Increasing the yield and quality of broadleaf planting stock through higher N fertilisation in the nursery

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Abstract

The planting of broadleaf species has increased in Ireland in recent years with a consequent upsurge in the demand for planting stock of common alder (*Alnus glutinosa* L.), downy birch (*Betula pubescens* Ehrh.), and pedunculate oak (*Quercus robur* L.). However, the yield of usable plants and the quality of planting stock produced in Irish nurseries could be improved. The better use of N fertiliser and cloches might help address this issue. To this end, the effect of 40, 80 (standard amount), 120 and 160 Kg N ha^{-1} (applied as calcium ammonium nitrate) on seedling growth and yield in these species was assessed. Seedbeds were sown with seeds of each species and were covered with cloches before seedling emergence had commenced. The cloches were removed in mid June, after which the fertiliser treatments commenced. Fertiliser was applied in five equal quantities at two-week intervals until mid August. Higher N fertiliser than the standard (and the 40 kg N ha^{-1}) amount improved growth and yield in all species. For example, 50, 48 and 67% of the seedlings had a mean height >40 cm in plots that received the highest N level, compared with 30, 21 and 24% in the plots that received the standard amount in alder, birch and oak, respectively. Differences in treatment responses to the two highest N levels were small in alder, but were less clear in birch and oak. Furthermore, seedlings grown at the highest N level also had higher root growth potential (a measure of plant quality) than those grown at the standard level, suggesting that the former plants would probably perform better in the field than the latter ones. The N cost per usable plant was lower for seedlings grown at the higher than the lower N rates in alder and birch, but not in oak, but further testing is needed to confirm this.

Introduction

The planting of broadleaf species in Ireland and many other European countries has increased in recent years. In Ireland, broadleaves accounted for less than 10% of planting in the 1980s and 1990s. Although exact figures are not available, it is estimated that broadleaves may now account for more than 20% of the current planting programme, most of these being produced in bare-root nurseries. There has been a similar increase in the planting of broadleaf species in some parts of North America (Davis and Jacobs 2005). Consequently, there has been a renewed focus on improving the yield and quality of planting stock of broadleaf species in the nursery (Schultz and Thompson 1996, O'Reilly et al. 2005, Wilson and Jacobs 2006).

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Recently, there has been some concern about the quality of broadleaf stock produced in Irish nurseries (O'Reilly 2006). For this reason, a project (QualiBroad, funded by COFORD) was undertaken in an attempt to address this issue for several commercially important broadleaf species: common alder (*Alnus glutinosa* L.), downy birch (*Betula pubescens* Ehrh.) and pedunculate oak (*Quercus robur* L.). The effect of seed factors, seed coverings and sowing date on germination under controlled environmental conditions and in field tests have already been examined in this project (De Atrip and O'Reilly 2005, Özbingöl and O'Reilly 2005, De Atrip and O'Reilly 2006, 2007a, 2007b, De Atrip et al. 2007, O'Reilly and De Atrip 2007). In addition, the impact of cloches and fertilisers on the growth and yield of seedlings in the nursery was investigated; the results from one of these nursery studies are reported in this paper.

Fertilisation is a major issue in the production of broadleaf planting stock and most of the prescriptions used in Ireland have been adapted from those used on conifer crops. Information on the effect of mineral nutrition on the growth of broadleaves in the nursery is limited (Wilson and Jacobs 2006). Most of the anecdotal evidence from Ireland suggests that higher rates of fertilisation would improve seedling growth, but there was no reliable information for most of the important broadleaf species. In particular, N availability may be a major factor limiting growth of seedlings in the nursery, according to one Canadian study (Burdett 1990).

Even if mineral nutrient levels are adequate, it may be difficult to grow broadleaves in nurseries located in areas that have relatively cool summer conditions, such as in Ireland. Broadleaf species appear to be particularly sensitive to environmental conditions (Mason 1994). It normally takes 2 years to produce stock in Ireland that is of comparable size and quality to imported 1-year-old material (Long 2006). Research carried out in Britain has revealed that cloches can be used to improve seedbed microclimate, and thus improve growth and yields in the nursery (Thompson and Biggin 1980, Thompson 1982, Stevenson and Thompson 1985). Cloches are lengths of polythene or fabric raised off the nursery bed, usually supported by wire hoops (Mason 1994). In a previous study, it has been shown that birch seedlings could be grown to target size (>40 cm) in one year in an Irish nursery with the aid of cloches (O'Reilly et al. 2005), and there was evidence that alder and oak would also grow better under cloches (unpublished data on file) than if left uncovered. However, there are also some practical constraints to the use of cloches. It is generally more difficult to apply fertilisers and other treatments to a crop under a cloche. Therefore, it may be preferable to start a crop under a cloche and then remove it relatively early in the summer, when conditions are favourable for growth anyway. Plants grown in this way might respond well to increased fertilisation. For this reason, in this study the effects of N fertilisation levels on plant growth and yield were investigated for alder, birch and oak seedlings that were grown under cloches until mid June.

