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Sowing and transplanting of broadleaves (*Fagus sylvatica* L., *Quercus robur* L., *Prunus avium* L. and *Crataegus monogyna* Jacq.) for afforestation of farmland

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Abstract

Transplanting of bare-rooted seedlings is the common practice for afforestation with broadleaves on former farmland in Denmark and southern Sweden. This is an expensive method and the development of less costly alternatives is needed. The present study included three field experiments, with different treatment combinations of transplanting and sowing of beech, oak, wild cherry and hawthorn, vegetation control, seed and seedling protection by small tubes. Establishment percentage as well as the growth of seedlings was recorded annually from 1995 to 1998. By the end of the experiments, transplanting generally resulted in higher establishment percentages for all species compared to sowing and sowing in tubes. However, sowing of oak resulted in high establishment percentages. There was a clear indication of rodent damage to seeds and seedlings in some of the experiments. Establishment percentage following sowing in tubes was generally better when compared to sowing only, but other problems for seedling development appeared in the tubes. The general effect of vegetation control on the survival of seedlings was minor. In contrast, vegetation control had a strong effect on seedling growth development. In conclusion, sowing of different broadleaved species has the potential to become a viable alternative to transplanting for afforestation of farmland. However, development of new methods for protection against mice and weeds are recommended.

Keywords: Forest restoration; Weed competition; Mice; Predation; Seeding tube; Sowing; Tree shelter

1. Introduction

European temperate broadleaved forest types used to cover much larger areas than they do today (Hannah et al., 1995). In Denmark and southern Sweden, this decrease in area is mainly due to human influence during the last 1000 years (Björse and Bradshaw, 1998; Bradshaw and Holmquist, 1999). Restoration of this nemoral forest is for several reasons believed to be a step towards sustainable forestry (Stanturf and Madsen, 2002). One type of restoration activity is afforestation of farmland. In Denmark for example, the goal of the afforestation program is to double the forested area within one tree generation (100 years) (Anonymous, 1994). The reasons why forest restoration for more broadleaved forest is believed to be a

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step towards a more sustainable forestry include firstly, that more broadleaved forests are needed to preserve forest biodiversity (Anonymous, 1997). Secondly, the broadleaved forests are popular for recreational purposes and tourism and hence ideal for multiple use forestry (Bostedt and Holgén, 2000). Third, hardwood timber prices are stable or increase over time (Abildtrup et al., 1997), which together with high growth rates for broadleaves on the better soils creates optimism for future profitability. Moreover, expected climate changes may improve conditions for broadleaves relative to e.g. Norway spruce (Sykes and Prentice, 1996), the dominant species today. Finally, afforestation of farmland contributes to a reduction of the subsidized agricultural production.

In Denmark and southern Sweden, transplanting of 2–3-year-old bare-rooted seedlings at a stock density of about 2500–5000 per hectare is the most common practice used for afforestation with broadleaves of former farm land (Henriksen, 1988). It is an expensive method. The cost per transplanted seedling is about 0.4–0.7 Euro including the seedling and the transplanting only. Thus, the development of alternatives is needed. Sowing of oak is an old regeneration technique (Thirgood, 1971) that has lately been revived (Willoughby et al., 1996; Küssner and Wickel, 1998; Ammer et al., 2002). The regeneration costs is one-third to one-half of the cost of transplanting seedlings (Bullard et al., 1992). For 1 Euro it is possible to get about 20–100 pretreated acorns or 100–200 beechnuts. The periodical large crops may result in even lower prices. Consequently, sowing has potential for reaching high stock densities at low costs, resulting in high stand quality.

On abandoned farmland, sowing is reliable for various oak species provided that the size of the regeneration areas are large enough and that measures are taken to control the herbaceous vegetation (Møller-Madsen and Honoré, 1992; Willoughby et al., 1996). However, in small fields or in forest openings, rodents are a major problem for sowing since they find and consume buried seeds or damage seedlings (Bullard et al., 1992). Concerning sowing, little research has been directed towards methods for protecting the seeds during seedling establishment. Furthermore, apart from sowing of oak, little is known of other broadleaved species.

