HMSO £1.70p net

Forestry Commission Leaflet 71

Ploughing of Forest Soils

D A Thompson

CONTENTS

FRONT COVER

Caterpillar D4D tractor with D60 plough on deep peat, Naver Forest, North Scotland. (*E6145*)

PLOUGHING OF FOREST SOILS

D A Thompson
*Silviculture (North) Branch,
Forestry Commission*

Introduction

Appropriate site preparation promotes successful crop establishment, and the availability of a wide range of cultivation machinery enables forest managers to cope with the diversity of soils encountered in British forestry. Ploughing is the most widespread method of mechanized site preparation used in the United Kingdom and it is important to select the most cost-effective combinations of equipment to meet the silvicultural objectives for the site. Although the principles of ploughing in agriculture and forestry are essentially the same, there are important operational differences. In particular, the long rotation lengths in forestry give managers the opportunity of cultivating the soil only once every 50 years or so. Afforestation programmes are frequently associated with irregular, hilly terrain and difficult ground conditions; the soils involved often have serious physical limitations to growth, and will very rarely have been cultivated previously. Forestry ploughing generally requires the use of robust heavy equipment, and outputs are low in comparison with typical agricultural operations. The resulting high costs, incurred at the beginning of a lengthy rotation, must be justified by the firm expectation of considerable improvement in forest establishment costs and tree growth rates. The anticipated influence of ploughing on tree stability in the future must also be considered.

This leaflet gives practical recommendations for ploughing forest soils in Great Britain, based on the best available information. It is not intended to present arguments to support these recommendations although it is inevitable that occasionally they may be introduced for the sake of clarity.

Why plough?

A primary objective of ploughing is to improve rooting conditions for the young trees. Increased soil aeration, drainage, temperature and nutrition are expected to encourage root growth (Taylor, 1970). Improved root development is expected to lead to increases in shoot growth, yield and resistance to wind loosening or windthrow.

Three kinds of physical change can occur when a plough passes through the soil: aeration by drainage, aeration by fragmentation, and soil mixing. The furrow, whether empty of soil or filled with loose soil, acts as an outlet for excess soil water (or as a sump creating a hydraulic gradient down which soil water tends to move). During this draining process, pores larger than about 0.06 mm diameter lose soil water and, unless they collapse, they fill with soil air. This is aeration by drainage.

The passage of a plough through soil causes aggregates to lift, shear and fragment so that their average size is reduced. This effect is very limited in wet gleys or peats and most marked in dry clayey soils, but provided waterlogged conditions do not prevail the volume of pore space is increased. Pores produced in this way are mainly large and will drain quickly under gravity. This is aeration by fragmentation.

Forest ploughs are designed to move soil material both vertically and laterally; this movement causes soil layers to become realigned relative to each other. This mixing of soil

Table 1 Ploughing recommendations

Soil group	*Objectives in order of priority*	*Ideal mouldboard assembly*	*Ploughing recommendation*
Freely draining	1. Weed suppression 2. Provision of a planting position 3. Soil mixing	D30/-/- or D45/-/-	D45/T60/t/I 3.6-4.8 on steep slopes D45/T60/m on side slopes S45/T60/m
Impeded	1. Disruption of impeding layer and increase in rooting depth available 2. Soil mixing 3. Weed suppression	S45/T60/- or S60/T90/-	For non-indurated weak ironpan soils: S45/T60/t/I 1.8-2.4 For non-indurated strong ironpan soils: S45/T60/t/I 0.06 or 2S45/T60/t/I 1.6 or S45/2T60/t/I 1.8-2.1 For weaker compacted or indurated soils: S60/T90/t/I 1.8-2.4 For strongly compacted or indurated soils: S60/T90/m/I 0.6-0.8 For steep slopes: S45/T60/m/I 1.8
Impervious	1. Rapid drainage of water from the soil 2. Rapid growth after planting on ridge 3. Provision of a wide rooting platform 4. Weed suppression 5. Provision of a planting position	D60/-/- or D60/T90/-	For deep peat, and for surface water gleys only where the impermeable layers reach close to the surface: D60/-/t/I 4.0 For gley soils and gentle slopes: D45/T60/t/I 3.6-4.8 For steep slopes: D45/T60/m/I 3.6-4.8 For peaty gleys and compacted clay gleys: D60/T90/t/I 4.2-4.8

horizons by ploughing alters the natural distribution of bacteria and fungi in the soil, leading to changes in nutrient cycling. It promotes the breakdown of accumulated surface organic matter and stimulates a rapid release of nutrients which can be taken up by plant roots.

All three physical changes to the soil occur to some degree with ploughing but it is possible by using different types of plough to emphasize any one aspect.

Ploughs

There are two basic types of forest plough which are distinguished by the presence or absence of a sub-soiler on the front of the plough. The sub-soiler is called a tine, and ploughs with tines fitted are termed tine ploughs. The effect of this tine is to shatter the soil in a vertical plane in front of and below the mouldboard. The mouldboard leading edge, horizontal when correctly set, also shatters, cuts and lifts the soil in a vertical plane. The mouldboard turns the lifted soil laterally. There is very little forward movement of soil during ploughing. Forest ploughs without tines are usually called draining ploughs; their function is to cut and lift soil and leave a clean furrow of a specific shape. There are also ploughs which do not fit neatly into either of these categories, for example those which have horizontal cutting edges but no tine and those which have short tines and draining mouldboards.

Ploughing is normally done with trailed ploughs because of the higher outputs obtained. Ploughs mounted directly on the tractor are more manoeuverable and are used to cope with steep or awkwardly shaped work areas and sites affected by frequent obstacles such as boulders or large stumps. Since it is possible to fit any mouldboard assembly to either trailed or mounted plough beams further reference to this aspect of ploughing technique will be made only when there is a specific reason for using one or the other.

Forestry Commission Leaflet 70 *Forest ploughs* (Thompson, 1978) gives the nomenclature and descriptions of forest ploughs currently available; the same nomenclature will be used in this leaflet (see Appendix I). Forest drainage recommendations are described in Forestry Commission Leaflet 72 *Forest drainage schemes* (Thompson, 1979) and are not included in this leaflet.

As indicated, forest ploughs fall into two groups: those designed for maximum aeration by fragmentation and mixing, and those designed for maximum aeration by drainage. The choice of which plough to use depends on the objective of ploughing, and this is usually determined by the soil type.

Some advantages and disadvantages

In addition to the soil drainage and mixing benefits described above, three further advantages can be expected from any type of forest ploughing. The first is suppression of ground vegetation by soil inversion. This achieves a level of weed control for the first few months after planting; the length of time a weed-free site is enjoyed depends on the vegetation type, soil type, ploughing method and time of year ploughing is done, the best time being after weed seeds have dispersed. The second benefit is a release of nutrients from the decay of any plants smothered by inversion of the surface layer. The third is the creation of an obvious place to plant the tree; there is a major saving in cost by simplifying the planting operation and easing supervision.

These advantages are generally obtained more readily and economically by ploughing than by most other methods of ground preparation. Broadly similar results are obtained from the various plough types but some are more effective than others in providing particular benefits. For example, draining ploughs usually give a uniform turf ridge profile in regular lines whereas tine ploughs usually produce a more irregular ridge in more uneven lines.

