Sitka Spruce in the 21st Century Establishment and Nutrition

Richard Schaible

Research Officer, Forest Service, Department of Agriculture for Northern Ireland.

Summary

Historically, new plantations of Sitka spruce were established on a wide range of soil types in the British Isles by providing a raised or otherwise weed-free planting position, using manual or mechanical techniques. Some of the benefits of mechanical ground preparation can be achieved using herbicides. The application to second rotation sites of the results of research and development of mechanical ground preparation methods for afforestation is speculative. Inputs of phosphatic and nitrogenous fertilisers have been necessary on most upland sites. Strategies are available to reduce N fertiliser requirements. Productivity may decline with successive rotations on some sites due to site degradation, but is likely to be increased on others due to improved establishment methods.

1. Introduction

In common with other tree species introduced to the British Isles from the Pacific coast region of North America, Sitka spruce (*Picea sitchensis* (Bong.) Carr) is highly productive compared to native European species. The predominance of Sitka spruce in timber and fibre production has come about for several reasons. It is relatively resistant to indigenous forest pests and diseases, it can be established on a wide range of sites using relatively simple methods and it has, in general, proved responsive to fertiliser applications on sites where the availability of nutrients is limiting to growth. The timber has good fibre properties for pulpwood production, and is a versatile whitewood that can be used in a wide range of structural and non-structural applications. Underlying these factors are the historical policy commitments of our governments in favour of the afforestation of marginal land and maximum timber production.

This paper addresses the extent to which the problems of growing Sitka spruce in the British Isles have been resolved. Past developments and current uncertainties in establishment practice and the use of fertilisers are reviewed, and suggestions are made regarding prospective information requirements in the future.

2. 20th century developments

2.1 Early development

Sitka spruce was first introduced to the British Isles in 1831; up to the early 1900s it was predominantly planted on favourable sites in gardens, arboreta and small plantations, often in mixture with Scots pine (Faulkner and Wood, 1957). The discovery that Sitka spruce could be easily established on upland blanket peat using a technique imported from Belgium known as 'turfing' took place at Corrour in the Scottish Highlands from around 1908 (Stirling Maxwell, 1951). This consisted of hand cutting and distributing sods at the desired tree spacing from parallel drains about 4m apart. Excess soil moisture and runoff was removed from the afforestation area by linking turfing drains to natural watercourses by means of additional 'cross' drains. It was also found that the initial growth of turf planted Sitka spruce was increased by the application of basic slag, a phosphatic fertiliser then readily available as a by product of the iron and steel industry. This was found to be inadequate, however, where vigorous heather (*Calluna vulgaris*) regrowth on and around turfs had occurred. The proposed solution was to plant in mixture with Scots pine, which would suppress the heather and enable the development of the spruce crop.

As a result of experience at Corrour and other areas, particularly the Lon Mor, a nearby Forestry Commission experimental reserve (Macdonald, 1945), Sitka spruce quickly displaced Scots pine and Norway spruce as the favoured species for state afforestation throughout upland Britain and Ireland (Robinson, 1931; McMahon, 1945). The establishment package of hand turfing and basic slag application was to become standard practice in these areas on peat and upland mineral soils, and remained so, until mechanised methods were developed (McMahon, 1945; Zehetmahyr, 1954).

2.2 Mechanisation of ground preparation for afforestation

A comprehensive review of the development of forestry ploughing techniques in Britain is given in Neustein (1976 a, b, c; 1977). Mechanised methods of producing raised planting positions on peat and poorly drained mineral soils were developed in the 1940s in the form of single and double mouldboard ploughs pulled behind crawler tractors (Zehetmayr 1954 & 1960). These were in widespread use by the late 1950s and enabled a greatly increased rate of afforestation, including the planting of sites which had previously been considered unplantable. On the wettest peats it was common practice to carry out 'pre-draining' using deep single mouldboard ploughs, such as the Cuthbertson 'F' type plough, before ploughing for planting with shallower 'P' type double mouldboard ploughs (Dallas, 1962;

O Carroll, 1962). Large single mouldboard ploughs were also used for cross draining on peat, whereas on mineral soils this was done by backactor diggers or tracked excavators.

Research into the effects of cultivation initially concerned the effects on growth of increasing intensities of cultivation, using open furrow ploughing techniques (Taylor,1970). The main factors limiting the application of this approach were perceived as being the availability of suitable machinery and cost. Early cultivation experiments on peat showed growth was greater on the large ribbons produced by the 'F' type plough than on the 'P' type plough ribbons, (Binns, 1962; Jack, 1965). However, there was concern that rooting would be excessively restricted by the closeness of the single mouldboard plough furrows and that the resulting stands would be unstable (Zehetmayr, 1954). A commonly used compromise was to alternate 'P' and 'F' type ploughing (Dallas, 1962). In the late 1950s an alternative approach to ploughing peatland known as tunnel ploughing was developed at Glenamoy, Co Mayo (O Carroll *et al,* 1981). The technique resulted in subsurface drainage channels and continuous ribbons for planting. Its main advantages lay in greater control of the water table, deeper rooting was possible, and radial root development was not restricted. Although widely used in Ireland in the afforestation of western blanket peat, tunnel ploughing was unsatisfactory on shallow or amorphous peats and required at least a slight slope. It was also unsuitable for peats containing pine stumps (D. G. Nelson, pers. comm). Further development of the technique enabled it to be used on amorphous and shallower peats and the production of mounds instead of ribbons (E. Hendrick, per. comm). Another cultivation technique based on excavating narrow trenches, known as vault draining, was tried in Northern Ireland (W. T. Wilson, pers. comm), however potential applications of all these methods were forestalled by a reduction in the rate of afforestation of peatlands generally in response to economic and other pressures (eg Farrell and Boyle, 1990).