The ultimate goal of our research is to develop new, reliable and less expensive regeneration methods for broadleaves. Here, we deal with different techniques for afforestation of farmland. The specific objectives of the study were: (1) to analyze the differences in survival and growth rates using transplanting, sowing and sowing in small protecting tubes and (2) to examine the effect of vegetation control on the survival and growth rates of seedlings and to examine the differences in survival and growth rates between different broadleaved species. The results are discussed with the aim of providing guidance to practical forestry in low costs afforestation.

2. Material and methods

This study comprised three experimental sites, two in Denmark and one in southern Sweden. All three experiments were fenced against browsing hare and deer. Experiments 1 and 3 were located in Denmark and initiated in spring 1995 and 1996, respectively. Experiment 2 was located in southern Sweden and comprised experiments that were initiated in 1995 and 1996.

2.1. Experiment 1

The first experiment was established on farmland at Research Center Foulum (56°50′N/9°56′E, 55 m a.s.l.), Denmark. The soil texture was sandy with 5% clay and 85% sand in the top 90 cm of the profile. The terrain was flat. The site was rotary cultivated before the start of the experiment in April 1995. The surroundings consisted of open agricultural land and broadleaved shelterbelts. One 4 m tall shelterbelt was located 5 m north of the experiment. In Denmark, the 30-year-mean monthly precipitation and temperature are 57 and 66 mm and 0.0 and 15.6 °C, for the months of January and July, respectively (Anonymous, 1995–1998a).

The experiment was a three-factorial study, each treatment was replicated three times in a randomized block design. The treatments were a combination of the following three factors: weed control: (1) with untreated control and manual hand weeding, stock type; (2) with sowing, sowing in narrow seeding tubes (diameter of 28 mm, 25 cm tall) and transplanting, tree species; (3) with beech (*Fagus sylvatica* L.), oak (*Quercus robur* L.), wild cherry (*Prunus avium* L.) and

Table 1
Plant material used for experiments started in 1995 and 1996

Species	Provenance (experimental year)	Germination ability/type of seedlings	No. of seeds/seedlings per spot
Seeds			
Beech	Maramures, Romania (1995)	62% (after 35 days at 5 °C)	4
	Gråsten, Denmark (1996)	62% (after 35 days at 5 °C)	3
Oak	Vestfold-Borre, Norway (1995)	61% (after 35 days at 23 °C)	3
	Schnerpenzeel, Holland (1996)	86% (after 35 days at 23 °C)	3
Wild cherry	Bornholm, Sweden (1995)	65% (after 135 days at 5 °C)	3
Hawthorn	Korterup, Denmark (1995)	8% (after 135 days at 5 °C)	3
Transplants			
Beech	Maramures, Romania (1995)	3/0, 30–50 cm	1
	Gråsten, Denmark (1996)	2/0, 30–50 cm	1
Oak	Fyn Østre, Denmark (1995)	2/0, 30–50 cm	1
	Helenaveen, Holland (1996)	2/0, 30–50 cm	1
Wild cherry	Bornholm, Denmark (1995)	2/0, 60–80 cm	1
Hawthorn	Korterup, Denmark (1995)	1/1, 60–100 cm	1

hawthorn (*Crataegus monogyna* Jacq.). In total there were 24 treatments and 72 plots. Each plot was $2\,m \times 2\,m$ and included 25 seeding points or 25 transplanted seedlings. Manual hand weeding was done in late June and mid-August in 1995. In 1996, manual hand weeding was only carried out in late August. During 1997 and 1998, no hand weedings were carried out. For details of seeds and seedlings see Table 1.

2.2. Experiment 2

The second experiment was set up in an abandoned field at the Swedish University of Agricultural Sciences at Alnarp (55°40′N/13°10′E, 15 m a.s.l.), Sweden. The soil texture was sandy loam and the site was flat. The site was free from herbaceous competitors at the start of the experiment in May 1995 due to repeated harrowing. The surroundings consisted of gardens and orchards. In southern Sweden, the 30-year-mean monthly precipitation and temperature are 53, 63 mm and −0.8, 16.6 °C, for the months of January and July, respectively (Anonymous, 1995–1998b).