Materials and methods

The nursery, seed material and sowing

The seedlings in this study were grown at the Coillte Ballintemple Nursery, Co Carlow (52º 44′ N 6º 42′ W, 100 m). The soil at Ballintemple is a sandy loam of pH 5.7, having an organic matter of 6-8%, and sand, silt and clay fractions of 66, 19, and 15%, respectively. The soil was sterilised in early September 2002 and the beds were formed three weeks later. The seeds from a single lot of each species (Table 1) were pretreated according to standard operational procedures. The seeds of alder and birch were soaked in excess water for 48 h at 3 to 4ºC, after which the excess water was drained, and then they were stored at the same temperature until the date of sowing (about 3-4 weeks after soaking). The oak acorns were stored at -3ºC from the date of arrival in nursery (7 October 2002) until the date of sowing. The seeds of alder and birch were covered with 3-5 mm of lime free grit just after sowing on 11 April and 15 April, 2003 respectively. The acorns were drill sown at 20 mm depth on 18 February 2003. Other details of seed viability, sowing rates and target seedling densities are given in Table 1.

Table 1: Seed lots of the alder, birch and oak used in the study in 2003.

Species	*Country and seed zone*	*Viable seeds*	*Sowing rate*	*Target density*	*Sowing date*	*Date cloches erected*
		number kg^{-1}	*m^2 kg^{-1}*	*number m^{-2}*		
Alder	Cork, Ireland 2002 (417)	126,760	280	180	11 April	16 April
Birch	Cork, Ireland 2000 (417)	149,000	600	180	15 April	21 April
Oak	NLS Helvoirt Netherlands 2002 (492)	87	1.5	100	18 February	24 March

Treatments and experimental design

The experiment was laid down as a randomised block design with four blocks (nursery beds), each block containing one replication of each of the four fertiliser treatments per species. Soon after sowing, perforated (P) clear polythene cloches (Sotrafa, Spain) were erected over each bed (each about 150 m long). The cloche was 35 µm thick and had 10 mm diameter perforations, with 200 perforations per m^2. All cloches were removed on 16 June. Each bed was divided into four plots (each approx. 20 m long). Each plot was assigned a different fertiliser treatment at random.

Four different levels of calcium ammonium nitrate (CAN) were applied in equal quantities on five occasions, at approximately two-week intervals from 18 June onwards, ending in mid August. The fertiliser contains 27% N as ammonium nitrate and 5% sulphur. The total amount of N applied was 40 (150 kg CAN ha^{-1}), 80 (300 kg CAN ha^{-1}), 120 (450 kg CAN ha^{-1}) or 160 (600 kg CAN ha^{-1}) kg ha^{-1}, hereinafter abbreviated to 40 N, 80 N, 120 N and 160 N.

Sampling, observations and measurements

Seedling density and height

The number of seedlings at two 0.5 m^2 sampling points, each located about 7 m from plot boundary, was recorded in autumn 2003. The height of 10 seedlings (in a single line in oak) at centre of each sampling point was measured also. The proportion of seedlings >40 cm was calculated from these data, providing information on the likely yield of usable plants. The minimum heights are 30, 40 and 45 cm and minimum diameters are 4, 4 and 6 mm for planting stock of alder, birch and oak, respectively in Ireland (Anonymous 2003).

Other morphological characteristics and root growth potential (RGP)

The effects of treatments on shoot and root dry weights, shoot to root ratio and root growth potential were assessed. This investigation was restricted to the standard (80 kg ha^{-1}) and the highest fertiliser treatment levels (160 kg ha^{-1}) only.

About 50 seedlings were lifted from the centre of each plot in February 2004 for study. The seedlings were bundled separately by plot and then dispatched to UCD where they were held at 0-2°C until the time of processing. The diameter and height of 10 plants sampled at random from each bundle were measured, after which the roots were excised from each plant at the root collar. The weights of the shoot and root of each plant were measured after drying the samples in an oven at 105 °C for 24 h. The sturdiness (height/ diameter) and shoot: root ratio were calculated from these data.