The mineral soil types on which some form of cultivation was considered necessary for establishment fall into two main groups: heathland soils, which are predominantly podsols and ironpan soils with a thin layer of peat, and gleys, particularly surface water gleys (Pyatt and Craven, 1978). Where the depth of organic matter is sufficient to significantly influence the planting medium, but not enough to prevent cultivation of the underlying mineral soil (conventionally 45 cm in Britain and 50 cm in Northern Ireland), these labels are prefixed with the term 'peaty'. It is important to note that on mineral soils an important function of ploughing was to reduce competition from vegetation. On drier sites it was common for trees to be planted on the side or in the bottom of plough furrows (Zehetmayr, 1960). At an early stage single mouldboard tine ploughs were introduced to heathland sites in order to rupture ironpans and improve aeration in the upper soil horizons (Zehetmayr, 1960). On some sites in Ireland it was only necessary to carry out ripping (Verling, 1967), while on a peaty ironpan site in the border region of South Scotland deep ripping resulted in reduced initial growth compared to open furrow ploughing (Quine and Burnand, 1991). Although early responses to increasing the intensity of soil disturbance were substantial (Zehetmayr, 1960; Taylor, 1970), in the longer term growth does not appear to be increased significantly (Wilson and Pyatt, 1984). Complete ploughing using the rotary mouldboard plough (Thompson, 1975) avoided most of the limitations of standard approaches to ploughing on heathland soils (Ross and Malcolm, 1982). However the long term effects of the treatment on tree growth and the nutrient economy of the site are unknown.

On surface water gleys it became clear that even shallow single mouldboard ploughing was detrimental to tree stability (Savill, 1976). Under Irish conditions mole drainage has been a successful alternative aid to establishment (Hendrick, 1989). However, as with tunnel ploughing, more care is required in cross-draining than with open furrow ploughing. In addition control of competing vegetation is more important in the first growing season because weed-free planting positions are not provided. Mole drainage appears to have considerable advantages for stability over open furrow ploughing, including double mouldboard ploughing, because radial rooting is not limited by adjacent open drains (Schaible, 1986; Hendrick, 1989). However, moling is unsuitable on peaty gleys; in these situations and in Britain the most common alternative to double mouldboard ploughing is mechanical mounding, either by excavator or using purpose build machinery.

With mechanised site preparation there was a tendency to cross drain at a lower intensity than hitherto. Ditching experiments laid down on deep peat and surface water gley soils showed that the potential for lowering the water table any further than was achieved by the cultivation systems described above was slight and would depend on development of the tree canopy and interception of rainfall (Savill *et al*, 1974; Savill, 1976). The main objective of cross drains was to tap water from springlines and plough drains, and if possible to eliminate wet areas which may become centres of instability (Pyatt, 1990a).

2.3 Nutrition

The practice of applying a handful of basic slag at planting was carried forward to establishment on ploughed sites, however the problem of early growth check in association with *Calluna* was no less apparent than on turfs. In Northern Ireland it was sometimes treated by deepening of plough furrows and placing the excavated spoil around trees (Jack, 1965). The most common counter measure on all upland soils where 'heather check' was anticipated remained to plant in mixture with Scots pine, and subsequently lodgepole pine (as seed supplies became more readily available) or Japanese larch, although more often as an insurance policy rather than to achieve a predictable result (Macdonald, 1953).

Formal nutrition research confirmed indications from investigations at the Lon Mor that ground mineral phosphate was more effective than basic slag, and that broadcast applications were more effective than placement in the planting hole or under the plough ribbon (Dickson, 1971). Useful as this information was, it did not reverse the established trend in Britain and the Republic of Ireland which was to favour the use of lodgepole pine over Sitka spruce on infertile peats (Edwards, 1962; O Carroll, 1962). In Northern Ireland the policy remained to plant Sitka spruce in anticipation of good timber yields once stands were established (Jack, 1965). The principal limitation to this appeared to be the supply of phosphate (P), even in the presence of vigorous *Calluna*. The phosphate requirement could be met by the application of 90 kg P/ha on one or two occasions (Dickson, 1971; Dickson and Savill, 1974). It is interesting to note that studies of upland blanket peat in Northern Ireland suggested that it was even more nutrient poor than at the Lon Mor (Dickson, 1962). It subsequently became apparent that, despite the provision of adequate quantities of phosphatic fertiliser, growth of Sitka spruce on oligotrophic peat in Northern Ireland was limited by the supply of nitrogen (N) within 8-10 years of planting (Dickson and Savill, 1974). The only reliable means of meeting this requirement appeared to be the repeated application of 100 kg N/ha at intervals of 3 or 4 years. In practice it has become customary to apply 150 kg N/ha at slightly longer intervals (Atterson, 1978).