A randomized block design with four blocks and two treatments with sub-plots (split-plot) was used in the experiment. The treatments were: herbicide treatment (H) and untreated control (C). The herbicide treatment consisted of three regular applications of glyphosate (0.65% active ingredient) during each of the growing seasons 1995–1997 in combination with manual weeding near the seedlings. In addition, propyzamide (0.5% active ingredient) was applied on one occasion in the H-treatment during the middle of December 1995 and 1996 to facilitate control of herbaceous competitors during the following growing season.

Within each treatment, seedlings of beech and oak were transplanted in species-separated rows in April 1995 and 1996. Acorns and beechnuts were also sown in additional species-separated rows at the same time. All rows were randomly mixed in each treatment. During 1995 and 1996, each row (1 m apart) consisted of 12 transplanting points. The seedlings or the seeds were transplanted or sown 50 cm apart. However, in 1996 the rows for sowing consisted of 24 seeding points 25 cm apart. Sowing was carried out in seeding tubes in six randomly selected seeding points per row. In 1995, narrow seeding tubes (diameter of 28 mm) were used whereas in 1996, wider seeding tubes (diameter of 38 mm, 25 cm tall) were used. In each seeding point for sowing, three acorns or four beechnuts were sown, respectively.

2.3. Experiment 3

The third experiment was set up in an abandoned field at Dageløkke, Kronborg Forest District (55°95′N/12°51′E, 15 m a.s.l.), Denmark. According to Anonymous (1998) the soil texture was sandy (diluvial sand). The terrain was relatively flat. The site was treated with glyphosate before the start of the experiment in May 1996. The surroundings consisted of open agricultural land, two nearby 5 m tall broadleaved shelterbelts, small hills and woodlands.

The experiment was a two-factorial experiment. Each treatment was replicated three times in a randomized block design. The treatments were combinations of the following factors: (1)stock type including sowing, sowing in narrow tubes (diameter of 28 mm) and sowing in wide tubes (diameter of 38 mm); and (2) tree species including beech and oak. In total there were six treatments and 18 plots. Each plot was $2\,m \times 2\,m$ and included 25 seeding points.

2.4. Plant material and usage

The same provenances were used to a large extent for both seeds and seedlings for all experiments in both 1995 and 1996. Likewise, the same lots for seeds and seedlings were used in the same year. This was, however, not possible in all cases (Table 1). Seeds and seedlings were obtained from the Tree Improvement Station (TIS), Humlebæk, Denmark. Before delivery, seeds were pretreated to break dormancy. Acorns were not pretreated except that they were taken out of the freezer-store (−2 °C) and stored at 4 °C for 4 weeks before delivery. In addition, the acorns used for the 1996 experiments were thermotherapy-treated in water for 2.5 h at 41 °C in the fall prior to storage at −2 °C. The beechnuts were pretreated at 4 °C and 32% moisture content. Hawthorn and wild cherry were pretreated at alternating warm (20 °C) and cold periods (5 °C), 14 days each, for a 3-month period in 1995. Apparently these two species were not optimally pretreated, since they germinated very slowly (wild cherry) or almost not at all (hawthorn) (Table 1). Following delivery of seeds, the germination rates were tested by TIS according to international guidelines (Anonymous, 1993).

The seedlings were of typical bare-root stock (Table 1), which had been root undercut at a depth of 15 cm at the end of the first growing season. According to normal procedures, the seedlings were harvested and brought to a cold store −2 °C during the autumn before transplanting in the experiments. The seedlings were transplanted manually using a spade.

Three or four seeds were sown in each sowing point (Table 1). In the treatments without sowing tubes, acorns were sown at a depth of 5 cm, beechnuts at a depth of 2 cm and wild cherry seeds and hawthorn seeds were sown at a depth of 1 cm. Before sowing in the tubes, tubes were placed upright in small 5 cm deep pits. The soil was brought back around the tube to stabilize it. Following sowing in the tubes, the seeds were covered with coarse sand. In experiment 3 at Dageløkke, vermiculite was used instead of sand to study if another material than sand could improve the establishment. However, it had no effect. In the tubes, acorns and beechnuts were covered with 3 cm of sand or vermiculite and wild cherry and hawthorn seeds with 1.5 cm of sand. All the tubes in the 1995 experiments (experiments 1 and 2) were made from polyethylene. Tube walls were approximately 2 mm thick, light brown and partially transparent. In the 1996 experiments (experiments 2 and 3), The tubes were made of biodegradable material (a mix of starch and cellulose). The tube walls were approximately 1 mm thick, white in color and partially transparent.