The RGP tests were carried out in early March 2004. The seedlings were planted in 3.5L pots containing a mixture (3:1; vol:vol) of peat and perlite. Each of the 14 pots (replicates) per treatment contained four seedlings, one seedling from each nursery block. The seedlings were allowed to grow for four weeks in an unheated greenhouse (temperatures approx. 15-20ºC during the day, 8-10ºC at night) and were watered every four or five days. At the end of the test, the seedlings were removed from the pots and the roots washed in tap water. The number of new white roots >1 cm long was counted.

Analyses

The data were analysed separately for each species according to a completely randomised block design. Proportion data were transformed to arc-sine square-root values before analysis. Treatment means were compared further using least significant means tests. All significant values reported are $p \leq 0.05$.

Results

Seedling density (Figure 1), mean height (Figure 2) and proportion of seedlings >40 cm tall (Figure 3) varied with treatment. The trend for treatment effects on mean height and proportion of plants >40 cm height was generally similar. Although the absolute increases in all parameter responses were largest in alder and birch, the relative response was similar also in oak. However, there were some species differences, mainly for the effect of the two highest fertiliser levels. For example in alder, there were 391 (160 N), 411 (120 N) plants m^{-2}, significantly higher than the 374 m^{-2} (80 N) and 365 m^{-2} (40 N) in the other treatment plots (Figure 1).

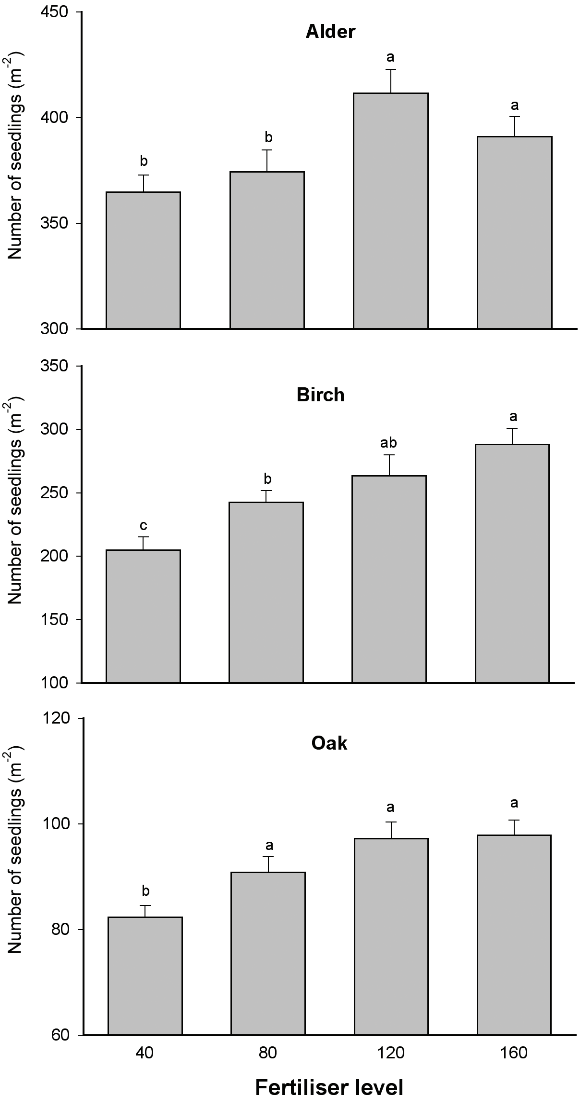

Figure 1: Effect of 40 to 160 kg N ha^{-1} N fertiliser on seedling density in nursery seedbeds of alder, birch and oak. Means with the same letter are not significantly different. Vertical lines are standard errors.