It was not known to what extent N requirements would be affected by increased interception of rainfall by the developing tree canopy. On the assumption that the release of organically held nitrogen in upland peats as a result of biological activity is limited by anaerobic conditions (Adams *et al*, 1972; Adams, 1974), it was thought that a reduction in water table through increased interception should be associated with an increase in the availability of nitrogen. However, although a reduction in water table depth under Sitka spruce crops on blanket peat may occur after fertiliser application (Farrell and O'Hare, 1974; Farrell, 1985b), the effect appears to be temporary (Farrell, 1985a). Studies in Northern Ireland have indicated only small differences in water table depth under nutrient deficient, post canopy closure Sitka spruce crops compared to unplanted virgin peat (Schaible, 1992). Under less extreme water table environments conceptual and empirical models predict that, once canopy closure has been achieved, the demands of the crop for nutrients supplied from the soil becomes relatively insignificant in relation to recycling processes within trees and litter (Miller, 1981 & 1986).

Significant responses to applied potassium (K) were also found to occur on peat soils (Dickson, 1969; McIntosh 1981 Dutch *et al.*, 1990). In Ireland it has been shown that significant quantities of K are supplied to most areas in precipitation (O Carroll and McCarthy, 1973). Although there is wide year to year variation it is not normal practice to apply K early in the rotation, in contrast to practice in Britain, where up to three K applications may be recommended (Taylor 1991). One exception is the midlands of Ireland, where K application is regarded as essential for establishment on reasonably fertile fen peats (Carey, 1977). In Northern Ireland K deficiency is limiting to growth in young first rotation Sitka spruce plantations on more fertile mesotrophic peat, where the native vegetation is dominated by grasses. The normal application rate is 100 kg K/ha (Atterson, 1978).

Early growth of Sitka spruce was also found to be limited by the availability of P on various mineral soil types. In Britain these included heathland soils (Zehetmayr, 1960), and, in Ireland, podsols and ironpan soils overlying old red sandstone (ORS), and on some gleys and peaty gleys (Carey, 1977; Adams *et al.*, 1970; Savill and Dickson, 1975). On heathland soils in northern Britain and on ORS areas in south-west Ireland growth check in association with *Calluna* was persistent in spite of P application. On some sites removal of the *Calluna* by hand pulling or cutting, herbicides or shading resulted in a growth response (Weatherell, 1953; Leyton, 1955). The latter effect provided justification for the establishment of spruce/pine nursing mixtures. On ORS in Ireland the problem was related to the earlier removal of organic material for fuel, however the underlying cause was essentially the same in that the soil supply of N was inadequate.

On the poorest heathland sites the prognosis was similar to that for infertile peats, i.e. that regular applications of N-fertiliser would be necessary to enable pure spruce crops to close canopy. On many sites in the ORS region of Ireland it appeared that the growth response to applied N was even more short lived than on oligotrophic peat in the north (Carey, 1977). An alternative solution to the problem came from field experimentation in the 1960s to examine the long term effects of planting 'nursing mixtures' (O Carroll, 1978) which had been commonly used in place of herbicide for establishment for several decades. After 16 years, growth of Sitka spruce was significantly greater in mixtures with pine or larch than in pure controls. Foliar analysis showed that this was associated with significantly greater uptake of N, even though *Calluna* had only been partially suppressed. Results from similar experiments planted on heathland soils and deep peat in Britain have demonstrated that the 'mixture effect' extends to other N deficient soil types, (McIntosh, 1983; Taylor, 1985; Carey *et al.*, 1988), however it may not be apparent where growth is also limited by availability of P.

The impact of nutrition research on the productivity of Sitka spruce in Northern Ireland is demonstrated by assessments of general yield class in permanent sample plots of different ages used for forest inventory, shown in Table 1. Over three decades of planting the average yield class of plantations on peaty soils and shallow and deep peat has increased by an average of 4. These definitions refer to soils with a surface organic horizon of 5-50 cm, 50-100 cm and >100 cm respectively, which are well represented over all regions of Northern Ireland apart from the south-east. The apparent increase on gley soils may include regional effects, in particular an increase in planting at lower elevation in the south west in the 1960s, while on well drained soils mean yield class has not increased. Similar increases in yield class with decreasing age have been reported from Northern Britain (Worrell and Malcolm, 1990).

Table 1: Mean Yield Class of Sitka spruce plantations on different soil types in Northern Ireland by planting year.

Planting Years	Brown earths/ Podsols	Gley soils	Peaty Podsols	Peaty gley soils	Shallow peat	Deep peat
1950-59	19.5	16.0	13.0	13.6	10.5	8.9
1960-69	19.1	19.6	15.8	15.4	14.5	11.3
1970-	19.0	20.8	16.5	16.0	16.0	14.2

3. Current uncertainties

3.1 Establishment of the second rotation

Potential problems with the establishment of the second rotation were discussed in papers given at a symposium of The Society of Irish Foresters in 1979 (Malcolm, 1979; Hendrick, 1979; Moloney, 1979). However, evidence from surveys of establishment success in the second rotation has suggested that initially the main problem has been in achieving an adequate stocking (eg Tabbush, 1988). Since by definition trees were previously satisfactorily established on second rotation sites, the source of this problem is the failure to recognise differences in the site brought about by growth and clearfelling of the first crop, or as stated by Malcolm in 1979, failure to exploit the increased variability of second rotation sites.