2.5. Measurements and calculations

The number of living seedlings and seedlings were recorded as well as the height (stretched length from ground to highest located living bud) at the end of each growing season or during the following winter. Percentage of establishment following sowing or transplanting were calculated as the quotient of the number of sowing or transplanting points with at least one living seedling and the total number of sowing or transplanting points per plot. Only the length of the tallest living seedling was recorded in each sowing point. In experiment 1, the two first inventories (June and July 1995) was done to follow the germination of seeds and establishment more carefully. Thus, they did not include length measurements, and only flushed seedlings were recorded as living seedlings. In experiment 3, length was not measured for beech.

During the 1995 growing season in experiment 1, soil water content was determined regularly along probes (0–50 cm soil depth) in the control treatment and in the treatment where herbaceous vegetation was controlled. Measurements were taken in six weeded and six control plots with transplanted beech and sown beech in tubes. Time domain reflectometry (TDR) was used for the soil moisture measurements (Topp et al., 1980; Rundell and Jarrell, 1991; Thomsen, 1994). A cable tester (Tektronix 1502C) was used for the measurements.

General linear model (GLM) procedures for analysis of variance were used to perform statistical tests on establishing percentages and lengths after calculating plot averages (SAS Institute Inc., Cary, NC). Only the values for 1998 was used in the analyses. Before analyzing establishing percentages, frequencies were transformed according to Zar (1984) using the formula:

$$p' = \frac{1}{2}\left(\arcsin\left(\frac{X}{n+1}\right)^{1/2} + \arcsin\left(\frac{X+1}{n+1}\right)^{1/2}\right)$$

where p' is the transformed frequency, X the number of living seedlings at the end of the experiments, and n the number of the total transplanting or sowing points. Where significant F-values occurred, the analysis of variance was followed by Tukey's multiple range test. Separate multiple range tests were made for the different species. In experiment 2, a separate test was carried out between sowing and sowing in tubes. In the comparisons, $P < 0.05$ was considered as indicating significant differences.

3. Results

3.1. Environmental conditions

Compared to the 30-year mean, precipitation was normal from May to September 1995–1998 with some exceptions (Table 2). Precipitation was low in July and August of 1995, in June and July of 1996 and in August and September of 1997. In 1998, precipitation was low in Denmark in May but in Sweden no period with low precipitation occurred. The same trends were found in Denmark and in Sweden. In experiment 1, the dry period during the 1995 growing season resulted in significantly less soil water (0–50 cm) in the control than in the weeded treatment (Fig. 1).

3.2. Experiment 1

Four years after the start of the experiment, the establishment percentages of transplanted seedlings of all species showed higher values than for sowing and sowing in tubes, except for oak (Fig. 2A–D). The effect of stock type on establishment percentage was strong in all species ($P < 0.0001$) (Table 3). However, a significant interaction for wild cherry and hawthorn was found between vegetation treatment and stock type ($P < 0.05$). Better establishment percentages were found for sowing in tubes compared to sowing only, except for oak where better establishment percentage was found for sowing only ($P < 0.05$). For

Table 2
Monthly total precipitation (mm) during the 1995–1998 growing seasons and 30-year mean in Denmark (Anonymous, 1995–1998a) and at the Malmö climatic station located 10 km southwest of experiment 2 (Anonymous, 1995–1998b)

Month	Precipitation				
	1995	1996	1997	1998	30-Year mean
Denmark					
May	54	61	69	29	48
June	58	23	60	79	55
July	28	34	62	93	66
August	24	63	43	61	67
September	95	55	45	60	73
Alnarp, Sweden					
May	45	151	71	45	44
June	77	22	67	59	54
July	31	54	60	68	63
August	17	37	10	47	62
September	79	64	23	67	62

