum temperature on large mounds was 1°C higher than on smaller (20 cm) mounds on the brown gley soil and 4°C higher on the peaty gley soil during sunny conditions. These results suggest that optimal conditions for root growth are reached more quickly on large mounds which can be important on cold wet soils in late spring. The accumulated temperatures above critical limits for root growth are higher on mounds than on an uncultivated site (Figure 1.3).

Cultivation, therefore, can improve the temperature regimes on a wide range of soil types. The form of cultivation needs to reflect the thermal conductivity of the soil, e.g. mounding on clay or fine textured soils and scarification on coarse textured soils.

Cultivation can also produce unwanted effects. Ploughing of organic horizons can lead to lower soil temperatures in spring in the

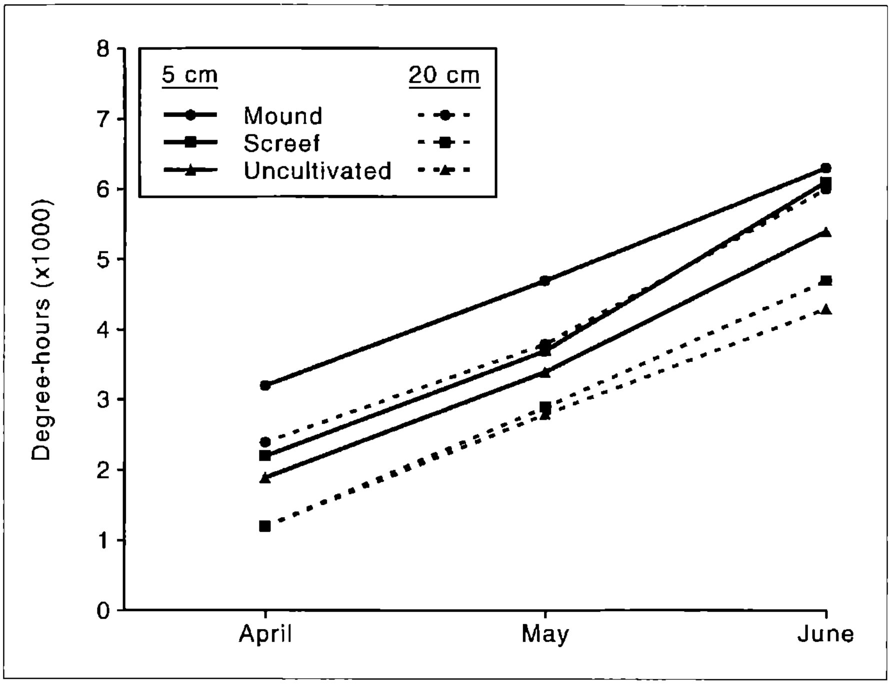

Figure 1.3 Degree-hours (x1000) above 5°C during April, May and June on a restocking site with a peaty gley soil in Kershope Forest (Experiment Kershope 48/86). Three cultivation treatments were compared: 30 cm high mounds, an area where the vegetation was removed ('screefed'), and an uncultivated control. Soil temperature was recorded at depths of 5 and 20 cm. [Ray and Anderson, 1990]

ridge owing to the low thermal conductivity of the two humus layers. This explains why the lower layers of the inverted ridge may remain frozen on peaty soils despite apparently favourable temperatures for planting and this can cause moisture stress to newly planted seedlings. Similar effects can occur on the ridge turned over by trench scarifiers on peaty ironpan or peaty gley soils with an organic horizon more than 25 cm deep. Mineral mounds will tend to freeze faster in winter than mounds of organic soil and will thaw quicker in the spring. Swedish studies (Lindström and Troeng, 1995) have also shown appreciably lower temperatures in mineral mounds overwinter in the absence of snow cover with a consequent risk of damage to seedling roots.

Treatments such as deep† complete ploughing which achieve the largest changes in temperature can also reduce nitrogen availability on nutrient poor soils owing to rapid mineralization and leaching.

†In this Bulletin the depth of cultivation is classified as follows: shallow=15–30 cm; medium=30–45 cm; deep=45–60 cm; very deep=>60 cm.

Soil temperature has a strong influence on root growth and uptake of water and nutrients.

Appropriate cultivation techniques can produce major beneficial changes in the temperature regimes on a wide range of soil types.

Air temperature

Low air temperatures near the soil surface can cause frost damage to planted trees or regenerating seedlings especially in spring and autumn. On calm, clear nights the air above grass/herb swards rapidly cools because the transfer of heat from the soil is reduced by the insulating effect of the humus and grass. As a result, a layer of freezing air can collect immediately above the vegetation. By contrast, cultivated soil stores more heat during the day and releases it to the overlying air at night, thus raising night-time temperatures (Sutherland and Foreman, 1995). Low and Greig (1973) observed that, on sandy soils at Thetford at 0.5 m above the ground surface, the air temperature over bare soil could be as much as 4°C warmer than over a grass sward.

Cultivation of a substantial proportion of the surface would therefore be of most value on level grassy sites or in depressions where frosts may be anticipated. Examples include freely drained littoral sands (soil type 15e: see Appendix 1) and sandy podzols or brown earths (soil type 1z, 3, 3m) where frost-sensitive species like Corsican pine, Douglas fir or beech may be planted. Mounding could influence the air temperature in frost hollows in tussocky grassland which would be most beneficial with southern provenances of Sitka spruce.

Cultivation can help reduce frost damage where the mineral soil is exposed.

Effects on soil moisture in wet soils

Although the soil water in wet surface horizons of some flushed soil types (flushed gleys and Juncus bogs) may be well-charged with oxygen, in most gley soils and peats the depth of rooting is severely restricted by water-tables rising to within 20–30 cm of the soil surface in late autumn and winter. Low oxygen concentrations in the subsoil can also restrict rooting.

Species differ in their tolerance of waterlogged soils. Thus Sitka spruce roots are sensitive to waterlogging (Coutts, 1982) and adventitious rooting occurs above anaerobic horizons (Coutts and Philipson, 1987; Coutts and Armstrong, 1976; Day, 1950). In lodgepole pine, oxygen can diffuse through aerenchyma cells in roots which can therefore penetrate some distance into waterlogged horizons (Philipson and Coutts, 1978, 1980). Generally, however, lowering water-tables in gley soils and peats increases aeration in the upper soil horizon which can encourage deeper rooting and benefit crop stability (Fraser, 1962).

The feasibility of improving soil moisture regimes by cultivation is limited by the hydraulic conductivity* of a given soil texture or by the humification of peat. Well-humified peat, which commonly occurs on blanket bogs, conducts water very slowly but peat from raised bogs with low humification (fibrous or raw sphagnum peat) has high conductivity. The relationship between soil texture and soil moisture content/soil moisture tension is described in Figure 1.4.

On **fine loamy** soils with gradients greater than 3–4° moling or ploughing at 4 m centres controls water-table very effectively to a depth of about 20–30 cm. However, deep cultivation and drainage on slowly permeable soils are now known to have less influence on water-table than the effects of canopy interception and stand transpiration (Savill, 1976; Pyatt and Craven, 1978; Pyatt *et al.*, 1985).

In **gley soils and peats**, removal of excess water from the planting position has usually been achieved by using a raised planting position such as the plough ridge, or a turf or mound. On a peaty gley soil in the Borders Carboniferous site region, ploughing was approximately 20% more effective than cut turves in lowering the moisture content of the peat but not the underlying subsoil (Pyatt and Booth, 1973). Similar effects can be achieved on restocking peaty gleys by excavator mounding with drains at 16 m intervals (Ray *et al.*, in preparation).

A very intensive technique of creating large-scale riggs and furrs on a **peaty podzolic gley** over Jurassic clay has been tried in the fairly dry climate of the North York Moors. This was one of the few examples where water potential* measured at 30 cm depth was significantly lowered (indicating drier soil) compared with single mouldboard ploughing (Read *et al.*, 1973). They also reported a lesser improvement with complete cultivation at 30 cm depth. A similar benefit from riggs and furrs was found at Kielder on a Carboniferous peaty gley.

On **a Culm clay soil** at Halwill, Devon, moling at 1.5 m intervals on a slope of 3.6° resulted in a more rapid fall in the water-table than on an unmoled site (Hinson *et al.*, 1970). Hendrick (1989) has suggested that soils with clay contents of between 30% and 50% are suitable for moling at 40–45 cm depth, on sites with a minimum slope of 4°. However, moling at 40 cm depth on a loamy peaty gley (<30% clay) in Eastern Tayside region produced a 4–17 cm lowering of the water-table compared

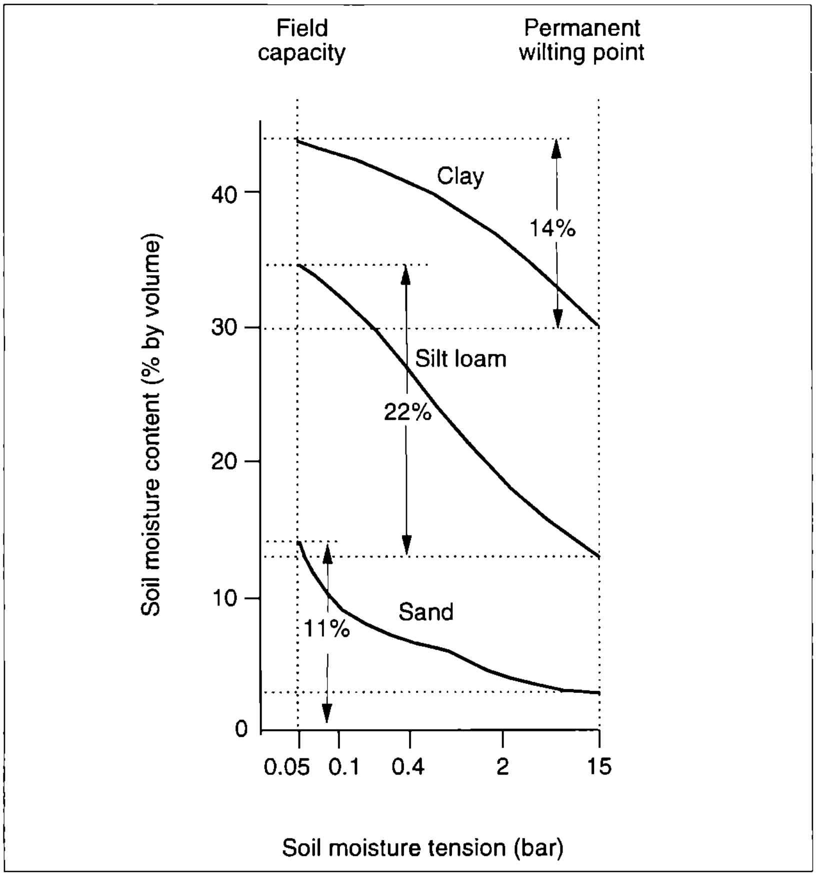

Figure 1.4 Relationship between soil moisture content and soil moisture tension (plotted on a logarithmic scale) for tree soils with contrasting textures. Arrows indicate available water capacity for each soil. [Source: Davies, 1987, Figure 6]

with ploughing alone (Quine, 1988). This indicates that moling can be effective on wet soils of a fine loamy texture with less than 30% clay. Attempts to use moling on sandy loams are generally unsuccessful because of the collapse of the mole channel.

On **deep peat** various approaches have been tried. In Caithness, ploughing lowered the water-table compared with untreated controls. However, there were no significant differences in borehole water level between three depths of plough furrow (30, 60, 90 cm) and three drainage ditch spacings in a 20-year-old Sitka spruce–lodgepole pine stand (Pyatt, 1988). The peat beneath shallow (30 cm) furrows had dried but the bottom of 60 cm and 90 cm furrows remained wet. This suggests that oxygen levels would be adequate for roots to cross shallow furrows whilst conditions for crossing deep furrows would remain unsuitable for more than 20 years. The lowering of water-table on moderately or well-humified deep peats appears to be more dependent on the formation of deep cracks which can be linked into deepened drains (Pyatt *et al.*, 1987; Pyatt, 1988). As noted above, these effects must be attributed to crop interception and transpiration in summer and are not due to cultivation *per se*.

In Ireland, narrow peat ribbons were extruded onto the surface while cutting 30 cm deep under-surface drainage channels with the Glenamoy plough. Peat mounds were also extruded whilst cutting similar sub-surface channels. These sub-surface channels are then linked by collecting drains. The long-term effects of peat mounds on water-table and oxygen levels are not known but O'Carroll *et al.* (1981) compared water-table levels between Glenamoy and conventional ploughing and found that the water-table was >30 cm lower in the Glenamoy treatment. These techniques are dependent on the absence of obstructions (e.g. tree stumps) in the lower peat horizons and on suitable peat of consistent depth, humification and wetness.

Cultivation has a major influence on the wetness of the surface layer and the planting position. However with few exceptions there is only a minor influence on the water-table in the deeper horizons of the soil.

The aim on wet soils is to provide a raised planting position to reduce the soil moisture content and increase oxygen levels to improve root development.

Effect on soil moisture in dry soils

In Britain, inadequate soil moisture for young plants is normally found only on lowland sites such as sands or clays in eastern and southern regions. It can, however, affect well-drained soils on steep southern aspects in the uplands in years with dry periods in late spring or early summer. The available water capacity is largely determined by the organic matter content, soil texture (Figure 1.4) and depth although it also varies with stoniness, soil structure, compaction and soil temperature.

On **freely drained sands and coarse textured soils**, because of poor capillary conductivity, there can be inadequate moisture transfer to the root systems of newly planted trees. Evapotranspiration from existing vegetation will also limit soil moisture available to planted trees (Fleming *et al.*, 1994). These conditions can be exacerbated if soil is placed as a mound over unconsolidated litter or brash which breaks the capillary rise of moisture from lower horizons (Sutherland and Foreman, 1995). Patch and trench light scarification has been used on these soils to provide a shaded planting position (i.e. in the furrow bottom), access to subsurface moisture, and removal of competing vegetation.

On **sands and coarse loamy soils in dry regions**, light surface cultivation improves survival but the greatest benefit comes from combining high degrees of weed control with the bedding* or furrowing technique (Prior, 1963) and using a planting position and depth which improves access to soil moisture.

Clay soils will continue to conduct water to the surface in dry weather but much of the water in these soils is held at tensions which make it unavailable to the roots of young plants. Damage by harvesting machinery (e.g. rutting) can worsen these conditions. Creation of mounds on clay soils in these lowland regions results in faster drying out because of the greater surface area exposed to evaporation. Cultivation of dry clays subject to summer drought appears to have little benefit compared with simple weed control by herbicides or mulches. As weed growth intensifies on clay soils in dry regions, it is the herbicide input or mulching area which should increase and not the cultivation or its intensity (Davies, 1987).

Cultivation of dry soils is only beneficial in certain circumstances. Effective weed control often produces better results.

Effects on soil bulk density

Tree roots will not penetrate soil horizons with bulk density in excess of 1.0–1.6 g cm^{-3} in coarse textured soils (Faulkner and Malcolm, 1972; Prévost, 1992) or 1.2 g cm^{-3} in fine textured soil. The limitations on rooting depth due to dense horizons will restrict tree growth and anchorage.

On an ironpan soil with a deep lying ironpan and induration, bulk density after medium depth complete ploughing was 0.9–1.1 g cm^{-3} compared with 1.2–1.6 g cm^{-3} in the undisturbed profile (Wilson and Pyatt, 1984). Rotary mouldboard deep complete cultivation on an ironpan soil has achieved reductions in bulk density from 1.5 g cm^{-3} to 1.0 g cm^{-3} with a corresponding rise in porosity from 42% to 58% (Ross and Malcolm, 1982).

Figure 1.5 illustrates the reduction in bulk density and increase in porosity from use of mounding and ploughing on a Scandinavian

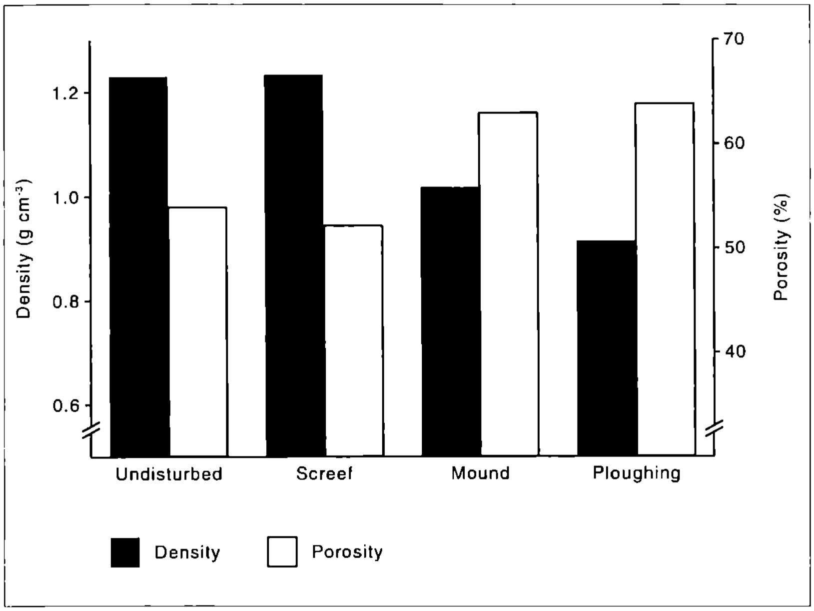

Figure 1.5 Soil bulk density and porosity at 10–20 cm depth after four different types of cultivation in Finland. [Source: Örlander et al., 1990 after Ritari and Lähde, 1978]

site compared with no cultivation or patch scarification (Ritari and Lähde, 1978).

However, spaced ploughing on ironpan soils affects root symmetry owing to the different bulk density between the cultivated and uncultivated parts of the site. The tendency for roots to follow the line of ploughing is probably caused by differences between the bulk density in the plough ridge and furrow from the undisturbed soil. In the cultivated soil there will be less mechanical resistance, higher oxygen content and a higher temperature. Rennie (1952) calculated that 38% of the site remained undisturbed after spaced furrow ploughing of a peaty ironpan soil at 1.5 m centres.

Bulk density on a **peaty gley soil** over a sandy clay loam in the Borders region of Scotland increased following crop interception and transpiration (Pyatt *et al.*, 1978) resulting in cracking in the lower Bg horizon. However, because of high winter water-tables, the spruce roots were unable to exploit these cracks. Generally, bulk densities less than 1.2 g cm^{-3} are only found in the uppermost horizons of such soils and rooting is confined to these horizons. This is an important reason for not disrupting the surface horizons of these wet clay soils by cultivation treatments which produce continuous furrows.

There are no cultivation treatments which can be used to reduce bulk density in **clay subsoils**. Incorporating humus as in riggs and furrs (Neustein, 1977) may be a solution, but it is only applicable in limited conditions in drier climates.

Tree roots will not penetrate horizons with bulk density in excess of 1.0–1.6 g cm^{-3} in coarse textured soils or 1.2 g cm^{-3} in fine textured soil.

Cultivation can substantially improve root penetration and fine root development in dense soil horizons on coarse textured soils. However, these improvements are not found on wet clay soils.

Spaced ploughing on dense soils can affect root symmetry, and subsequent tree stability.

Effects on soil nutrients

The relationship between cultivation and soil and plant nutrition is a very complex one as many factors are involved, e.g. moisture, temperature, weed competition, microbial activity, and standard fertilizer inputs.

In afforesting **heathland and other nutrient deficient soils**, phosphorus and potassium requirements have to be met by application of fertilizers (Taylor, 1991). The nitrogen essential for early growth is obtained mainly from mineralization in surface organic matter, i.e. humus, peat and tree litter and from the turn-over of fine roots. Cultivation can indirectly affect the rate of mineralization by raising temperatures for biological activity, by improving aeration, by reducing bulk density, and by the 'mixing effect' when humus is incorporated with the mineral soil (van Goor, 1977).

After cultivation for restocking on **Podzols**, Örlander *et al.* (1990) quote levels of 30 ppm and 40 ppm available ammonium nitrogen in the surface horizons of inverted mounds and ploughing respectively. These values compared with a normal background level of 1–2 ppm. On a well-drained, fine-textured soil mineralizable nitrogen has been found to be twice as high on rotary mulching* compared with an untreated surface (Bedford and McMinn, 1990). Greater levels of total nitrogen and available phosphate were also recorded by Turvey and Cameron (1986) five years after a bedding* treatment with the Rome 'plough' on a sandy podzol when restocking *Pinus radiata*. This treatment concentrated surface humus in a zone just below the apex of the bed (Attiwell *et al.*, 1985) where planting lines were located and, when accompanied by weed control, produced significantly greater yield and height at five years. Similar results of shorter duration were reported by Burger and Pritchett (1988) on sandy soils with a raised ground water-table prepared by disc bedding for pine restocking. Total nitrogen reserves were reduced below that for brash-chopping alone. Long-term data from cultivation trials in Scandinavia (Örlander *et al.*, 1996) show 16–30% lower levels of total soil nitrogen on cultivated areas some 60 years after treatment: however, this did not affect tree growth and yield.

On soils low in nitrogen, if cultivation is too deep and intensive there is a very sharp decline in foliar nitrogen after an initial stimulus to growth. For demanding species such as Sitka spruce the period of satisfactory foliar nitrogen concentrations may last only three years resulting in rapid decline in height growth and check if nitrogen fertilizer is not applied. On such soils, mounding or patch scarification would be preferred to disc trenching or ploughing, but care is required to ensure that mixing of topsoil and subsoil is minimized.

When restocking **wet peaty soils**, adequate nitrogen for early growth should generally be available without requiring the use of cultivation (Taylor, 1990). However, on these soils, the spatial pattern of nutrient release from brash after clear-felling may be affected by the brash mats used for machine travel which can cover 35–65% of the surface area (Titus and Malcolm, 1991). Cultivation is often combined with brash raking to provide planting positions at regular spacing. Unfortunately, brash raking tends to concentrate material into heaps and windrows which may also cause a spatial imbalance in nutrient release. Therefore, on soils of very poor nutrient regime (Pyatt and Suárez, 1997), the cultivation method should also provide an even distribution of brash across the site.

Some types of cultivation can bring up chalk into the surface soil and, **on thin acid soils over chalk**, exacerbate chlorosis in pines with consequent loss of vigour (Wood and Nimmo, 1961).

Cultivation stimulates biological activity causing more rapid mineralization, particularly of nitrogen.

On soils low in nitrogen there is only a short-term improvement in nutrient availability. Shallow mixing of humus or peat with mineral soil appears to be the best way of maintaining the long-term nutrient status of the site.

Do not bury humus beyond the reach of juvenile root systems or at depths where organic turnover is slow. Minimize the mixing of topsoil and subsoil.

Chapter 2

The effects of cultivation on tree survival, growth, yield and stability

In this chapter, we present experimental results of using different cultivation techniques for both new planting and restocking. The approximate locations of the experiments mentioned in the text are shown in Figure 2.1. These results are collated by soil groups and conclusions made about the effects of the different techniques.

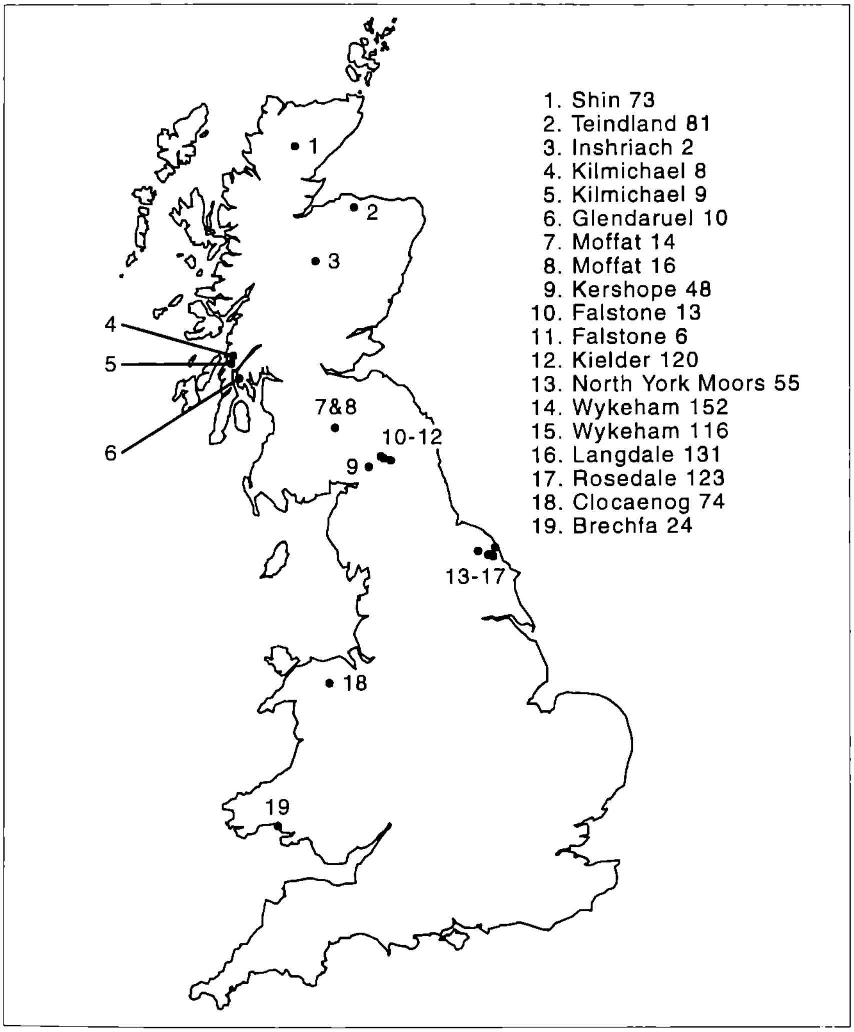

Figure 2.1 Location of experiments in Britain referred to in this publication.