The initial problem in establishing plantations and achieving stocking targets on second (and subsequent) rotation sites is due to the reduced availability of planting microsites. Planting is made difficult and arduous by the residues from harvesting (Nelson and Dutch, 1991) and tree roots. The distribution of residues will depend to a large extent on the harvesting process, but can vary from a low relatively uniform cover to non-uniform piles or well defined bands which have been compressed by the passage of extraction machinery. If the previous crop was established on hand spaced turves raised planting positions will not be available. Where the remains of plough ribbons are available for planting it is difficult to maintain modern spacing specifications, which are normally wider than the original ploughing specifications. Moreover windthrow in crops established on plough ribbons usually results in peeling of the combined root plate-plough ribbon mass (Savill, 1976) and this creates particularly difficult conditions for replanting, where the choice of alternative microsites is limited by the area occupied by the old plough drains. The reduction in area for planting is exacerbated further by the need to plant away from the edges of stumps to avoid unduly restricting radial rooting in areas of moderate to high wind-risk (Quine *et al*, 1991).

Protection requirements are probably the most important secondary factors influencing establishment success of Sitka spruce in the second rotation. The outstanding protection requirement is against damage caused by the insects *Hylobius abietis* and *Hylastes* spp, which utilise tree stumps and dying roots for breeding. Replanted trees are vulnerable to attack, however the amount of damage sustained can vary widely between and across sites. Other protection requirements will vary widely and will not be significantly different in character from those of first rotation plantations. Some losses may also occur due to competition from the vigorous regrowth of vegetation. If the regrowth includes scrub or coppice replanted trees are also vulnerable to fraying damage. However the vegetation coverage of clearfelled sites is seldom uniform, and this complicates weed control.

A general response to dealing with the difficulty of establishment has been to upgrade plant handling and insecticidal protection measures (Tabbush, 1988; Stoakley and Heritage, 1990; Mason, 1991). However given the uncertainty attached to the risk of damage from *Hylobius*, a risk assessment procedure would be a useful aid to targeting protective measures. Experience suggests that plant handling methods which lead to improved vigour in the first growing season will also mitigate the effects of pine weevil damage by influencing the rate at which damaged tissues are replaced.

Strategies to increase the availability of planting microsites involve treating residues and the provision of new raised planting positions, using purpose built machinery or excavators with specially designed buckets (Nelson and Quine, 1990). Residues may be moved slightly to allow placement of mounds, pushed into windrows, or burned, although the latter may lead to *Rhizina* infection, with possible undesirable consequences (Seaby, 1977). Provision of raised planting positions makes planting easier and minimises weeding requirements, however it still may be difficult to achieve stocking targets without including an element of direct planting, because of stumps and the mounding drains themselves. On heavy mineral soils mounds do not always improve survival (eg Nelson and Watterson, 1992). On better drained mineral soils scarification provides better access to planting microsites through residues and some cultivation. Optimum strategies will clearly be site specific.

3.2 Natural regeneration

Natural regeneration of Sitka spruce may often occur on clearfelled sites, however there is, as yet, no basis for predicting its occurrence or abundance (Clàrke, 1992). Where it is prolific some form of treatment is required; densities in excess of 300,000 stems/ha have been recorded in Northern Ireland forests. Mechanical respacement before thicket stage is ineffective without treatment of cut stumps with herbicide to prevent regrowth, while delaying the operation can result in loss of diameter increment. On some sites the option of mechanical respacement may not exist because of extreme nutrient deficiencies brought about by competition. Chemical control of Sitka spruce regeneration is possible using the herbicide imazapyr (Nelson, 1990), however this is not a suitable method of preliminary respacement before a later mechanical selection. In spite of the respacing requirement it is possible that under some circumstances use of natural regeneration may result in lower establishment costs.

3.3 Maintaining productivity on N deficient sites

With the benefit of hindsight, much of the pessimism of the 1970s regarding the future N-fertiliser requirements of Sitka spruce on deep peat in Northern Ireland appears to have been unjustified. A similar prognosis has been made regarding the requirements of crops growing on low level blanket bogs in the west of Ireland (Farrell and Boyle, 1990). In northern upland peatland forests 2-4 applications of urea have been sufficient to achieve and maintain closed canopy conditions in most pure spruce crops, although on some experimental sites annual growth is still dependent on applied N after five applications, even though closed canopy conditions have existed for a number of years. With hindsight this might be a reflection of the preference for site uniformity and absence of slope in the laying out of experiments. However the suggestion is that in very high water table environments, such as flat peaty sites, it becomes less likely that nitrogen requirements for the maintenance of stand conditions will ever be met by litter breakdown, even after repeated application of N-fertilisers. Under these circumstances even the potential of species mixtures is questionable.

On infertile mineral soils the application of sewage and other sludges can be effective means of supplying nutrients (eg Wolstenholme *et al.*, 1992), and may be an alternative to the application of urea.

3.4 Nutrient deficiencies in second rotation stands

Results from fertiliser experiments on clearfelled sites in the Republic of Ireland and upland Britain (Hendrick 1979; Taylor, 1990) suggest that fertiliser applications at planting are unnecessary for most second rotation Sitka spruce, if growth in the first rotation was satisfactory. On some old red sandstone sites however, responses to applied P were significant, while on heathland sites in Britain it is suggested that nitrogen deficiency could be expected in pure crops. It has been suggested that fertiliser requirements on deep peat will be reduced, compared to the first rotation, because of physical changes brought about by the previous crop. These include irreversible drying and cracking, and are more likely to occur under crops with significant amounts of lodgepole pine (Pyatt and Craven, 1978; Pyatt, 1990b). Growth data from a cultivation experiment on shallow peat in Northern Ireland (Schaible and Dickson, 1990) suggest that nutrient availability will influence growth in the second rotation on some upland peats after about five years from planting. In this experiment the availability of N and P was increased by draining and providing raised planting positions; borehole studies indicated that the effect of the drains in lowering the water table was minimal, suggesting that the origin of the nutritional advantage lies in the mineralisation of the spoil generated by drainage, as suggested by Savill *et al.*, (1974). Intensive cultivation and the planting of spruce/pine or spruce/larch mixtures are treatments which will be fully explored in the second rotation on deep peat. The planting of mixtures is also recommended for replanting heathland sites (Taylor, 1990), although on nutrient poor sites a second rotation of mixtures may require management to ensure that the availability initially of P and subsequently of N and K is adequate.