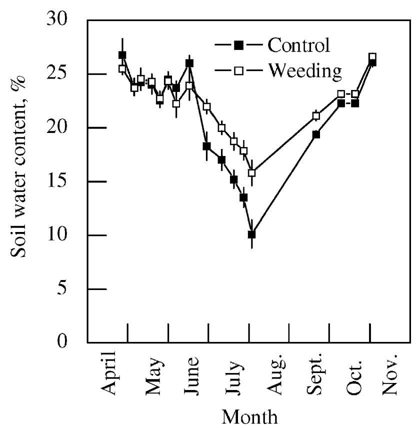

Fig. 1. Mean soil water content (vol.%) from plots in control and weeding treatments (0–50 cm depth) during the 1995 growing season at Foulum, Denmark (mean ± S.E.).

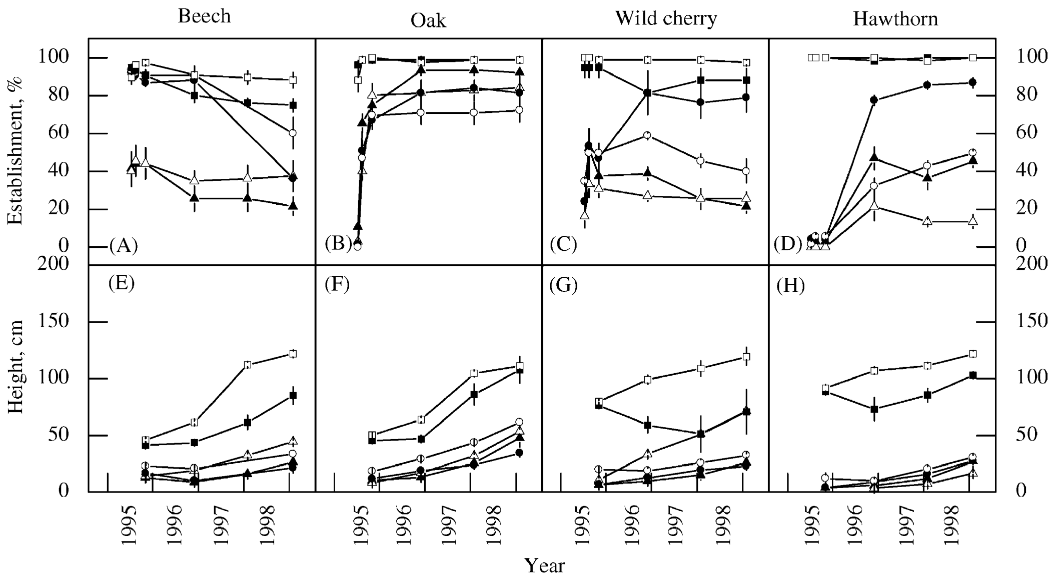

Fig. 2. Mean establishment percentages (A–D) and mean height (E–H) of different stock types for two treatments and 4 years at Foulum, Denmark (experiment 1). Transplanting (■), sowing (▲) and sowing in tubes (●). Filled symbols denote control treatment and open symbols denote weeding treatments (mean ± S.E.). For a description of treatments see the text.

beech, establishment percentage was better when weed control was carried out ($P < 0.05$). Establishment percentages for seedlings of all species did not change much after the first 2 years of the experiment, except for sown beech seedlings in tubes where further mortality occurred, even in the weeded treatment (Fig. 2).

Four years after start of the experiment, the heights of transplanted seedlings of beech, oak and wild cherry remained greater than seedlings derived from sowing and sowing in tubes ($P < 0.001$) (Fig. 2E–G). Within species, there were no differences in height between seedlings derived from sowing in tubes and sowing. Weed control had a positive effect on height growth in all species ($P < 0.05$). However, there was an interaction between stock type and weed treatment for hawthorn ($P < 0.05$).

