An Evaluation and Comparison of Mechanised and Manual Tree Planting on Afforestation and Reforestation Sites in Ireland

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ABSTRACT

Recent labour shortages and rapid increases in labour costs in Irish forestry have directed attention to mechanised, containerised tree planting systems as an alternative to the traditional manual planting of bare-rooted stock. The objective of this study was to compare mechanised planting with manual operations, on both reforestation and afforestation sites, using Sitka spruce (*Picea sitchensis* (Bong.) Carr.) plants in three container types (i.e. hard container, root trainer, fen container). The Bräcke tree planting machine was selected for the study, as it is capable of handling a wide range of site conditions and a variety of plant types and sizes. A qualitative analysis of the collected data showed that, in general, manual planting scored significantly higher than mechanised planting for plant position and planting quality. However, the quality of planting resulting from mechanised operations was well within acceptable operational requirements. On the reforestation site, plant growth after one growing season was investigated. No overall significant differences in height growth and root collar diameter increment were found in the first growing season between mechanised and manual planting operations. Plants grown in 'fen containers' had the highest relative increase in height growth and root collar diameter, irrespective of planting method. The results showed that the Bräcke planting machine was capable of planting a range of containerised plants to an acceptable standard on both reforestation and afforestation sites. Further research to optimise the combination of machine, plant size and container type should result in improvements in both the quality and productivity of the planting operations.

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INTRODUCTION

The mechanisation of planting work has been an objective in forestry for many years. Development work on planting machines on a world-wide scale has been driven by labour shortages and increased labour costs. However, in Ireland, manual planting of bare root stock has, until recently, been the preferred option. Low costs and a plentiful supply of labour in rural areas have meant that the mechanisation of planting work was not an issue until the end of the 1990s. However, a dramatic shift in the labour market towards urban areas has meant that forestry contractors are finding it increasingly difficult to source labour to fulfil planting contracts. Costs have increased substantially because of this and many contractors have no alternative but to look at increased mechanisation of planting work.

Many different types of planting machines have been invented [1, 2, 10, 14, 15]. Some planting machines are capable of planting both bare root and containerised stock, while others are limited to one or the other. The more sophisticated automated machines tend to use containerised planting stock because of the uniformity of the root mass [5]. The limiting factors for the use of planting machines have been slope, rough ground conditions, rocks and tree stumps [6, 10]. The majority of traditional planting machines are only suitable for agricultural type ground conditions with very few obstructions [2, 8]. However the development of high-technology machines such as the Silva Nova planting machine [7, 17] and the Bräcke boom-mounted planting head has widened the scope for mechanised planting on difficult terrain and particularly on reforestation sites [6, 16].

The objective of this study was to evaluate, in detail, the quality of mechanised planting on afforestation and reforestation sites and to compare the results with those for manual planting on the same sites. A distinction was made between afforestation and reforestation, in order to evaluate the impact of the presence of stumps and slash on the planting quality. For this study the Bräcke planting machine was selected. This machine was reputed to be capable of handling a wide range of site conditions and a wide variety of plant types [14]. The assessment included an evaluation of planting quality, plant mortality and plant growth in the first growing season after planting, for a

range of containerised plant types. Productivity data were also collected but the analysis of these is not included in this article. However, some preliminary results are included in the discussion.

MATERIALS AND METHODS

Introduction

The planning for the series of trials reported in this article began in October 1998 [4]. An afforestation site and a reforestation site were selected in Co. Wicklow, on the east coast of Ireland. The reforestation site had previously carried a crop of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karsten). This crop had been clearfelled in 1997. Harvesting on the site was carried out by harvester and most of the slash had been piled into windrows at 25 m centres. The site was level and at an elevation of 100 m. The predominant soil type was brown podzolic with patches of podzolised gley. The afforestation site consisted of an unplanted area in a plantation of Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco). The predominant vegetation was grass. The site was at an elevation of 300 m and had a north-easterly aspect. The soil type was shallow brown earth with a high boulder content. Because of the nature of the soil, it tended to be very free draining.

Experimental Design

A randomised block design was used for both sites. Five replications of all combinations of four container plant types and two planting methods were included on each site. The five plots for each planting method / plant type combination contained 36 seedlings per plot.

Containerised Plant Types

The species used in this study was Sitka spruce (*Picea sitchensis* (Bong.) Carr.) which is the most widely-used plantation species in Ireland. Containerised plants of two provenances ('Washington' and 'genetically improved') from three Irish nurseries (Aughrim, Smith, and Tuam) and one English nursery (Cheviot) were chosen because they were the principal planting stock suppliers on the Irish market. Three different container types were used by these nurseries (Table 1). The 'Hard' or 'Hiko' container is circular in shape and tapers from top to bottom. It is constructed of rigid hard plastic and is very durable. The container has a smooth interior and exterior surface. The smooth interior surface wall causes spiral root growth. Plants are removed from these containers before planting. The 'Root trainer' is made from light, plastic material and is not very durable. The container is of square construction and has a vertically ribbed interior to discourage spiral rooting. The side of the container opens to allow the plant to be extracted easily. Plants are removed from containers before planting. The 'Fen' container is made from peat. It allows the plant roots to grow through the walls of the container when planted out. The 'Fen' container is square at the top and comes to a point at the bottom. The 'Fen' container is planted with the seedling.