Where harvesting systems involve the concentration of residues some redistribution of nutrients is inevitable. Studies of the effect of harvesting residues on nutrient availability suggest that in the short term nutrient release from litter decomposition is of greater significance than release from residues (Carey, 1980; Titus and Malcolm, 1991; Fahey *et al,* 1991). Studies of nutrient release on a peaty gley clearfelled site in Northumbria indicated that while losses of N and P were unlikely to give concern, losses of K were substantial. Nutrient inputs to litter from slash were significant and the possibility that banding of residues could lead to uneven growth in the longer term was not discounted (Titus and Malcolm, 1992). In a review of recent studies of the possible effects of harvesting residues, or 'whole tree harvesting', (Nelson and Dutch, 1991) it was concluded that there is little evidence to suggest that this practice will result in nutrient deficiencies in the second rotation except on poor sites. In Ireland this might include soils derived from old red sandstone (Carey, 1980) and oligotrophic blanket peat. If this is the case the redistribution of residues to a more even coverage before planting or early fertiliser application would be desirable practices on these site types.

4. Looking Ahead

4.1 Establishment

It has been accepted that research to develop methods of establishment that enhance crop stability is of great importance to forestry on soils with impeded drainage. On gley soils in Ireland there are indications that this has been at least partially successful (Hendrick, 1989), while on peats future uptake in terms of new planting is limited. The application of the results of cultivation research to second rotation crops will be problematic because of the presence of stumps, root plates and residues, and on some soils, because of changes brought about by the previous crop. In this context mounding is essentially a mechanised method of turfing and scarification a mechanised equivalent of screefing. For many decades of new planting these treatments were considered necessary either to provide local drainage, or to increase available moisture and provide a local and temporary reduction in competition from vegetation. If the latter role is fulfilled by the use of herbicides, the requirement for either raised or depressed planting positions on mineral soils is open to question, unless the site is prone to waterlogging or drought in the first few months from planting. Neither option is likely to enhance conditions for root development compared to direct planting, and hence neither will offer the prospect of improved stability. In addition, the practice of mounding by excavator and forming parallel drains may create problems for establishing third rotation crops on mineral soils, depending on drain width and mound volume. However, apart from eliminating or minimising weeding requirements, there is also evidence that cultivation may reduce pine weevil damage (Orlander *et al*, 1990). On surface water gley soils in Northern Ireland a technique of ripping has been successfully applied which does not result in the shearing of root plates and widespread disruption of surface drainage (Schaible, 1992). It may provide a means of increasing the stability of second rotation stands on wet mineral soils. On peaty sites much will depend on the degree of shrinkage of the organic horizon (Malcolm, 1979). On shallow peaty gleys it may be possible to introduce subsurface drainage channels into the mineral soil for the second rotation, while on peaty ironpans it should be possible to rupture pans where this was not done prior to planting the first crop. It remains to be seen whether it will be possible to introduce subsurface drainage tunnels to clearfelled deep peats. Clearly there is a wide range of site preparation options to use on clearfelled sites, each with a particular set of advantages and disadvantages depending on site conditions determined by soil type, the rate of revegetation and protection requirements.

Compaction or rutting damage of mineral soils is sometimes caused by timber extraction machinery, in spite of the use of residues and small poles to bed extraction routes. Whilst the area affected is generally small in proportion to a felling coupe, this type of damage is distributed linearly and is often continuous, and therefore may have a disproportionate effect on the stability of the successor crop. In the clearing of windthrown areas the supply of brash for bedding extraction routes is reduced, and ground conditions are often wet to begin with. Under these conditions it is difficult to avoid ground damage and the potential exists for a reduction in productivity in second and subsequent rotations through slow establishment, reduced growth and poor stability. Little work appears to have been done to investigate remedial measures on surface water gley soils where the implications for stability may be the most serious.

4.2 Nutrition

It is likely that the nutritional management of upland forests will evolve to take account of cheaper and more environmentally benign materials and practices. Some of these, such as the use of cultivation on organic soils, the planting of mixtures and the use of sewage sludges, have already been discussed as practical possibilities, while others are largely experimental. The application of high (7.5-15 t/ha) rates of ground limestone to deep peat (Dickson, 1984) has been shown to enable the mineralisation of organically held N. It will be technically far easier to apply on clearfelled sites than on virgin peatlands by utilising timber extraction routes. Liming of peat also enables the establishment of alders in the milder western half of Northern Ireland (Dickson, pers. comm), which may then fix atmospheric nitrogen for the use of Sitka spruce planted in mixture, or possibly as a successor crop. Likewise the use of other nitrogen fixing species such as lupins or *Ulex gallii* is potentially useful on heathland soils on ORS in Ireland (O Carroll, 1982; O'Toole *et al.*, 1984).