There are three possible disadvantages connected with forest ploughing. Firstly, spaced furrows present an obstacle to rooting at right angles to the direction of ploughing in the horizontal plane. This reduces the number of large roots which can develop in this direction (Deans, 1983). At the same time, the turf ridge encourages rooting parallel to the ploughing direction. Such an asymmetrical root system may be unstable, particularly when rooting is shallow. Therefore, unless ploughing increases the depth of rooting it may reduce tree stability against wind.

Secondly, ploughing an area accelerates runoff and may lead to erosion and deleterious sedimentation in streams important for fish breeding. Such effects can be minimized by careful planning and execution of the ploughing operation. Further information on this aspect is available in Forestry Commission Leaflet 78 *The management of forest streams* (Mills, 1980).

A third potential disadvantage concerns the appearance of land ploughed for forestry. Good ploughing practice normally follows the lie of the land. However, care needs to be taken to avoid the creation of ploughing patterns which are visually intrusive in the landscape.

Soils

Soil types reflect the geology, climate and topography of a site, and in consequence usually provide a sound basis for allocating silvicultural techniques to sites. This is particularly true of forest ploughing, the purpose of which is to modify the soil for the subsequent benefit of trees. A general classification of forest soils in upland Britain has been developed by Pyatt (1970, 1977, 1982) and Toleman (1975), but this classification is necessarily more complicated than one required to determine which plough to use. In practice, ploughing is an imprecise operation, superimposed on large tracts of land on which soil types often change over very short distances. For ploughing purposes, soil types can be broadly grouped into four classes.

Ploughing specific soils

Freely draining soils

Soil types	*Codes**
Brown earths	1, 1d, 1u, 1z
Podsols	3, 3p
Intergrade ironpan soils	4b
Argillic brown earth (calcareous soils)	12t
Freely drained sand (littoral soils)	15e, 15i

*Pyatt, 1982

Freely draining soils are recognized by the absence of any serious obstacle to rooting or rapid movement of water down the profile to bedrock (or, for practical purposes, to a depth of more than 60 cm). Several intergrades exist which also meet these requirements in spite of thin peaty layers, incipient ironpans or slight gleying. Ploughing is not expected to improve soil structure but there may be some benefits from soil mixing. The main objective in ploughing these soils is the provision of weed-free planting positions.

Tine ploughs function better than draining ploughs in freely draining soils because such soils are relatively dry and usually consist of mineral horizons. The requirement for a weed-free planting position means that a maximum surface area of upturned turf should be provided by each pass of the plough. It may be that soil from lower down the profile is less quickly invaded by weeds than that just under the turf, so it is advantageous to have this lower material on the surface. Furthermore, soil mixing may give benefits in increased nutrition. The plough utilized should preferably have a double mouldboard assembly cutting a furrow 30 to 45 cm deep. The most appropriate type in common use has the plough code D45/T60/- (Thompson, 1978).

On some soils, for example those developed on calcareous or sandy parent materials, it is inadvisable to cut down below the turf because the material beneath is unstable or the soil pH is too high. In these cases it is advisable to plough as shallowly as possible.

Impeded soils

Soil types	*Codes**
Man-made soils (freely draining)	2s
Ironpan soils	4, 4p, 4z
Ironpan on induration	4zx, 4x
Indurated gley soils	6zx, 7zx

*Pyatt, 1982

Impeded soils have a distinct layer, usually at a depth of 30 to 100 cm, which may be compacted, cemented or indurated. Induration consists of a very dense layer usually more than 30 cm thick and is commonly thought to have resulted from a long cycle of freezing and thawing at the end of the last Ice Age and subsequent deposition of a cementing layer of aluminium (Pyatt, 1970). This layer sometimes prevents free drainage down the profile and always obstructs deeper rooting. Quite often its position is marked by a change in colour which is more obvious than the change in soil density or hardness. Although this layer is most often associated with dry soils, reduced vertical drainage frequently causes a thick layer of gleyed soil to develop above the impeding zone. Whereas ploughing ironpan soils is relatively simple because the pan tends to be a quite distinct thin layer above freely draining soil and merely requires shattering at frequent intervals, indurated and compacted layers are usually quite thick. Sub-soiling such soils disturbs the area around the implement but does not usually break through into a freely rootable layer below. It should be the objective in ploughing these soils to make them freely rooting and draining down to a depth of 60 cm.

Impeded soils require aeration by fragmentation and this is best achieved by the shattering action of a tine plough. Also, there is likely to be considerable benefit from any soil mixing which the same type of plough can achieve. Two aspects to ploughing impeded soils require to be decided: first the depth; and second the intensity of ploughing. For ironpan soils, where there is no induration, depth of ploughing is determined by depth of the pan. As this is usually less than 60 cm a S45/T60/- mouldboard assembly will suffice. However, in soils with thick compacted or indurated layers the objective is to loosen soil down to 60 cm and a mouldboard assembly cutting down to this depth must be employed, namely a S60/T90/-.

There are four intervals (spacings) between passes of the plough which are commonly used. The first is equivalent to double mouldboard ploughing and is twice the planting distance, i.e. between 3.6 and 4.8 m. The second is at the planting distance, that is 1.8 to 2.4 m. Third is a closer version of the second in which the original surface is left completely covered by disturbed soil but not all the soil is inverted; the interval usually lies between 0.9 and 1.2 m. Finally there is complete ploughing in which all soil is inverted and the interval between plough passes is between 0.6 and 0.8 m. The interval chosen should be related to the intensity of ironpan, compaction or induration. When these are weak then the interval may be wide (S45/T60/-/I 1.8-2.4 or S60/T90/-/I 1.8-2.4 – see note on p.16), but where there is a strong ironpan or dense compacted or indurated layers, complete ploughing gives the best results in terms of altering soil structure (S45/T60/-/I 0.6-0.8 or S60/T90/-/I 0.6-0.8). At present, experimental evidence suggests that the difference in cost:benefit ratios for complete ploughing and spaced ploughing (at 2.1 m intervals) is only marginal. Other benefits such as reduced weeding (particularly of heather), improved long term tree stability, or ease of subsequent access, may make complete ploughing more attractive but accelerated mineralization of nitrogen may be disadvantageous.

Two special ploughs of interest in the context of impeded soils are the S45/2T60/t and 2S45/T60/t. The first, a twin-tine plough, is useful for strong ironpan soils without severe induration or compaction because it gives a result in which there is a line sub-soiled under the turf on which trees are to be planted. The second, a twin-furrow plough, is useful because it gives cheaper complete ploughing for soils with weak ironpans, compacted or indurated layers.

When induration or compaction is particularly well developed, ploughs will not seek their design depth unless heavily weighted down. Experience has shown that one of the simplest ways of doing this is to use a large tractor and a mounted plough. By operating a thrust through double-acting hydraulic rams weight can be transferred from tractor to plough.

It is important to remember that tree roots thrive best in a moist but aerated humus layer, particularly during the first few years after planting. For this reason planting on a site which has been completely ploughed should be done with care, selecting only those micro-site positions where humus is close to the surface. If this is not done, up to two years may be lost while the root systems explore the site and the tree suffers visibly from nitrogen deficiency. However, in areas such as parts of east and southern England where there is a high water deficit during the summer associated with rainfalls of less than 1,200 mm, humus tends to become irreversibly dried after ploughing and is a poor medium for rooting. In these soils, it is better to plant into mineral rather than humus material.