Table 3
Statistical analysis of differences in establishment percentage (transformed values) for beech in experiment 1 in 1998 (GLM-procedure, type III sum of squares)

Source of variation	Establishment percentage			
	d.f.	MS	*F*	*P*
Block	2	0.0156	0.65	0.5414
Treat	1	0.3279	13.76	0.0040
Type	2	0.8999	37.77	<0.0001
Treat × type	2	0.0041	0.17	0.8429

3.3. Experiment 2

By the end of the 1998 growing season, the establishment percentage of transplanted beech seedlings was much better than that of beech seedlings derived from sowing ($P < 0.05$) (Fig. 3A and C). For oak seedlings, the difference in establishment percentage between transplanting and sowing was slight, and only significant for seedlings established in 1995 ($P < 0.05$) (Fig. 3B and D). In general, establishment percentage of sowing in tubes approximated that for transplanting. However, only beech seedlings originating from sowing in tubes in 1995 had significantly better establishment percentage than those derived from sowing only ($P < 0.05$). By 1998, the effect of weed control on establishment percentage was minor. Establishment percentage for beech and oak did not change much after the two first growing seasons (Fig. 3A–D). However, without weed control there was a trend towards increased mortality for both species.

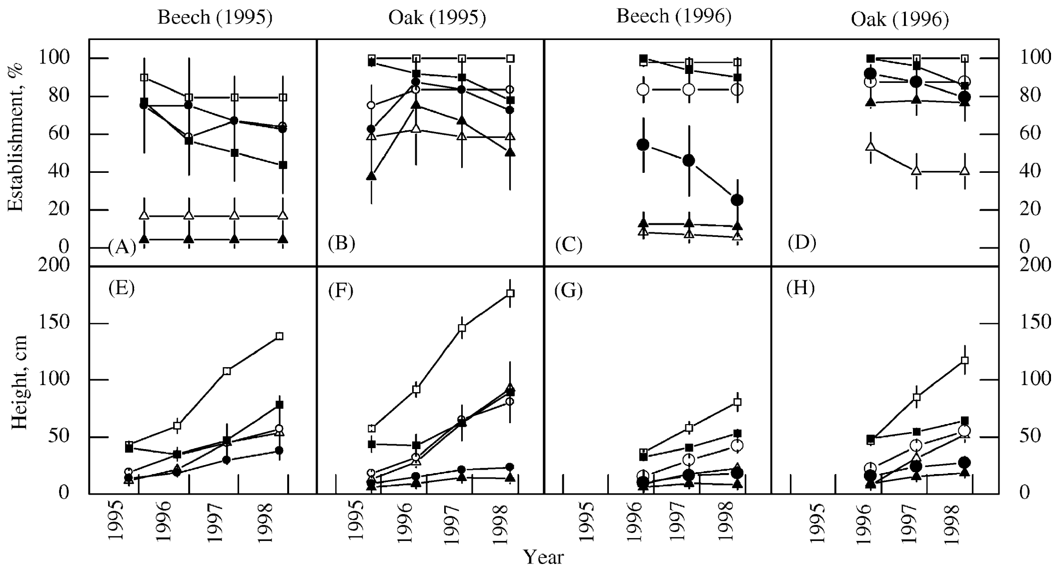

Fig. 3. Mean establishment percentages (A–D) and mean height (E–H) of different stock types in two treatments and in 4 years at Alnarp, Sweden (experiment 2). Transplanting (■), sowing (▲), sowing in 28 mm tubes (•) and sowing in 38 mm tubes (●). Filled symbols denote control treatments and open symbols denote weeding treatments (mean ± S.E.). For a description of treatments see the text.

By contrast, the effect of weed control on height growth was strong for both species by the end of the 1998 growing season ($P < 0.05$) (Fig. 3E–H). However, this effect was not significant when transplanted oak seedlings and seedlings growing in tubes were compared following transplanting in 1995 (Fig. 3F). The heights of transplanted seedlings of beech and oak were still greater in 1998 compared to sowing in tubes ($P < 0.05$). Due to missing values for the sowing treatment, few significant effects on height development were found between sowing and sowing in tubes or transplanting.