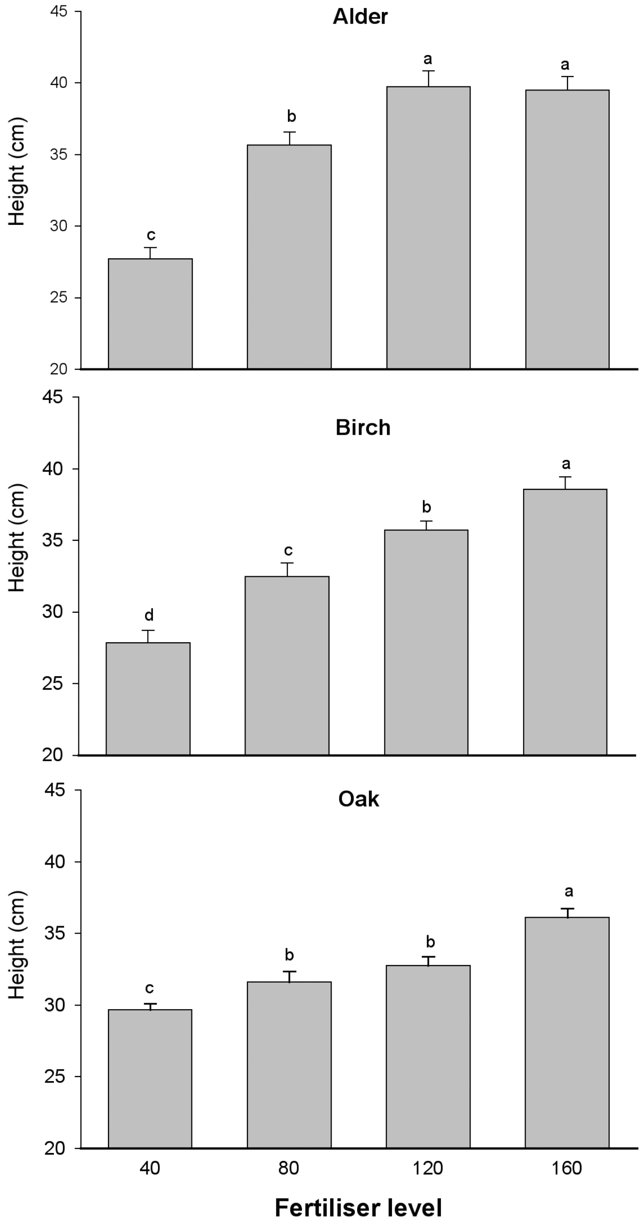

Figure 2: Effect of 40 to 160 kg N ha^{-1} N fertiliser on mean seedling height in nursery seedbeds of alder, birch and oak. Means with the same letter are not significantly different. Vertical lines are standard errors.

Mean height in alder was 39 (160 N) or 40 cm (120 N), significantly greater than the 36 cm (80 N) and 26 cm (40 N) height of seedlings from the other treatment groups (Figure 2).

About 48% (120 N) and 50% (160 N) of the alder seedlings exceeded the target height of 40 cm, significantly more than the 30% (80 N) and 8% (40 N) that were in this category in the other treatment plots (Figure 3).

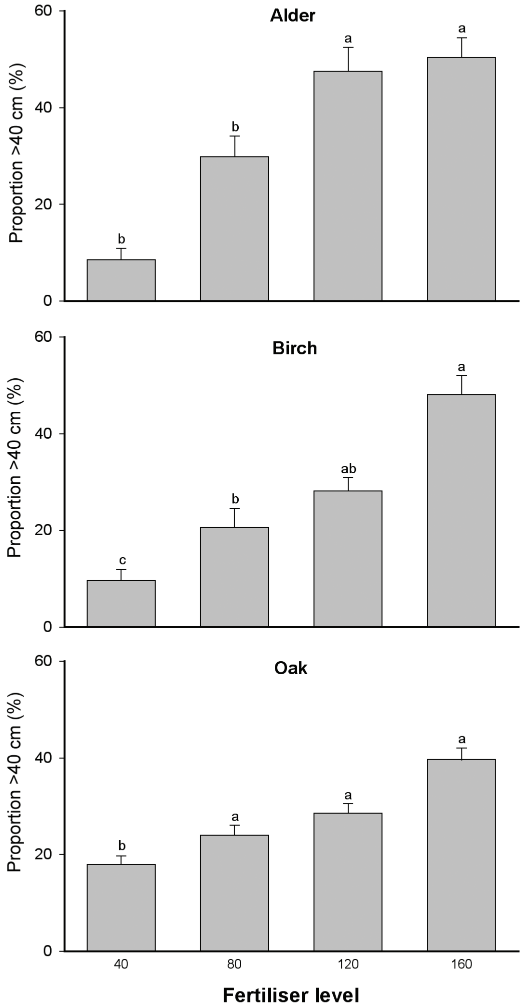

Figure 3: Effect of 40 to 160 kg N ha^{-1} N fertiliser on the proportion of seedlings that exceeded 40 cm height in nursery seedbeds of alder, birch and oak. Means with the same letter are not significantly different. Vertical lines are standard errors.