Impervious soils

Soil types	*Codes**
Brown earth with slight gleying	1g
Man-made soils (clayey)	2m
Surface water gleys (clayey and loamy)	7, 7f, 7h
Brown gley	7b
Peaty gleys (clayey and loamy)	6, 6f
Podzolic gleys	6z, 7z
Ground water gleys	5, 5p
Juncus bogs	8a, 8b
Molinia bogs	9a, 9b, 9c, 9d
Unflushed blanket bogs	9e, 11a-11d
Unflushed raised, flat or basin bogs	10a, 10b
Eroding bogs	14, 14h, 14w
Sand with shallow water table (littoral soils)	15g, 15w

*Pyatt, 1982

Impervious soils have a layer of material with low porosity which extends downwards below a depth of between 20 and 60 cm. The small sizes of soil pores is such that draining can exert little influence in removing soil water from them. Fortunately, the upper layers are relatively freely draining, although subjected to temporary waterlogging because of the almost impermeable soil below. Rooting is largely restricted to these upper layers because the lower layers remain anaerobic for most of the year. Furthermore, permanent rooting into the impermeable layers is only known to be possible in some deep peats. In these cases the peat is dried by tree roots so that it shrinks and fissures; these openings then permit the rapid drainage of surplus water.

In order to maximize the volume of soil available to a root system, ploughing impervious soils is intended to remove as much water as possible from the relatively permeable upper layers. Rooting depth will be relatively shallow in these soils and therefore tree crops will tend to be susceptible to windblow damage. This condition is alleviated to some extent if a wide root plate develops, therefore ploughing should give the widest possible potential root platform.

Draining ploughs or even tine ploughs can achieve aeration of the freely draining upper soil horizons found in impervious soils provided a continuous clean furrow is made. Since the furrow must remove as much water as possible it must be deep enough to reach into the impermeable lower layers. Moreover, provided trees are planted in a humus layer, there is a clear relationship between the rate of growth during the establishment phase and the size of turf. This is almost certainly the result of increased nutrient mineralization following better aeration (Binns, 1962) and of increased soil temperature. Relatively little soil mixing occurs in this type of ploughing. For these reasons a furrow depth of between 45 and 60 cm is commonly accepted.

Our present generation of ploughs gives drainage through open furrows, and a compromise is needed between the requirements for rooting space, for drainage and for mutual shelter. Recommendations have been made that conifers in upland Britain should be planted at a square spacing of between 1.8 and 2.1 m or at reasonable rectangular equivalents (Low, 1974). The recommendation for ploughing impervious soil is either D45/T60/t/I 3.6-4.8 or D60/ – /t/I 3.6 – 4.8, that is double-mouldboard ploughing with intervals between furrows of between 3.6 and 4.8 m. Ploughing at intervals closer than 3.6 m means that the tractor squashes one of the ridges thrown out on a previous run. At the other extreme an interval wider than 4.8 m would result in spacing between successive rows of trees being excessive for the early development of mutual shelter and for future timber quality.

Adjustments to planting distance along ridges can be used to achieve a desired density of trees per unit area. However, in a rectangular spacing pattern the longer dimension should not be more than one third greater than the shorter. Matching desired plant spacing to furrow spacing can be a problem on these soils where windthrow-susceptible stands are likely to develop. The objective is to place the tree not less than 50 cm from the side of a furrow. The side of the furrow should be sloping at as gentle an angle as possible so as to avoid roots

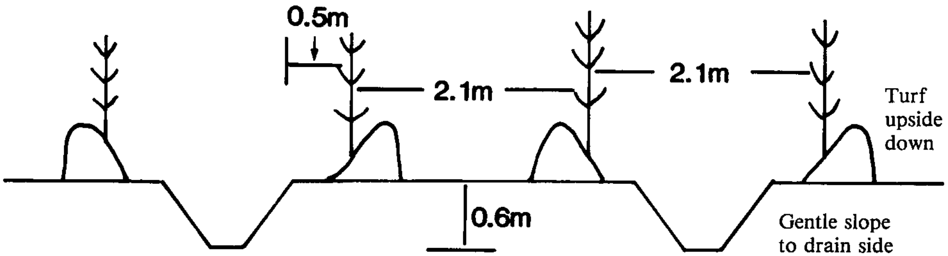

FIGURE 1a D60/-/t ploughing in which side discs are used and a turf is placed away from the furrow, with planting position on ridge side adjacent to drain

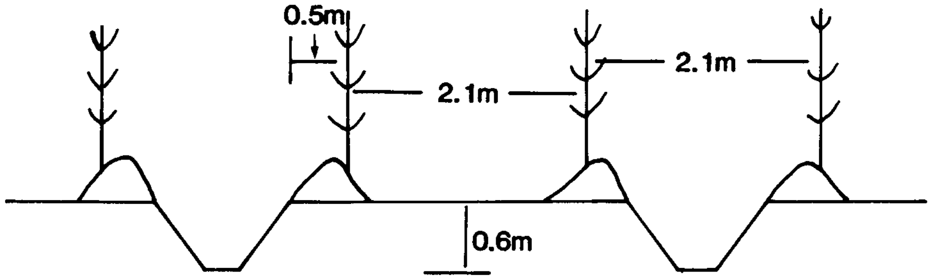

FIGURE 1b D60/-/t ploughing without the side discs which places the turf ridge immediately adjacent to the furrow, with planting position on ridge side facing away from drain

turning sharply downwards when growing towards the furrow bottom. The turf ridges should be as close to the centre of the platform as possible so as to encourage full use of the platform in developing stable root architecture (see Figure 1). This is easier to achieve on gley soils than in deep peats where a hinged turf may have to be used.

Unploughable soils

Soil types	*Codes**
Skeletal soils and rankers	13b, 13g, 13p, 13r, 13s, 13z
Some eroding bogs	14h, 14w

*Pyatt, 1982

Unploughable soils are those in which standard forest ploughs cannot operate properly. As a result these soils are not sufficiently altered to enable trees to grow satisfactorily. It has been found that about one per cent of all soils in Forestry Commission planting areas of upland Britain are in this category. They usually occur in small pockets in otherwise ploughable land.

Recommendations

Table 1 summarizes ploughing recommendations with regard to soil groups, objectives and plough type. It should be noted that very often a tine plough is recommended although subsoiling is not necessarily needed for the site in question, because a tine protects the mouldboard from excessive wear in rocky soils.