3.4. Experiment 3

Two years after the start of experiment in 1996, there were no differences in establishment percentages between the three different stock types for beech (Fig. 4A). For oak, establishment percentage was better for sowing compared to sowing in the widest

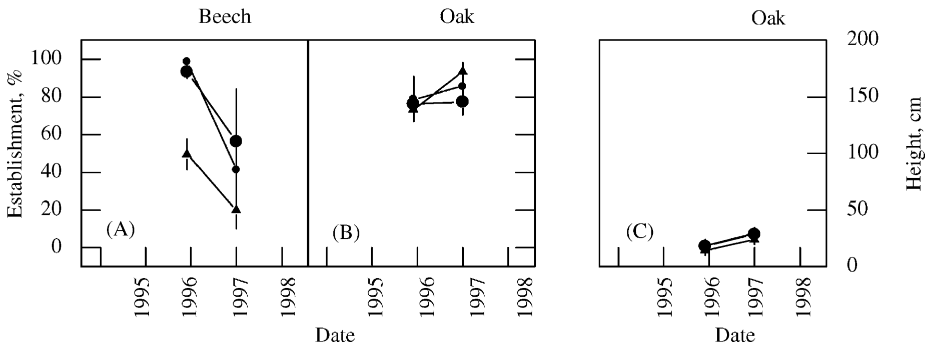

Fig. 4. Mean establishment percentages (A–B) and mean height (C) of different stock types during 1996 and 1997 at Dageløkke, Denmark (experiment 3). Sowing (▲), sowing in 28 mm tubes (•) and sowing in 38 mm tubes (●) (mean ± S.E.). For a description of treatments see the text.

tubes ($P < 0.05$) (Fig. 4B). Height development for oak was similar for the three different stock types (Fig. 4C).

4. Discussion

Transplanting of bare-rooted seedlings proved, in accordance with common experience, to be an effective and reliable afforestation method. In comparison, sowing resulted in poorer establishment percentages for all species, except oak. This result was clear from the first growing season. However, the germination of wild cherry and hawthorn was delayed. In consequence, establishment percentage of these two species following sowing increased during the second growing season. Hawthorn in particular, continued to germinate throughout the third and fourth growing seasons. In experiment 2, it was obvious that mice had dug acorns and beechnuts out of the ground and consumed or removed many seeds. Only some seed coats remained spread around the holes that were made by mice. This is consistent with earlier studies on sowing, where excessive rodent damage was recognized as an important cause of early losses (Johnson, 1981; Bowersox, 1992; Bullard et al., 1992) and has also been found in studies on natural regeneration in beech and oak forests (Watt, 1923; Korstian, 1927). However, in experiments 1 and 3, no such observations were made. According to Vander Wall (1998) mice use olfactory stimuli to detect buried or covered seeds which results in successful digging behavior. Beechnuts and acorns, due to their high energy content, are among the most preferred seeds for different mice species (Jennings, 1976). For beech in experiment 2, almost none of sown beechnuts developed into seedlings if the seeds were not protected. Most beechnuts disappeared during the first week after sowing in 1995 and 1996.

Compared to beech, wild cherry and hawthorn, oak showed superior establishment percentage following sowing. Mice digging for buried acorns was also observed in experiment 2, but not to the same extent as for beechnuts. Beechnuts have a higher energy content per gram dry mass than acorns (Jensen, 1985). Which might explain why so many more beechnuts than acorns disappeared. Furthermore, the success for rodents in finding seeds usually decreases as the depth of burial increases (Nilsson et al., 1996; Küssner and Wickel, 1998; Vander Wall, 1998). Thus, a deeper sowing of acorns compared to beechnuts alone or in combination with the lower energy content per gram dry mass, were probably also important for explaining the difference in disappearance percentages between beechnuts and acorns in experiment 2. However, in other experiments concerning reforestation on forest land we found that mice prefer acorns to beechnuts (data not shown).

Experiments 1 and 3 were located in an open agricultural setting, whereas experiment 2 was surrounded by gardens and orchards. This may have supported a relatively high mouse population density around experiment 2 and consequently more damage caused by mice at this site, since mice prefer heavily vegetated habitats (Kikuzawa, 1988). Annual differences in the sizes of mice populations between the experimental sites may be another possible explanation.

Establishment percentages following sowing in tubes was better than unprotected sowing, which shows that the tubes can protect the seeds and seedlings against the mice. In many cases sowing in tubes resulted in almost the same establishment percentages as for transplanting. Similar tubes were evaluated by Bowersox (1992) in experiments concerning reforestation of oak sites in the eastern United States, with comparable results.