Cultivation and survival and early growth on different soil types

BROWN EARTHS

New planting

Satisfactory survival and height growth can normally be achieved on brown earths without cultivation provided weeds are effectively controlled (Davies, 1987; Williamson, 1992; Willoughby and Moffat, 1996). On freely drained soils with severe moisture deficit during the growing season, cultivation can improve survival and growth when combined with weed control.

A recent experiment in North Yorkshire (Figure 2.2) illustrates this clearly. Grass invasion of the scarified area resulted in poorer survival and height growth than in treatments with spot weed control or intensive cultivation.

Restocking

Improved survival after cultivation on brown earths has frequently been demonstrated and relates to the weed control obtained from cultivation (Tables 2.1 and 2.2). The use of cultivation or herbicides has improved survival by 5–15%, varying with species, plant quality and plant handling. This could represent 10–25% in general forest practice. Species that are sensitive to soil temperature and soil moisture will be more responsive to cultivation (e.g. Douglas fir). Russell *et al.* (1989) found positive responses to cultivation in height, weight and depth of rooting of Douglas fir were correlated with lower bulk density and the increase in moisture and nitrogen from incorporated organic matter. Similar effects occur in Corsican pine planted on the sandy soils of Breckland in Eastern England.

Generally, cultivation treatments on brown earths resulted in greater height growth at six years than no cultivation (Tables 2.1 and 2.2). However, intensive weed control gave similar height growth at six years to patch scarification or ploughing, treated with herbicides as required (Table 2.2). This confirms that the primary benefit from cultivation on brown earths is to initiate effective weed control. The extent to which it does so is related to the weed species at the site, their competitive vigour and to the surface area of the cultivation treatment. The latter will also affect microsite soil and air temperatures which are important for some species, e.g. Corsican pine and Douglas fir, on sites prone to radiation frosts.

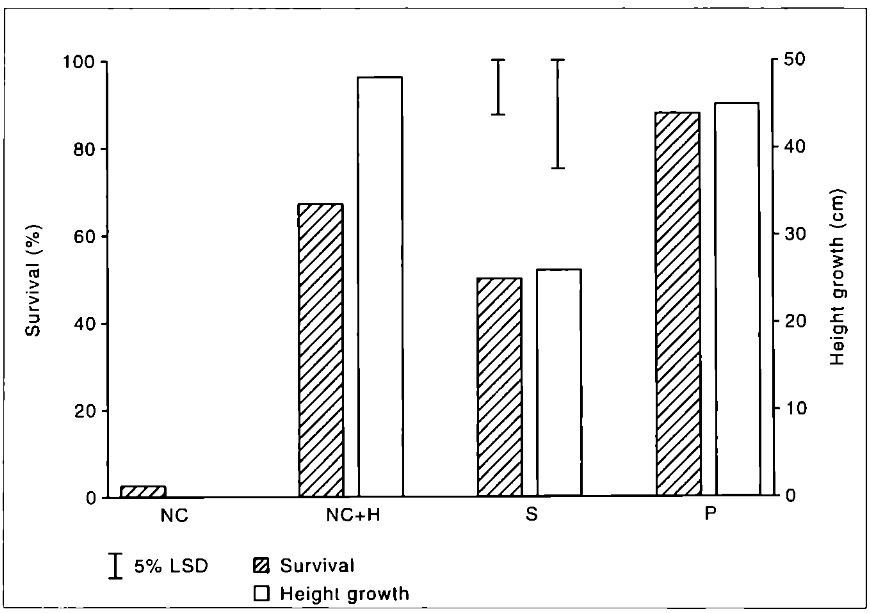

Figure 2.2 Survival and height growth of Japanese larch after two years on a new planting site on a brown earth soil in Yorkshire. Treatments are: no cultivation (NC); no cultivation with herbicide (NC+H); disc trench scarification (S); and medium depth double mouldboard ploughing (P). [North York Moors 55 P91]

Table 2.1 Survival percentage and 6-year height (m) of Sitka spruce on restocking sites on brown earth (Kilmichael), peaty gley (Falstone), and ironpan soils (Wykeham). Cultivation treatments are compared with no cultivation ± weed control by herbicide

Treatment	*Brown earth (Argyll) (Kilmichael 9 P85)*			*Ironpan soil (E. Yorks) (Wykeham 152 P85)*		*Peaty gley (Borders) (Falstone 13 P85)*	
	Survival % at 6 years	*Height at 6 years*	*Height at 10 years*	*Survival % at 6 years*	*Height at 6 years*	*Survival % at 2 years*	*Height at 6 years*
No cultivation, no herbicide	88	2.00	14.6	76	1.73	94	1.97
No cultivation + intensive herbicide	98	2.39	5.4	93	1.86	94	1.92
Scarification Bräcke patch	94	2.31	5.0	97	1.90	88	1.83
TTS Disc Trench Scarifier – mid position of planting	97	2.30	5.0	98	1.97	98	1.93
Mounds (manual or Smalley backacter)	100	2.67	5.9	100	1.93	98	1.77
Spaced single mouldboard ploughing (S60/T90)	-	-	-	99	2.05	-	-
Spaced single mouldboard ploughing (S60/T90) + herbicide	97	2.43	5.6	-	-	98	1.83
5% LSD	5.3	0.26	0.6	4.9	0.29	6.5	0.14

Table 2.2 Interaction of herbicide and cultivation treatment on survival and early height growth of Sitka spruce on a brown earth restocking site in Argyll. (Kilmichael 8 P84)

Treatment	*Survival (%) 1 year*	*Mean height (cm) 6 years*
No cultivation, no herbicide	92	158
No cultivation, herbicide	97	235
Patch scarification, no herbicide	92	170
Patch scarification + herbicide as required	94	248
Complete tine ploughing (S60/T90/m), no herbicide	96	222
Complete tine ploughing (S60/T90/m) + herbicide as required	98	254
5% LSD	6.1	38.6

PODZOLS

New planting and restocking

This soil type has not been considered of major importance for experimental work in Britain.

The afforestation experiment at Inshriach (Figure 2.3) showed improved growth of two pine species after ploughing compared with no cultivation (Mason, 1996).

In Scandinavia, trees planted on mounds showed improved survival and growth compared with those on patch scarification and on an uncultivated control (Edlund and Jonsson, 1986; Fries, 1993). A series of 50–70 years old Swedish experiments with Scots pine showed improved height growth and long-term site productivity resulting from a range of surface cultivation treatments (Örlander *et al.*, 1996).

On a restocking site in Ireland, there was improved early growth of Sitka spruce and Douglas fir following either medium ploughing plus deep tining or deep ripping when compared with no cultivation (Hendrick, 1979).

In general, results are similar to brown earths or ironpan soils depending upon whether there is any barrier to rooting.

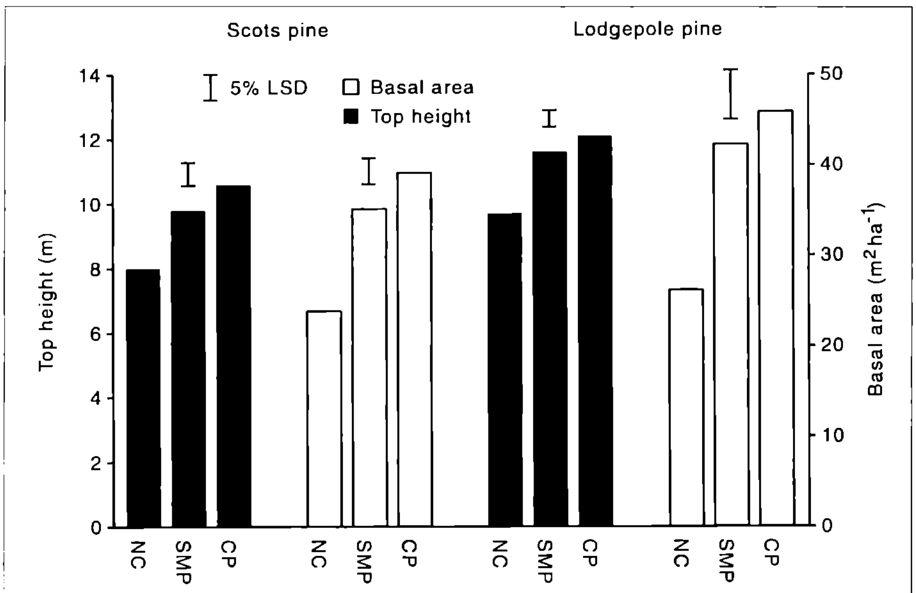

Figure 2.3 Top height and basal area of Scots pine and lodgepole pine at age 30 years in a comparison of no cultivation (NC) with single mouldboard (SMP) and complete ploughing (CP) at new planting on an upland podzol on stony fluvio-glacial deposits. [Inshriach 2 P62, after Mason, 1996]

IRONPAN SOILS

New planting

For heathland ironpan soils, Zehetmayr (1960) concluded that, for 10-year height growth, complete ploughing to 35 cm depth was the most effective of a range of treatments on these sites for Japanese larch, Scots pine and Sitka spruce. Spaced ploughing to 35 cm was least effective and complete ploughing to 15 cm gave an intermediate result.

The addition of subsoiling to complete ploughing treatments in later experiments has not substantially altered these conclusions (Thomson and Neustein, 1973; Wilson and Pyatt, 1984; Quine and Burnand, 1991). Lodgepole pine also responds well to greater intensities of cultivation on both ironpan and peaty ironpan soils (Miller, 1986; Quine, 1987a).

Survival and growth of Sitka spruce was poorest on a ripping (60–70 cm) treatment on a peaty ironpan soil/grass site in the Southern Uplands (Quine and Burnand, 1991; Figure 2.4). At eight years of age on this site type the best growth was found on complete ploughing. Similar benefits from complete ploughing occurred in another experiment in this area on the same site type (Table 2.3). Here, best initial growth of Sitka spruce, noble fir and hybrid larch was on a rotary mouldboard treatment after complete cultivation to 60 cm. In Sitka spruce these differences had largely disappeared by year eight, but still persisted in the other species especially in noble fir. Poorest growth was generally on prototype mound ploughing where the ironpan was not disrupted.

Restocking

All forms of cultivation have resulted in significantly better survival and generally better growth than direct planting even where intensive herbicide regimes were used to control vegetation (Table 2.1). After two growing seasons, survival and growth of Sitka spruce on mounding was significantly better than on manual screefing or on an uncultivated control (Nelson and Ray, 1990; Table 2.4).

The improvement in establishment success as a result of cultivation is even more dramatic with sensitive species such as Douglas fir (Sharpe *et al.*, 1990; Table 2.5).

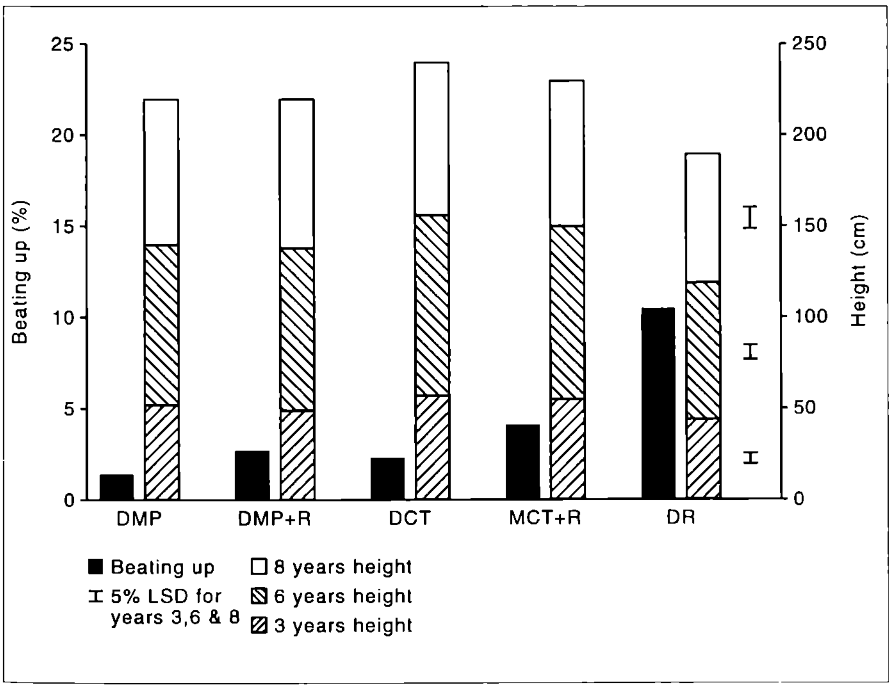

Figure 2.4 Beating up and height growth of Sitka spruce in new planting on a peaty ironpan soil with various cultivation treatments. Elevation 380–427 m. Treatments are: double mouldboard ploughing (DMP); double mouldboard ploughing plus deep ripping (DMP+R); deep complete ploughing (DCT); medium complete ploughing plus deep ripping (MCT+R); deep ripping (DR). [Quine and Burnand, 1991; Moffat 16 P82]

Table 2.3 First year survival and early height growth of Sitka spruce, noble fir and hybrid larch on an afforestation site on a peaty ironpan soil in the Southern Uplands on different cultivation types. (Moffat 14 P83)

Treatment	*Sitka spruce*			*Noble fir*			*Hybrid larch*		
	Survival (%)	*Height (cm) 3 years*	*Height (cm) 8 years*	*Survival (%)*	*Height (cm) 3 years*	*Height (cm) 8 years*	*Survival (%)*	*Height (cm) 3 years*	*Height (cm) 8 years*
Double mouldboard ploughing (45 cm)	96	70	275	81	29	138	93	84	300
Single mouldboard ploughing (60 cm)	98	78	275	95	39	185	89	75	285
Rotary mouldboard complete ploughing (60 cm)	98	83	283	94	43	220	94	89	318
Deep (90 cm) ripping plus handcut turves	98	65	288	86	31	158	94	76	280
Helical mound plough	95	62	256	71	32	140	81	70	280
Ridge replacement plus deep ripping	98	78	283	93	38	188	89	80	298
5% LSD	-	5.7	21.5	-	6.1	26.7	-	9.6	30.0

Table 2.4 Survival percentage and 2-year height increment (cm) of Sitka spruce after two seasons in restocking on three soil types, comparing no cultivation with mounding and screefing. (After Nelson and Ray, 1990)

Treatment	*Kielder*		*Kilmichael*		*North York Moors*	
	Survival (%)	*Height increment (cm)*	*Survival (%)*	*Height increment (cm)*	*Survival (%)*	*Height increment (cm)*
No cultivation	94.5^{a}	25.4	97.0^{a}	27.9	81.0^{a}	15.3
Screef	93.5^{a}	21.9	99.0^{b}	28.8	87.5^{b}	13.0
Mounds	98.6^{b}	36.9	99.6^{b}	29.6	96.4^{c}	27.4
5% LSD	-	8.0	-	17.0	-	5.7

Note: 1. Percentage survival figures with different superscripts are significantly different at $P<0.05$.

2. Soil types were: Kielder – surface water gley; Kilmichael – loamy gley; North York Moors – ironpan soil.

Table 2.5 Two-year survival and height increment of well-handled Douglas fir and Sitka spruce undercut plants on an ironpan soil in North Yorkshire with and without cultivation. (North York Moors 21 P87) (Adapted from Sharpe *et al.*, 1990)

Treatment	*Species*	*Survival (%)*	*Height increment (cm)*
Cultivation (50 cm mounds)	Sitka spruce	96^{a}	42.7^{a}
	Douglas fir	95^{a}	30.1^{b}
No cultivation	Sitka spruce	81^{b}	11.5^{c}
	Douglas fir	54^{c}	-

Note: 1. Survival and height values with different superscripts are significantly different at $P<0.05$.

2. Insufficient Douglas fir survival with no cultivation to make increment data reliable.

When more intensive deep cultivation and ripping treatments were used on a heathland site in East Yorkshire, survival of Sitka spruce was *c.* 15% higher than on the uncultivated control; there was also a *c.* 10% improvement with lodgepole pine (Table 2.6). At six years height growth of both Sitka spruce and lodgepole pine was significantly greater on the cultivated treatments than the uncultivated control. Early growth of spruce was also improved on the deep complete ploughing compared to spaced ploughing or ripping (Table 2.6).

After canopy closure, significant differences occurred in basal area between non-cultivated and cultivated treatments.

However, in spruce there was no difference between the different types of cultivation whereas lodgepole pine showed a positive response to the more intensive soil disturbance. The response for spruce agrees with results from the older Teindland afforestation experiment (Wilson and Pyatt, 1984). The loss of advantage over time for intensive cultivation treatments is correlated with availability of nitrogen which declines rapidly after 3–4 years.

Cultivation of this soil type improves survival and provides improved early height growth. However, rapid early growth has not been sustained on the more intensive forms of cultivation, particularly for species such as Sitka spruce where nitrogen availability is important.

SURFACE WATER GLEYS

New planting

On wet surface water gleys, all forms of cultivation that alleviate waterlogging have been shown to be superior to direct planting. This is exemplified by some comprehensive studies in Ireland (Hendrick and Dillon, 1983; Hendrick, 1989; Figure 2.5). All treatments had satisfactory survival after one year. Height growth was invariably poorest on flat planting. At three out of four sites, differences in height growth between cultivation treatments (e.g. moling or ripping v. ploughing) were minor. At the fourth site (Cuilcagh), early growth of trees planted on moling was poorer than on double mouldboard ploughing.

Growth on ripping was similar to ploughing provided the sites had a slope of at least 3°. Rooting investigations at seven years at the Ballyfarnon 1 site showed a rooting depth of 56 cm over moling compared with 22 cm with ploughing.

These trends were translated into greater resistance to uprooting at 16 years (Hendrick, 1989; Table 2.9). At this age, there were also differences in basal area at both Cuilcagh and Scotstown; all three cultivation treatments were significantly different from the control, but there were no differences between cultivation. Note that the poorer initial growth

Table 2.6 First year survival, height (m) and basal area ($m^2\ ha^{-1}$) of Sitka spruce (SS) and lodgepole pine (LP) on an ironpan soil on a restocking site in North Yorkshire. (Wykeham 116 P71)

Treatment	*Survival (%)*		*6-year height*		*Basal area*				*Top height*	
					15-year		*20-year*		*20-year*	
	SS	*LP*	*SS*	*LP*	*SS*	*LP*	*SS*	*LP*	*SS*	*LP*
Uncultivated	79	80	1.37	1.70	16.7	17.8	29.4	30.0	10.6	10.2
Deep (65 cm) spaced tine plough	92	91	1.68	2.07	19.5	22.3	33.0	33.7	11.1	10.5
Very deep ripping	95	89	1.67	2.01	20.7	22.4	32.9	34.7	10.9	10.2
Deep (65 cm) complete tine ploughing	96	90	1.79	2.15	19.3	24.0	34.1	35.1	10.9	10.3
Deep complete tine ploughing + very deep ripping	97	93	1.77	2.16	17.2	25.9	31.5	37.8	10.8	10.7
5% LSD	4.2	7.2	0.07	0.15	3.6	2.6	3.9	2.7	0.5	0.4

of trees planted on moling had not persisted.

Restocking

On a surface water gley at Kielder survival of Sitka spruce planted on mounds was significantly better than on uncultivated ground or screefing but on a loamy gley in Argyll there was no improvement over screefing (Table 2.4).

On an indurated podzolic gley on an almost flat site in the Black Isle, Sitka spruce and lodge-pole pine had significantly greater mean height at 10 years after planting on deep double or single mouldboard spaced tine ploughing than on very deep ripping with a mole subsoiler or on deep complete ploughing (Miller, 1986).

The results emphasise the positive role of surface drainage from spaced furrow ploughing on gley soils.

Drainage of the microsite is paramount on wet surface water gleys to avoid risks of windthrow. Mounding can achieve the required raised position more effectively than other treatments. There is a marked rise in water-table after clearfelling on these sites which underlines the need for the raised planting position. On weedy sites, mounding may also provide early weed control.

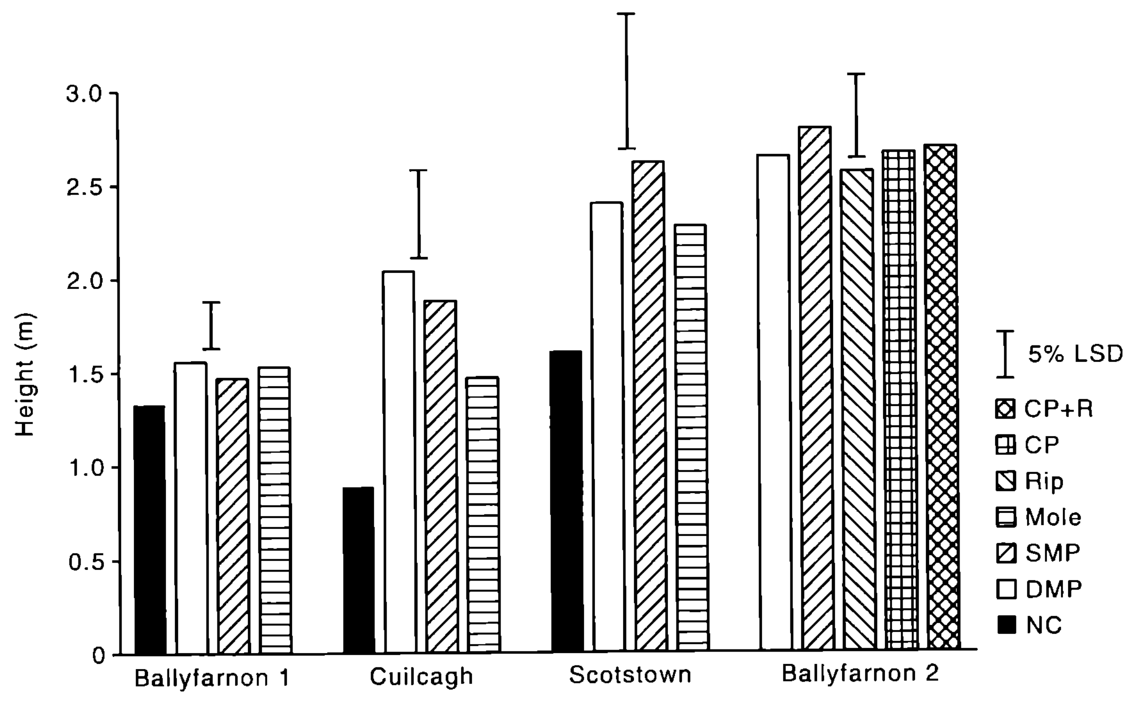

Figure 2.5 Six-year heights (m) of Sitka spruce on different types of site preparation in new planting on surface water gleys in Ireland. Treatments are: no cultivation (NC); double mouldboard ploughing (DMP); single mouldboard ploughing (SMP); mole drainage; ripping, complete ploughing (CP); complete ploughing plus ripping (CP+R). [After Hendrick and Dillon, 1983]

PEATY GLEYS

New planting

Early research suggested that spaced ploughing with ridge planting resulted in higher survival and greater early height growth than other treatments (Zehetmayr, 1954). The average improvement in survival over other treatments was around about 6-8%. However, this improvement has to be set against the serious loss of root symmetry caused by ploughing (e.g. Savill, 1976).

On a Jurassic clay in East Yorkshire, a rigg and furr cultivation treatment resulted in significantly better height growth of Sitka spruce, but not of Scots pine, in comparison with shallow complete ploughing and spaced single mouldboard ploughing (Read *et al.*, 1973). However, this may only apply on peaty gleys on clays in relatively dry areas where mixing with humus is beneficial.

An experiment in West Scotland (Figure 2.6) compared treatments that might provide improved root symmetry and result in a lower water table to promote greater rooting depth. Mounding or hand-cut turves over moling did incur some penalty in survival and early height growth compared with medium double mouldboard ploughing. However, these differences had disappeared by year 10. An experimental ridge replacement technique (i.e. inverted ridge returned to the furrow) was as effective as ploughing on this soil.

Restocking

In older experiments, cultivation always promoted improved survival of Sitka spruce (Table 2.7). Early height growth tended to be greatest on ploughing or mounding with few differences between other cultivation treatments or flat planting. In a more recent experiment at Falstone (Table 2.1) there were few differences in survival or growth between treatments. Lower survival with Bräcke patch scarification was due to the lack of a raised planting position resulting in waterlogging over winter (McMinn, 1982).

In the Falstone experiment height growth was least on patch scarification and mounding because of wet planting positions and poor quality mounds respectively. The no cultivation treatments were planted adjacent to the stumps of the felled trees and were in a slightly raised position.

There have been no significant interactions between cultivation and herbicide application where this has been tested. A raised planting position is the critical factor on this soil type.