Table 2 Plough versatility

Ploughs	*Soils*						
	Freely draining	*Impeded*			*Impervious*		
	Brown earths/ podsols	*Ironpans/Indurated soils*			*Gleys*		*Deep peats*
		Non-indurated, non-peaty, peaty	*Induration or compaction weak*	*Induration or compaction strong*	*Surface water*	*Peaty*	
For afforestation sites							
S45/T60/t	●●●●●●●	●●●●●●●	○○○○○○○	○○○○○○○	○○○○○○○	○○○○○○○	
S45/T60/m	●●●●●●●	●●●●●●●	○○○○○○○	○○○○○○○	○○○○○○○	○○○○○○○	
S60/T90/m	●●●●●●●	●●●●●●●	●●●●●●●	●●●●●●●	○○○○○○○	○○○○○○○	
D60/-/t		○○○○○	○○○○○○○	○	●●●●●●●	●●●●●●●	●●●●●●●
D60/T90/t	○○○○○○○	○○○○○○○	○○○○○○○	○○○○○○○	●●●●●●●	●●●●●●●	○○○○○○○
D15/-/m	●●●●○○○	○○○○○○○	○○○○○○○	○○○○○○○	○○○○○○○	○○○○○○○	○○○○○○○
D45/T60/t	●●●●●●●	●●●●○○○	○○○○○○○	○○○○○○○	●●●●●●●	●●●●●●●	○○○○○○○
D45/T60/m	●●●●●●●	●●●●○○○	○○○○○○○	○○○○○○○	●●●●●●●	○○○○○○○	○○○○○○○
S60/T90/t	●●●●●●●	●●●●●●●	●●●●●●●	○○○○○○○	○○○○○○○	○○○○○○○	
D60/T90/m	●●●●●●●	○○○○○○○	○○○○○○○	○○○○○○○	●●●●●●●	○○○○○○○	
D90/-/t		○○○○○			○○○○○○○	○○○○○○○	○○○○○○○
S45/2T60/t	●●●●●●●	●●●●●●●	●●●●●●●	○○○○○○○	○○○○○○○	○○○○○○○	
2S45/T60/t	●●●●●●●	●●●●●●●	●●●●●●●	○○○○○○○	○○○○○○○	○○○○○○○	
S60/-/t		○○○○○	○○○○○○○		○○○○○○○	○○○○○○○	○○○○○○○
For restocking sites where adequate traction is possible							
S60/T90/m	○○○○○○○	●●●●●●●	●●●●●●●	●●●●●●●	○○○○○○○		
D60/T90/t	○○○○○○○	○○○○○○○	●●●●●●●	○○○○○○○	●●●●●●●	●●●●●●●	○○○○○○○

●●●● main objectives can be met
○○○○ main objective not met but adequate turf for planting is produced

Ploughing areas of varied soils

It is unusual in Great Britain to find large tracts of uniform soil type. On most areas to be ploughed there is a mosaic of different soils, each of which, if treated correctly, might well require a different ploughing specification. In practice it is not possible to be so precise and a compromise is required in which most of the soils receive treatment close to their ideal ploughing prescription.

The first step in deciding which ploughs are to be used is to group soils for which there are similar objectives. This has been outlined in the previous section. The second step is to examine the versatility of each plough to determine how it functions on different soil types. Table 2 attempts to summarize the usefulness of each plough type; there are fuller descriptions in Forestry Commission Leaflet 70 (Thompson, 1978). Finally, an investment appraisal can be made by comparing the costs of various combinations of ploughs with expected benefits on different soils.

The method of investment appraisal may be illustrated by a simple example. An area of 100 ha with two soil types – 30 ha of impeded soil (ironpan soil with induration) and 70 ha of impervious soil (clayey peaty gley) – may be ploughed with one tractor and a D60/-/t

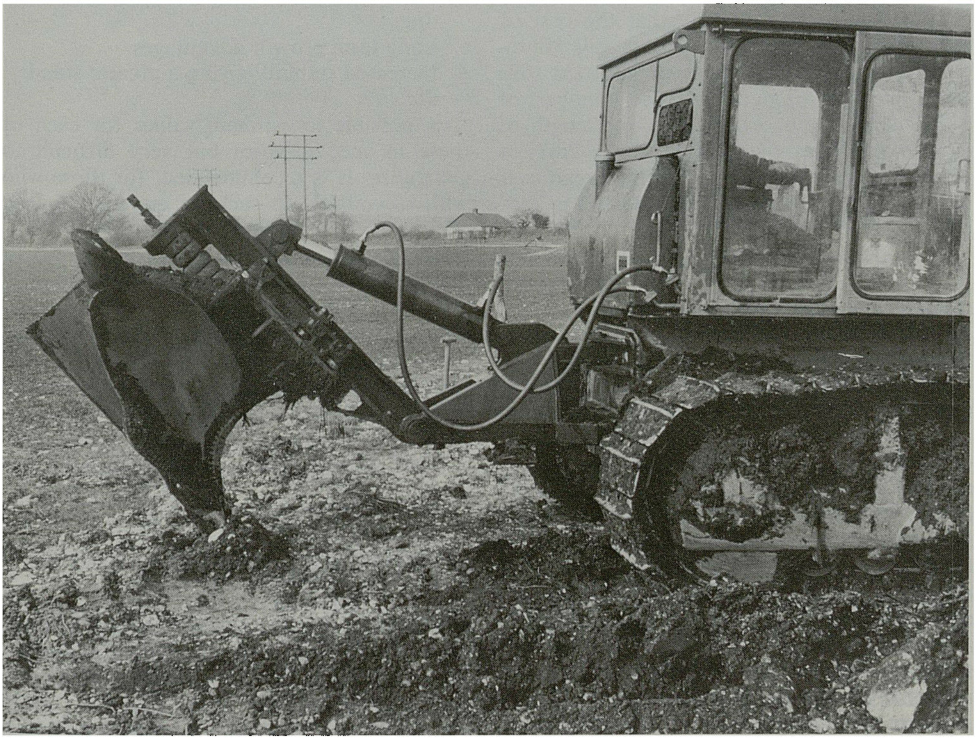

PLATE 1. Caterpillar D6 tractor with S60/T90/m mounted deep single mouldboard tine plough (for deep ploughing of indurated or compacted mineral soils) working a restored gravel pit, Wareham, Dorset. *(C5245)*

plough at an estimated cost of £40/ha. Because this type of plough is not ideal for impeded soils a reduced growth rate is likely. In this example a reduction of one Yield Class (2 m^3/ha/annum) is assumed on the 30 ha concerned. The alternative is to plough the impeded soil with a second tractor and tine plough, say S60/T90/m. The cost of ploughing will undoubtedly be higher on the 30 ha (say an extra £50/ha) thus increasing the total cost by £1,500. But the Yield Class and hence discounted revenue on the same area will be increased. Assuming that a rise of one Yield Class raises discounted revenue calculated to the year of ploughing at the chosen discount rate by £80/ha, the discounted revenue will increase by £2,400 and hence net discounted revenue by £900 (£2,400 – £1,500).

In practice, it is unlikely that the cost of ploughing the 70 ha of impervious soils will remain the same if the areas of impeded soils were ploughed separately. The number of turns would probably increase, the length of runs would be reduced and the cost of transporting equipment to the site spread over a smaller area. If these considerations are significant they will increase materially the total cost of ploughing. In this example, they are taken to have increased the cost by £5/ha, which amounts to £350 over the 70 ha. Thus the total cost of ploughing as a result of bringing in the second tractor and plough is increased by £1,850 (£1,500 + £350) and the net discounted revenue now becomes £550 (£2,400 – £1,850).

Estimating costs can be done very approximately using the comparative figures in Table 3. There are many elements to the total cost and these are considered more thoroughly in Appendix II. The benefits from using one plough rather than another are less easy to value. Briefly, they are of four types:

a. Savings in weeding costs after planting.
b. Short term growth advantages after planting.
c. Long term growth advantages.
d. Increased stability giving a greater stand life.