Since the data for all measurements (Figures 1-3) changed little as fertiliser was increased from 120 to 160 N in alder, this suggests that growth and yield had been maximised. The response also declined, but had not levelled off, as fertilisation level was increased in birch and oak.

Not surprisingly, the trend for the effect of treatments on total number of seedlings m^{-2} >40 cm tall (proportion data adjusted for actual seedling density differences) (Table 2) mirrored that described for a component parameter, proportion of seedlings >40 cm tall (Figure 3). In alder, there were nearly 200 plants m^{-2} in both the 120 and 160 N treatment plots, compared with only 111 (80 N) and 31 (40 N) in the other treatments (Table 2). Treatment differences were larger in birch and oak. In birch, there were 139 plants of that size in the 160 N treatment plots versus only about 20 in plots that received the lowest fertiliser level. The equivalent values in oak were 39 and 15 plants m^{-2}, respectively.

Table 2: Number of seedlings >40 cm tall and amount of N fertiliser applied per usable seedling in each fertiliser treatment.

Rate of N	*Alder*		*Birch*		*Oak*	
	Number >40 cm	*N per plant*	*Number >40 cm*	*N per plant*	*Number >40 cm*	*N per plant*
40 Kg N	31.1	1.28	19.6	2.04	14.7	2.71
80 Kg N	111.5	0.72	50.0	1.60	21.8	3.68
120 Kg N	195.4	0.61	74.1	1.62	27.7	4.33
160 Kg N	197.0	0.81	138.8	1.15	38.7	4.13

The total amount of N used per seedling >40 cm tall differed among species, with oak using the most N. The lowest N per plant was achieved at 120 N in alder, 160 N in birch, and 40 N in oak.

The effects of the highest compared with the standard fertiliser rates on other morphological traits were evaluated also. Seedlings that received the highest fertiliser level had significantly larger shoot dry weight (2.11 versus 1.53 mg) and root dry weight (2.01, 1.55 mg) in alder, whereas seedlings that received the highest N level in birch were significantly less sturdy than the those that received the standard treatment (9.3, 8.5) (Table 3). Seedlings that received the most fertiliser also had higher RGP than seedlings that received the standard amount in all species. For seedlings that received the 160 N and 80 N (standard) treatments, RGP was 57.5 and 34.2 in alder, 30.3 and 12.6 in birch and 17.2 and 7.9 in oak, respectively. None of the other treatments had a significant effect.

Discussion

The main finding of this study was that the application of higher fertiliser levels than the standard (80 N) rate improved the growth, yield and quality of seedlings in all three species. In particular, the RGP of seedlings grown at the highest fertiliser level was greater than in those that received the standard level. In this study, the extra

Table 3: Morphological characteristics and root growth potential of seedlings in plots that received the standard (80 kg N ha^{-1}) and highest level (160 kg N ha^{-1}) of fertiliser. Means that are significantly different ($p \leq 0.05$) are indicated (*).

	Alder		*Birch*		*Oak*	
	80	160	80	160	80	160
Diameter mm	4.71	5.17	3.76	3.71	6.06	6.23
Height cm	31.0	35.7*	30.9	32.8	31.0	34.2
Sturdiness[1]	6.65	7.02	8.50	9.30*	5.22	5.52
Shoot dry weight g	1.53	2.11*	1.02	0.96	3.15	3.49
Root dry weight g	1.55	2.01*	0.56	0.53	9.19	8.42
Shoot: root ratio	2.43	1.33	2.12	2.11	0.35	0.43
Root growth potential	34.2	57.5*	12.6	30.3*	7.9	17.2*

[1]Sturdiness is height (cm) divided by diameter (mm). Low values indicate more sturdy plants.

nutrient reserves might have enhanced the RGP response for other reasons too, as discussed below. The new standard fertiliser treatment for alder, birch and oak in Coillte nurseries is 120N, a change that was initiated mainly in response to the results of this study.