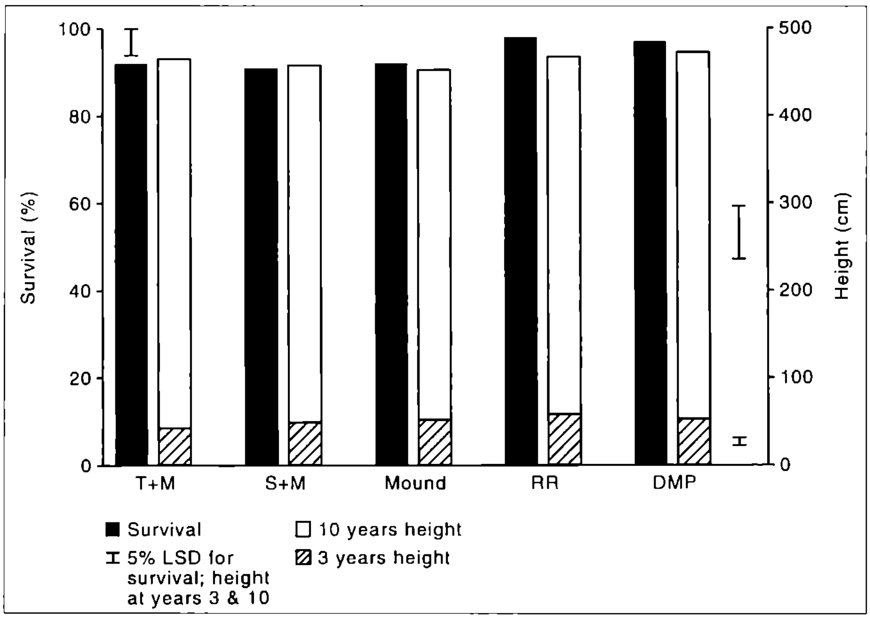

Figure 2.6 Survival, 3-year and 10-year heights of Sitka spruce in new planting on experimental cultivation treatments on a loamy peaty gley in West Scotland. Treatments are: handcut turves plus moling at 60 cm (T+M); scarification plus moling (S+M); mounding; ridge replacement ploughing (RR); double mouldboard plough (DMP). [Glendaruel 10 P84]

Table 2.7 First year survival and 6-year height growth of Sitka spruce after various cultivation treatments in restocking of peaty gley soils

Experiment	*Region*	*No cultivation*		*Ripping*		*Mole*		*Mound*		*Double mouldboard plough D60/T90*		*Complete plough*		*5% LSD*
		Survival (%)	*Height (cm)*	*Survival (%)*	*Height (cm)*	*Survival (%)*	*Height (cm)*	*Survival (%)*	*Height (cm)*	*Survival (%)*	*Height (cm)*	*Survival (%)*	*Height (cm)*	
Falstone 6 P80	Borders Carboniferous	84	176	93	173	94	176	95	213	90	197	-	-	9.2/21.2
Langdale 131 P79	East Yorkshire Estuarine	60	142	83	142	82	153	-	-	84	183	-	-	11.3/24.1
Clocaenog 74 P75	Ordovician	82	200	-	-	91	229	-	-	94	240	-	-	4.2/17.0
Rosedale 123 P72	East Yorkshire Estuarine	81	100	-	-	-	-	-	-	90	138	98	132	3.4/25.8

Note: First LSD figure refers to survival, second to height.

DEEP PEATS

New planting

On deep peats and peat-clad moraines (peaty ironpan soil/peaty gley complex), early research (Zehetmayr, 1954) indicated that ploughing gave better survival and early height growth than planting on upturned turves. Subsequently, shallow to medium (25–35 cm) double mouldboard ploughing has been recommended to eliminate the need for step-cutting (Neustein, 1976) on less exposed sites. There may also be stability benefits from reducing the frequency of deep furrows.

Varying the height of double mouldboard ridges has been examined in an experiment on a deep blanket peat in North Scotland (Figure 2.7). After 15 years, growth of Sitka spruce on the shallowest ridges was around 10% less in height and 20% less in diameter than that on the deepest ridges.

However, differences between the other treatments were insignificant. Growth trends for lodgepole pine in the same experiment were similar to those for Sitka spruce.

Some recent re-examination of site preparation techniques on deep peat in Ireland showed that lodgepole pine planted on mounds, formed from tunnel underdrainage, had similar growth rates to trees on the narrow peat ribbon extruded by the Glenamoy plough (Carey and Hendrick, 1986). There is no alternative to a raised planting position as the three year mean height of trees direct planted at two positions relative to the tunnel underdrainage was only 58% and 72% of those on mounds or the Glenamoy plough ribbon. Mounding appears to be the most promising technique for promoting root symmetry in lodgepole pine.

Restocking

Growth was enhanced on mounding compared with direct planting of Sitka spruce in the restocking of a 35-year-old Sitka spruce stand monitored by Schaible and Dickson (1990).

Trees planted on mounds continued to show the greatest mean annual height growth for over 10 years. Nitrogen levels in foliage were highest when mounding was supported by intensive drainage.

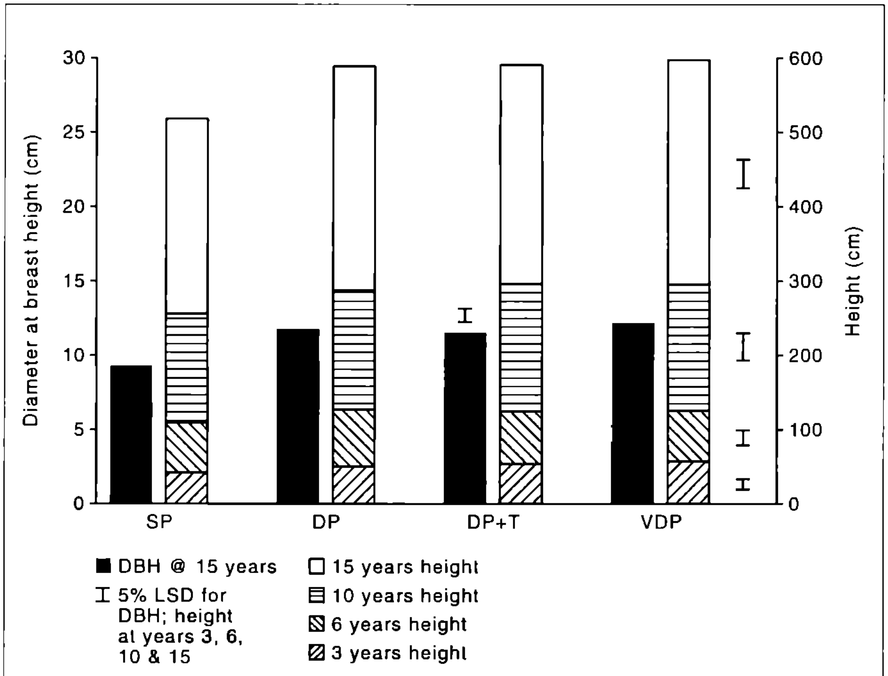

Figure 2.7 Effect of depth of double mouldboard ploughing on early height growth and diameter at breast height (dbh) of Sitka spruce in new planting on deep blanket peat. Treatments are: shallow ploughing (SP); deep ploughing (DP); deep ploughing plus very deep tine (DP+T); very deep ploughing (VDP). [Shin 73 P78]

LITTORAL SOILS

New planting and restocking

This is a minor site type in British forestry and little systematic research has been undertaken on these soils. However, one restocking trial at Pembrey Forest in south Wales showed major improvements in survival of Corsican pine when planted on mounds compared to disc trench scarification (Table 2.8). These trends were consistent on both the freely drained 'dunes' and on the 'slacks' with winter waterlogging. There were effects due to the planting position chosen on the scarified trench with the poorest survival and growth occurring with trees planted at the top of the trench.

The benefits from mounding probably reflect lower levels of frost damage during the establishment. There were no effects of cultivation upon tree growth.

Table 2.8 Percentage survival and height growth after 4 years of Corsican pine planted on two cultivation types on a restocking site on a littoral sand at Pembrey Forest. (Brechfa 24 P89)

Cultivation		*Dune*		*Slack*	
		Survival (%)	*Height (cm)*	*Survival (%)*	*Height (cm)*
Mounding		77.5	67.8	73.7	78.2
Disc trench scarification					
	– top	5.0	52.0	18.8	45.2
	– hinge	23.8	66.9	22.5	67.0
	– furrow	20.0	52.7	46.2	66.7
5% LSD		14.7	27.8	29.6	27.5

Effects of cultivation on survival and early height growth in new planting

The success of cultivation in influencing survival and early height growth in new planting depends upon a careful targeting of technique to the adverse features at the microsite. Although treatments which promote good survival and early height growth are essential, some cultivation techniques which provide the best height growth at six years, e.g. spaced ploughing on gleys and deep spaced ploughing on ironpan soils, have not encouraged depth and symmetry of spread of rooting for stability. Early differences in growth rates of trees planted on different types of cultivation may diminish over time on both ironpan soils and gleys. On brown earths and drained cultivated soils, herbicides provide an alternative tool for weed control and plant size can be tailored to meet competition anticipated on these sites.

Effects of cultivation on survival and early height growth in restocking

Cultivation for restocking has been shown to be important for survival on all soil groups although intensive use of herbicides and larger planting stock can be substitutes on brown earths and some surface water gleys. On ironpan soils, cultivation aids survival and growth but more intensive forms of cultivation have provided no lasting benefit in height growth; lighter cultivation techniques, i.e. dry mounding or scarification appear to be just as effective. On peaty gleys and peats, mounding has resulted in much improved growth and survival.

Cultivation and natural regeneration

Use of cultivation to promote natural regeneration needs to consider the ecological characteristics of the species to be regenerated. Timing of cultivation should be linked to that of maximum seedfall. Cultivation may not always be desirable since, in semi-natural woodlands, protection against grazing may be sufficient provided that the vegetation is not too competitive (Gong *et al.*, 1991).

In broad terms, pioneer species such as birches, larches and pines will benefit most from cultivation which provides a bare mineral soil seedbed (e.g. disc scarification), and therefore increased soil temperature and more favourable soil moisture for the germinating seeds. The type of vegetation is also of great importance and cultivation can be used as a means of modifying an unfavourable seedbed (e.g. grass swards). Surface humus layers tend to dry out rapidly and are therefore a poor germination environment so cultivation can help by exposing the moister mineral soils underneath.

Most British studies on the role of cultivation to provide a seedbed for conifer natural regeneration have been in the native pinewoods of eastern and central Scotland. At Glenmore, hand cultivation of 0.8 m wide strips was more effective than patch cultivation. The strips produced a stocking of 5330 seedlings ha^{-1} compared with 3630 ha^{-1} on patch cultivation and 250 ha^{-1} on the untreated surface (Henman, 1961).

At Glentanar, Low (1988) assessed 2 m^2 plots centred on 0.8 m^2 scarified patches five seasons after treatment and found an average of 13 Scots pine seedling survivors per patch which compared with failed seeding away from the fringes of the patch. Of the seedlings which subsequently survived, 85% were found within the part of the plot from which vegetation and humus had been removed by scarification; most of the remainder were on the inverted turf or disturbed zone round the patch. Most successful regeneration occurred in the first three years after cultivation and conditions for seedling recruitment appeared to decline quickly due to vegetation growth from the fringes and as a result of competition from weeds on the screefed mineral surface.

These results agree with studies in Sweden (Örlander *et al.*, 1990) and in North America (Prévost, 1992) which concluded that the quantity of regeneration was positively influenced by the intensity of site preparation. For this reason, disc trench scarification was preferable to patch scarification. Disc trench scarification of **brown earths** after seeding fellings at Grizedale has resulted in poor and sporadic regeneration of larch and the site reverted rapidly to *Deschampsia flexuosa*. Scarification needs to cover more of the site to achieve satisfactory seedling stocking because of the haphazard distribution of seed.

Worrell and Nixon (1991) reviewed results from use of cultivation in the regeneration of oak and concluded that burying acorns by rotovation or discing at time of maximum seed fall is a successful method of increasing regeneration. Light surface cultivation has been generally successful with Scots pine, birch and oak.

Organic soils, i.e. **peaty gleys, peaty ironpan soils and deep peats**, do not appear to require cultivation for conditions to be favourable for regeneration provided competition from vegetation is not severe (Nixon *et al.*, 1994). Cultivation of **gleyed soils** is unlikely to be a satisfactory way of achieving natural regeneration because of the difficulty of providing a raised, weed-free germination site.

Cultivation is most useful in promoting natural regeneration of pioneer species since it provides a bare mineral soil seedbed. Cultivation must be timed to coincide with a good seed year.

Cultivation appears unnecessary on organic soils where there is minor competition from vegetation.

The effects of cultivation on yield

Early research demonstrated that cultivation of new planting sites on peaty podzols, ironpan soils, peaty gleys and peats improved growth compared with no cultivation (Zehetmayr, 1954, 1960). Interim results from experiments comparing more intensive cultivation with or without subsoiling on heathland ironpan soils and other indurated soils suggested that intensive cultivation on these sites could increase yields 'in proportion to the volume of soil disturbed' (Taylor, 1970). As a result, Thompson (1984) tentatively predicted gains of up to one yield class for Sitka spruce and lodgepole pine from the use of complete deep tine ploughing compared with standard spaced shallow tine ploughing on four soil groups/types. He also suggested there would be a lower terminal height* (Miller, 1985) for stands on spaced single mouldboard ploughing on non-indurated gleys and peats compared with spaced double mouldboard ploughing.

Studies of longer-term growth of stands on different cultivation treatments, particularly on **heathland sites** (Thomson and Neustein, 1973; Wilson and Pyatt, 1984) have shown that there can be major changes in the rankings between treatments at different stages of stand development. Similar changes in rankings have been observed in other heathland ironpan soil experiments (Quine, 1987).

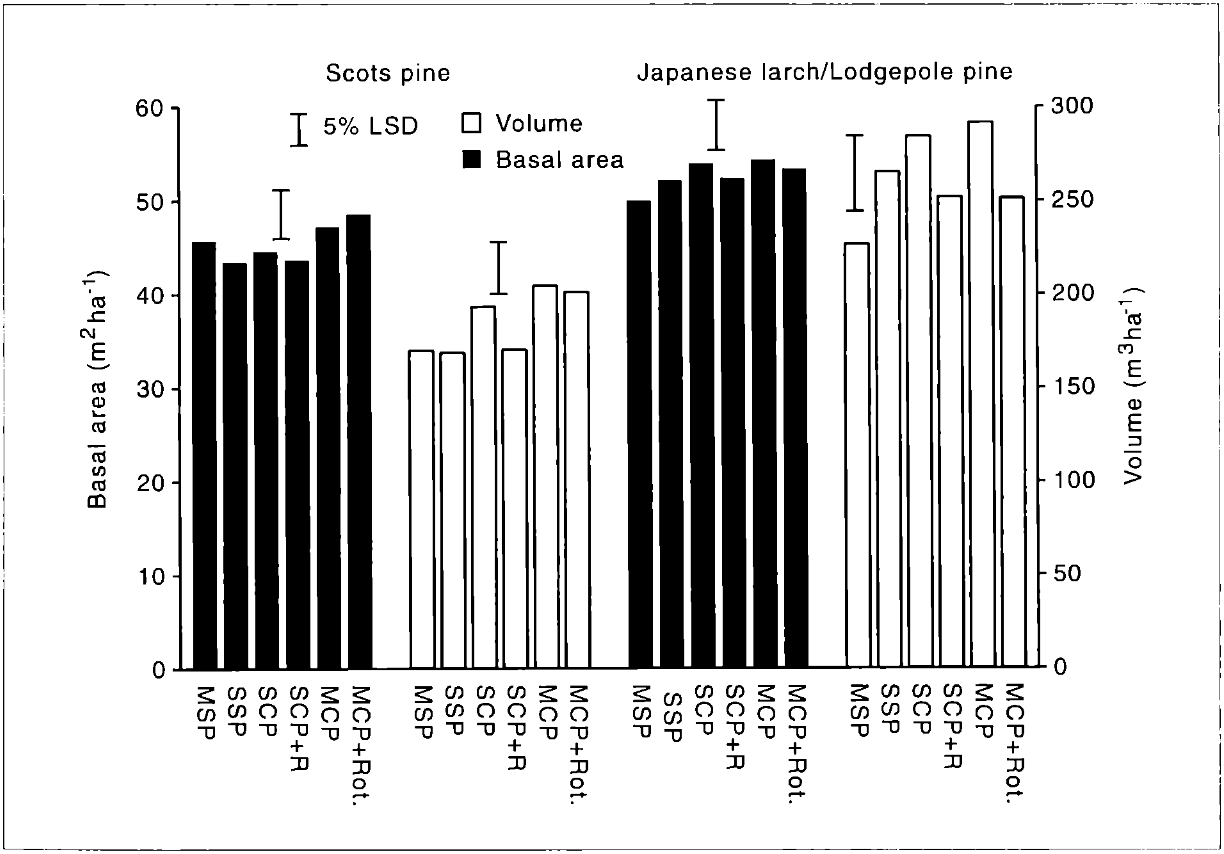

Figure 2.8 Basal area and volume production of Scots pine and of a Japanese larch/lodgepole pine mixture at age 30 after afforestation of a heathland ironpan soil at Teindland. Treatments are: medium spaced ploughing (MSP); shallow spaced ploughing (SSP); shallow complete ploughing (SCP); shallow complete ploughing plus ripping (SCP+R); medium complete ploughing (MCP); medium complete ploughing plus rotovation (MCP+Rot). [After Wilson and Pyatt, 1984]

Wilson and Pyatt (1984) distinguish three phases of height growth response to cultivation. The first 10 years see rapid growth often with a major response to increased intensity of cultivation. The second phase occurs during the initial pole stage when slower growth and a reversal of previous growth trends may be found. The third stage is from about year 20 onwards where differences in height are limited, but benefits in basal area and volume growth may be found. These changes may reflect inherent site limitations upon stand growth imposed by factors such as soil moisture availability and nitrogen turn-over. The benefits of intensive cultivation during the first phase are probably due to positive effects of cultivation on soil temperature, early nitrogen release, or the timing and intensity of *Calluna* re-invasion.

On a **nutrient-poor indurated ironpan** soil at Teindland, Scots pine at 30 years had significantly greater volume production on medium depth (33 cm) complete cultivation than on spaced single mouldboard tine ploughing (Figure 2.8). Shallow complete ploughing was not as good as medium complete ploughing, and additional subsoiling was disadvantageous. On the same site, a mixture of Japanese larch and lodgepole pine had greater volume production on both types of complete ploughing compared with medium spaced tine ploughing.

On an **upland heath podzol** at Inshriach complete ploughing to 30–40 cm depth provided the highest yield in Scots pine and lodgepole pine in comparison with single spaced tine ploughing (Mason, 1996; Figure 2.3). Basal area of Scots pine on spaced tine ploughing was 47% greater than on no cultivation and 64% greater on complete ploughing than on no cultivation. After 30 years, these differences represented an increase from Yield Class 6 to 8 as a result of cultivation.

There is little evidence that different forms of cultivation influence yield class on **gleys and peats** although they can greatly influence stability. In Irish comparisons of cultivation on **surface water gleys** (see Figure 2.5), Hendrick (1989) found no significant differences in the basal area production of Sitka spruce at approximately 16 years. However, cultivation treatments showed about 50% greater basal area than no cultivation. In restocking on **shallow peat** in Northern Ireland, Sitka spruce was significantly more productive on mounds than on direct replanting when measured at 16 years. A further growth response was obtained from doubling the drainage intensity but this was not significant (Schaible and Dickson, 1990).

Some cultivation is essential to achieve satisfactory yields on soils with severely adverse features. However, only on **podzol and ironpan soils** has the form of cultivation proved to be significant for further raising of yield class and only for pines and larches (Wilson and Pyatt, 1984). Earlier indications that the yield class of pure Sitka spruce could also be raised on these sites by intensive deep cultivation (Thompson, 1984) have not been supported in later assessments. Taylor (1991) recommended that these sites should be replanted with pure pine or larch or a mixture of Sitka spruce and Scots pine to avoid growth check of Sitka spruce due to serious nitrogen deficiency.

The influence of types of cultivation on height growth and basal area is generally minor after canopy closure and of much less significance than the impact on root development and stability. Subsequent growth is more dependent upon other more permanent site factors such as general water-table, exposure, altitude, nutrient availability, or drought stress.

Some cultivation is essential for satisfactory growth and yield on soils with adverse features. However, the type of cultivation is generally unimportant for growth.

Impacts of cultivation on root form and development

Cultivation has a profound influence upon root form and development because it affects many aspects of the rooting environment, e.g. soil moisture and temperature, pore space, oxygen concentration, distribution of organic matter, nutrient mobilisation, and the physical configuration of the surface. These effects vary according to the cultivation technique, the nature of the adverse soil features and the physiological characteristics of the species.

Ironpan soils

The rooting patterns of Sitka spruce, Japanese larch, and three pines on spaced and complete ploughing on heathland, mainly ironpan soils, were investigated by Yeatman (1955). **Species responded differently but a general pattern was that roots only exploited the well aerated and porous soil in the disturbed parts of the profile.** Yeatman recognised the importance of making comprehensive improvements in aeration by disruption of the thin organic horizon, and the horizon above the ironpan (Wilson and Pyatt, 1984).

There was less depth and spread of rooting on spaced tine ploughing than on complete ploughing in 7-year-old Scots pine (Thomson and Neustein, 1973). Surface root spread was much more extensive on medium depth (30–40 cm) complete ploughing than on shallow (15–25 cm) complete ploughing. Spaced tine ploughing was also associated with the tendency for root alignment along the line of tine cultivation (Yeatman, 1955; Wilson and Pyatt, 1984) or along the spoil ridges, with the risk of toppling in species with high shoot/root ratio (Edwards *et al.*, 1963; Thomson and Neustein, 1973; Mason, 1985).

A two-layered root system typical of spaced shallow ploughing was replaced on complete ploughing and on intensive deep cultivation/ subsoiling by a more even distribution of roots, with primary descending roots and sinkers from long lateral roots (Yeatman, 1955).

Similar improved rooting after complete rotary mouldboard cultivation and deep complete ploughing on an ironpan soil was reported by Ross and Malcolm (1982) in a Japanese larch/Sitka spruce mixture. Roots were localized in lumps of organic matter throughout the profile and showed no particular alignment. Root development was remarkably rapid on these intensive forms of cultivation reaching a depth of 60–65 cm in 2.5 years and extending horizontally up to 250 cm in the 20–30 cm horizon in 3.5 years.

Wilson and Pyatt (1984) also observed dense rooting in the buried organic bands in medium depth complete ploughing although it was noted that rooting occurred only in the soil with lower bulk density. Root development of 8-year-old Sitka spruce on a peaty ironpan soil was similar on a range of different cultivation types (Quine and Burnand, 1991).

Gleys and peats

The asymmetrical pattern of rooting observed after spaced ploughing on heathland ironpan soils is even more pronounced on gley soils and peats. Grossly asymmetrical rooting of Sitka spruce was observed by Savill (1976) on shallow single mouldboard ploughing on fine textured gleys with a high winter water-table (20–25 cm). Roots which crossed plough furrows were few and small in diameter. Even the presence of shallow ditches, which had been cut to provide turves for a planting site, presented a significant barrier to rooting.

In studies of Sitka spruce rooting on deep peat and peaty gleys (Coutts, 1983a), the main structural roots (3–10 in number) were determined as early as year six when the nutritional and aeration effects of cultivation were still pronounced and long before the canopy had a major influence on the water relations of the site. On single mouldboard ploughing on deep peat, both lodgepole pine and Sitka spruce roots had a strong tendency to develop in the plough ridge rather than on the original surface (Coutts *et al.*, 1990) and at the edge of furrows, branching of roots was frequent. Lodgepole pine rooted more deeply than Sitka spruce but had more asymmetrical rooting.

Similar observations on rooting of Sitka spruce on double mouldboard ploughing on fine textured surface water gleys have been made by Hendrick (1989). In comparison with ploughing, root systems on moled sites had a more symmetrical form with a greater vertical rooting component. Studies of lodgepole pine on gleyed soils in Alberta, Canada showed 5 cm deeper rooting after deep ripping compared with no cultivation (Nadeau and Pluth, 1997).

In studies of the root systems in Sitka spruce in restocking on peaty gleys, trees at the 'between-stump' position without a mound had shallower but more symmetrical roots whilst the 'at stump' position resulted in pronounced asymmetry (Quine *et al.*, 1991; Quine, 1990). Trees on mounds had deeper and better developed rooting on mounds with organic matter. Major root asymmetry from planting at stumps without mounds has also been reported on similar site types (Prest *et al.*, 1991)

Rooting of Sitka spruce up to 1 metre in depth on well drained deep peat on single mouldboard ploughing was recorded at Rumster, Caithness (D. G. Pyatt, unpublished data). Forty-four-year-old lodgepole pine planted on deep peat had no tap roots or long laterals but had an intensive system of medium-sized similar roots adjacent to the downward projection of the stem and down to 1 metre depth (Booth and Mayhead, 1972).

Major root asymmetry can be caused by ploughing on gley soils; and on peats where drain maintenance and deepening has been neglected. Root sytems of Sitka spruce are deeper and much more symmetrical over moling on fine textured surface water gleys. On well drained deep peat, rooting of lodgepole pine and Sitka spruce can be deep even although initial root symmetry may have been poor (Pyatt, 1990b).

Techniques of cultivation can have a major effect on the symmetry of root systems.

The effects of cultivation on stability

Cultivation can either improve tree stability or induce earlier instability depending upon the soil type and the method of cultivation used. The cultivated profile influences the development of root architecture and subsequent stability on potentially shallow rooting soils such as ironpan soils, gleys and peats.