There was no difference in seedling height development following sowing in tubes or unprotected sowing. We observed rapid growth of seedlings in the tubes. The fast growing individuals of beech and cherry in particular were, however, severely damaged by winter frost and their tops died back leaving dead plant material in the tube. The development of frost hardiness of seedlings growing in the tubes seemed to be delayed. Such damaged seedlings resprouted in many cases in the tubes but they were hindered in their further development due to the dead plant material from the previous growing season. This happened more rapidly in the weeded plots than in the non-weeded plots leading to an earlier obstruction of further seedlings and reduced establishment percentages. Consequently, height development data for seedlings sown in tubes show the pooled height development for resprouting individuals and newly germinated seedlings (cherry and hawthorn). In addition, the latter two species had poorer establishment percentages following sowing in tubes in weeded plots compared to non-weeded plots. Probably, it was a result of a faster growth rate resulting in earlier obstruction of development of seedlings followed by mortality. Together with the fact that using tubes increases the costs of establishing new stands, this leads to the conclusion that sowing in tubes is not an attractive method of forest establishment.

The general effect of vegetation control on the establishment percentages of all species was found to be minor. In experiment 1, however, vegetation control was only carried out intensively during 1995 and once in 1996. In experiment 2, vegetation control was carried out intensively during 1995–1997 and there was a tendency for lower establishment percentages with time in the control treatment. Each year in experiment 2, we observed rodent damages to established seedlings in the control treatment. When the herbaceous vegetation developed in experiment 3, rodents started to damage beech seedlings in particular. This agrees with research on seedling survival in grassy fields, where a substantial number of the established seedlings are damaged or consumed by rodent herbivores, and thus disappear over time (Lüpke, 1987; Manson et al., 2001).

In contrast, weeding had a strong positive effect on seedling growth in both experiments 1 and 2. This is in agreement with previous studies of transplanted seedlings (e.g. Schmaltz, 1964; Davies, 1985) and for sowing (Ammer et al., 2002). In experiment 1, the control treatment had less soil water content in 1995 compared to the weeded treatment. Data presented in another paper from experiment 2 (Löf, 2000), showed that dry periods in 1995–1997 also resulted in lower soil water potentials in the control treatment compared to the weeded treatment. This indicates that soil water stress can limit the growth of broadleaved seedlings during the establishment phase on farm land.

In all experiments, sowing or sowing in tubes resulted in small seedlings if no vegetation control was carried out. This finding is important, since it may take several years for the seedlings following sowing to grow above the herbaceous vegetation. Small and slow growing seedlings are more sensitive to damage by e.g. mice, voles and other pests than larger ones (Gill, 1992). Therefore, a successful regeneration by sowing in the initial phase, may develop into patchily distributed regeneration with low stock density if no measures are taken to control the natural vegetation. To be a reliable regeneration method, sowing on farmland has to be combined with an effective method of vegetation control. Similar conclusions were drawn by Willoughby et al. (1996). Effective vegetation control can be achieved using herbicides (Willoughby, 1999). However, these methods are criticized from an environmental point of view and there is a need to develop alternative methods (Wagner, 1993). Since the size of the seedlings is small in the initial phase when using sowing, vegetation control must continue for several years.

In conclusion, this study indicates that sowing of a variety of important broadleaved species has the potential to become an effective regeneration method, provided that weed competition is limited and the seeds and seedlings are protected from rodents and other pests. In the present study the highest percentages of establishment was found following transplanting but reasonably good establishment was found for direct sown oak. Specific economic calculations, which include i.e. the cost of transplants, acorns, planting, sowing and stock density are needed to make the management decision. A number of techniques like herbicides, repellents and mechanical protections may be relevant for immediate use or for further development to improve sowing. However, the increasing demands for more environmentally friendly and inexpensive methods of forest establishment calls for alternative approaches. This may include careful selection of sites and periods for sowing when small populations of mice or other pests are present. Alternatively, silvicultural techniques such as site preparation or nurse crop pioneer species like poplar, alder or birch may offer the means to control the pests and weeds.

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