4.3 Environment x nutrient interactions

Acid deposition and other forms of atmospheric pollution may affect Sitka spruce plantations in ways which have not yet been experienced in Ireland or upland Britain. The effects will be difficult to interpret as pollution events are weather related and episodic in character, and may interact strongly with previous or subsequent climatic conditions. The effects on trees may be mediated through changes in insect populations and in the susceptibility of trees to insect attack, particularly the green spruce aphid *Elatobium abietinum* (eg Warrington and Whittaker, 1990). Defoliation of trees disrupts established patterns of nutrient cycling and temporarily affects growth. On wet sites recovery may be limited because of changes in soil moisture resulting from reduced interception of rainfall. Predictions of global warming and climatic instability suggest it would be advisable to consider the fact that most upland Sitka spruce plantations are growing on soils which are poorly buffered against drought and acidic deposition, and which are potentially susceptible to irreversible changes.

5. Conclusions

Although productivity on some sites may decrease with successive rotations because of site degradation, this will be balanced by increases on other sites resulting from improved establishment methods. Speculation on future developments in establishment and nutrition practices for Sitka spruce based on current and historical trends is difficult because of the potential changes to sites brought about by the first rotation and changes in climate and atmospheric inputs. Tangible differences between past and future practices will be in the degree of within and between site variation that will need to be accommodated as a result of the effects of previous rotations, and in the degree of choice of treatments available to the manager. Consequently systematic application of silvicultural treatments will be less satisfactory than prescriptions based on site appraisal, recognition of predetermining site factors, and an understanding of interrelationships between these factors and the mechanisms involved. This approach would enable decisions affecting the establishment, nutrition and stability of forest crops to be derived from first principles. It is essential if past experience is to be used successfully to deal with future challenges.

Acknowledgements

Much of this paper is based on conversations with the late Dr David Dickson. The summary of inventory data in Table 1 was provided by Dr D J Kilpatrick, Department of Agriculture, Newforge Lane, Belfast. I thank Pat Hunter-Blair and Dr Kerry Garrett for their helpful comments and encouragement.

REFERENCES

ADAMS, S. N., JACK, W. H., and DICKSON, D. A. (1970). The growth of Sitka spruce on poorly drained soils in Northern Ireland. Forestry 43: 125-133.

ADAMS, S. N., DICKSON, D.A. and CORNFORTH, I.S. (1972). Some effects of soil water tables on the growth of Sitka spruce in Northern Ireland. Forestry 45: 129-133.

ADAMS, S. N. (1974). Some relations between forest litter and growth of Sitka spruce on poorly drained soils. J. appl. Ecol. 11: 761-766.

ATTERSON, J. (1978). Current fertiliser use in plantations. [in] The Ecology of Even Aged Plantations ed. by Ford, E.D., Malcolm, D.C. and Atterson, J. Proc. IUFRO Div. I, Edinburgh. pp 313-326.

BINNS, W. O. (1962). Peat as a substrate for the growth of forest trees. Irish Forestry 19: 32-55.

CAREY, M. L. (1977). Nutritional disorders in Sitka spruce in the Republic of Ireland. Irish Forestry 34: 40-47.

CAREY, M. L. (1980). Whole tree harvesting in Sitka spruce. Possibilities and implications. Irish Forestry 37: 48-63.

CAREY, M. L., McCARTHY, R. G. and MILLER, H. G. (1988). More on nursing mixtures. Irish Forestry 45: 7-20.

CLARKE, G. C. (1992). The natural regeneration of Spruce. Scottish Forestry 46: 107-129.

DALLAS, W. G. (1962). The progress of peatland afforestation in Northern Ireland. Irish Forestry 19: 84-93.

DICKSON, D. A. (1962). The indicator value of peatland vegetation. Irish Forestry 19: 14-32.

DICKSON, D. A. (1969). Uptake of nutrients following fertilisation of Sitka spruce on deep peat in Northern Ireland. J.Sci.Fd Agric. 20: 420-423.

DICKSON, D. A. (1971). The effect of form, rate and position of phosphatic fertilisers on growth and nutrient uptake of Sitka spruce on deep peat. Forestry 44: 17-26.

DICKSON, D. A. and SAVILL, P. S. (1974). Early growth of *Picea Sitchensis* (Bong.) Carr on deep oligotrophic peat in Northern Ireland. Forestry 47: 57-88.

DICKSON, D. A. (1977). Nutrition of Sitka spruce on peat – problems and speculations. Irish Forestry 34: 31-39.

DICKSON, D. A. (1984). Effects of ground limestone and urea on growth of Sitka spruce on deep oligotrophic peat in Northern Ireland. Proc 7th Int Peat Congress, Dublin (3): 255-263.

DUTCH, J. C., TAYLOR, C. M. A. and WORRELL, R. (1990). Potassium fertiliser – Effects of different rates, types and times of application on height growth of Sitka spruce on deep peat. Research information Note 188, Forestry Commission.

EDWARDS, M. V. (1962). The progress of peatland afforestation in Great Britain. Irish Forestry 19: 102-109.

FAHEY, T. J., STEVENS, P. A., HORNUNG, M., and ROWLAND, P. (1991). Decomposition and nutrient release from logging residue following conventional harvest of Sitka spruce in North Wales. Forestry 64: 289-301.