Instability arising from cultivation can occur at the juvenile stage of crop development (Edwards *et al.*, 1963; Mason, 1985; Pfeifer, 1983). In the classic Teindland experiment on an **ironpan soil**, furrow bottom planting on spaced tine ploughing resulted in 22–29% wind-loosened stems in lodgepole pine at age eight compared with only 3–5% on complete ploughing (Edwards *et al.*, 1963). Other results from this experiment show that stem straightness quality was significantly affected at age 20 (Thomson and Neustein, 1973). Over 50% of lodgepole pine trees planted on shallow single furrow ploughing had swept stems compared with around 20% on complete ploughing. Straightness of Scots pine stems was less affected by cultivation, but the incidence on spaced ploughing was still five times higher than on complete ploughing.

Windward roots are of major importance for anchorage in shallow root systems (Coutts, 1983b, 1986) These roots are the second largest component of resistance to overturning after the soil, and if furrows limit their spread, anchorage will be severely weakened. Tree pulling studies by Booth and Mayhead (1972) showed the turning moment of turf-planted Sitka spruce on **deep peat** at 44 years to be twice as high with turf drains at 4.1 m spacing compared with turf drains at 1.2 m.

Further evidence of the importance of uninterrupted root spread on **wet gley soils** with a high water-table was provided by a survey of windthrow after storms in Sitka spruce stands aged 25 years (Savill, 1976). Turf planted stands were almost unaffected (0.4% windthrown) but stands 1 m shorter in dominant height on ploughing had 23% windthrown and a further 9% unstable. Root restriction by plough furrows was identified as the cause of these large differences in stability.

Fraser (1962) drew attention to the importance of rooting depth in conferring resistance to overturning and suggested that 15 cm increased depth produced a 25% increase in resistance. Moling has been shown to lower the water-table (Hinson *et al.*, 1970)

Table 2.9 Measured turning moments for Sitka spruce from tree pulling on two cultivation treatments at age 12–15 years on clayey surface water gleys in Ireland. (After Hendrick, 1989)

Site	*Treatment*	*Dbh (cm)*	*Maximum turning moment (kNm)*
Ballyfarnon 1	Double mouldboard ploughing	16.0	10.0
	Mole	16.0	18.5
Cuilcagh	Double mouldboard ploughing	14.5	11.5 [a]
	Mole	14.5	21.9
Scotstown	Double mouldboard ploughing	16.4	12.0 [a]
	Mole	16.4	17.1

Note: [a]Some trees on the mole treatment snapped at these sites.

and increase rooting depth compared with ploughing (Hendrick, 1989) or in conjunction with ploughing (Quine, 1988). Hendrick found that resistance to uprooting of Sitka spruce on **surface water gleys** at age 12–15 years was 43–90% higher on moling than on double mouldboard ploughing (Table 2.9).

Greater stability would result from greater stiffness of the root plate which can be achieved by an increase in rooting depth, especially if the root plate contained a larger proportion of mineral soil. Shallow root systems can have an increased weight component if there is an appropriate increase in width and symmetry of the root plate (Coutts, 1986). In principle, **moling and mounding are the only treatments which can contribute to improved stability on gley soils and peats.** Ploughing on gley soils and deep ploughing on peats weaken the resistance to windthrow by limiting the radius of root plates and promoting asymmetry (Coutts *et al.*, 1990).

An area of particular concern is the role of cultivation when restocking wet soils after previous ploughing. Limited studies indicate that the filling in of furrows by litter and brash encourages better root spread than in the first rotation. However, root spread will be inhibited by any ponding that results from poorly drained first rotation ploughing (e.g. contour ploughing). New drainage is necessary to reduce ponding and mounds should be used to provide planting sites between ridges.

Cultivation can improve rooting conditions and benefit stability but there are limitations. For instance, it will not substantially increase the depth of rooting in surface water gleys on steeper slopes. However, excavator mounding with intensive drainage on peaty gleys on gentle slopes (0–3°) can lower the water-table by 7–15 cm and allow deeper rooting and better stability.

The main structural roots are determined in the first 6–8 years and their distribution is critically affected by cultivation.

Cultivation techniques which provide marginal benefits in early growth may imperil long-term stability.

Chapter 3

Impacts of cultivation on the environment

Cultivation can affect the wider environment as well as meeting the objectives of improving the survival, growth and stability of forest trees. For example, the area for treatment may lie in a zone covered by specific guidelines with respect to cultivation type and the landscape effects of cultivation, e.g. ESA or water catchment; or be covered by the specific treatments permitted within ancient semi-natural woodland or SSSIs. Consultation with the appropriate statutory bodies will often be necessary in such circumstances. These specifications may require some adaptation of prescriptions or of the application of a technique and some areas may need to be left uncultivated and/or unplanted for visual and other reasons. Such examples could include viewpoints, herb-rich sites or valuable wetland habitats. Further discussion of these issues can be found in the *Forests and soil conservation guidelines* (Anon., 1998) and in the *Forest & water guidelines* (Anon., 1993). Table 3.1 summarises the impacts and suggests measures which can be used to counteract them.

Table 3.1

Aspect	*Impact*	*Potential mitigation*
Landscape	Ploughing and, to a lesser extent, disc trench scarification can have a strong visual impact on the landscape because of the length of time before revegetation occurs. It can also give rise to rigid planting patterns due to the regular spacing of the plants and the rows. This can be particularly strong on landforms with gentle, even slopes (Anon., 1994).	The visual effect of subsoiling (ripping), moling, mounding and patch scarification is much smaller and, where silviculturally acceptable, these can be used to minimize harsh visual impacts in sensitive areas. However, whatever the cultivation technique, trees planted on lines of cultivation will still develop into continuous rows and be a strong feature in the landscape. Alternative spot cultivation techniques combined with irregular spacing may therefore need to be used in sensitive areas (Anon., 1990; Anon., 1994).
Archaeology	Physical disruption caused by some forms of cultivation, particularly subsoiling or ploughing, can seriously damage archaeological remains. This may include abandoned agricultural settlements of various ages. They should not be cultivated (Barclay, 1992).	As well as any scheduled sites, preliminary ground survey should check for unmapped or unscheduled archaeological remains. The operational plan will need to take account of these and leave adequate buffer land uncultivated around them (Anon., 1992).

Aspect	Impact	Potential mitigation
Erosion	There can be risk of wind erosion if intensive cultivation is used on sand dunes and other freely drained littoral soils (soil type 15e). Cultivation can induce erosion on the steep sides of eskers and kames and continuous furrows (e.g. from ploughing or disc trenching) present a major risk of erosion, especially on loose solifluction drifts. The nature of some techniques, e.g. ripping, subsoiling or deep tine ploughing may also present environmental risks in terms of scouring, sediment movement and erosion on moderate to steep slopes where there is high rainfall or seasonal peak rainfall.	The operational plan should note that lines of cultivation will require to be interrupted at intervals to reduce sediment carry (Anon., 1993). Where the risks are high, alternatives to continuous furrows (e.g. mounding) should be adopted. In sensitive catchments, only a proportion of the catchment should be cultivated in any one year. For detailed evaluation of erosion risk on different soil types, refer to Chapter 4.
Sediment †	The sites most at risk are steep to moderate slopes with mineral soils, unconsolidated loamy or coarse loamy textures, and in areas which have high rainfall intensity and duration. The forms of cultivation which are potentially hazardous are all types of ploughing, disc trenching (especially in the plough mode), and subsoiling (ripping and moling), i.e. the forms of surface or subsurface cultivation which form continuous channels. The consequent transport and deposition of sediment not only blocks roads and culverts but has important effects upon the turbidity and quality of drinking water supplies and seriously affects spawning beds of fish in streams (Mills, 1986).	These values can be substantially reduced by the use of less intensive cultivation and the use of appropriate uncultivated buffer zones. The main effect reducing initial erosion in furrows and drains is the 'armouring' of surfaces by stones. The speed of this development depends on stone size and abundance. Subsequently surfaces and furrows become revegetated with a great reduction in rate of erosion. Implementation of the *Forest & water guidelines* (1993) is essential to reduce these effects to a minimum. In a two year study in a Scottish upland stream where cultivation and drainage was constrained to less than 10% of the catchment area and the Guidelines were followed, Orr (1990) found no significant changes to salmonid fish stocks which could be attributed to these treatments.

† There have been few studies on sedimentation, peak flow and water yield during operations in plantation catchments. Some have distinguished the effect caused by cultivation from the contribution made by drainage, roading and canopy changes (Moffat, 1991; Soutar, 1989). Carling *et al.* (1993) estimated that double mouldboard ploughing at 4.1 m spacing on soft schists on erosion-susceptible slopes in Kintyre could result in sediment yields of 1.4 to 6.4 tonnes per 200 m run length of plough furrow in the first year after cultivation. Moling on the same site was calculated as yielding 7.2 tonnes. Ploughing and cross-drainage in new planting has sediment yields 2.5 to 4 times that from undrained grazing land during the period when many new cultivation channels have been opened, soil surfaces exposed and drains cut (Francis and Taylor, 1989). Sediment yields on ploughed catchments are generally 1.2 to 4 times higher than on unafforested catchments although rates usually decline rapidly after site preparation (Worrell and Hampson, 1997).

Aspect	*Impact*	*Potential mitigation*
Plant communities	Cultivation may alter the frequency of plants in communities and encourage ruderal or invasive species. On former arable farmland, this can take the form of introducing noxious weeds, e.g. docks, thistles, ragwort and wild oats, which subsequently seed and spread to surrounding arable land.	Minimal cultivation techniques can reduce these effects. Similar considerations apply to improved grassland. In native and semi-natural woodland, cultivation may need to be used with discretion if there are rare species present, e.g. *Moneses uniflora* in native pinewoods. The long-term effects of cultivation upon ground vegetation are not well known. However, a preliminary survey of three long-term cultivation experiments including the Inshriach and Teindland sites has shown few differences between vegetation communities after different types of cultivation (Humphrey *et al.*, 1995).
Nutrient loss	Intensive cultivation of podzols or ironpan soils can lead to rapid mineralization of organic nitrogen. Ground cover and newly planted trees may not be capable of taking up the mineralized nitrogen, especially during restocking, and some net losses from the site may occur. On podzolic soils or freely/imperfectly drained littoral sands with low nitrogen levels, such leaching may affect the nutrient sustainability of the site.	Re-distribution of slash evenly across the site during cultivation is a useful example of good environmental practice (Titus and Malcolm, 1992). Avoid deep cultivation on soils low in nitrogen (Anon., 1998).
Soil fauna and insects	The soil fauna can be altered by cultivation. Parry and Rodger (1986) found that scarification introduced more diversity of Carabid species into a native pine-wood but greatly reduced Collembola and numbers of small Arachnida. Weevil damage is usually reduced in proportion to the intensity of cultivation treatments owing to the increased amount of bare ground and the reduction of concealment in the humus and vegetation. Thus Schaible and Ridge (1994) found less damage to Sitka spruce from *Hylobius* in the first year after planting when trees were planted on mounds compared with direct planting. Similar results have been reported from Sweden (Örlander *et al.*, 1990). Bare ground round the planted tree can prevent the occurrence of vegetation or brash 'bridges' which *Hylobius* weevils may cross.	

Plate 1. *A Menzi Muck walking excavator preparing mounds on an upland brown earth restocking site in Argyll.* (51200)

Plate 2. *The prototype rotary mouldboard plough developed in the 1970s and used for complete cultivation to a depth of 60 cm.*

Plate 3. *The lighter TTS–10 scarifier used to bare the mineral soil surface on podzols and brown earths. The discs are not powered.* (38635)

Plate 4. *A Donaren 280 scarifier working in the disc trench setting on a restocking site on an upland brown earth soil in North Wales. The discs on this machine are powered.*

Plate 5. *A tracked excavator being used to prepare mounds on a peaty gley restocking site in Kielder Forest. A mounding bucket would be preferable to the drainage bucket shown here.*

Plate 6. *A prototype deep mole plough used in a number of restocking experiments in the late 1970s and early 1980s. The mole comprises a 25 cm diameter oxygen bottle welded on to the base of a drainage plough with a 10 cm tine sock. The mole was created at depths of 60–90 cm.*

Plate 7. *A TTS–35 Delta scarifier with powered discs mounted on the back of a modified Timberjack skidder.* (38651)

Plate 8. *A double mouldboard trailed plough preparing an afforestation site on deep peat in Shin Forest in north Scotland in the late 1970s. This is deep cultivation at a depth of around 60 cm.*

Plate 9. *A Maclarty mounder working on a flushed peat afforestation site in south-west Scotland.*

Plate 10. *A Bräcke patch scarifier preparing intermittent planting spots on a moist brown earth site with light grass cover.* (38644)

Plate 11. *Teindland 81. Soil profile of the medium complete ploughing treatment 45 years after cultivation. Compare with Plate 12 and note the disruption of the surface peat layer and the greater dryness of the profile due to the effect of the trees.*

Plate 12. *Teindland 81. The profile of the ironpan soil (FC code 4zx) in the uncultivated control areas. Note the peat layer, the ironpan and the strong indurated layer of Old Red Sandstone. This is typical of the soil under the trees planted in the 1800s – see front cover illustration. While cultivation can be used to ameliorate the surface conditions, it cannot be expected to disrupt the massive induration.*

Plate 13. *A typical brown earth soil (code 1) from Inchnacardoch Forest near Fort Augustus. Cultivation benefits on this deep-rooting soil are mainly due to improved weed control.*

Plate 14. *An unflushed hill peat (type 11) of c. 60 cm depth from Myherin Forest in north Wales. Initial cultivation of this soil should seek to provide a raised planting position through the use of mounding combined with drainage. Planting of lodgepole pine in mixture with Sitka spruce on this soil could result in cracking of the peat and eventual disruption of the compacted ironpan underlying the organic soil.*

Plate 15. *A sandy littoral soil with a shallow water table (type 15g) from Roseisle Forest near Elgin in north-east Scotland. Cultivation should provide a raised planting position through mounding to reduce the frost risk and provide all round stable rooting.*

Plate 16. *A flushed* Molinia *peat soil (type 9b) from the coalfield forests in south Wales. The depth of peat may be more than 3 m. Cultivation of peat soils must provide a raised planting position and should be accompanied by drainage to remove excess water from the site.*

Plate 17. *A stony podzol (type 3s) overlying fluvioglacial gravels in Inshriach Forest in the Spey valley of northern Scotland. The aim of cultivation is surface mixing of the upper horizons plus shattering of any deeper compacted layer using winged tines.*

Plate 18. *A surface water gley soil (type 7) over carboniferous lithology in the forests of south Wales. Cultivation must provide a raised planting position on these fertile, wet soils. Mounding will provide the most stable rooting on this soil type and may be combined with moling to provide greater sub-surface drainage.*

Plate 20. *A mole drain created at 40 cm below the planting position on a surface water gley soil in Ireland.*

Plate 19. *An ironpan soil with a thin layer of peat (type 4p) in the Moffat hills of southern Scotland. Cultivation should aim to disrupt the compacted layer so that roots can exploit the freely rooting horizons below the pan. It will also aerate and mix the upper organic horizons.*

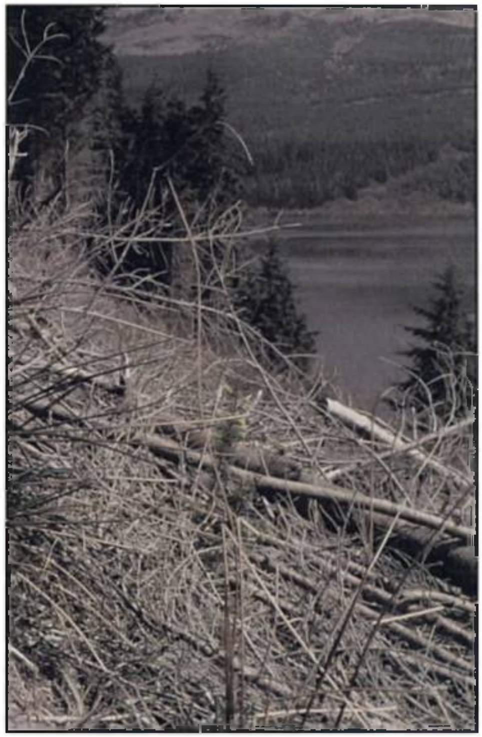

Plate 21. *(Top Left) A Sitka spruce plant growing on a mound on a flushed gley soil on a steep slope in Argyll. Notice that the mound has provided early weed control plus easy identification of the planting location for the planters and those involved with subsequent maintenance.* (51190)

Plate 22. *(Above) As in Plate 21, but with no cultivation. The planting position will have been harder to find and subsequent maintenance could be more difficult.* (51191)

Plate 23. *(Left) Patch scarification of a podzol to promote natural regeneration in the Glentanar native pinewood.*

Plate 24. *A newly planted peaty gley afforestation site in southern Scotland with mounds similar to those produced by the Maclarty mounder.* (39793)

Plate 25. *The prototype rotary mouldboard plough carrying out complete ploughing of an afforestation site on a peaty ironpan soil in the Moffat hills in south Scotland.*

Plate 26. *Medium depth double mouldboard ploughing on the same site and soil as in Plate 25.*

Plate 27. *A traditional form of cultivation on afforestation sites in upland Britain; deep double mouldboard ploughing on a gleyed soil in Loch Ard Forest near Aberfoyle. While this is a technique which provides a raised planting position and some surface drainage, the long-term effect of the upturned plough ribbon and the plough furrow, particularly on this soil type, is to promote an asymmetrical root system which is susceptible to early windthrow. Cross drains would be essential to reduce the erosion risk on these long plough runs. Mounding would be a much better option on these soils.*

Plate 28. *Experiment Inshriach 2 P62 (see Figure 2.3). Scots pine after 6 years growth on a podzol cultivated with medium depth single furrow ploughing. Note the abundance of heather.*

Plate 29. *As in Plate 28, but showing Scots pine planted without cultivation. Note the smaller size of the trees in this treatment.*

Plate 30. *The same treatment as in Plate 28, but after 35 years growth. Note that the heather has been replaced by a* Deschampsia flexuosa *dominated sward.*

Plate 31. *The same treatment as in Plate 29 after 35 years. The trees are still smaller and have a patchier stocking than on the cultivated site. Effects on ground vegetation are similar.*

Plate 32. *The beneficial effect of a raised planting position on a peaty gley. The three Sitka spruce trees are all 2 years old. The right-hand tree planted on the upturned mound is a healthy colour with good extension growth; the tree planted on the soil surface has survived, but has poor foliage colour and has made little growth; the left-hand tree planted in the shallow scrape has died as a result of waterlogged roots in anaerobic conditions.*

Plate 33. *Experiment Wykeham 116 P71 (see Table 2.6). Restocking of an ironpan soil on a heathland forest in north-east England. The uncultivated treatment one year after planting.*

Plate 34. *As in Plate 33, but showing the deep complete ploughing treatment.*

Plate 35. *The uncultivated treatment (see Plate 33) after 26 years showing pure Sitka spruce.*

Plate 36. *The deep complete ploughing treatment (see Plate 34) after 26 years showing Sitka spruce on the left and lodgepole pine on the right.*

Choosing the appropriate cultivation technique

Chapter 4

Site survey and preliminary considerations

The main factors affecting the choice of site preparation technique are:

- the size of the area to be treated;
- the site conditions and related constraints;
- the environmental constraints;
- the availability of appropriate machinery for the work specified in the operational plan;
- the versatility of machinery in relation to the soil/site mosaics to be treated;
- the cost of treatment in relation to the potential range of benefits.

It is rare for there to be only one treatment option but there are penalties (e.g. loss of growth, instability) for not using the best recommendation. The final stage in the selection procedure is to test that the selected technique(s) integrate well with the plant size and type and the physiological requirements of the species to be used. They should fit comfortably within the overall establishment regime proposed including the drainage and weeding prescriptions.

Chapter 5 considers the constraints presented by different soil types to tree growth and defines the most suitable cultivation prescription for each. Chapter 6 discusses different cultivation techniques. The other issues to be considered before implementing a cultivation programme are discussed in this Chapter.

Site survey

To select and deploy cultivation techniques effectively, an essential preliminary is to make a soil/site survey which records the environmental constraints, the slope classes, terrain roughness, and soil types. It is essential to dig soil pits to a depth of up to 80 cm to check on limits to rooting depth, e.g. the presence of an indurated layer or a ploughpan. In addition, where restocking is concerned, it is essential that cultivation is planned before harvesting begins. The planning should include specification of brash length, orientation, and stump heights. This background information can be converted to an operational plan by selecting the prescriptions for the soil and site conditions (Chapter 5 and Tables 4.1–4.6) and rationalising them along the lines proposed by Thompson (1984) for ploughing. These prescriptions may need to be modified before cultivation begins, e.g. in the light of brash density.

Issues for consideration

Intensity of cultivation in relation to species choice and type of woodland

The intensity of cultivation to be applied in some circumstances will vary according to the physiological and/or nutritional requirements of the species or mixture to be planted. For example, in the afforestation of ironpan soils on *Calluna* heathland, a less intensive form of cultivation could be accepted if pure Scots pine was to be used whereas complete cultivation would be recommended if a Sitka spruce/pine mixture was being planted.

Conversely, the use of Corsican pine, Douglas fir or larches would require cultivation on a weedy brown earth for high survival in restocking but could be omitted for less demanding species, e.g. Sitka spruce although a larger, better quality plant would be needed.

The main reason for creating the proposed type of woodland should be considered. A less intensive form of cultivation could be accepted in a new native woodland if an irregular structure of tree growth was desired. Where this approach is being considered, it is essential that a careful site survey is undertaken to see where cultivation would be most effectively deployed.

Soil complexes

Many sites consist of a mosaic of several soil types which makes it impractical to use the specific treatment for every soil type prescribed in Chapter 5. The first step in these circumstances is to identify the major soil group, then group other soils where similar techniques can be used, e.g. dry mounding on an ironpan soil with mounding on a peaty gley in restocking. The next step is to extend the limits of a technique as far as is silviculturally sensible, e.g. by varying the setting of a disc trencher into the plough setting. The use of other techniques on the remaining soils depends upon whether there is a sufficient area of ground available to justify the cost of bringing in the machine. Using this simplification of the potential techniques, and grouping common slope classes, it is possible to overcome most of the difficulties caused by soil complexes.

Slope and terrain

Slopes over 50% are not generally suitable for safe operation of most cultivation equipment although use of tracked power units and provision of safe access routes can take scarifier units and mounted ploughs up to 60–65% slopes. Two-way cultivation is normally limited to 15–20% slopes. Broad slope limits for some outfits are suggested in Appendix 3: wetness of surface during operations affects traction and these limits may not be achieved in wet conditions. Walking excavators are now being used to cultivate steep slopes. Their cost may be justified by the benefits of better establishment but manual screefing may also be an option.

Boulders larger than scale 3 in terrain classification are a major impediment to scarification machinery, greatly reducing the number of effective spots which can be formed. Very large (>40 cm diameter) stumps have a similar effect and, when present on gley soils and peat, will inhibit mounding.

High stumps (>10 cm tall) will also present a barrier to the effective use of machinery.

Site area

The minimum treatment area required to justify bringing in specialist cultivation machinery is likely to range between 5 and 20 ha with larger areas required for the bigger machines. Operational efficiency can be affected by the distance between work sites and the total area of a given cultivation type to be treated in a locality in one season. In site preparation on farms, heavy agricultural tractors can be used on a local basis on small areas (e.g. 1 ha or less), with agricultural subsoilers and backactor equipment.

Vegetation

The effectiveness of cultivation can be limited by vigorous plant cover such as dense *Calluna* taller than 15 cm or dense bracken more than 1.5 m in height. Woody *Calluna* restricts the contact between over-turned spoil and the original soil surface so that air pockets occur. These may cause root desiccation shortly after planting. Burning should be considered before site cultivation wherever *Calluna* is more than 5 cm tall. This treatment can also temporarily favour other species which are less competitive for nitrogen, e.g. *Molinia, Agrostis, Deschampsia flexuosa.*

Small mounds (*c.* 20 cm high) produced by continuous mounders can fall back into the hole because they are not heavy enough to press down the tussocky growth of *Molinia, D. caespitosa or Calluna.* Dense tall bracken should be treated with herbicide before any cultivation, leaving a sufficient interval of time for translocation of herbicide. Dense growth of woody species such as rhododendron should be cut down and chemically treated (including the regrowth) before any attempt at cultivation is made.

Timing of cultivation in relation to weed growth

Timing of cultivation should be tailored to the vegetation type and the appropriate weed control strategy. On upland restocking sites where weed recolonization will be slow, e.g. peaty gleys, cultivation of felled areas can be delayed for 12–18 months to form more cost-effective biennial programmes. The more weedy site types (soil types 1, 6f, 7f, 7c) should not be cultivated before August/September, or later in mild parts of the country, in order to obtain the maximum benefit from reduction in weed competition.

On these site types, an effective herbicide regime is required to complement cultivation. Such areas should be identified in a preliminary survey. The regime may include the use of contact herbicides to control existing perennial weeds before cultivation, followed by application of residual herbicides after cultivation. If tractor mounted boom sprayers are to be used to apply herbicides, then the cultivation technique chosen should not worsen the surface roughness of the site.

Particular care is needed with fertile sites which have been used for arable cropping or which have been under grass as these can contain a large spectrum of broadleaved and other weed seeds. These sites have to be tackled using a 'minimum disturbance' principle (Williamson, 1992; Willoughby and Moffat, 1996).