It is possible to estimate values for each of these in specific cases but very difficult to generalize. It is recommended, for those who wish to embark on such an exercise, that an

Table 3 Ploughing costs compared

Ploughing specifications	*One-way ploughing*		*Two-way ploughing*	
	Output (ha/h)	*Ratio*	*Output (ha/h)*	*Ratio*
S45/T60/m/I 2.0	0.15-0.30	100	0.30-0.40	100
S45/T60/t/I 2.0	0.20-0.40	76	0.35-0.45	88
D45/T60/m/I 4.0	0.30-0.50	58	0.55-0.75	53
S60/T90/m/I 1.0	0.05-0.10	533	0.15-0.20	325
S60/T90/m/I 2.0	0.15-0.30	173	0.25-0.40	170
D60/T90/m/I 4.0	0.30-0.50	95	0.55-0.75	92
D60/-/t/I 4.0	0.30-0.60	50	0.50-1.00	50
D60/T90/t/I 4.0	0.30-0.60	91	0.50-0.90	91

The ratio is based on the average cost of ploughing with the first plough in each column; -/T90/m/- ploughs require a 140-180 hp tractor, and the -/T90/t/- ploughing usually requires two tractors in tandem (although a single heavy tractor can sometimes be used on firmer sites).

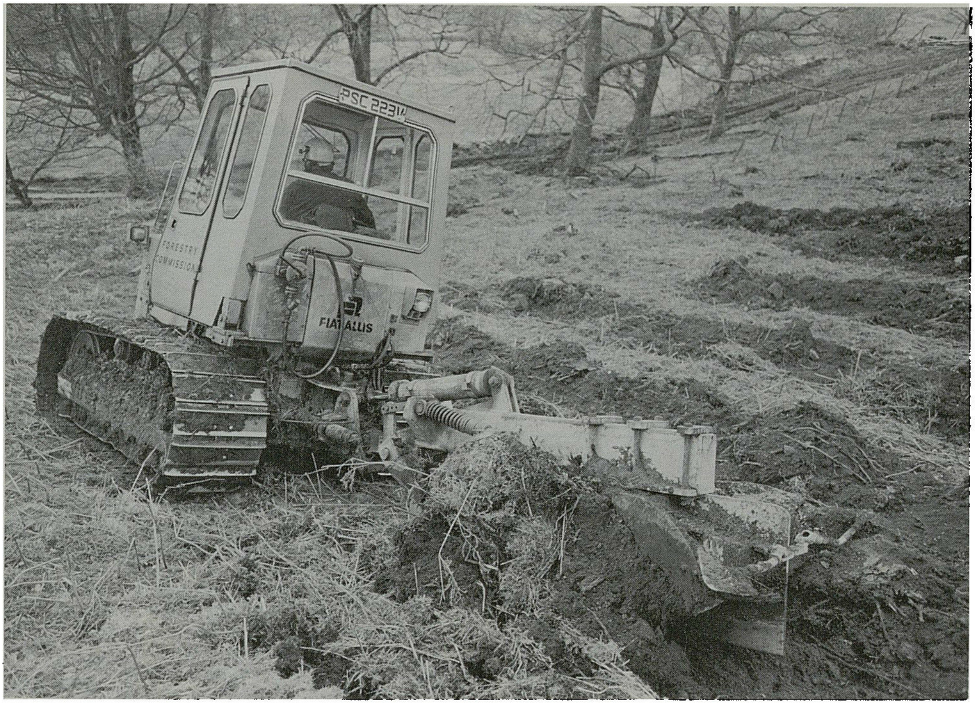

PLATE 2. A Fiat 90 tractor with a mounted double mouldboard tine plough (S45/T60/m) working a mineral soil down a steep hillside, Glenary Forest, W. Scotland. *(ED 1669)*

estimate be made of the monetary yield from using the ideal plough and that this value be reduced for other ploughs which might be used. An example is given in Appendix III.

Practical ploughing considerations

In addition to trying to maximize benefits by matching ploughs to soils there are practical considerations in organizing ploughing. Decisions will fall into two categories; those associated with direction of ploughing and those with the order in which ploughs are used.

Ploughing is normally done straight down slope but because plough runs are nearly parallel and micro-topography is rarely uniform only a small proportion of any ploughing is exactly perpendicular to contours. Ploughing across slopes with double-mouldboard ploughs is unsatisfactory because there is a tendency for the upper turf to roll back into the furrow and the lower turf to roll away down hill. Similarly, single-mouldboard ploughing across a slope can be dangerous because tractors can slip sideways. The steepness of slope which can be ploughed is limited by the power of the tractor; however, it will be rare for slopes of more than 30 degrees to be ploughed in safety. At the other extreme, when slopes are gentle, it may be possible to do two-way ploughing if the tractor is sufficiently powered to pull the plough uphill. Opportunities for reducing costs by maximizing lengths of run, reducing turning times and by two-way ploughing are explained further in Appendix II.

Although the purpose of ploughing is to improve tree growth there is an impact beyond the immediate site. Ploughing can increase the amount of sediment in streams, although the proper use of cross drains will minimize this effect (Thompson, 1979). It is prudent to stop plough furrows short of streams, lochs and lakes so that any water in them has to flow over the surface before reaching these outlets. Nevertheless, water can also flow through the soil and this may be important in reducing the impact of acid deposition on stream acidity.

Visual considerations are also important; wherever forest ploughing is carried out it creates a new pattern in the landscape, which because of its influence on planting position, will persist until canopy closure. As far as possible, geometric ploughing layouts and long straight furrows which contradict natural landform curves and irregularities should be avoided. However, the most efficient method of ploughing to cover a maximum of ground surface is to plough in parallel lines with relatively few changes in direction. This is particularly true where slopes are gentle. More frequent changes in direction than would normally be contemplated in such areas, particularly if associated with prominent topographical features, will minimize the impact of ploughing on the landscape. In those areas close to roads or railways variations in ploughing direction may also alleviate the monotonous flicker of furrow as seen by travellers.

There are limitations imposed by tractors which will affect the order of ploughing. Tractors suitable for ploughing hard ground may not be able to cross intervening soft ground easily and the hard ground should be ploughed first (Figure 2a). Trailed ploughs require more space to turn than mounted ploughs. On soft ground, such as deep peat, all ploughing is trailed and therefore there are occasions when the soft ground should be ploughed first so that tractors can turn on unploughed hard

FIGURE 2 Examples of three typical combinations of hard and soft ground conditions with recommendations for operational deployment of ploughs