Both mean height and yield of plants (>40 cm) differed little between the two highest levels of treatment in alder, but not in birch and oak. This suggests that 160 N was close to optimal for growing alder in 2003. It may be necessary to use even higher levels of fertilisation in further studies to determine the level at which the response reaches a plateau in birch and oak. The fact that higher N levels improved RGP is particularly promising. In previous studies, RGP was associated with better field performance in ash (*Fraxinus excelsior* L.) seedlings in Ireland (O'Reilly et al. 2002) and in pedunculate oak and northern red oak (*Quercus rubra* L.) in France (Garriou et al. 2000). Although morphological attributes frequently predict field performance of broadleaved seedlings (Jacobs et al. 2005a), they do not always do so, as found for green ash (*Fraxinus pennsylvania* Marsh) in one US study (Jacobs et al. 2005b). Physiological characteristics at the time of planting also greatly influence field performance in broadleaves (O'Reilly et al. 2002, Mortazavi et al. 2004, Wilson and Jacobs 2006). RGP was the only physiological parameter considered in the present study, although this parameter is often considered the most important one (O'Reilly and Keane 2002).

Although the morphological responses to higher N levels might reach a plateau (as shown for alder in this study), the optimum nutrient concentration in foliage is often reached at higher N levels than is needed for growth (Birge et al. 2006, Salifu and Jacobs 2006). Luxury consumption has little effect on growth, but it increases nutrient reserves; these reserves may be available after planting (Birge et al. 2006). This may partially explain the better RGP recorded for seedlings given the highest fertiliser level (Table 2). However, the RGP response to the 160 N and the standard

(80 N) levels of fertilisation only was evaluated in this study, so it is possible that RGP was maximised at 120 N.

A high proportion of the seedlings in this experiment reached the target height dimensions (>40 cm). These results are particularly encouraging when considered in light of other advances that have been made in seed research in the COFORD-funded QualiBroad project. The newly developed seed protocols should deliver higher, faster and more uniform seed germination in alder, birch (De Atrip and O'Reilly 2005, 2006, 2007a, 2007b, O'Reilly and De Atrip 2007) and oak (Özbingöl and O'Reilly 2005, Doody and O'Reilly 2008) compared with the standard seed pretreatment method. In addition, alder and birch seeds that received the new pretreatments germinated quickly at low temperatures (De Atrip et al. 2007), suggesting that it may be feasible to sow early and thus improve growth and yields. Therefore, it is likely that fertiliser and cloche treatment responses might have been even greater if the seed had received the newly developed pretreatments before sowing.

The number of useable seedlings (defined as proportion >40 cm tall) in the nursery beds at the end of the growing season was greater in those given more than the standard level of fertiliser. Since the treatments commenced well after germination had ceased, it is likely that increased nutrient availability allowed more seedlings to survive in beds that received the most fertiliser. High seedling bed densities increase competition for nutrients and water, potentially affecting post-planting performance for up to five years in broadleaf species (Schultz and Thompson 1996).

The use of higher N than the standard level might reduce total nutrient use in the nursery because less bed space would be required to produce a given number of plants, thus also reducing costs. However, the pattern of response to fertilisation was not entirely consistent among species (Table 2). The lowest N cost per usable plant was achieved at 120 N in alder, 160 N in birch, and 40 N in oak. Nevertheless, the 40 N treatment makes little sense for oak since the amount of bed space required to produce seedlings would be huge, thus increasing other costs. Oak also consumed more N per usable plant than alder or birch. Alder was the least costly, perhaps reflecting the fact that this species can also fix N (Arnebrant et al. 1993). The environmental impacts of fertiliser usage in nurseries has been the focus of attention in other countries (Juntunen and Rikala 2001), and similar concerns might be raised in Ireland. If the total amount of N required to produce a given number of usable seedlings can be reduced, then there would be potential benefits for the nursery environment. However, further research is needed to confirm this.

The exponential method of fertilisation (where fertiliser supply is matched to plant growth) may be superior (and is more environmentally friendly) to the conventional method of application for growing broadleaves (Birge et al. 2006, Salifu and Jacobs 2006), but this method was not evaluated in this study. In particular, there is evidence that seedlings grow poorly if fertiliser levels are too low during the early rapid growth period (Fan et al. 2004). Further studies are needed to examine the use of exponential loading, the relationship between morphological quality and field performance, and on the importance of stored nutrients for performance after planting in the field.

Conclusions

The results of this study showed that higher N fertiliser levels than the standard amount resulted in better growth and yield of seedlings in alder, birch and oak (which had been covered with cloches until mid June). The response differences between the two highest N levels (120 and 180 N) were small for most parameters in alder, suggesting that the optimum level was close to 120 N, but the trend was less clear for birch and oak. Further studies are needed to refine these prescriptions, especially to take account of year-year variations in weather conditions and plant size at time fertilisation commences. In addition, studies are needed to determine if seedlings grown under high N levels in the nursery will perform well in the field.

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