Timing of cultivation in relation to soil settling

Cultivation should not take place when soils are wet since there is a risk of machinery damaging the soil structure. This is a particular concern on fine-textured gley soils. Moling has to be carried out in dry conditions to ensure successful creation of the mole channel. As a general rule, cultivation should be carried out in late summer or early autumn to allow overwinter settling of the cultivated microsite.

Mounding on fine textured soils should take place at least two months before planting to permit settling and weathering of the mound surface. Otherwise, there is a risk that the mounds are eroded by sudden rainfall and roots of the planted trees are left exposed to the air.

Similar problems of settlement can also occur on some coarse textured soils such as ironpan soils with a silt component such as those that occur over Passage Beds sandstone in the North York Moors and over Tunbridge sandstone.

Ploughing of friable peats (soil type 11a on eastern sites) can result in cracking and erosion of the upturned ridge. These should be left to overwinter before planting.

Brash

There are a number of options for treating brash such as pulverising the residues or moving the material into windrows or piles (Low, 1985). The option chosen will depend upon the type and amount of residue and include:

- using the mulching head on excavators;
- using spring-loaded rakes or toothed buckets on excavators;
- by mounders with mattocks in a locked position;
- by rotary flails or bladed heavy rollers;
- by some scarifiers with downward pressure in the horizontal disc or cone setting;
- or by burning after piling or windrowing.

Raking is not safe on slopes over 30% but disc/cone scarifiers can operate up to 50–55% with a Caterpillar or Timberjack tractor as the prime mover. Raking is not technically feasible when boulder roughness exceeds 3.

Light brash, such as from felling pines or larches over 50 years old, is not a deterrent to efficient operation of scarifiers and mounders. However, moderate or dense brash from spruces (particularly from trees under 40 years of age) and any heavy wood residues and tops >1 m in length become obstacles to comprehensive preparation of microsites at the planned spacing.

It can take a number of years for heavy spruce brash to break down, e.g. where a brash mat has been used to allow extraction machinery to travel over the site. The cultivation machinery needs to be able to cope with this physical barrier. Disc trenching works best with brash lengths < 0.5 m whereas mounders and excavator mounders operate better with 2–3 m brash lengths.

Heavy bent branches and split logs should be removed to roadside during harvesting. To maintain site productivity, brash lanes made for passage of harvesting machinery across wet soils should be re-distributed (Titus and Malcolm, 1992).

The harvesting plans should be integrated with any cultivation prescriptions so that these problems are reduced to a minimum. Effective mounding when restocking gley soils is not practicable over the whole site where the brash mat is dense and covers over 35% of site area. Such conditions require some pulverising of brash by disc trenchers operating at the horizontal setting; or nosing/raking of the brash by mounder buckets.

Windthrown stands may have abnormal volumes of split logs and upturned root plates which may be difficult to cultivate. However, excavator mounders can normally be used in these situations.

Brash presentation or treatment can have several harmful effects:

- More than one pass increases the risk of potential soil damage (from rutting on wet soils and compaction generally);
- windrows have a lasting effect (10 years) on the landscape;
- windrows or piles of brash provide cover and breeding sites for pests;
- nutrients are differentially distributed across the site if windrowing or piling are used with subsequent variation in tree growth;
- irregular growth and wide spacing of trees planted adjacent to windrows may result in loss of timber quality;
- pile burning can lead to groups of trees being killed by the fungal pathogen *Rhizina undulata*;
- weed re-colonization can be accelerated on the exposed areas.

The benefits of treatment are the exposure of many more planting positions (easing the cost of planting and enhancing the quality of planting position) and the provision of clear surfaces where continuous mounders and other machines can consistently achieve their designed specifications.

Previous site preparation

On gleys on agricultural land, stone drains or tile drains from the original field drainage system can be common. Where this is still operating effectively, it should be left undisturbed and cultivation should be confined to very shallow subsoiling at row spacing or mounding by the scrape method. Where the under-drainage has visibly failed, surface treatments should again be superficial but it will be necessary to impose new open drains.

When restocking in the uplands, more than 75% of sites where the original stand was planted after 1950 will have been ploughed. On brown earths, podzols and ironpan soils, first rotation ploughing will not normally present any major obstacle to recommended restocking cultivation treatments such as scarification. However, on gleys and peats, there may be more than 2000 stumps per hectare on plough ridges at relatively close spacing together with harvesting debris. These conditions can present severe difficulty for continuous mounders. In addition where there is contour ploughing, furrows may be holding water which has to be removed by drainage. The best option is to use excavator mounders to provide new planting positions while breaking the old plough ridges and improving drainage.

Chapter 5

Cultivation recommendations for specific soil groups

We now examine the characteristics of each major soil group to recommend appropriate cultivation techniques. The soil classification used is listed in Appendix 1 and Appendix 4 gives a simple outline of the vegetation communities associated with different soil types.

BROWN EARTHS

Soil types 1, 1b, 1d, 1u, 1z, 12b, 12t.
Main phases 1c, 1a, 1ua, 1da, 1e, 1x.

Distribution

Brown earths are an important group of fertile, typically freely drained soils comprising about 14% of the total forested area of Britain. However, there is much variation in their frequency between regions. In mid and north Wales on solifluction drifts on slaty rocks of Silurian and Ordovician age, they may amount to more than 50% of the forest area. They are also frequent on the sandstones of Somerset and Devon, Brecon, Hereford, Berwickshire, Eden–Lockerbie basin, Strathmore and the Howe of the Mearns. They also occur on the greywacke/shales of the eastern Southern Uplands.

Elsewhere in the uplands, brown earths occupy steep slopes with rock outcrops on slaty rocks, mica and hornblende schists, phyllites, and impure sandstones where they often occur in complex with surface water gleys in the gulley systems. Examples are the Lake District, central Southern Uplands, central and west Perthshire, east Argyll, the Great Glen and Strathglass.

Another important group are the brown earths on basic and intermediate igneous rocks which are found in the east on the Cheviots, Pentlands, Ochils, North Fife hills and the Sidlaws; and in the west, in complex with other soils, in the Renfrew and Dumbarton Hills, Lorne, south Morvern, Mull and Skye. Shallow and indurated phases are common on the andesites in the east. In the lowlands, brown earths are common on loamy drifts and sediments.

Soil/site characteristics

These soils generally have freely drained A and B horizons, with a high % pore space, and high biological activity. Their fertility means that there is a large seed bank and vigorous weed growth. The vigour of the weeds increases from north to south in Britain or with decreasing altitude.

a. Rooting depth: >45 cm.
b. Upland topex value: >35.
c. WHC soil score: 0–2.5.
   Shallow phase: 2.5–5.0 depending on the penetration of rock.
   [*Note*: on soil phase 'a', rooting depth is mainly within 30–45 cm but there is often root penetration into fissures in well-weathered rock.]
d. Frost risk: Low. Moderate on gentle/flat inland lowlands.
e. Erosion risk: Moderate on steep upland sites.
f. Nitrogen deficiency category (Taylor and Tabbush, 1990, p.8): A; B in soil type 1e only.
g. There may be a 'plough pan' below 25–30 cm on soil phase 1c (agriculturally cultivated for some time) and the weed seed bank may be exceptionally high on these sites and contain 'noxious' weeds.

h. If there is effective weed control, soil moisture is generally not limiting for establishment with the exception of:
   i. shallow phases in the east;
   ii. coarse loamy textures in warm eastern or southern lowlands;
   iii. steep slopes with a southern aspect;
   iv. soil type 1s on southern aspects.

Limitations

a. Weed growth (shading) and weed competition (moisture and nutrients).
b. Soil moisture (as above).
c. Rooting depth – e.g. soil types 1x, 1a, 1da.
d. Roughness (mapping notation +) and steepness for machinery.
e. Frost – on flat inland sites with a predominantly grass sward.

Cultivation specifications

The main objective is to provide a weed-free planting site or regeneration surface, maintained by herbicides for at least 2–3 years after cultivation. The distance of the planted tree from the competing weeds should be not less than 0.5 m (Davies, 1987). Cultivation is not required if good weed control can be achieved by other means (Davies, 1987; Williamson, 1992) but it will often be beneficial with sensitive species.

The aim should be to use a technique such as shallow mounding which can provide a weed-free site for the first growing season. Cultivation is desirable on frosty sites where it is intended to plant tender species.

Minimal cultivation (e.g. subsoiling) can be used on cultivated brown earths to avoid activating the seed bank. The same principle applies where buried broom or gorse seed is abundant. However, there is a danger of weed species present elsewhere on the site outcompeting the planted trees unless herbicides or other effective weed control measures are used. Subsoiling is not suitable for soil type 1e as it has no impact on *Calluna* and provides no seeding surface for *Agrostis* or *Festuca* sp. to displace it.

Achieving successful natural regeneration on these fertile soils will depend mainly upon careful manipulation of the canopy to prevent excessive weed colonization before seedfall.

Cultivation prescriptions

See Table 4.1.

Table 4.1 Cultivation prescriptions for brown earths

[A = best general option, B = an acceptable alternative, C = a lesser alternative with some penalties]

Operation	*Prescriptions: General*	*Prescriptions: Specific soil type*
New planting	A. Disc trench scarification – shallow setting A. Shallow mounding *c.* 20 cm B. Shallow agricultural spaced ploughing (S25/–/t) (improved grassland) C. No cultivation (higher herbicide input)	**1g.** Mounding **1c.** (weed rich and/or plough pan problems). Weed control is essential A. Shallow mounding B. No cultivation. Use sub-soiler to break up plough pans (45–60cm) depths **1x.** (Induration). Subsoiler 45–60 cm **1e.** A. Ploughing (D30/T45/t) B. Disc trench scarification (deep setting) **Frosty flats** A. Ploughing (D30/T45/t) B. Disc trench scarification (plough setting) C. Mounding
Restocking	A. Disc trench scarification B. Patch scarification (light to moderate weed growth only) C. No cultivation (rapid replanting, higher herbicide input required – not advised for Corsican pine, Douglas fir, most broadleaves)	**1g.** Mounding
Natural regeneration	A. Combination of superficial cultivation (disc trench scarification or discing) at seedfall plus follow-up herbicide	

Notes: 1. Herbicide application is often an essential prerequisite on these soils.

2. Preplanting or pre-cultivation spraying of herbicide in rows or overall may be needed for bracken-covered sites. Cultivation alone weakens rhizomatous weeds for a short period only.

PODZOLS

Soil types 3, 3m.
Main phases 3p, 3g, 3c.

Distribution

Podzols are freely drained strongly acid soils, located mainly in eastern and southern regions and supporting a dry heathland vegetation or *Vaccinium* heath and bracken heath in woodland. They comprise about 8% of the forest area. The distribution is extensive only on moderate to steep slopes over those sedimentary and metamorphic rocks which weather into coarse textured materials; and on the irregular topography of fluvioglacial sands and gravels.

In the uplands, these soils mainly occur on solifluction drifts and till on the siliceous sandstones and conglomerates of the Old Red Sandstone; on Moine psammite, Dalradian quartzite and quartzose mica schists; on granites; and on the grits and sandstones of the Carboniferous and Jurassic sediments in north-east England. The other main occurrences, of a different type with deeper horizons, are on fluvioglacial sands and gravels such as occur in the Spey, Nairn, Findhorn, Dee, Esk and Tay valleys. In southern Britain, they are associated with Bunter sandstone and pebble beds, Folkestone and Tunbridge sandstones, Greensand and Tertiary sands of the Hampshire and London basins.

As podzols intergrade to podzolic gleys, the B horizon contains grey patches and some mottling (soil type 3g). These are of local occurrence, for example on the lower slopes of moraines in moist to wet native pinewoods. A plough pan can be produced in podzols with sufficient silt and clay, both in fluvioglacial and sedimentary parent materials (soil types 3c and 3mc). In extreme cases, this can lead to poor aeration in the pan and prevent deep rooting. In lowland sands, impedance can occur when there are silty or clayey bands in the profile, or where the water-table lies within 1 m of the surface (soil type 3mg).

Peaty podzols tend to occur in the eastern Grampians and east Perthshire/Angus at higher elevation; or further west in wet climates over valley moraines. Where cultivation is concerned, these are allied more closely to ironpan soils with an organic horizon less than 10 cm thick.

Soil/site characteristics

These soils are generally freely drained. The exceptions are the imperfectly drained gleyed type (3g) and also the peaty podzols (3p) where the organic horizon has poor aeration and permeability. Weed growth is normally light, but bracken may be a problem on some lowland sites. *Calluna* can also cause difficulties, particularly since the soils are generally low in N and P.

a. Rooting depth: >45 cm. Where induration occurs, this almost invariably lies below 45 cm.
b. WHC topex value: >35 (foothills).
c. WHC soil score: 0–2.5 (soil type 3g).
d. Soil moisture: There is low water holding capacity on soil type 3m (especially on gravels).
e. Frost risk: High on terraces and kettleholes.
f. Erosion risk: Generally low, but moderate on steep slopes.

Limitations

a. Low availability of nitrogen, and phosphorus.
b. Cementation in hardpan podzols [soil type 3m].
c. Ploughpan in 3mc [a legacy of agricultural cultivation].
d. Low water-holding capacity.
e. Organic seal at surface – soil type 3p.
f. *Calluna* competition.
g. Frost risk – moderate on lowland podzols.

Cultivation specifications

The main objective is light surface (20–25 cm) soil/humus mixing of the F (and H where present) and Ea horizons to activate the release of nitrogen and to encourage capillary transfer of moisture direct to the plant.

Shallow spaced tine ploughing would normally be preferred to disc trenching for this reason.

A specific objective in hardpan podzols is to increase pore space by shattering the cemented horizon using winged tines down to 45–65 cm. The same objective applies to ploughpan podzols (soil types 3c, 3mc) with compaction at 20–30 cm. Deeper cultivation can be applied to peaty podzols, soil type 3p, owing to the larger nitrogen reserves and the need for breaking up and incorporating the organic horizon. The specification for soil type 3p is similar to that for weak ironpan and intergrade ironpan soils.

Cultivation should also aim to delay the adverse influence of *Calluna* by encouraging a temporary invasion by *Deschampsia flexuosa* or other fine grasses. Cultivating a large surface area can favour heavy birch regeneration where birch seed sources are present. However, such treatments can also favour pine and larch natural regeneration in restocking where seed trees are retained in shelterwood regeneration.

On heathland podzols, ripping is an unsuitable treatment as it provides no superficial soil mixing and does not reduce the dominance of *Calluna* on the site. However, it has specific uses for dealing with a ploughpan or cementation in lowland podzols (soil type 3m). Hunter and Skinner (1986) have described ripper-bedding cultivation in New Zealand which should be suitable for the treatment of hardpan podzols and lowland gley podzols (soil type 3g) but the technique has not been evaluated in Britain.

Cultivation prescriptions

These are shown in Table 4.2.

Manual screef planting or natural regeneration on an unprepared surface, such as short *Vaccinium*/light bracken heath, are always options but early growth is slow due to low nitrogen release and trees remain vulnerable to browsing for a longer period. Generally, Douglas fir and Corsican pine respond strongly to cultivation at both new planting and restocking on this soil group. Cultivation is necessary on peaty podzols (soil type 3p) at new planting; in restocking, this soil type can be grouped with typical ironpan soils.

Table 4.2 Cultivation prescriptions for podzols
[A = best general option, B = an acceptable alternative, C = a lesser alternative with some penalties]

Operation	*Prescriptions: General*	*Prescriptions: Specific soil type*
New planting	A. Spaced tine ploughing (D30/T45/t) B. Disc trench scarification – plough setting C. Dry mounding, Patch scarification, Screefing (light sandy soils) } (unsuitable for nitrogen demanding species, e.g. spruces, firs)	**3m.** Lowland podzol Agricultural spaced ploughing S25/–/t **3m(x).** Hardpan podzol A. Ripping 60 cm B. Ripper-bedder **3p.** Peaty podzol A. Ploughing (D45/T60/t) B. Disc trench scarification (deep setting) **3c.** Cultivated podzol. As brown earth type lc (Table 4.1)
Restocking	A. Patch scarification B. Disc trench scarification C. No cultivation (not satisfactory for demanding species)	**3m.** Lowland podzol Spaced shallow agricultural ploughing (S30/–/t) **3m(x).** Hardpan podzol Ripper 60 cm **3p.** Peaty podzol Dry mounding
Natural regeneration	A. Disc trench scarification	

IRONPAN SOILS

Soil types 4, 4b, 4z
Main phases 4p, 4a, 4pg

Distribution

Ironpan soils are a very widespread group of strongly acid, imperfectly drained soils occurring mainly in cool or moist to wet climates at the middle and upper plantable range of elevations on a wide variety of lithologies and drifts. They are a major group of upland soils amounting to about 20% of the forest area, and are capable of improvement. They are most extensive on the conglomerate and sandstone foothills around the Moray Firth Basin; on Dalradian schists in Grampian and Tay Regions; on the tabular sandstone plateaux of the North York Moors; and in the central Southern Uplands, Wales, Dartmoor and Exmoor.

Generally, ironpan soils are located on gentle slopes on convex topography or tabular plateaux over coarse loamy till or weathered drifts. They can also occur on solifluction drifts, often on northern aspects on upper slopes and are common on moraines in combination with peats and peaty gleys. Their complex distribution in this terrain makes it difficult to prescribe specific treatment for this soil type.

The texture range is wide, from silt loams to coarse loamy sand, and induration or compaction is often present, except on shallower drifts. In soil type 4zx on coarse loamy drifts, e.g. Moine psammite, Dalradian quartzite and Old Red Sandstone siliceous conglomerate, the ironpan may be strongly developed, lying at 35–50 cm depth and resting on a strongly indurated BCx horizon. In contrast, on loamy drifts such as Silurian/Ordovician slaty rocks and Dalradian schists/phyllites or on impure sandstones and siltstones, the ironpan tends to lie at 10–20 cm from the mineral soil surface and there is a thick friable B horizon below the ironpan (typical soil type 4). The shallow phase, soil type 4a, is common on slaty rocks at higher elevations in Wales where the drift is thin over shattered bedrock.

Soil type 4b, intergrade ironpan soil, is encountered on solifluction drifts and residual drifts mainly in Wales and southern Scotland at the transition to upland brown earth. Steepness is the main technical problem of this type as well as shallowness to bedrock in soil type 4ba. Peaty ironpan soils (soil type 4p) are associated with moraines in wetter climates or with convex topography at higher altitudes. In wetter climates peaty ironpan soils intergrade to peaty gleys or blanket peats and the B horizon may show signs of gley pockets (soil type 4pg).

Soil/site characteristics

These soils are imperfectly drained with an organic seal at the surface. They are poorly aerated in the surface horizons and may have a high bulk density in the Eg horizon. Soil type 4pg also has imperfect drainage in the B horizon. The major weed problem is the occurrence of *Calluna* which will compete with spruces and firs for available nitrogen. Other weed competition is less important in most instances. The soils are typically low in phosphorus and available nitrogen wherever *Calluna* dominates. K may be deficient as the peat thickness increases beyond 30 cm.

a. Rooting depth: 20–45 cm (limiting on soil type 4a).
b. WHC topex value: 10–15.
c. WHC soil score: 0.0: (2.5 in soil type 4p) (5.0 in soil types 4a, 4pg).
d. Soil moisture: Adequate (low in soil type 4zs for pole-stage stands).
e. Frost risk: Low except on upland plateaux (e.g. North York Moors).
f. Erosion risk: Moderate on sloping sites especially on transitions to wetter soils.

Limitations

a. Organic seal at the surface.
b. Low aeration and high bulk density of Eg horizon.
c. Low availability of nitrogen (heathland types).

d. Soil depth (soil types 4a, 4ba).
e. Deep-lying ironpans (soil type 4z).
f. Induration above 45–50 cm (soil type 4zx).
g. Low water-holding capacity (soil type 4zs).
h. Depth of organic matter in soil type 4p which makes it difficult to reach and break the ironpan when the peat horizon is 30–45 cm.
i. Imperfect drainage of B horizon (soil type 4pg).
j. *Calluna* competition.
k. Frost on plateau sites.

Cultivation specifications

The aims are firstly to aerate and mix the organic horizon, and secondly to disrupt the compact Eg horizon and ironpan extensively. Removing compaction will improve aeration and thus facilitate rapid penetration of anchorage roots to the B horizon (Pyatt and Craven, 1978). Mixing of the surface soil and humus layers is important on heathland ironpan soils to activate the release of nitrogen and reduce reinvasion of *Calluna*.

On heathland sites, medium complete cultivation of new planting sites has given improved growth; spaced ploughing has resulted in rooting orientated along the line of cultivation, leading to instability. Well cultivated ironpan soils, soil type 4c, may be treated as brown earths.

Very intensive cultivation of heathland ironpan soils with shallower organic horizons can result in too rapid mineralization of and depletion of available nitrogen for some species, e.g. Sitka spruce, although this has not affected lodgepole pine and grand fir.

Ripping alone is an unsuitable treatment as its effects are too localised, survivals are lower and higher weeding input is necessary on grass moorland. There is also no impact on *Calluna* competition.

Cultivation prescriptions

See Table 4.3.

Medium complete ploughing has generally given the best growth but prescriptions can be adapted to reflect the soil characteristics, the vegetation type and the tree species/mixture.

Cultivation should not create continuous channels which would allow water movement down slopes. Cross-drains should intercept waterflow at regular intervals according to slope.

Table 4.3 Cultivation prescriptions for ironpan soils

[A = best general option, B = an acceptable alternative, C = a lesser alternative with some penalties]

Operation	*Prescriptions: General*	*Prescriptions: Specific soil type*
New planting *(No general prescription is possible. See options and notes 1–3)*	1. Complete tine ploughing (2S45/T60/t) (ericaceous type) 2. Spaced tine ploughing (D45/T60/t or m) (grass type) Shallow mounding and ripping 3. Disc trench scarification – deep setting	**4z.** A. Deep complete ploughing (S60/T90/m or 2S45/T60–90/t) B. Spaced tine ploughing (D45/T60/t) (Scots pine only) C. Spaced tine ploughing + ripping (D45/T60/t + R) **4p.** A. Spaced deep tine ploughing (D45/T60/t) B. Mounding + subsoiling **4pg.** A. Mounding + subsoiling
Restocking *(See also note 4 below)*	A. Disc trench scarification B. Dry mounding C. Patch scarification	**4z.** A. Spaced tine ploughing (S45/T60–90/t) at 1.8 m B. Mounding + ripping >50 cm
Natural regeneration	A. Disc trench scarification	

Notes:

1. New planting option 1 refers to the typical heathland ironpan soil where it is intended to use Sitka spruce in pine/spruce or larch/spruce mixtures.
2. New planting option 2 is more appropriate for ironpan soils with mixed or grassy vegetation or over better quality lithology (Categories A and B – Taylor and Tabbush,1990); or to heathland ironpan soils or more quartzose drifts where it is intended to plant pure Scots pine, and high yield is not an objective (Option B for soil type 4z). Note that this has possible stability penalties because of poor root architecture and this can be avoided by use of mounding.
3. New planting option 3 refers to better quality ironpan soils with a thin organic horizon and a weak discontinuous ironpan at 10–25 cm; and to integrade 4b.
4. If the ironpan was not broken in the first rotation, then follow the appropriate new planting prescriptions.

SURFACE WATER GLEYS (non-peaty)

Soil types 7, 7b, 7z, 7k.
Main phases 7f, 7l, 7e, 7c, 7h, 7zx.

Distribution

Surface water gleys are poorly drained mineral soils with a high water-table which varies seasonally according to the amount of rainfall. Surface water gleys comprise about 15% of the forest area, decreasing in frequency with increasing altitude or rainfall when they are replaced by peaty gleys.

In the lowlands, they are strongly represented on clayey and loamy sediments, e.g. Gault Clay, London Clay, Northampton Clays, Jurassic shales, and impure sandstones of the Lower and Upper Old Red Sandstone. In the warmer and drier lowlands, the intergrade to brown earth–brown gley (soil type 7b) is a type of local importance; as also is the podzolic gley (7z) where a sandy or gravelly layer overlies a loamy or clayey subsoil. Silty gleys of very poor structure are found in the Weald. Calcareous gleys (soil type 7k) are found on a few Jurassic and Cretaceous clays in lowland Britain.

In the foothills and on some lower plateaux, surface water gleys may be quite extensive at lower and middle altitudes on Carboniferous shales, Silurian/Ordovician slaty rocks, igneous rocks and some impure sandstones. These are all of the clayey and loamy type, with texture of the B horizon varying from clay loam to sandy clay loam and silty clay loam. The most extensive forest examples are in Durham, Northumberland, Cumbria, Roxburghshire and Devon (Culm) on the Carboniferous loamy tills. Elsewhere in the uplands, surface water gleys normally occur on relatively narrow receiving sites with some natural shelter or in a gulley/re-entrant complex with brown earths on steep slopes (soil types 7f, 7f(x)). Throughout the general distribution of surface water gleys, a minority type with strong flushing in the A horizon (soil type 7f) may be identified on receiving sites. As well as having higher nutrient and oxygen supply, this is commonly a very wet soil and has exceptional weed vigour which requires special treatment. A site-specific cultivation treatment may be difficult to apply in this situation.

On the foothills of the Dalradian rocks and lower slopes in Argyll and on granites generally, surface water gleys of lighter loam texture are frequent. These are more permeable and have less dense B horizons than the first category.

Solifluction drifts on andesite with an indurated horizon at 30–35 cm commonly have gleys on induration (soil type 7x) associated with *Nardus* grassland.