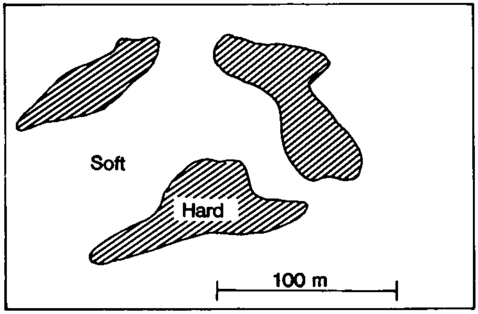

FIGURE 2a Plough hard ground first

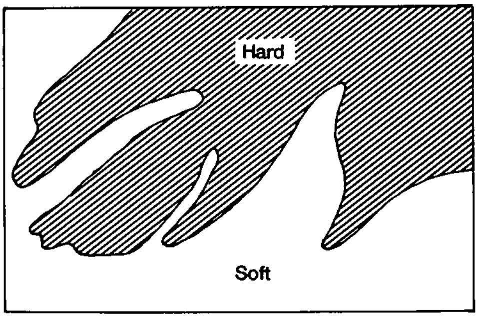

FIGURE 2b Plough soft ground spurs first

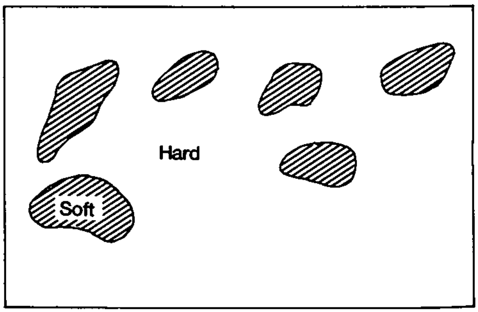

FIGURE 2c Plough soft ground with hard ground. Plough when dry

PLATE 3. A CEW 70 trail plough (D60/-/t) working on a peat/clay soil at Glenary Forest, W. Scotland. *(ED 1667)*

ground (Figure 2b). Soft ground becomes even softer when it is wet therefore it is better to plough it when dry; this is particularly important when ploughing across pockets of soft ground with hard ground equipment. This is likely to occur where the pockets are too small to be treated as a separate ploughing subject (Figure 2c).

It is usually preferable to begin ploughing at the point furthest from the access because frequent travelling along the same ride by tractors cuts up the surface, making access more difficult, whereas on unploughed ground any practical route can be used. Finally, it is usual when large ploughing programmes are undertaken to try to plough on a year-round basis. However, the ideal time for ploughing, when planting is to be done in the spring, is late August to October of the preceeding year. At this time ground vegetation finishes fruiting and vegetative growth slows down; weed suppression by ploughing is maximized and at the same time the turf ridge has time to settle down before planting in the spring.

Suggested procedure

1. Soils to be ploughed should be identified on a soil map and the approximate total area of each calculated.
2. The positions of roads and rides should be selected and identified on the ground.
3. Ploughs and tractors available for use should be chosen.
4. An appraisal should be made to choose the best combination of ploughs for the area to be ploughed.
5. The tractors and ploughs should be ordered for the time of year when it is desired to plough.
6. A ploughing plan should be made giving the direction and sequence of ploughing.
7. Roads and rides should be marked on the ground by ploughing a shallow furrow on either side.
8. The ploughing itself is undertaken.

APPENDIX I

FOREST PLOUGHS

Standard ploughs

S45/T60/m	Mounted single mouldboard tine plough (shallow)
S45/T60/t	Trailed single mouldboard tine plough (shallow)
S60/T90/m	Mounted single mouldboard tine plough (deep)
D45/T60/m	Mounted double mouldboard tine plough (shallow)
D45/T60/t	Trailed double mouldboard tine plough (shallow)
D60/-/t	Trailed double mouldboard plough (shallow)
D60/T90/m	Mounted double mouldboard tine plough (deep)
D60/T90/t	Trailed double mouldboard tine plough (deep)

Special ploughs

D15/-/m	Mounted double mouldboard plough (very shallow)
D90/-/t	Trailed double mouldboard plough (deep)
S60/T90/T	Trailed single mouldboard tine plough (deep)
S60/-/t	Trailed single mouldboard plough (shallow)
S90/-/t	Trailed single mouldboard plough (deep)
S45/2T60/t	Trailed twin tine plough
2S45/T60/t	Trailed twin furrow plough

Note: When describing a ploughing specification the interval between furrows, in metres, is added as a suffix to the plough name. For example, D60/T90/t/I 4.0, describes ploughing with a trailed deep double mouldboard tine plough at an interval of 4 m between furrows.

APPENDIX II

COSTS OF PLOUGHING

There are three groups of parameters needed to calculate the cost of ploughing. First, there are those associated with the area and ploughing specification; second, those associated with the ploughing equipment and techniques used; and finally the costs of the various parts of the operation.

Area and ploughing specification

Size of area
As a generalization, cost per hectare will decline with increasing size of area ploughed with one ploughing outfit and under one specification.

Interval between plough runs
Interval (I) is used to describe the spacing in metres between plough furrows; with all but twin ploughs this is synonymous with the interval between adjacent tractor runs. Twin-furrow ploughs used for complete ploughing produce two furrows for each tractor run so the interval between tractor runs for this type of plough is twice the interval between furrows. If the tractor runs are close together the total distance travelled by the tractor and the number of turns made will be high for each hectare ploughed. In this way interval determines the time spent ploughing and turning, that is unproductive time, in each hectare.

Average furrow length
Short furrows involve turning more often than long furrows for the same area ploughed.

Slopes
Steepness of slope will affect the speed of ploughing, but more importantly, it determines whether or not two-way ploughing is possible.

Ploughing equipment and techniques

Average tractor speed
The weight of plough, the mouldboard efficiency, the weight of soil moved and drawbar pull (or traction) achievable by the tractor all determine the speed of ploughing. It may be important to have the correct range for each tractor gear so that few gear changes are needed in each plough run. Average tractor speed includes the speed in each direction in two-way ploughing but excludes time spent turning.

Average turning time
This is defined as the time between lifting the plough at the end of a run and lowering it into the ground at the start of the next run. In two-way ploughing this can be very short, but in one-way ploughing when the start of the next run is at the opposite end of the last furrow ploughed this can be a considerable time.

Utilization
Inevitably, time is spent on non-productive activities and can be markedly influenced by how the work is organized.

Supervision time
A complicated scheme of ploughing requires more supervision than a simple scheme.

Unit costs

Cost of tractors and ploughs
Machine costs must include a charge for the capital employed and a depreciation allowance. It is common in times of high inflation to include an element for this by using replacement cost in calculating depreciation allowance. In addition to these fixed charges there are running costs associated with fuel, lubricants and maintenance. A simple crude formula for calculation of this average cost is:

$$\frac{\text{Capital cost (£)} \times 3}{\text{Life of the machine (SMH)}} = \text{Cost (£)/hour}$$

Standard machine hours (SMH) is an estimate of the number of hours a machine is available for productive use; for example it is common to base estimates on a yearly total of 2,000 hours — in other words 50 weeks at 40 hours/week. SMH includes time spent moving between sites or during repairs. SMH can be translated into Productive Machine Hours (PMH) by estimating the percentage time actually worked during the normal day.

Operator costs
These should include costs of all personnel required while ploughing, including safety men or banksmen. Also it should include any overheads associated with their employment (termed labour oncost in the Forestry Commission).

Transport costs
There are fixed costs associated with the movement of equipment into the area to be ploughed. They can be as expensive as those for a low loader travelling a long distance or as cheap as the cost of the outfit moving under its own power from one place to another close by.

Supervision costs
These are relevant only in so far as the level of supervision varies between the ploughing options under consideration.