FARRELL, E. P. and O'HARE, P. J. (1974). Depth of water table in a *Picea sitchensis* fertilisation experiment on blanket peat. Irish Forestry 31: 36-45.

FARRELL, E. P. (1985a). Long-term study of Sitka spruce on blanket peat. 1. The response to fertilisers and lime. Irish Forestry 42: 76-91.

FARRELL, E. P. (1985b). Long-term study of Sitka spruce on blanket peat. 2. Water-table depth, peat depth and nutrient mineralisation studies. Irish Forestry 42: 92-105.

FARRELL, E. P., and BOYLE, G. (1990). Peatland forestry in the 1990s. 1. Low-level blanket bog. Irish Forestry 47: 69-78.

FAULKNER, R. and WOOD, R. F. (1957). Picea sitchensis. [in] Exotic forest trees in Great Britain. Forestry Commission Bulletin 30. HMSO, London.

HENDRICK, E. (1979). Site amelioration for reforestation. Irish Forestry 36: 89-98.

HENDRICK, E. (1989). The effect of cultivation method on the growth and root anchorage of Sitka spruce. Irish Forestry 46: 19-28.

JACK, W. H. (1965). Experiments on tree growth on peat in Northern Ireland. Forestry38: 20-40.

LEYTON, L. (1955). The influence of artificial shading of the ground vegetation on the nutrition and growth of Sitka spruce in a heathland plantation. Forestry 28: 1-6.

MACDONALD, J. A. B. (1945). The Lon Mor: twenty years research into wasteland peat afforestation in Scotland. Forestry 19: 67-73.

MACDONALD, J.A.B. (1953). Thirty years development of afforestation technique on difficult ground types in south-west Scotland. Forestry 26: 14-21.

MALCOLM, D. C. (1979). Some effects of the first rotation on site properties. Irish Forestry36: 76-88.

McINTOSH, R. (1981). Fertiliser treatment of Sitka spruce in the establishment phase in upland Britain. Scottish Forestry 35: 3-13.

McINTOSH, R. (1983). Nitrogen deficiency in establishment phase Sitka spruce in upland Britain. Scottish Forestry 37: 185-193.
McMAHON, F. (1945). Sitka spruce in Irish Forestry. Irish Forestry 2: 66-71.
MASON, W. L. (1991). Improving quality standards for conifer planting stock in Great Britain. Scottish Forestry 45: 28-41.
MILLER, H. G. (1981). Forest fertilisation: some guiding concepts. Forestry 54: 157-167.
MILLER, H.G. (1986). Carbon x nutrient interactions – the limitations to productivity. Tree Physiology 2: 373-385.
MOLONEY, B. (1979). Treatment of lop and top. Irish Forestry 36: 99-104.
NEUSTEIN, S. A. (1976a). A history of plough development in British Forestry I. Introduction and early developments. Scottish Forestry 30, 2-15.
NEUSTEIN, S. A. (1976b). A history of plough development in British Forestry II. Historical review of ploughing on wet soils. Scottish Forestry 30, 89-111.
NEUSTEIN, S. A. (1976c). A history of plough development in British Forestry III. Historical review of ploughing on drier soils. Scottish Forestry 30, 253-274.
NEUSTEIN, S. A. (1977). A history of plough development in British Forestry IV. Mounted ploughs (and other regeneration equipment). Scottish Forestry 31, 2-12.
NELSON, D. G. (1990). Chemical control of Sitka spruce natural regeneration. Research Information Note 187, Forestry Commission, Edinburgh.
NELSON, D. G. and QUINE, C. P. (1990). Site preparation for restocking. Research Information Note 166, Forestry Commission, Edinburgh.
NELSON, D. G. and DUTCH, J. C. (1991). The silvicultural implications of utilising harvesting residues for energy. [in] Wood for Energy: the Implications for Harvesting, Utilization and Marketing, Ed. by Aldhous, B.A. Proc. Discussion meeting, Edinburgh, April, 1991. Institute of Chartered Foresters and Department of Environment. pp 148-159.
NELSON, D. G. and WATTERSON, D. (1992). Silviculture (North). Forestry Commission Report on Forest Research 1991. HMSO, London.
O CARROLL, N. (1962). The progress of peatland afforestation in the Republic of Ireland. Irish Forestry 19: 93-101.
O CARROLL, N. and McCARTHY, R. (1973). Potassium supplied by precipitation and its possible role in forest nutrition. Irish Forestry 30: 88-93.
O CARROLL, N. (1978). The nursing of Sitka spruce 1. Japanese larch. Irish Forestry 35: 60-65.
O CARROLL, N., CAREY, M. L., HENDRICK, E. and DILLON, J. (1981). The Tunnel Plough in peatland afforestation. Irish Forestry 38: 27-40.
O CARROLL, N. (1982). The nursing of Sitka spruce 2. Nitrogen-fixing species. Irish Forestry 39: 17-29.
ORLANDER, G., GEMMEL, P. and HUNT, J. (1990). Site preparation: A Swedish Overview. B.C.Ministry of Forests Research Branch, Victoria, B.C.
O'TOOLE, P., DOWDS, J. and FARRELL, E. P. (1984). Nitrogen accumulation by *Ulex galli* (Planch.) in a forest ecosystem. Irish Forestry 41: 14-29.
PYATT, D. G. and CRAVEN, M. (1978). Soil changes under even-aged plantations. [in] The Ecology of Even Aged Plantations ed. by Ford, E.D., Malcolm, D.C. and Atterson,J. Proc. IUFRO Div. I, Edinburgh. pp 369-388.
PYATT, D.G. (1990a). Forest Drainage. Research Information Note 196, Forestry Commission, Edinburgh.
PYATT, D.G. (1990b). Long term prospects for forests on peatland. Scottish Forestry 44: 19-25.
QUINE, C. P., BURNAND, A. C., COUTTS, M. P., and REYNARD, B. R. (1991). Effects of mounds and stumps on root architecture of Sitka spruce on a peaty gley restocking site. Forestry 64: 385-401.