In heathland areas, e.g. Black Isle, Moray and Lowland Angus, non-peaty podzolic gleys occur on sandy loam drifts over indurated till (soil types 7x, 7zx).

Lowland cultivated gleys (soil type 7c) are an allied type but are usually less wet owing to artificial drainage.

Soil/site characteristics

These soils are poorly drained with high winter water-tables and anaerobic conditions below 20–25 cm. The B horizon is dense or indurated thus impeding lateral or vertical drainage. The water-table is appreciably lower in brown gleys (soil type 7b), cultivated gleys (soil type 7c), and some podzolic gleys (soil type 7z). The permeability of the soils varies from low to very low on clays and upland loamy tills, but can be moderate on a well-fissured lowland clay that is prone to cracking in summer. Vigour of competing weed growth is generally high, particularly on the flushed phases. Soil nutrient status is generally good with adequate phosphate and moderate to high nitrogen (the ericaceous 7e phase is an exception).

a. Rooting depth: 20–35 cm.
b. WHC topex value: 15–25.
c. WHC soil score: 10 (5 in soil types 7b and 7z).
d. Soil moisture: Seasonal deficit in rooting zone in Eastern areas and South Lowlands.
e. Frost risk: High.

f. Erosion risk: Low to high depending on texture, slope and rainfall. High on steep slopes with loose loamy drifts.

Limitations

a. High seasonal water-table with anaerobic conditions in Eg and B horizons.
b. Dense Bg horizon in clayey and loamy drifts.
c. Indurated BC horizon in soil type 7zx, 7x.
d. High weed vigour especially on soil types 7c, 7f, 7k.
e. Frost damage.
f. Allelopathic effect of *Calluna* in podzolic gley (soil type 7z) and ericaceous phase (soil type 7e).
g. Drought on lowland clays.

Cultivation specifications

The main objectives are: to provide a raised planting position with the conditions for uninterrupted shallow root development in all directions; and to suppress weed growth around the planting position. Lowering the water-table to encourage deeper rooting is also a theoretical objective but is not often technically feasible.

The continuity of the Ag horizon should be preserved, with the exception of necessary drains to remove excess water.

A specific objective on soil type 7f is to reduce initial weed competition. In addition, in frost hollows and on cool upland sites it is desirable to raise the planting position and provide a dark surface for absorbing radiation. Larger mounds are beneficial for these situations. Indurated gleys on gentle gradients of 0–2° are the most difficult sites because there is no evidence that deep subsoiling is beneficial where there is no effective drainage gradient.

Cultivation prescriptions

See Table 4.4.

Ploughing will seriously increase windthrow hazard on this soil type because of its tendency to produce asymmetrical root systems. Mounding best meets the specification for a raised planting position and all round root spread. Moling or subsoiling, where technically feasible, can lower the water-table and are the only means of increasing rooting depth without interfering with root spread.

In restocking, plough ridges from the first rotation provide raised planting positions and furrows filled-in by leaf litter can be crossed by roots. Provided the plough furrows follow the drainage gradient and planting is done away from the old stump, no cultivation is a feasible option. However, the weeding and frost protection advantages of mounds would be foregone.

Cultivation needs to take place quickly after felling on these soil types because of the speed of weed colonization. For the same reason, on new planting sites, cultivation in the winter before planting will provide the best weed control.

All cultivation treatments need to be supported by a drainage network with emphasis on subsurface drainage wherever it can be used.

Table 4.4 Cultivation prescriptions for surface water gleys

[A = best general option, B = an acceptable alternative, C = a lesser alternative with some penalties]

Operation	*Prescriptions: General*	*Prescriptions: Specific soil type*
New planting	**Gradient >3°:** A. Moling and mounding (fine loamy texture and relatively stone-free) A. Subsoiling and mounding (soil textures other than fine loamy) B. Subsoiler/screefer (herbicide input will be higher) **Gradient <3°:** A. Mounding	**7f.** Flushed gley. Large mound **7c.** Cultivated gley. Mounding only **7z, 7x** Subsoiling and mounding All treatments require drainage
Restocking	A. Excavator mounding (smaller areas) B. Continuous mounding (larger areas) C. Direct planting (on plough ridge away from stump)	7f. Large mound All treatments require drainage or maintained drains
Natural regeneration	A. Discing (oak) B. Disc trench scarification at seedfall	

Notes:

1. New planting option A should be used wherever it is technically feasible, i.e. on clayey and loamy gleys with relatively low stone content. Subsoiling replaces moling wherever tills/drifts are more stony. Both require a minimum of 3° gradient to be effective.
2. Mound size should be increased to 30–40 cm x 50 cm x 50 cm on soil type 7f or on delayed restocking site where *Deschampsia caespitosa* and other grasses or *Juncus* spp. have re-established.
3. On soil type 7c (arable), noxious weed invasion at new planting is a major risk from using any extensive technique like ploughing. Moler or subsoiler only with mineral screefer is desirable but care should be exercised to avoid disturbance to any previous stone or tile drains.

PEATY GLEYS

Soil types 6, 6z.
Main phases 6x, 6p, 6l, 6e, 6f.

Distribution

Peaty gleys are poorly or very poorly drained organo-mineral soils with a high winter water-table. Peaty gleys are the largest soil group in the uplands and they comprise about 25–30% of the national forest area. However, in parts of the moist cool uplands where dense loamy or clayey tills predominate on gentle slopes, plateaux and depressions, this may rise to 50–65%, e.g. in the Borders and North Pennines, central Southern Uplands, central Scotland and West Cumbria. Other major areas of this soil type are on the mid-Wales Silurian/Ordovician plateaux, the Welsh coalfield valleys and the Glamorgan Pennant Sandstone plateaux, the Culm clays in Devon, and the Jurassic clays in the higher parts of the North York Moors.

Loamy peaty gleys (soil type 6l) are common on impure sandstones, granite and the Dalradian and Moine schists. B horizons are more permeable in these soils.

In wet western and northern regions, peaty gleys occur in complex with peats and peaty ironpan soils, and boulders and rock outcrops are more frequent.

Peaty gleys on induration (soil type 6x) form another major group which are widespread on stony coarse loamy drifts of the Moine psammite and granulite, and of the siliceous sandstones and conglomerates of the Old Red Sandstone. The organic horizon is usually thin (5–15 cm) and the BCx horizon is indurated. The main distribution is eastern, from East Sutherland to East Angus, with concentrations around the Moray Firth. In drier lowland parts of this region sites with a deeper coarse loamy drift over the indurated layer can be found. These peaty podzolic gleys (soil type 6zx) are associated with better growth owing to the lower water-table.

Soil/site characteristics

The soils are poorly or very poorly drained with a high winter water-table and anaerobic conditions below 20–25 cm. The water-table can be appreciably lower in summer in soil types 6z and 6zx. The permeability of the soils is often very low, but is somewhat better on coarser textured gleys. Weed vigour is generally low except on soil type 6f where it is more vigorous. *Calluna* check is potentially a serious problem for spruce on soil types 6z, 6e and others. The soils are generally low in phosphate, N is limiting on soil types 6e, 6z, and K is also limiting on soil type 6p on certain lithologies (Taylor and Tabbush, 1990).

a. Rooting depth: 20–25 cm.
b. WHC topex value: 5–15.
c. WHC soil score: 10 (but 7.5 on soil type 6l where adequately drained).
d. Soil moisture: This is generally not limiting but seasonal deficits in rooting zone do occur in podzolic gleys (6z), gley on induration (6x) and on some sandstones, e.g. Pennant in the South Wales coalfield.
e. Drainage gradient: Frequently low.
f. Frost risk: Generally low, but can be high in depressions.
g. Erosion risk: Generally moderate, but can be high on steep loose loamy drifts, e.g. mica schists and Old Red Sandstone. However it is low where the peat is thick and the mineral soil is not exposed.
h. Water quality: Ploughing can cause an increase in solid suspensions and turbidity.

Limitations

a. High seasonal water-table with anaerobic conditions close to surface.
b. High density and poor permeability of B horizon on clayey and loamy drifts or high bulk density in indurated BCx horizon (soil types 6x, 6zx).
c. Drainage gradient of >3° required for moling treatment.
d. High stone/boulder content limits use of moling/subsoiling operations on some lithologies (see below).

e. *Calluna* check to spruces on soil type 6e, 6p moorland type, 6z, 6zx.

f. Frost – depressions only.

Cultivation specifications

The main objective is to provide a raised planting position and conditions of uninterrupted root development in all directions. Mounding is the most acceptable specification using 25–30 cm mounds.

Lowering the water-table by moling to encourage deeper rooting is possible in new planting on loamy gleys and stone-free clays. Elsewhere this will be achieved primarily by canopy interception. On restocking sites, spoil ditches created during mound formation can form part of the drainage system. Moling and subsoiling, where practicable and where there is a gradient of >3°, should be used at new planting to achieve gains of up to 10 cm in rooting depth with consequent improvements in stability. Good weed control may be necessary to achieve satisfactory establishment. The best conditions for effective moles are in stone-free fine loams and clays, e.g. Jurassic clay and Carboniferous shale tills; and on Lowland clays. Granite and schist tills can be dealt with by subsoiling but tills of psammite, granulite, conglomerates, sandstone and quartzite present serious difficulties due either to stoniness or too sandy texture.

Cultivation prescriptions

See Table 4.5.

In both new planting and restocking, 25–30 cm mounding by continuous mechanical mounders or by discontinuous technique (excavators) is the practice most favoured for improved stability. Wherever feasible, it should be accompanied by moling or subsoiling to 35–45 cm.

In new planting, **shallow** double mouldboard ploughing should be used as a **last** resort but it carries the risk of lowering terminal height. In restocking, the raised planting position of old ploughing ridges can be used in lieu of new mounds provided planting is not close to stumps.

All cultivation treatments need to be accompanied by a drainage network. Cultivation and drainage can be expected to increase *Calluna* competition wherever it is present.

Table 4.5 Cultivation prescriptions for peaty gleys

[A = best general option, B = an acceptable alternative, C = a lesser alternative with some penalties]

Operation	*Prescriptions: General*	*Prescriptions: Specific soil type*
New planting	A. Moling (to 35–45 cm) + continuous mounding (20–30 cm) B. Continuous mounding (20–30 cm)	**6zx.** A. Subsoiler (40–50 cm) + continuous mounder (gradient >3°) B. Double mouldboard spaced ploughing (D45/T60/t) (gradient <3°) **6f.** Mounding 30–40 cm **Stony gleys** Substitute subsoiling for moling All treatments require drainage
Restocking	A. Continuous mounding B. Discontinuous mounding C. Direct planting on plough ridge away from the stump Brash raking before mounding is advised	
Natural regeneration	Nil	

Note: Spaced ploughing (e.g. D35/–/t) is not recommended because of the increased risk of windthrow.

PEATS

Soil types 8, 9, 10, 11
Main phases 8c, 9b, 9d, 9e, 10b, 11b, 11c.

Distribution

Peats are very poorly drained soils with over 45 cm depth of organic matter. About 12% of forest land is on deep peat with the highest frequency being in Caithness, Lewis, and western Galloway (Wigtownshire) where they may comprise more than 55% of the total. In other parts of Highland Region, particularly on the Moine psammite, peat soils are about 35% of the forest area and in the upland Borders and Central Scotland Carboniferous regions they represent 15%. Most peat soils are 45 cm to 2 m deep but they vary considerably in humification and in the proportions of moorland plants forming the dominant vegetation.

Raised bogs (soil types 10a, b) have fibrous peat with low humification and high porosity but the surface is nearly flat and they are highly saturated. Basin or fen peats (soil types 8a–8d) are well humified and highly saturated. Blanket bogs (soil groups 9 and 11) are partly humified beneath a fibrous surface. Where depth is less than 2 m and precipitation is not very high, peat cracking will occur under a tree canopy on soil groups 9 and 11.

In extensive basins and on gentle topography, few other soil types will be found amongst deep peats. However, on more shedding or broken terrain and in morainic landscapes, the peats are intermingled with peaty ironpan and peaty gley soils which causes difficulty in choosing the best cultivation techniques.

Soil/site characteristics

The soils are initially poorly or very poorly drained with a high water-table for at least 9 months of the year and have anaerobic conditions below 10 cm. The permeability of the deep peats varies, being relatively high on soil types 10a, 10b; moderate on 11a; and low on all others unless cracking has occurred. The vigour of competing weeds is generally low, but is moderate on group 9a, 9b and can be high on group 8. The soils are generally low in potassium, low in phosphorus except on 8a, 8b; and low in available nitrogen on 9e, 10, 11.

a. Rooting depth: 20–25 cm unless peat cracking has occurred, when lodgepole pine can root to 50–60 cm or more.
b. WHC topex value: Soil type 10, 0–10; others,5–15.
c. Soil score: Generally, 10; after peat cracking, 5–7.5.
f. Frost risk: High on soil types 8, 9a, 9e, 10.
e. Water quality: Ploughing causes short-term increase in suspended solids and turbidity.

Limitations

a. A high water-table. (However, this can fall dramatically if cracking develops and deep drains are maintained.)
b. Low soil strength which can make the sites difficult for machinery access.
c. A very low drainage gradient on soil types 9e, 10 and a slight gradient on soil types 8, 9a–d, 11.
d. High frost risk on soil types 8, 9a, 9e, 10; moderate risk on soil types 9b–d; low risk on soil type 11.

The remains of pieces of wood (e.g. pine stumps) in the peat at <1.0 m depth can obstruct under-drainage, usually on soil types 9 and 11. Boulders projecting from the underlying till surface can have a similar effect in shallow blanket peats of 45–75 cm depth.

Cultivation specifications

A raised planting position is essential and can be obtained from mounds or shallow (<30 cm deep) double mouldboard ploughing. Peat cultivation must be accompanied by drainage which should be maintained and deepened periodically. Ploughing has the disadvantage of affecting root orientation and directing roots along the ridge (Coutts *et al.*, 1990). Therefore, mounding is to be preferred for better root spread.

Where peat is uniformly deep, moderately well-humified, and contains no wood or boulder obstructions within 60–70 cm of the surface, mounding with peat tunnels would be the preferred technique, with 90 cm deep collecting drains at 70 m intervals. This technique is not suitable for raised bogs (soil type 10) as the peat is too fibrous and the gradient is too low. Mounding has been demonstrated as the best treatment for restocking blanket peat in Northern Ireland (Schaible and Dickson, 1990).

Where peat depth is more variable or stumps are present, or on fibrous peats, shallow double mouldboard spaced ploughing or mechanical continuous mounding with superimposed drainage are the only alternative specifications. Ploughing to 60 or 90 cm depth gave some improvement in growth over 25 cm depth ploughing but differences were relatively minor and, as rapid root crossing of furrows is vital for achieving wide root plates, 30–35 cm is normally the maximum furrow depth which should be used. Exceptionally, on soil types 10a/b, with a deep *Sphagnum* layer, this may need to be 35–40 cm.

Cultivation prescriptions

See Table 4.6.

Only particular sites, such as extensive moorland with deep peat and no wood/boulder obstructions, will be suited to the best technique of mounds and tunnels. This is an unsuitable technique where there are moraines or areas of peaty gley exist. Where peat comprises around 40–70% of a new planting area, **shallow** double mouldboard ploughing (D30–35/–/t) is recommended. Where peat percentage is lower, cultivation should be the same as on peaty gleys, using either continuous or discontinuous mounding.

Table 4.6 Cultivation prescriptions for peats

[A = best general option, B = an acceptable alternative, C = a lesser alternative with some penalties]

Operation	*Prescriptions: General*		*Prescriptions: Specific soil type*	
New planting	A.	Spaced ploughing (D30–40/–/t)	**8.**	30–40 cm mounds
	B.	25–30 cm mounds and tunnels (wood-free peats >70 cm deep)	**10a.**	Spaced ploughing (deep *Sphagnum*) (D35–40/–/t)
	C.	25–30 cm mounds	All treatments require drainage	
Restocking	A.	25–30 cm mounding (continuous or discontinuous)		
	B.	Nil (direct planting on old ridge of ploughing away from the stump		
	Brash raking before mounding is advised			
Natural regeneration	Nil			

GROUNDWATER GLEYS

Soil types 5, 5b, 5z.
Allied soil types 15i, 15g, 15w.

Distribution

Groundwater gleys are a minor percentage of the forest area but can be locally frequent on the permeable alluvium of valley floors and in the slacks behind dune systems (e.g. Tentsmuir, Pembrey). Water-table is determined by the level of the groundwater which may be from 15 cm to 60 cm, according to soil type.

Soil/site characteristics

These soils are poorly or very poorly drained with anaerobic conditions below 40 cm (or even 20 cm in soil type 15w). The weed regrowth is vigorous apart from nutrient poor sites. Nutrition is generally good with moderate to high N availability. Soil types 15i and 5z are exceptions being low in N and P.

a.	Rooting depth:	20–25 cm.
b.	WHC topex value:	5–15.
c.	WHC soil score:	7.5 (5 in soil types 5b and 5z).
d.	Soil resistance:	Low (much drain collapse).
e.	Frost risk:	Very high.

Limitations

a. High water-table, often unalterable by drainage.
b. High weed vigour on most sites.
c. Low soil strength (affecting drains).
d. Traction difficulties in soil type 15w.
e. Frost is a general limitation.

Cultivations specifications

The requirement is for a raised planting position with uninterrupted root growth in all directions. Provision of large mounds is needed to reduce frost damage and weed competition.

Cultivations prescriptions

Continuous or discontinuous mounding with large (30–40 cm) mound specification is recommended. Alternatively, these sites can be excavated in parts and treated as wet woodlands with limited planting of appropriate broadleaves (e.g. willows, poplars, alders, downy birch) on mounds. If poplars are being planted on these sites for commercial reasons, then some drainage will be required for satisfactory growth (Jobling, 1990).

LITTORAL SOILS (freely drained)

Soil types 15.
Main phases 15d, 15e.

Distribution

Freely drained littoral soils are confined to wind deposited dunes and terraces (links), usually in complex distribution with slacks with groundwater-tables (included in groundwater gleys above). They may comprise from 35–65% of forested areas of coastal sands. Examples are found in Anglesey, Pembrey, Tentsmuir, Culbin and Lossiemouth.

Soil/site characteristics

These soils are very freely draining with poor retention of soil moisture. They are extremely low in humus and available nitrogen. Wind erosion is a high risk as the sites often have little vegetation and unstable slopes can occur (e.g. soil type 15d). Weed competition for moisture is acute and rooting depth is commonly greater than 60 cm. Locally pH may exceed 7.0.

Limitations

a. Low soil moisture retention.
b. Very low nitrogen.
c. Soil slips and limiting slopes for machinery on soil type 15d.
d. Wind erosion of the sand is a high risk.

Cultivations specifications

The main aim is to remove vegetation from the microsite whist conserving humus close to the tree. Provision of some physical shelter from abrading sand particles and from onshore salt deposition in the first two years is another desirable objective. Because of potential wind erosion, any extensive cultivation technique, even disc trenching, is to be avoided near the shore line.

In some countries, e.g. New Zealand, pre-cropping with legumes has been used to build up nitrogen/humus levels in the soil before new planting.

In restocking, it is important to conserve all harvesting residues – needles, bark, tops – in situ to augment the organic content of the sand.

Cultivation prescriptions

Screefing would be the preferred option on this site type. Patch scarification is a satisfactory alternative, particularly where it is combined with good vegetation control.

However, mounding should be considered if there is a risk of frost and/or sensitive species (e.g. Corsican pine, Douglas fir) are being used.

Chapter 6

Cultivation techniques

The general aim of cultivation is to make improvements to the microsite which result in:

- enhanced survival and improved, uniform early growth;
- reduced establishment costs;
- good access and prepared planting sites on restocking sites with moderate or heavy brash.

On most soil groups cultivation can provide the unrestricted rooting vital for long-term stability. On wet soils, it can improve local drainage and rooting depth. Good management involves combining a given species and plant type with one (or very few) standard cultivation techniques for each site type, in order to achieve consistently successful establishment.

Classification

As mechanical development continues, it is more logical to classify cultivation techniques by the type and extent of site treatment rather than by specific machines. The following classification distinguishes between techniques that treat extensive areas of the site and those that treat the planting spot and its immediate surround (Table 6.1). The advantages and limitations of various operations and techniques are then described.

Table 6.1 Cultivation classifications

Technique	*Extensive*	*Planting spot*
No cultivation	Mechanical weeding Overall herbicide/mulch	Hand weeding Spot herbicide/mulch
Scarification	Disc trenching Furrowing Bedding (dry soils)	Screefing Patch scarification
Subsurface treatments	Moling Subsoiling Ripping (deep subsoiling)	
Mounding	Bedding (wet soils) Rigg and furrs	Dry mounding Continuous mounding Discontinuous mounding
Ploughing	Deep tine ploughing Shallow ploughing Complete ploughing Agricultural ploughing	

Where appropriate, machine combinations can allow both extensive and spot techniques to be used on the same site, e.g. mounder-scarifier, or moling with mounding.

No cultivation

The effectiveness of no cultivation depends upon the quality of plants used and the amount of vegetation competition that is expected, and it is only appropriate on some sites. It is primarily applicable in new planting and restocking of **freely drained brown earths** where herbicides can be used to control weed competition for moisture and light. On steep brown earths (>50%) with a ground roughness of >3 which machines cannot traverse, no cultivation is the only suitable technique. On frosty sites or where sensitive species like Douglas fir or Corsican pine are planted, it is less beneficial than disc trenching because of its limited effect upon soil and air temperatures.

Direct planting is also possible for pines when restocking on **podzols** but nitrogen uptake is usually poorer and early growth much slower than after scarification. Rooting symmetry and depth of rooting on these soil groups are unlikely to differ between no cultivation and mechanical cultivation treatments. Where there are potential problems in restocking when brash residues limit the number of available planting positions, cultivation may be favoured for operational reasons.

On **ploughed peaty gleys and peats** which are relatively weed-free, no cultivation is an alternative restocking technique, provided the planting position used is the maximum distance between stumps on the ridges to provide symmetrical root systems, and the original ploughing was correctly aligned (Quine, 1990). On restocking gleys and peats with very large spruce stumps similar practice has to be followed though rooting symmetry is less good than on mounding. Where no cultivation is proposed, taller and sturdier plants are preferred. These should be in the best physiological condition with above average root collar diameter to compete with vegetation.

Apart from the situations noted above, no cultivation is generally the poorest option for achieving good survival and early growth, particularly if the soil has a high water-table (gleys, ironpans, peats). However, no cultivation is the safest technique to use whenever the environmental impact of cultivation (e.g. sedimentation in water catchments) is the prime concern.

Scarification

Mechanical scarifiers have been designed to perform shallow continuous or discontinuous cultivation up to a depth of 20 cm on freely and imperfectly drained soils. These are normally of a coarse loamy texture (up to silt loam) and with the F/H layer less than 10–15 cm deep. The aim is to prepare planting positions by scraping off surface vegetation and redistributing brash. Soil, humus and litter are mixed to provide a bare microsite with increased soil temperature, reduced competition from weeds, and possibly reduced weevil damage where a larger surface area is treated. Desirably, scarification should provide a mix of humus and mineral soil to improve availability of nitrogen. However, mixing of surface horizons and subsoil should be minimized.

Slopes above 30% can be difficult or unsafe for mechanical scarifiers unless modern prime movers (e.g. Timberjack 460) are used. Terrain roughness greater than 3 causes difficulty for operating the equipment and results in excessive wear. On the steepest slopes, screefing by hand with mattocks can be used.

Scarifiers can be widely used for new planting, for preparing surfaces for natural regeneration, for restocking on suitable soil types and, in the case of disc trenchers, for rearranging brash. In new planting on **brown earths**, scarification must be carefully combined with herbicide treatments to obtain the best results since scarification alone will only give short-term weed control. In restocking, scarifiers operate best in light brash such as that found with older pine, larch and Douglas fir. In moderate brash, efficiency of cultivation decreases, and two passes may be necessary in heavy brash. The lighter spot scarification techniques – scalping, patch scarification and dry mounding – cannot be applied effectively in moderate or heavy brash conditions. Powered disc scarifiers with downward hydraulic pressure can be used solely for brash treatment as a preparatory treatment to cultivation.

Scarifiers can be employed widely on sites in eastern, central and southern Britain and the brown earth and ironpan soils in Wales. In the west and north, uses are more site-specific and may be confined to sloping ground with brown earths and podzols and to moraines or for pulverising brash before mounding. Walking excavators can be used both to rake brash on steeper slopes to assist direct planting and to provide shallow screefing.

Scarification techniques can be sub-divided as shown in Table 6.2.

Table 6.2 Techniques for scarification

Extensive techniques (e.g. disc trenching, furrowing) cultivation of 15–30% of the site.	*Spot techniques (e.g. screefing, patch scarification, dry mounding) cultivation of 5–8% of the site.*

Disc trenching

Description

Disc trenching is continuous row scarification, with great flexibility in the width and depth settings of the machinery (up to 20 cm depth and from 0.4–1.0 m width). Most of the litter and humus is moved to the outside of the cultivated area.

The planting position is normally at the mid-point of the angled trench which is taken as the hinge between trench and ridge. The flatter setting of the disc is more appropriate on weedy sites, e.g. brown earths.

Benefits

Disc trenching raises soil temperature more effectively than any other scarification treatment except bedding. It is capable of overcoming rougher site conditions than patch scarification and will operate on moderate brash and up to terrain roughness 3 and slope class 50–55% (with crawlers).