The nomographs in Figures 3 and 4 can be used to estimate ploughing costs. In practice it is usual to include transport cost but exclude supervision in these estimates. To illustrate the use of the nomographs, an example is given in Table 4 based on assumed estimates of various features such as average furrow length, tractor speed and turning times. It would be unusual for a ploughing operation to be contemplated for which many of the features calculated in the example could not be estimated. For example, outputs can usually be based on previous ploughing operations in the same area. The example given demonstrates a possible benefit from using two outfits on an area rather than one outfit with a safety man. Calculation of the worth-whileness of each option is explained in the main text.

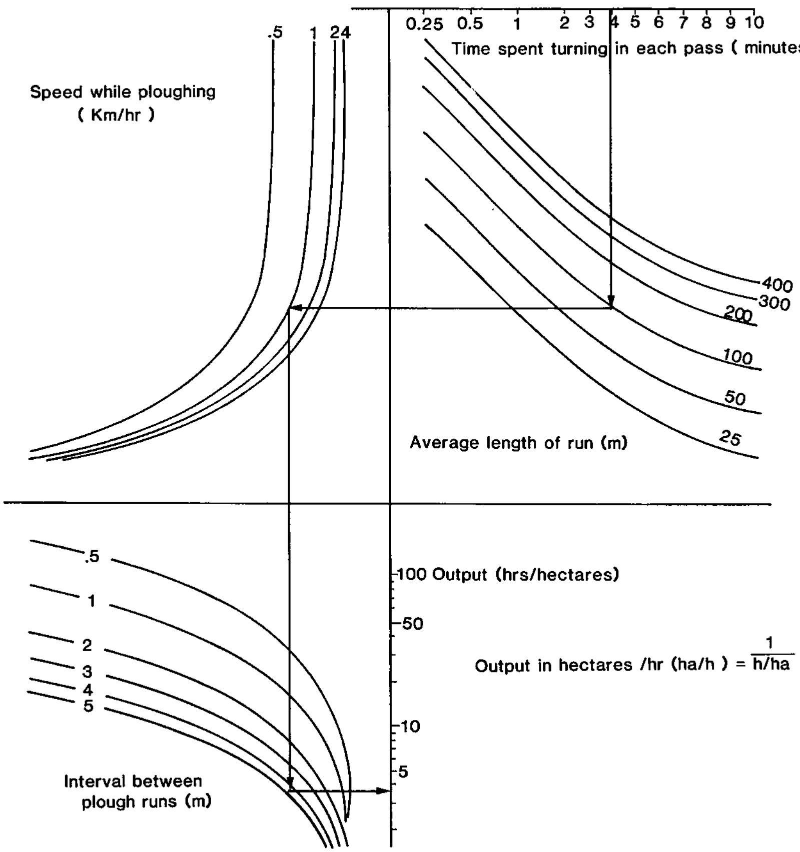

FIGURE 3 Nomograph showing a method of calculating ploughing outputs under a range of operating conditions

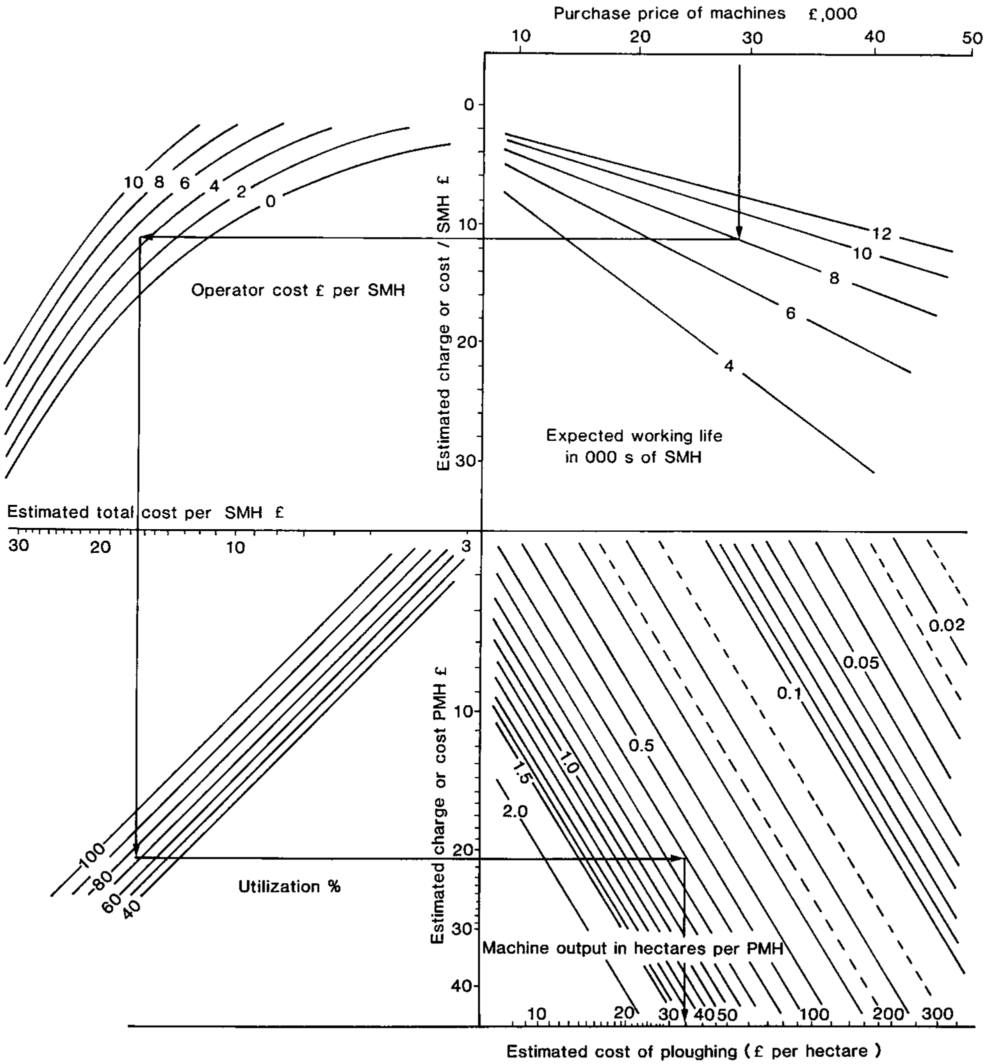

FIGURE 4 Nomograph showing a method of calculating ploughing costs over a range of economic conditions

Table 4 Example of calculations on three ploughing options for a site with several soil types (Total area 200 h

Soil type	*Two-way ploughing possible*	*One-way ploughing possible*	*Unploughable*
Unploughable	—	—	20 ha
Impervious	122 ha	10 ha	—
Impeded	18 ha	10 ha (all indurated)	—
Imperfect (freely draining)	—	20 ha (scattered throughout the area)	—
	140 ha	40 ha	20 ha