QUINE, C. P. and BURNAND, A. C. (1991). Early growth and root architecture of Sitka spruce in relation to cultivation of a peaty ironpan afforestation site. Scottish Forestry 45: 175-182.
ROBINSON, R. L. (1931). Use of Sitka spruce in British afforestation. Forestry 5: 93-95.
ROSS, S. M. and MALCOLM, D. C. (1982). Effects of intensive forestry ploughing practices on an upland heath soil in South east Scotland. Forestry 55: 155-177.
SAVILL, P. S., DICKSON, D. A., and WILSON, W. T. (1974). Effects of ploughing and drainage on growth and root development of Sitka spruce on deep peat in Northern Ireland. Proc. Int. Symp. on Forest Drainage, Jyvaskyla-Oulu, Finland.
SAVILL, P. S. and DICKSON, D. A. (1975). Early growth of Sitka spruce on gleyed soils in Northern Ireland. Irish Forestry 32: 34-49.
SAVILL, P. S. (1976). The effects of drainage and ploughing of surface water gleys on rooting and windthrow of Sitka spruce in Northern Ireland. Forestry 49: 133-141.
SAVILL, P. S. (1977). Environmental and soil factors affecting the growth of conifers in Northern Ireland. Ph.D. thesis, Queens University of Belfast.
SCHAIBLE, R. (1986). Annual Report on Research, Development and Technical Work, Department of Agriculture, Northern Ireland. pp 221-223.
SCHAIBLE, R and DICKSON, D. A. (1990). Effects of drainage intensity and planting position on the growth and nutrition of second rotation Sitka spruce on shallow peat. Irish Forestry 47: 19-27.
SCHAIBLE, R. (1992). Annual Report on Research and Development, 1990/91. Department of Agriculture for Northern Ireland. pp 124-125.
SEABY, D. (1977). Rhizina undulata on Picea abies transplants. Eur. J. For. Path. 7:186-188.
STIRLING-MAXWELL, J. (1951). The Lock Ossian Plantations - An early experiment in afforestation. Reprinted in Scottish Forestry 43: 212-225 and 44: 40-49.
STOAKLEY, J. T. and HERITAGE, S. G. (1990). Approved methods for insecticidal protection of young trees against *Hylobius abietis* and *Hylastes* species. Research Information Note 185, Forest Commission, Edinburgh.
TABBUSH, P.M. (1988). Silvicultural principles for upland restocking. Forestry Commission Bulletin 76. HMSO, London.
TAYLOR, C. M. A. (1985). The return of nursing mixtures. Forestry and British Timber 14(5):18-19.
TAYLOR, C. M. A. (1990). The nutrition of Sitka spruce on upland restock sites. Research Information Note 164, Forestry Commission, Edinburgh.
TAYLOR, C. M. A. (1991). Forest fertilisation in Britain. Forestry Commission Bulletin95. HMSO, London.
TAYLOR, G. G. M. (1970). Ploughing practice in the Forestry Commission. Forestry Commission Forest Record 73, HMSO, London.
THOMPSON, D. A. (1975). Cultivation. Forestry Commission Report on Forest Research 1975. HMSO, London.
TITUS, B. D. and MALCOLM, D. C. (1991). Nutrient changes in peaty gley soils after clearfelling of Sitka spruce stands. Forestry 64: 251-270.
TITUS, B. D. and MALCOLM, D. C. (1992). Nutrient leaching from the litter layer after clearfelling of Sitka spruce stands on peaty gley soils. Forestry 65: 389-416.
VERLING, P. (1967). Use of rippers as an alternative to the Clark plough. Irish Forestry 24: 75-76.
WARRINGTON, S. and WHITTAKER, J. B. (1990). Interactions between Sitka spruce, the green spruce aphid, sulphur dioxide pollution and drought. Environmental Pollution 65: 363-370.
WEATHERELL, J. (1953). The checking of forest trees by *Calluna*. Forestry 26: 37-40.
WILSON, K. and PYATT, D. G. (1984). An experiment in intensive cultivation of an upland heath. Forestry 57: 117-142.

WOLSTENHOLME, R., DUTCH, J., MOFFAT, A. J., BAYES, C. D. and TAYLOR, C. M. A. (1992). A manual of good practice for the use of sewage sludge in forestry. Forestry Commission Bulletin 107. HMSO, London.

WORRELL, R and MALCOLM, D. C. (1990). Productivity of Sitka spruce in Northern Britain 2. Prediction from site factors. Forestry 63: 119-128.

ZEHETMAYR, J. W. L. (1954). Experiments in tree planting on peat. Forestry Commission Bulletin 22. HMSO, London.

ZEHETMAYR, J. W. L. (1960). Afforestation of upland heaths. Forestry Commission Bulletin32. HMSO, London.