It is a robust, versatile technique which can be extensively used to replace ploughing on brown earths and podzols. It can also be employed on ironpan soils in restocking where the pan was broken at the time of afforestation.

Effects

When freshly prepared, disc trenching is moderately visible in the landscape and, on slopes, should be controlled using the same guidelines as ploughing, i.e. lifting trenchers to break up the length of run.

There is a moderate erosion risk on slopes and initially, there can be sediment movement and an effect on water quality.

Nutrient losses are larger than with patch scarification or dry mounding. There can be soil compaction on the sides of the trench in some soil textures, e.g. silt loam, from the cutting action of the discs.

Recommendations

Heavy log residues should be removed during harvesting and lop and top should be cut into 1 m lengths.

The larger surface area prepared makes this a more suitable technique for natural regeneration than patch scarification.

Screefing

Description

Screefing is the formation of shallow mineral scrapes (approx. 10 cm depth x 20–30 cm^2) on freely drained loose sandy soils with low humus content and light weed growth in dry regions. The bottom of the scrape is used as the planting position.

Benefits

The effect is to provide a weed-free spot where there is some shading and lesser evaporative demand in the first growing season. Capillary moisture in the sand at the bottom of the screef is more readily available to the tree.

Effects

There is a slight effect on air and soil temperature and a temporary effect on weed control. It has no visual impact on the landscape.

Recommendations

The scrapes can be created by locally designed equipment mounted on an agricultural tractor or by using the lighter forms of two row scarifier at a shallow setting (TTS10 or Leno 77).

It is only suitable when there is very shallow humus and light weed growth, e.g. sandy kames and eskers, friable podzols on sands in the lowlands, or on freely drained littoral sand (soil type 15e).

It is not effective in restocking if brash cover is moderate to heavy.

It is not recommended for weedy sites or moist to wet soils including ground water gleys where the bottom of the scrape would become waterlogged in winter.

Table 6.2 *(continued)*

Extensive techniques (e.g. disc trenching, furrowing) cultivation of 15–30% of the site.	*Spot techniques (e.g. screefing, patch scarification, dry mounding) cultivation of 5–8% of the site.*

Furrowing

Description

Furrowing is a form of trenching technique using a tilted blade or V-plough head to make a shallow (15–25 cm) V-shaped furrow on loose sandy soils with very free drainage in dry sites (primarily in southern and eastern England). The planting position is in the bottom of furrow.

Benefits

The benefits of the furrow are to provide partial shade, reduce plant transpiration and position the plant where the roots have access to capillary moisture. Weed competition is temporarily reduced which also increases the moisture availability.

Effects

This type of scarification can be as visible in the landscape as ploughing.

Recommendations

The technique can be used with pines on southern lowland sandy soils and very freely drained littoral sands (e.g. soil type 15e) for both new planting and restocking where light pine brash occurs.

It can cope with dense weed swards better than bedding or scalping.

Creating furrows deeper than 25 cm can result in nitrogen deficiency as humus is placed too far from the plant. It is not a suitable technique for hardpan podzols, ironpan soils or any wet soils.

Patch scarification

Description

Patch scarification is the discontinuous removal of surface humus to expose mineral soil, usually to depths of 15 cm in patches some 40 cm wide by 70 cm long and about 2 m apart. Optimum patch surface area is 0.25–0.35 m² (Örlander *et al.*, 1990). The planting position is normally within10–15 cm of edge of the scrape to take advantage of the humus–soil mix there.

The normal machinery is a two row patch scarifier using mattock wheels (Leno 81, Bräcke scarifier).

Benefits

The performance is best in restocking on podzols with a pronounced F layer with light brash cover. It can be used when restocking podzols, typical ironpan soils or brown earths with weak weed growth.

Effects

Patch scarification has less effect on soil and site temperature than disc trenching owing to its depressed position. It is a technique which scores highly on environmental grounds because it is not very visible in the landscape and there is a limited amount of ground disturbance. Too small an area is cultivated for it to be an efficient seedbed preparation for natural regeneration of pine. However, there is less risk of invasion by birch than with disc trenchers.

Recommendations

The technique is particularly suited to light soils in the eastern and southern lowlands of Britain. It should not be used on weedy sites where colonization and competition is too rapid.

Bedding

Description

Bedding is the formation of continuous narrow shallow aerated beds up to 50 cm wide on freely drained sandy or sandy loam soils, using inward-set concave double or treble discs providing 15–20 cm cultivation depth.

Benefits

The treatment increases pore volume and improves soil moisture availability through partial weed control, particularly in the first year. There can be drought risks at planting if there has been no precipitation for a long period. Bedding has a positive impact on soil and air temperature which can be useful for the establishment of frost tender species.

Table 6.2 *(continued)*

Extensive techniques (e.g. disc trenching, furrowing) cultivation of 15–30% of the site.	*Spot techniques (e.g. screefing, patch scarification, dry mounding) cultivation of 5–8% of the site.*
Recommendations The technique could be appropriate for new planting with light vegetation cover (bracken excluded) on sandy and coarse loamy soils, in regions in southern and eastern Britain with a high potential water deficit in the growing season. Agricultural equipment can be used but is not robust enough for restocking. Suitable equipment (Eden bedding discs) has been designed and used for restocking in New Zealand, British Columbia and Australia (Turvey and Cameron, 1986) usually following windrowing of brash. Bedding alone is inadequate when there is a plough pan or cementation (soil type 3mx) and must be combined with ripping or subsoiling (see below). Even or gently rolling terrain is a requirement for bedding. It is not used on slopes much above 15% and is unsuitable for bouldery soils or terrain roughness 2 or above.	

Subsurface treatments

This group of treatments can be divided into moling, subsoiling and ripping. Planting can occur in the limited surface cultivation which occurs along the line of the shank which carries the implements. However, these treatments are frequently combined with other forms of surface cultivation to provide planting positions. Examples of these combined treatments are moler-mounder, moler-screefer, subsoiler-screefer – the latter two being created by attached small mouldboards (screefers).

Use of subsurface treatments in restocking is rare because stumps, roots, brash and previous ploughing seriously disrupt the passage of the shank or cause frequent breakages of the subsurface channel. On new planting sites, it is worth considering whether one of these treatments could improve a limiting soil condition since the opportunity will not occur again. Table 6.3 discusses various soil types which can be treated in this way.

Moling

Description

Moling is the technique of inserting continuous subsurface channels in firm (nearly stone-free) clay and fine loamy soils to act as drainage channels. Suitable soil types are surface water gleys, humic gleys and thin peat peaty gleys. Depth of channel is usually 35–45 cm and spacing 2 m or 4 m.

Benefits

The effect is to lower water-table and reduce waterlogging peaks, thus encouraging deeper rooting and increased stability. Effective moling depends upon the operation being carried out in the driest months of the year since in wet conditions the soil collapses behind the mole channel.

Suitable drifts are infrequent in upland Britain. Examples are the tills on Carboniferous shales and some igneous rocks, and Estuarine (Jurassic) clays in the North York Moors. Suitable drifts are more common in the lowlands, e.g. London Clay, Northampton Clay, Jurassic clay.

Recommendations

Moling is not recommended for soils on drifts with stones and boulders when subsoiling must be substituted. Soils of very poor structure such as the Weald Clay (silts) are also unsuitable because of the collapse of the mole channel.

Table 6.3 Prescriptions for subsurface treatments

Soil type (number)	*Texture*	*Limitation*	*Objective*	*Technique*	*Specification* *Depth (cm)*	*Specification* *Spacing (m)*	*Planting site*
Surface water gley (7) Thin peat peaty gley (6) >2° gradient	Fine loamy Stone-free	Drainage Low permeability	Mole drain channels	Moling or Moling-screefer or Moling & mounding	40	2	Mole channel or screefer spoil
Surface water gley (7l) Peaty gley (6l) >2° gradient	Loamy slight to moderate stony	Drainage	Subsoiler drain channel	Subsoiler + Mounder or Subsoiler-screefer 45–60 cm	40–45	4	Mound by supplementary mounding screefer spoil
Surface water gley (7x) on induration Podzolic gley on induration >2° gradient (7zx)	Coarse loamy	Drainage High bulk density in subsoil	Subsoiler Shatter surface of indurated layer	Winged subsoiler + mounder or Winged subsoiler + D45/T60/t or m	45–60	4/2	Mound or plough ridge
Lowland podzol with cementation (3mx) Cultivated podzols with ploughplan (3cx)	Sandy	Cementation at depth	Shatter cementation	Winged ripper	60–70	2	Rip channel
Ironpan soil (4zx)	Coarse loamy	Deep lying ironpan – perched gleyed horizon	Breach ironpan Reduce bulk density in other horizons	Winged ripper + D45/T60/t or m	50–70	2	Plough ridge
Peaty ironpan soil (4pg) with B(g) horizon	Loamy	Strong ironpan Gleyed B horizon	Breach ironpan Provide drainage channels	Subsoiler + mounder Subsoiler + D45/T60	45–60	2	Mound or plough ridge
Cultivated brown earth (1c)	Loamy	Ploughpan	Restore B horizaon to friable	Subsoiler	45–60	2	Subsoiler channel
Brown earth with induration at <45 cm (1x)	Loamy	Induration restricting rooting depth	Shatter surface of indurated layer	Winged subsoiler	30–50	2	Subsoiler channel

Subsoiling

Description

Subsoiling is a method of breaking the soil structure (e.g. ploughpan formations) without any mixing of the horizons. It can be used in combination with other techniques such as ploughing. It is usually carried out at depths of 45–60 cm.

Benefits

This technique can be used in two distinctive ways:

- to form irregular loose drainage channels in loamy gley soils (or in slightly stony fine loamy gley soils which are beyond the technical range of moling); or
- to reduce the bulk density of indurated or ploughpan horizons relatively near the surface (30–50 cm). For this function shoes should be fitted to the shank to break the pan between lines of subsoiling.

Recommendations

This should be a standard operation on any soil with a shallow indurated horizon. It is also a more versatile and robust drainage technique than moling and may have much wider use in the uplands.

Caution

Gradient is a key factor in the functioning of mole or subsoiler channels in gley soils. Such channels do not conduct water efficiently at gradients less than 2° and it follows that moling or subsoiling in flat wet loamy or clayey gleys is difficult to justify.

Moling or subsoiling on moderate slopes presents a serious erosion hazard unless accompanied by frequent cross-drains and regular inspection to check that spoil carried down the channel does not block drains. Drains should be laid out according to the guidelines given by Pyatt (1990a). Considerable care is needed in the depth-setting of equipment on agricultural gley soils which may have tile or stone drains. Unless these former drains show many fractures, mounding with no moling or subsoiler drainage channels may be the safer prescription.

Ripping

Description

Ripping (50–70 cm) is used to deal with deeper lying soil features, e.g. cementation in hardpan podzols, or the compact Eg/strong ironpan at 40–55 cm in soil type 4zx. The equipment used is similar to rock ripping equipment and requires a prime mover with a very high drawbar pull (D6 or D7 tractor units).

Benefits

Ripping is an expensive technique which can only be justified for a few specific purposes. There is little evidence that major changes can be made to the bulk density of indurated subsoils below 45 cm and there is little to justify ripping of the indurated layer when it is this deep.

Mounding

Mounding is the provision of regularly spaced heaps of soil to provide a planting spot. Formerly, mounds were dug manually (see Sutton, 1993 for a description of 19th century techniques) but they are now constructed by purpose-built mechanical continuous mounders (e.g. Donaren 870 mounder, Sinkillä mounder, MacLarty mounder) or by excavator mounders with suitable tracks. Helical ploughing (e.g. Table 2.12) was an attempt at breaking the plough ridge to simulate mounding on new planting sites.

It is convenient to distinguish between mounding on drier mineral soils (dry mounding) and mounding on peats and gleys (wet soil mounding).

Dry mounding

Description

Dry mounding is a technique for forming freely drained mounds (up to 20 cm high) of soil, soil/humus or of humus capped with mineral soil on dry or moist soils, usually of a coarse loamy texture.

Benefits

The effect is to form a raised, well-drained planting position on the mound which has higher soil temperature, less weed competition and improved weevil protection compared with patch scarification.

Effects

Nutrient turn-over is slower than with disc trenching. The mound can be too loose if used in very dry conditions and there can be a risk of winter desiccation from freezing winds as the planting position is higher than in disc trench or patch scarification. Mineral mounds will also freeze more readily than scarified patches. Mounding should be used with caution on sites subject to summer drought.

The end-result is visible in the landscape but less than with disc trenching or tine ploughing. In restocking, most mounds are concealed by general brash cover.

Recommendations

Mounds can be created on scarified patches by hydraulic shovels (Bräcke mounder-scarifier) or can be conventionally formed by a continuous mounder (Sinkillä HMF mounder). On small sites, small excavators can be used. A cap of mineral soil (10–15 cm deep) or compression by the mounder mattock is desirable to press down the loose humus/soil or brash/humus/soil mix.

The technique has proved to be a suitable alternative to disc trenching for restocking site preparation on podzols; typical ironpan soils, and also imperfectly drained brown earths (soil type 1g). Terrain and brash restrictions are similar to patch scarification.

Wet soil mounding

Description

The formation of heaps of peat or mineral soils or peat/soil mixtures to form a raised planting position on wet soils.

Benefits

The beneficial effects are improved drainage of the microsite, improved survival, a warmer planting position, less frost risk, and initial reduction of shading and competition by weeds. Rooting symmetry is very good so that improved stability may be anticipated.

Effects

There can be plant losses due to root exposure if mounds are planted before settlement or if there is winter desiccation due to the mounds being frozen. The risk of freezing is greater on mounds of mineral soil than with peats. There can also be deaths in dry springs if the mounds dry out.

Growth rate may be slightly less than on ploughing. On gleys with ericaceous vegetation (soil types 6e, 6pe, 7z), the intensity of herbicide treatment may need to be increased because suppression of *Calluna* by mounds is weaker than on ploughing.

Recommendations

The size of mounds advised for general situations is 20–30 cm in height and 50 by 50 cm wide (i.e. 60–70 l of soil). The height should be increased by 10 cm on very weedy site types e.g. flushed gleys and flushed peats (soil types 7f, 6f, 8a–d) and by 20 cm in poplar/willow culture on fertile groundwater gleys (soil types 15g, 15w). Some form of drainage will be required to remove any subsurface water from the site.

Mounding is strongly recommended as the general specification for new planting on gley soils (soil types 5, 6 and 7) as it provides better root symmetry than ploughing and has less impact in the landscape. Mounding must always be accompanied by effective drainage. Continuous mechanical mounders are more cost-effective than excavator mounders on larger scale gley soil sites but, on small sites, the case is reversed.

On flat, deep peat soils, there can be problems with ponding and with the quality of the mound produced by continuous mechanical mounders.

In restocking, the efficient operation of continuous mechanical mounders is seriously affected by the roots, stumps and dense brash on both gley soils and peat soils. whilst continuous mounders are capable of operating on the brash-free lane at about 70–80% effectiveness, intermittent raking of brash in windrows is required before a satisfactory mound spacing can be achieved. Brash raking by continuous mounders is more effective when lop and top is cut to 3 m lengths and placed across the direction of machine travel. Excavator mounding is more versatile the tougher the conditions become.

Riggs and furrs

The creation of riggs and furrs is a technique which may be considered for dense clay soils in some eastern areas. The riggs must be formed in dry seasons without serious soil compaction and where the gradient is less than 2°, precluding the use of subsurface treatments. The ratio of organic material to mineral should not be high to allow effective mixing. Therefore, peaty podzolic gleys over a fine loamy subsoil may be a better subject than wet peaty gleys.

Control of *Calluna* competition is better than on mounding but the visual effect is prominent. This is also a very expensive technique which is only justified in exceptional circumstances. Bedding techniques have been used in New Zealand to create miniature riggs on clays in dry regions but there is only limited experience of this in Britain.

Raised planting positions and greater overall weed control can be obtained by re-shaping the soil surface and mixing topsoil into continuous beds or riggs which can accommodate from one up to five rows of plants (Booth, 1967). The side rows may suffer from nutritional deficiency and some waterlogging, the influence of subsoil being greatest at this point. Riggs need to have drainage and/or subsurface drainage to remove surface water from the site.

Ploughing

Ploughing is the most intensive cultivation technique available with the possible exception of deep ripping. Large robust ploughs, trailed or mounted, are used to form continuous ridges and furrows (minimum 35 cm deep). Smaller ploughs, similar to heavy agricultural ploughs, can be used in lowland Britain. Normally, it is the ridge which is planted but in very freely drained soils, the furrow may be used or the mid-trench position in weedy brown earths. Ploughing has several short-term advantages, but also a range of potential disadvantages (see Table 6.4).

The history of the development of ploughs in British forestry has been described by Neustein (1976, 1977; see also Taylor, 1970; Thompson, 1978). Thompson (1984) gave recommendations for the use of ploughs for broad soil groups and cultivation objectives. These are outlined as a footnote[1] to Table 6.4 to provide a contrast with current thinking.

Increasing recognition of the disadvantages has led to a reduction in the use of ploughing (Anon., 1993). Examination of Tables 4.1 to 4.6 will show that on many site types ploughing is no longer the preferred option. For instance, scarification combined with herbicides is the recommended option for brown earths at new planting and for the restocking of podzols and ironpan soils.

Shallow single mouldboard ploughing (S25/–/t), equivalent to furrowing, is a useful technique for ex-agricultural improved grass sites on sandy soils. However, ploughing should not be used on cultivated loamy brown earths (arable status, soil type 1c) or cultivated surface water gleys (soil type 7c) where it promotes invasion by undesirable weeds.

Complete ploughing is only justified on ironpan soils at new planting (soil types 4z, 4zx and typical 4-ericaceous).

Ploughing at new planting greatly increases the risk of instability on fine loamy surface water gleys because it interrupts the friable A or Ah horizon and the bottom of the furrow rests on the wet compact Bg horizon. Shallow ploughing on peaty gleys is slightly less hazardous but is a poor alternative to mounding, again for stability reasons.

On deep peat, shallow/medium (30–35 cm) double mouldboard ploughing remains an

Table 6.4 Advantages and disadvantages of ploughing

Short-term advantages	Short- and long-term disadvantages
It is a versatile technique which can be used on several soil types where these are mixed on one site.	Ploughing has promoted marked asymmetry of rooting on gleys, peats and ironpan soils, with damaging effects on stability in windy zones.
It gives a consistent output and is relatively cheap compared with other techniques, especially on new planting sites.	Run-off is rapid and soil water turbidity is increased for several years, thus affecting water quality.
It provides higher soil temperatures and reduced frost risk.	The continuous furrow pattern increases the risk of erosion on moderate and steep slopes.
There is higher survival than with manual mounding or screefing techniques.	Nutrient release is very rapid and, because vegetation cover is depleted by the cultivation and the trees are too small to use all available nutrients, there can be nutrient losses from site particularly where fertilizer application follows ploughing.
Good weed control is obtained.	Nitrogen mineralization proceeds too fast on soils low in nitrogen. This can result in later growth check to sensitive species.
There is rapid nutrient release.	On many soils, more of the site is cultivated than is necessary for the improvement of the micro-environment which the plant requires for establishment.
There can be reduced weevil damage in restocking.	In restocking, ploughing becomes technically difficult and expensive because of stumps, roots and slash. When deeper ploughing is used to overcome these obstructions, the disadvantages noted above are emphasized, including asymmetry of rooting.
Rough steep slopes can be tackled with mounted outfits.	The practice is strongly intrusive in the landscape, especially on slopes.
On restocking freely drained sites, by using the plough as a V-blade, light brash is cleared to provide easy access to planting positions.	

[1] For new planting on brown earths and podzols, the aim was to provide 30–45 cm depth of mineral soil cultivation. On ironpan soils, tines (subsoilers) 45–60 cm deep were attached. These could be upgraded to reach up to 90 cm for an indurated or deep lying ironpan or podzolic gley on induration. Site preparation on fine loamy gley soils and peats required the ploughing of 45–60 cm ridges set slightly back from the furrow, with 60 cm subsoilers added for compact fine loamy or indurated gleys. Mounted ploughs were favoured for cultivating restocking sites on mineral soils to increase flexibility on stump-covered ground. Hook (sickle) beams were used in heavy brash conditions to overcome clogging of the head.

acceptable prescription. Owing to the presence of wood layers or frequent occurrences of peaty gley or projecting boulders from underlying till, most upland blanket peats are not suitable for the tunnel and mound technique. Where the *Sphagnum* or vegetation layer is deep, the ridge depth can be increased to a maximum of 40 cm.

Selection of appropriate machinery

Machinery and equipment best suited to carry out the prescription in the circumstances of slope class, roughness, soil mosaic, vegetation and brash should be selected. For site preparation on very small areas of agricultural land, adaptations of agricultural or small civil engineering equipment should be considered provided they can meet the specification for the soil/site type.

Current machines and equipment which will perform various operations and techniques in average conditions are listed in Appendix 2 and their slope limitations are shown in Appendix 3. More detailed information can be obtained from Forest Research's Technical Development Branch or reference made to Coates and Haeussler (1987).

If site types on an area are very varied, it is necessary to select versatile machines or equipment. Continuous mounders are versatile but their ability to cope with extensive site preparation on peats is uncertain. Double mouldboard tine ploughs were formerly regarded as very versatile in new planting but should be excluded from gley soils on the grounds of poor rooting pattern in relation to stability. This restricts their value on sites with mixed peaty podzols and peaty gleys. The combination of mounding with sub-surface treatment such as moling or subsoiling on gleys (with the exception of tunnel mounding on some deep peats) can now be achieved using the MacLarty moler/mounder.

Chapter 7

Economic evaluation of the benefits of cultivations

As noted in Chapter 2, the choice of cultivation technique is governed by the potential impact upon establishment success and longer-term stand growth. Because of the length of time between stand regeneration and final harvest, it is customary to evaluate options by discounting relevant expenditures and revenues back to present values and comparing their benefit cost ratios (Busby and Grayson, 1981; Insley *et al.*, 1987). This approach is particularly important when considering cultivation options since expenditure is incurred at the beginning of the regeneration process and can therefore have a considerable impact upon the overall profitability of a particular forestry investment.

There are four aspects that should be considered when seeking to undertake an economic appraisal of cultivation options. These are:

- saving in establishment costs;
- longer-term impacts upon stand growth;
- influence upon stand stability;
- impact upon the wider environment.

Apart from the method based upon savings in total establishment cost, the estimation of the financial benefits of cultivation is difficult. This is primarily because the existing experimental evidence is inadequate to allow us to quantify long-term responses of the major species to different cultivation techniques on the major site types in Britain. However, the difficulty of evaluating long-term benefits or costs does not mean that these should be ignored when appraising cultivation options. Sensitivity analysis can be used to test the impact of a range of assumptions. If long-term

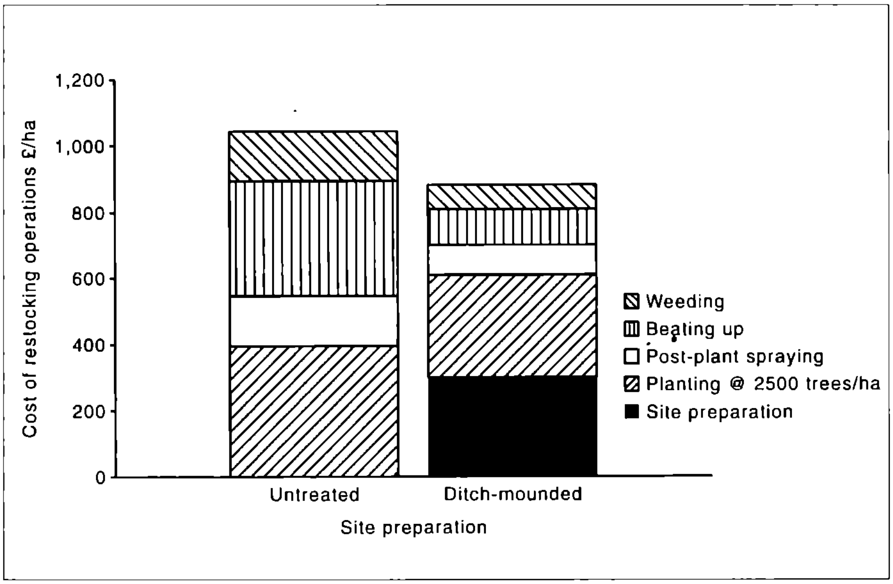

Figure 7.1 Establishment costs for two different restocking systems in Argyll. [Source: Morgan and McKay, 1996]

implications are ignored, this may lead to the continuing use of cultivation techniques that are convenient, familiar, and which benefit short-term growth, but are sub-optimal over the life of a stand.

Saving in establishment costs

The traditional way of ranking cultivation options is to assume there are no long-term effects of cultivation upon the growth and yield of a stand after it is established. Therefore it is possible to evaluate options by comparing the total cost of establishment operations, including cultivation, until the trees are established which is normally when the trees are about 1.5 m tall. The option which provides for the 'least cost' establishment package will be chosen. Since costs of cultivation technique, weeding and beating-up are readily available, this method is comparatively easy to apply. The range of additional costs that could be incurred by cultivation is outlined in Table 7.1. This highlights the comparative cheapness of ploughing relative to other techniques and the greater expenditure involved in cultivating restocking sites. However, such increases are often compensated by lower planting costs (e.g. £70–80 ha^{-1} for planting on mounds as against £100–120 ha^{-1} for direct planting of an uncultivated site). There should also be lower beating-up costs (both in terms of the percentage losses and of the cost of planting replacement trees), lower protection costs and fewer and less costly weeding operations, as a result of cultivation. For example, the cost of mounding when restocking surface water gleys in Argyll was more than justified by savings in the total establishment cost (see Figure 7.1).