	Option 1 *One outfit and a safetyman*		*Option 2* *Two outfits* *(no safetyman required)*	
The site	(a)	(b)	(a)	(b)
Ploughing feasibility	two-way	one-way	two-way	one-way
Area	140 ha	40 ha	140 ha	40 ha
Ploughing specification	D60/-/t/I 4.0	D60/-/t/I 4.0	D60/-/t/I 4.0	S45/T60/m/I 2.
The outfit and operators				
Capital cost	£30,000		£30,000	£27,000
Estimated total machine hours	9,000 hours		9,000 hours	9,000 hours
Estimated cost per hour	£10.00/hour		£10.00/hour	£9.00/hour
Cost of operators and safetyman (excluding oncost)	£5.00/hour		£3.00/hour	£3.00/hour
Transport cost	£160		£160	£90
Utilization %	50		50	50
Ploughing				
Estimated running time	0.25 min	3.00 min	0.25 min	2.00 min
Length of run	240 m	120 m	240 m	120 m
Estimated tractor speed	2.0 km/h	1.5 km/h	2.0 km/h	1.8 km/h
Output rate (from Figure 3)	0.8 ha/h	0.4 ha/h	0.8 ha/h	0.24 ha/h
Cost				
Ploughing cost (from Figure 4)	£35.00/ha	£70.00/ha	£26.00/ha	£75.00/ha
Transport cost	£0.9/ha	£0.9/ha	£1.1/ha	£2.0/ha
Total cost/ha	£35.9/ha	£70.9/ha	£27.1/ha	£77.0/ha
Grand total	£5,025	£2,836	£3,794	£3,080
Overall cost	£7,862		£6,874	
Unit cost	£43.67/ha		£38.18/ha	

Option 3
Three outfits (one for the indurated soils)
No safetyman required

(a)	(b)	(c)
two-way	one-way	one-way
122 ha	30 ha	28 ha
D60/-/t/I 4.0	S45/T60/m/I 2.0	S60/T90/t/I 2.0
£30,000	£27,000	£35,000
9,000 hours	9,000 hours	9,000 hours
£10.00/hour	£9.00/hour	£11.50/hour
£3.00/hour	£3.00/hour	£3.00/hour
£160	£80	£120
50	50	50
0.30 min	1.20 min	1.50 min
200 m	50 m	60 m
2.0 km/h	1.8 km/h	1.6 km/h
0.8 ha/h	0.22 ha/h	0.19 ha/h
£32.00/ha	£90.00/ha	£110.00/ha
£1.3/ha	£2.7/ha	£4.3/ha
£33.3/ha	£92.7/ha	£114.3/ha
£4.063	£2,781	£3,200
	£19,044	
	£55.80/ha	

APPENDIX III

ASSESSMENT OF PLOUGHING BENEFITS

Ultimately, the benefits from different ploughing specifications become apparent in the form of different total revenues from the tree crops produced. Comparisons between crops which may be felled at different ages can only be made using discounted revenues, and for ploughing these must be discounted to the start of the rotation. Since the objective is to compare alternative treatments, a nominal discount rate can be used and in this leaflet 5 per cent has been chosen.

Ploughing can affect two aspects of crop production: firstly, the rate of growth can be changed, thus altering the mean annual increment or yield class; secondly, by changing the rooting medium, tree rooting and hence wind stability are affected, resulting in either lower or greater terminal heights. If the best ploughing specification gives a particular yield class and terminal height, then the effects of all other ploughing specifications can be expressed in terms of revenue foregone, by reduced

Table 5 Effect of ploughing specifications on crop yield class (YC) and stability (in relation to optimum treatment) for Sitka spruce YC 10-18

Ploughing specification	*Soils*			
	Imperfect soils	*Non-indurated ironpan soils*	*Indurated ironpan and gley soils*	*Non-indurated gley and deep peats*
S45/T60/-/I 2.0	−¼	−½	−1X	−1X
S60/T90/-/I 2.0	−¼	−¼	−½	−1X
S60/T90/-/I 1.0	—	—	—	−½
D60/-/-/I 4.0	−¾	−1	−1½	—
D60/T90/-/I 4.0	−¼	−1	−1	—

X represents a reduction in terminal height of 2 m. Figures give reduction in Yield Class

Table 6 Effect of ploughing specifications on crop yield class (YC) and stability (in relation to optimum treatment) for Lodgepole pine YC 6-12

Ploughing specification	*Soils*			
	Imperfect soils	*Non-indurated ironpan soils*	*Indurated ironpan and gley soils*	*Non-indurated gley and deep peats*
S45/T60/-/I 2.0	—	−¼	−¼X	−1X
S60/T90/-/I 2.0	—	—	−X	−1X
S60/T90/-/I 1.0	—	—	—	−½
D60/-/-/I 4.0	—	−¼	−¼	—
D60/T90/-/I 4.0	—	—	−¼	—

X represents a reduction in terminal height of 2 m. Figures give reduction in Yield Class yield class, or lower terminal height. Tables 5 and 6 give suggestions as to reductions in yields for standard ploughing specifications with Sitka spruce and Lodgepole pine respectively. The amounts shown are tentative and based on a wide range of experience and experimental evidence. For any particular site region improvements in the forecast can be made.

The examples given are presented to demonstrate the method which can be used in calculating ploughing benefits. Nevertheless, ploughing remains an imprecise operation.

ACKNOWLEDGEMENTS

The author expresses his thanks to many people in the Forestry Commission who contributed to the preparation of this leaflet; in particular Mr J Atterson and Mr A J Grayson whose comments during drafting stages were extremely helpful. Prior to publication the text was revised by Dr A J Low, Dr D G Pyatt and Mr K F Miller.

REFERENCES

BINNS, W.O. (1962). Some aspects of peat as a substrate for tree growth. *Irish Forestry* **19** (1), 32-55.

DEANS, J.D. (1983). Distribution of thick roots in a Sitka spruce plantation, 16 years after planting. *Scottish Forestry* 37 (1), 17-31.

LOW, A.J. (1974). *Initial spacing in relation to establishment and early growth of conifer plantations.* Forestry Commission Research and Development Paper 110. Forestry Commission, Edinburgh.

MILLS, D.H. (1980). *The management of forest streams.* Forestry Commission Leaflet 78. HMSO, London.

PYATT, D.G. (1970). *Soil groups of upland forests.* Forestry Commission Forest Record 71. HMSO, London.

PYATT, D.G. (1977). *Guide to site types in forests of north and mid Wales.* Forestry Commission Forest Record 69. HMSO, London.

PYATT, D.G. (1982). *Soil classification.* Research Information Note 68/82 SSN, Forestry Commission.

TAYLOR, G.G.M. (1970). *Ploughing practice in the Forestry Commission.* Forestry Commission Forest Record 73. HMSO, London.

THOMPSON, D.A. (1978). *Forest ploughs.* Forestry Commission Leaflet 70. HMSO, London.

THOMPSON, D.A. (1979). *Forest drainage schemes.* Forestry Commission Leaflet 72. HMSO, London.

TOLEMAN, R.D.L. (1975). *National soil classification.* Forestry Commission internal report.

First published 1984

HER MAJESTY'S STATIONERY OFFICE

Government Bookshops

49 High Holborn, London WC1V 6HB
13a Castle Street, Edinburgh EH2 3AR
Brazennose Street, Manchester M60 8AS
Southey House, Wine Street, Bristol BS1 2BQ
258 Broad Street, Birmingham B1 2HE
80 Chichester Street, Belfast BT1 4JY

Government publications are also available through booksellers

ODC 237.1 : 232.216 : (410)

ISBN 0 11 710042 0

Printed in the UK for HMSO Dd 0736991 C35 6/84

Leaflet 71: Ploughing of Forest Soils

HMSO