Table 7.1 Range of costs (£96/97) for different cultivation techniques in Britain

Technique	*Cost (£ ha^{-1})*	
Ploughing – new planting	50 – 80	
MacLarty mounder – new planting	70 – 100	
Scarifying – new planting	80 – 120	
Disc trench scarification – restocking	120 – 200	
Continuous mounder – new planting	120 – 200	(Donaren)
Continuous mounder – restocking	120 – 250	(Donaren)
Excavator – brash rake	100 – 150	
Excavator – mounder	225 – 350	
Walking excavator	300 – 400	

However, this example will not apply on all sites. Thus, cultivation may seem less attractive on a peaty gley site where vegetation competition is limited (hence lower weeding costs) and careful planting and plant handling ensures high initial survival. In such circumstances, the use of cultivation would have to be justified because of benefits to long-term stability. The important lesson is that foresters should have separate models of establishment costs for the major site types in their area that identify the contribution of different operations to the overall cost.

While the approach of choosing the 'least cost' establishment package may justify investment in cultivation, it is less satisfactory for choosing between cultivation treatments. This is because problems that occur later in the rotation such as poor root architecture after ploughing of gley soils or lesser growth because of a failure to disrupt an ironpan will not be considered.

Longer-term impacts upon growth

It should be evident from a study of longer-term experiments (see Chapter 2) that differences between no cultivation and cultivation can persist well beyond the establishment phase. In the case of the experiment at Inshriach such differences can represent potential increases in mean annual volume increment of 2 m^3 ha^{-1} yr^{-1} over a normal rotation. Such benefits are due to the efficiency of establishment rather than to cultivation per se, but they should be allowed for in evaluation of establishment and hence cultivation options.

These differences between cultivation and no-cultivation are thought to be due to the speed with which the trees initially exploit the site and not to a change in the site potential. They can thus be evaluated as 'years saved' to rotation age for stands of a common yield class. There is increasing evidence, at least for Sitka spruce (South and Mason, 1993; Lee, 1992), that percentage differences in height growth at 6–10 years can be translated into similar volume gains later in the rotation. Therefore, the best way of accounting for anticipated longer-term growth differences due to cultivation over no-cultivation will be as follows:

1. Estimate the anticipated unimproved (i.e. uncultivated) yield class for the species and site.
2. Calculate the anticipated percentage growth difference due to cultivation 6–10 years after planting.
3. Find the volume at rotation for the species, unimproved yield class and yield model.
4. Multiply the predicted rotation volume by the percentage growth difference to estimate the predicted volume gain from cultivation.
5. See what this volume gain represents in terms of years saved.
6. The 'years saved' can be used to adjust discounted revenue. For example, if, on a rotation of 45 years, the discounted revenue (at 6%) is £600 ha^{-1}, a saving of 5 years would increase discounted revenue to £803 ha^{-1}. The increase in discounted revenue can be set against any increase in discounted expenditure arising from the cultivation treatments.

This is clearly a more complex set of calculations and is probably not necessary except in those situations (e.g. on steep terrain) where cultivation proves to be so expensive that benefits from easier establishment are insufficient on their own to justify its introduction. The procedure outlined above is broadly similar to the calculations of 'adjusted age' for accommodating fertilizer response proposed by Edwards and Christie (1981).

While this procedure for comparing cultivation and no-cultivation has sound experimental backing, it could be risky to use

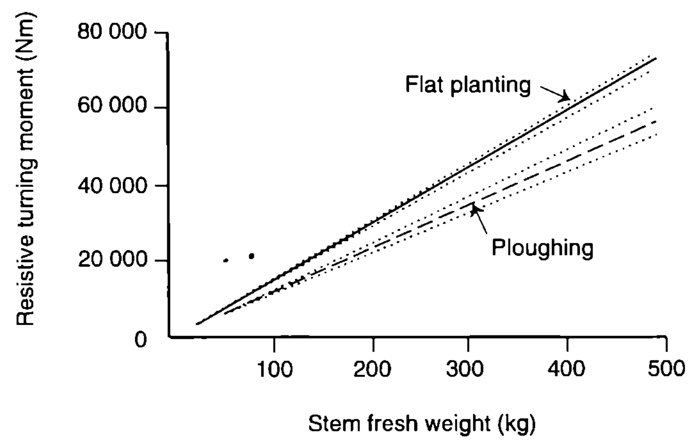

Figure 7.2 The difference in anchorage (expressed as resistive turning moment) for spruce trees planted on ploughing as opposed to turf or flat planting on gleyed soils in Britain. A higher turning moment indicates greater resistance to over-turning. The dotted lines show the 95% confidence limits of the regressions with number of trees for flat planting = 527 and for ploughing = 87. [Source: Nicoll and Ray, unpublished]

it to distinguish between different types or intensities of cultivation. Some evidence (Wilson and Pyatt, 1984) is that there may be appreciable changes in rank over time between cultivation treatments whereas other data suggest differences are reasonably consistent. Evaluating different cultivation techniques will depend upon a more detailed analysis of the limiting factors at a particular site. Managers wishing to undertake such an analysis can be assisted by the appropriate specialist in Forest Research (the Forestry Commission Research Agency).

The only exception to this advice will be on podzol or ironpan soils where cultivation can be used to increase the amount of rootable soil volume. Provided other limiting factors (e.g. nutrition, soil moisture) do not intervene, then improved growth will result from trees planted on types of cultivation that disrupt the impermeable horizon compared to those that only cultivate the surface layers (Zehetmayr, 1960). As noted in Chapter 2, such growth benefits are likely to be limited to pines and larches. However, for these species, the benefits represent a permanent change in site potential and can be expressed as a change in yield class possibly by up to 4 m^3 ha^{-1} yr^{-1}. The amount of increase will again depend upon the particular site and interested readers should consult Forest Research specialists.

Influence upon stand stability

It will be evident from Chapter 2 (also Figure 7.2) that certain cultivation techniques (e.g. spaced furrow ploughing) can increase the risk of windthrow on wet, shallow-rooting gley and peat soils. On these soils it is essential to encourage symmetrical root systems and also increase rooting depth where this is possible.

The occurrence of windthrow is a probabilistic function of the interaction of a critical wind speed and a particular stand structure. Cultivation that induces asymmetrical root systems will reduce the critical wind speed required to over-turn trees. However, it is not possible to say that adopting certain cultivation techniques will reduce the amount of windthrow by x %. The degree to which this affects the probability of damage will be site specific and calculated using the replacement to the windthrow hazard classification (Quine, 1994). Greater stability will lead to a longer rotation; this benefit can be expressed in terms of discounted revenue and compared against any increased establishment costs due to the use of alternative cultivation techniques.

Non-market values

It should also be apparent that cultivation, particularly of the more intensive kinds, can produce negative environmental impacts (e.g. increased sediment load, more intrusive in the landscape). Normally, these impacts are covered in the relevant Forestry Commission Guidelines, so that the choice of cultivation techniques is constrained to meet environmental requirements. However, the manager should always be aware of the need for a trade off between cultivation techniques that optimise timber production and those that accommodate a wider range of interests.

Conclusion

This Bulletin has described the effects of cultivation on the microsite and upon the wider forest environment. The forester can use this guide to formulate prescriptions and select techniques which are appropriate to different site types and environmental considerations. In outlining options, the recommendations favour those techniques which present least risk of damage to the environment and which best promote rooting patterns favourable to the stability of trees and stands. The general theme has been to work within the limitations of the site.

While large Scandinavian machines and equipment are appropriate in larger cultivation programmes, in this country, such equipment is unlikely to be cost-effective on the small scale of farms and lowland woodlands. Factors of ownership and scale are further compounded by the very rapid changes in geology, soils, climate and weed growth within short distances that is so characteristic of Britain. However, with a sound appreciation of the microsite specifications required for different soil types, slope classes and weed potential, equipment can be designed to suit these conditions. The increased use of tracked excavators with mounding buckets to cultivate restocking sites is an example of this process.

Cultivation is only one element in the achievement of cost-effective establishment. A cultivation technique has to be carefully integrated with other silvicultural specifications to be successful. Successful establishment depends upon the matching of species, site, soil and vegetation to create a sustainable forest. The careful husbandry of the forest soil is of paramount importance in sustaining site fertility and productivity. Cultivation has an important role in the management of forest soils and the forester must use this technique wisely for the long-term benefit of the forest.

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Appendix 1

Soil groups, types, codes and phases

The main mineral and shallow peaty soils (peat <45 cm deep)

	Soil group	*Soil type*	*Code*
Soils with well aerated subsoil	Brown earths	Typical brown earth	1
		Basic brown earth	1b
		Andic brown earth	1d
		Upland brown earth	1z
	Podzols	Typical podzol	3
		Hardpan podzol	3m
	Ironpan soils	Typical ironpan soils	4
		Intergrade ironpan soil	4b
		Podzolic ironpan soil	4z
	Limestone soils	Rendzina	12
		Brown calcareous earth	12b
		Argillic brown earth	12t
Soils with poorly aerated subsoil	Ground-water gley soils	Typical ground-water gley	5
		Brown ground-water gley	5b
		Podzolic ground-water gley	5z
	Peaty gley soils	Typical peaty gley	6
		Peaty podzolic gley	6z
	Surface-water gley soils	Typical surface-water gley	7
		Brown gley	7b
		Podzolic gley	7z

Peatland soils (peat >45 cm deep)

	Soil group	*Soil type*	*Code*
Flushed peatlands	*Juncus* bogs (basin bogs)	Fen bog	8a
		Juncus articulatus or *acutiflorus* bog	8b
		Juncus effusus bog	8c
		Carex bog	8d
	Molinia bogs (flushed blanket bogs)	*Molinia, Myrica, Salix* bog	9a
		Molinia bog; *Molinia, Calluna* bog	9b
		Molinia, Eriophorum vaginatum bog	9c
		Molinia, Eriophorum vaginatum, Trichophorum bog	9d
		Trichophorum, Calluna, Eriophorum, Molinia bog	9e
Unflushed peatlands	*Sphagnum* bogs (flat or raised bogs)	Lowland *Sphagnum* bog	10a
		Upland *Sphagnum* bog	10b
	Calluna, Eriophorum, Trichophorum bogs, (unflushed blanket bogs)	*Calluna* blanket bog	11a
		Calluna, Eriophorum vaginatum blanket bog	11b
		Trichophorum, Calluna blanket bog	11c
		Eriophorum blanket bog	11d
	Eroded bogs	Eroded bog	14
		Deeply hagged bog	14h
		Pooled bog	14w

Other soils

	Soil group	*Soil type*	*Code*
	Man-made soils	Mining spoil, shaly or fine textured	2g
		Mining spoil, stony or coarse textured	2s
	Rankers and sketetal soils	Brown ranker	13b
		Gley ranker	13g
		Peaty ranker	13p
		Rock	13r
		Podzolic ranker	13z
		Ranker complex	13c
		Scree	13s
		Humic skeletal soil	13h
	Littoral soils	Shingle	15s
		Dunes	15d
		Sand with deep water-table	15e
		Sand with moderately deep water-table	15l
		Sand with shallow water-table	15g
		Sand with very shallow water-table	15w

Key to soil codes:

Suffix	*Name*	*Description*
a	Shallow	Predominantly 30–45 cm depth of soil to bedrock
c	Cultivated	Considerable alteration to physical or chemical properties or to vegetation by former agricultural use
e	Ericaceous	Vegetation contains sufficient *Calluna* (dominant to frequent) to become a weed problem after planting
f	Flushed	Considerable enrichment with nutrients from flush water, as indicated by the presence and vigour of tall *Juncus* species, *Deschampsia caespitosa* or *Molinia*
g	Slightly gleyed	Subsoil slightly mottled or with grey patches
h	Humose	Topsoil contains between 8 and 25% organic matter by weight
i	Imperfectly aerated	Applied to gley soils with less prominent grey colouration than usual for the type (but which do not qualify as 7b)
k	Calcareous	Used for gley soils which have pH >7.0 in the A or B horizon
i	Loamy	Used for surface-water gley soils and peaty gley soils where the texture throughout the profile is not finer than sandy clay loam
P	Peaty (or deeper) peat phase	Surface horizon containing more than 25% organic matter by weight. Thickness definitions: 3p and 5p = 5–45 cm of peat 4p = 15–45 cm of peat 6p = 25–45 cm of peat (note that types 6 and 6z also have a peaty horizon 5–25 cm thick)
S	Extremely stony	Stones occupy more than 35% of the soil volume
x	Indurated	Has strongly indurated material within 45 cm of surface. Implies loamy texture. Where indurated material is only moderately developed or is at depths of 45–60 cm, (x) is used

Where more than one suffix is used they are placed in the order: l, p, h, x, g, i, s, a, f, k, c, e

Source: Pyatt, 1982 [see also Pyatt and Suárez, 1997].

Appendix 2

A classification of cultivation operations, with examples of machines which perform them. Machine is listed first, with the prime mover second.

Operation	*Whole site treated*	*Machine example*	*Planting spot only treated*	*Machine example*
Brash treatment	Brash rearrangement	TTS35 Delta H/large skidder	Piling	Raumfix rake/Volvo
	Brash rearrangement	Wadell cone scarifier/Caterpillar D7	Intermittent windrow	Walton spoon mounder/Hymac121
	Windrowing	Raumfix rake/Volvo		Sinkillä mounder/Caterpillar D4 B rake setting
		TTS10/4WD agricultural tractor >80HP		
Scarification	Disc trenching	TTS35/large skidder	Screefing	Leno 2 row scarifier/light skidder
		Donaren 180D/large skidder		TTS10/large agri tractor
	Disc trenching (fully powered)	TTS35 DeltaH/large skidder	Patch scarifying	Leno 77/81 2 row scarifier/large skidder
		Donaren 280D/large skidder		Bräcke 2 row scarifier/large skidder
	Cone scarifying	Wadell/Caterpillar D7		
	Furrowing	V plough/Caterpillar D7		
	Bedding (± subsoiling)	Eden discs plough/Caterpillar		
Sub-surface treatments	Moling	Moler (45 cm)/Caterpillar D6		
	Subsoiling	Subsoiler (45–60 cm)/Caterpillar D7		
		Subsoiler (45 cm)/large agricultural tractor >200 HP		
	Ripping	Winged ripper (60–90 cm)/Caterpillar D7 or 2		
Mounding	Helical ploughing	Helical plough/Caterpillar D6	Dry mounding	Bräcke 2 row mounder scarifier/large skidder
				MacLarty mounder (intermittent)/Caterpillar D6 or D4
	Bedding	Eden bedding disc plough/Caterpillar		Bucket/Excavator
	Riggs	Blade/Caterpillar or Excavator		
		Bucket/Excavator		
			Continuous humus mounding	Donaren 870D/Caterpillar
				MacLarty mounder (intermittent)/Caterpillar D6 or D4
			Tunnel mounding	Difco/Caterpillar wide track
			Discontinuous humus mounding	Bucket/Diggers various
Ploughing	Deep tine ploughing	D45/T45–60/t or m/Caterpillar D6 or D7F	Excavator mounding	Walton spoon mounder/Hymac 121
	Shallow peat ploughing	D30/–/t/Caterpillar D4 or D6		(or any 14–18 tonne tracked base)
	Complete ploughing	2S45/T60/t/Caterpillar D7		Lännen S10
	Agricultural ploughing	Gang S30/–/t/medium tractor		

Appendix 3

Provisional slope limits for different cultivation machines in average weather conditions; data are for 1996

Cultivation outfit	*Limiting slope %* *2-way*	*1-way*	*Side slope*	
Leno patch scarifier	0–30	50	15–20	depending on 4 x 4 machine
Bräcke dry mounder scarifier/Timberjack 380	0–20	50	20	depending on access
TTS10 disc trencher + County	15	35	15	
TTS35 + Timberjack 380 or 460	20	50 up to 65	20	
Subsoiler	15	20	N/A	risk of erosion above 20% slopes
MacLarty mounder + D6	0–28	40 (55)	20	mounted (D4)
MacLarty mounder/moler/ripper + D6	2–20	N/A		
Double mouldboard tine plough (t)	15	50		no contour ploughing
Double mouldboard tine plough (m)	15	65	15	
Walking excavator mounder, e.g. Menzies Muck 4000, 5000, 6000 Kaizer Spyder	70		-	only up and down slope. Only cost competitive on slopes of >50%
Tracked excavators with mounding or screefing heads	25	45	-	up and down bucket steeper slopes. Different base machines according to slope

Appendix 4

Simple key to vegetation communities associated with soil types and soil groups (peats excluded)

Soil group	*Typical dominant vegetation*	*Soil type variants*
Brown earths	Fine grasses, *Holcus*, bracken, bramble, foxglove, many herbs – *Viola*, etc. (Invasive species: broom, dwarf gorse, birches)	1x *Nardus*, *Agrostis* 1e *Calluna*, *Genista* *Potentilla erecta* (species-rich heath)
Podzols	a. *Calluna*, *Vaccinium myrtillus*, *Erica cinerea*, *Deschampsia flexuosa*, feather mosses b. *Calluna*, light bracken, feather mosses (Lowland) (Invasive species: D. *flexuosa*, broom, birch, *Calluna*)	3g *Calluna*, sparse *Molinia* 3p *Calluna*, *Vaccinium vitis-idaea*, *Arctostaphylos*, feather mosses
Ironpan soils	a. *Calluna*, *V. myrtillus*, *D. flexuosa* (Heathland types) b. *Calluna*, *Molinia*, *Trichophorum* (Moorland types) c. *Nardus*, *Agrostis*, *Carex binerva*, *V. myrtillus* (Grassland types) (Invasive species – as podzols)	4z *Calluna*, *Juncus squarrosus*
Surface water gleys	a. *Holcus* spp., *Deschampsia caespitosa*, *Dactylis glomerata*, *Juncus effusus*, *Ranunculus*, *Cirsium* b. *Nardus stricta*, *Agrostis*, *Festuca* (Invasive species: *Salix*, *Alnus*, *Juncus effusus*, downy birch)	7f *Deschampsia caespitosa*, *Juncus acutiflorus*, herbs – *Cardamine*, *Ranunculus* 7e *Calluna*, *Erica tetralix*
Peaty gleys	a. *Molinia*, *Calluna**, *Erica tetralix* (grass moorland) * Fire climax may eliminate *Calluna* and *E. tetralix* b. *Molinia*, *Calluna*, *Trichophorum*, *Erica tetralix*, *Sphagnum* (North and West moorland type)	6e *Calluna*, *Erica tetralix*, *Juncus squarrosus* 6f *Molinia*, *Myrica*, *Carex* spp. 6p *Molinia*, *Eriophorum*, *E. tetralix* (intergrade to soil type 11d cottongrass moorland)
Groundwater gleys	a. *Deschampsia caespitosa*, *Holcus*, herbs, *Salix*	5z *Erica tetralix*, *Calluna*, *Sphagnum*
Littoral soils (freely drained)	*Ammophila arenaria*, *Carex arenaria*	

Bedding	To cultivate with inward set discs to provide a continuous shallow narrow 'rigg' or loose raised bed along the planting line. On compacted coarse loamy soils, it may be accompanied by tining/subsoiling along or offset from the planting line. On sloping fine-textured gley soils in dry regions it maybe used to improve soil structure and provide local shedding of excess water as a form of miniature rigg.
Cultivation	Cultivation is the tilling of the soil and its vegetation or brash cover with implements to provide a favourable environment for efficient establishment and early uniform growth of plants or regeneration; to adjust water relations; and to improve root anchorage for better wind-firmness, where appropriate. It includes treatments variously described as bedding, discing, furrowing, moling, mounding, peat tunnelling, ploughing, ripping, scalping, scarifying, and subsoiling.
Cultivation technique	An operation undertaken with specially designed equipment to make changes to the physical properties and biological activity of the soil or site in a manner appropriate to the site conditions, the establishment prescription, and the physiological requirements of the species. (An underlying principle is that its application should enhance or maintain soil productivity and minimize adverse impact(s) on the environment.)
Discing	Shallow surface cultivation using an inclined disc or set of disc *without* shaping the surface into narrow riggs (when it is described as 'bedding'). It is not usually capable of being carried out over stumps although there have been attempted designs with spring-loaded discs, sometimes front-mounted.
Disc trenching	Continuous row scarification by toothed discs forming trenches 10–20 cm deep and 0.4–1.0 m wide. Discs may be passive or powered an hydraulic pressure may also be applied downwards for increased depth or pulverising effect. Disc rotation is usually with the direction of travel and variable in speed from 0–40 rpm. Normally used on coarse loamy freely or imperfectly drained soils with less than 15 cm humus/peat horizon.
Drainage	The removal of excess water from the site (Pyatt, 1990a; Henman, 1963).
Dry mounding	A variant of mounding on freely drained soils where a discrete mound (10–20 cm in height) is formed as a planting site.
Furrowing	Continuous formation of shallow V-shaped furrows to 15–25 cm by a blade (V-blade, divider or shallow plough) on coarse loamy or sandy

soils to form furrow-bottom planting positions on very dry or very freely draining sites. Surface humus and brash are thrown away from the planting position.

Heat capacity The capacity of the soil to change temperature for a specific amount of heat input or loss. Dry and moist soils have lower heat capacity than wet soils.

Heliplow A forest plough with a curved mouldboard (helical plough) designed to produce an interrupted ridge on organic or organo-mineral soils to simulate mounding preparation.

Hydraulic conductivity This is the ability of the soil to conduct water. It is influenced by factors such as soil texture and structure which affect the pore size distribution, bulk density and water content and temperature. Thus fine textured gleys or humified peats have low hydraulic conductivity while coarse sands have high conductivity under wet conditions, but low conductivity in dry conditions.

Induration Compact soil of high bulk density (1.2–1.8 g cm^{-3}) which is low in organic matter and usually coarse loamy in texture. It normally occurs at depths from 30–75 cm and extends for 30–50 cm or more. It represents a relic permafrost layer and may have been reinforced as a result of soil processes to become brittle and platy on the surface.

Moling Passing a pointed cylinder mounted on the lower edge of a bar through the subsoil at 25–45 cm depth to form a subsurface drainage channel for free water. Mole channels are intercepted at intervals by collecting drains. The addition of 'wings' to the mole can help in fracturing compacted layers.

Mounding Formation of discrete heaps of soil, usually 20–30 cm height, at the intended planting spacing. Mounds can be prepared manually or by excavator/bucket (discontinuous); by a braked scalping tool or gouger (continuous spot); or as spoil extruded from underground peat tunnels. A further distinction is between 'spoil' mounds where the mound is formed from soil taken from shallow spoil drains and 'hinge' mounds where the source of the soil is immediately adjacent to the mound.

Peat tunnelling 20 cm^2 tunnels cut in deep peat at 30–50 cm depth, the extruded peat being laid as a ribbon or reconstituted into mounds.

Ploughing To cultivate soil in continuous ridges and furrows. The equipment invariably (forest ploughing) has a mouldboard and, usually, trimming discs.

Riggs and furrs Large scale undulations constructed by earth mover blades or long-arm excavator. The top of the rigg may be up to 1.5 m above the original surface and overall width 10–20 m. Cross-ripping may be used. The riggs may accommodate 4–8 rows of plants at normal spacing. [Historical applications in previous agricultural land use are noted by Booth (1967).]

Ripping To cultivate deeply with a long heavy shank mounted on a tool bar to design depths of 30–105 cm for the purpose of shattering compaction/induration; or disrupting deep-lying ironpan or cementation. The basic design is similar to a rock ripper. Normally the equipment is drawn by a heavy category of tractor.

Screefing Preparation of shallow scrapes/depressions which are intended as weed-free mineral soil planting spots on dry soils. There is no soil mixing as in patch scarification and surface vegetation and/or humus is removed from the scrape.

Scarification Breaking up surface litter, humus and vegetation to expose mineral soil to a shallow depth, usually not >15 cm. The action may be continuous (disc trench scarification) or discontinuous (patch scarification). Unlike scalping, the objective in patch scarification is to achieve some mixing of organic matter with mineral soil.

Step cutting The process of cutting a section out of a peat ridge or large mound to form a lower sheltered planting position closer to the vegetation mat. This can be done manually or mechanically on ploughing (Neustein, 1976).

Subsoiling (equivalent to ripping when deep) To cultivate with a subsoiler up to 40–50 cm depth, using a medium length shank designed for 20–65 cm operational depth. The shank may have winged attachments to provide more lateral shock. The function is to reduce bulk density within normal rooting depth; to disrupt ironpan formations at intermediate depth (10–35 cm); or to provide seepage channels at 35–50 cm in stony gley soils outside the scope of moling. A light narrow single mouldboard may be fitted to provide a screefed planting position beside the subsoiler channel. This condition is termed a 'subsoiler screefer' or sometimes as a 'ripper-screefer'.

Terminal height The height by which it is predicted than 40% of a stand will be windthrown and remaining trees will be clearfelled and replanted. Used as part of the Windthrow Hazard Classification (Miller, 1985).

Thermal conductivity The capacity of the soil to conduct heat. Wet mineral clay soils have high thermal conductivity; dry sands and peat/humus have low thermal conductivity.

Water potential A measure of the free energy per unit of soil volume, expressed in Pascals (sometimes bars).

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