Mechanised Planting

The Bräcke planter is a compact unit that attaches to an excavator boom and is designed to plant containerised stock (Figure 1). For stability reasons, the excavator must weigh in excess of 12 tonnes, and it must be equipped with an air compressor. The planter used in these trials was mounted on a 22 tonne Komatsu excavator. For this trial, the plant magazine, which is mounted on the top of the unit, was fitted with a planting tube with a diameter of 70 mm. This tube size was considered suitable for the range of seedling and container sizes used in the study.

The planting process begins when the hydraulically operated digging shoe, which is mounted on the bottom of the planter, turns over a sod, creating a mound of soil. The mound is consolidated by pressing it down with the shoe. With the shoe still on the ground the operator

Table 1. Plant and container specifications.

	Nursery			
	Cheviot	Aughrim	Smith	Tuam
Container type	Hard[1]	Root Trainer	Fen	Hard[1]
Container cell size (cc)	200	90	90	200
Plant age (yr)	2	2	1	2
Plant height range (cm)	20 - 40	20 - 30	15 - 30	20 - 40
Provenance	Genetically Improved	Washington	Washington	Washington

[1] also called 'Hiko'

triggers the planting mechanism. A metal 'beak' at the end of the planting tube is driven into the mound through a hole in the digging shoe. The beak opens to create the planting hole. A plant is dropped down from the magazine into the newly created hole. When the plant is in the soil, the firming foot consolidates the soil around the tree before the planter is lifted and moved to the next planting position. As the planting tube is raised, a jet of compressed air and water (circa 25 ml) serves both to prevent the seedling from lifting with the tube and also to keep the inside of the tube clean. It has the additional beneficial effect of moistening the soil directly around the seedling.

Figure 1. The Bräcke planting machine.

Manual Planting

Mounding for the manual planting was carried out by the Bräcke planting machine. The manual planting was done by two skilled forest workers who planted alternate lines in each plot. The workers carried the containerised plants in planting bags. Planting spades were used to plant the trees using the notch method. This involves the cutting of slits in the ground in a 'T' or 'L' shape. After the second cut is made the spade is used to lever open the slit and the tree is carefully placed into the ground, making sure the root system is not distorted. The ground is then gently firmed around the tree by treading down.

Data Collection

On the reforestation site, planting position, planting quality, plant height and root collar diameter were assessed after planting in April 1999 and again in April 2000. On the afforestation site, details relating to planting position, planting quality, height and root collar measurements were also taken in April 1999, but because of wide-spread rabbit damage in this trial during 1999, further assessment was abandoned.

Plant Position and Planting Quality Assessments

As this study was part of a research project investigating the operational feasibility of replacing manual planting with mechanised planting, it was felt that, instead of analysing each factor separately, an integrated analysis strategy was required. A project team, consisting of research foresters and operational foresters, devised scoring systems to assess the overall planting position and planting quality (Tables 2 and 3). The scores were based on both short-term effects (e.g. cost of filling in, adequate stocking levels, grant approval) and long-term effects (e.g. successful establishment, growth, quality of the stand and the timber) of each of the factors. To evaluate the impact of the selected scores on the results, sensitivity analysis was carried out using modified scoring systems (Tables 2 and 3). The first set of sensitivity analysis scores for plant position was used to evaluate the elimination of deep or very deep planting as a negative factor in the analysis. This was done as a result of studies carried out by Örlander *et al*. [11], which showed that deep planting can be beneficial in certain cases. The second set was designed to carry out the evaluation based purely on the presence or absence of seedlings at each planting spot. The first set of sensitivity analysis scores for planting quality was designed to evaluate the impact of an increase in the penalty associated with low quality planting on the results of the analyses. The scores for both 'acceptable' and 'marginal' planting quality were reduced by two points relative to the score for 'firm', expressing the increase in penalty associated with both. In the second sensitivity set the scores for both 'acceptable' and 'marginal' planting quality were increased by two point s relative to the score for 'firm', expressing a decrease in the penalty associated with low quality planting similar in magnitude to the increase in the penalty in the first set.

Average plot scores for plant position and planting quality were calculated based on the rated classification of all 36 trees in each plot.

Growth Assessments

In order to overcome the impact of differences in the size of plants at time of planting on the evaluation process, relative height growth (i.e., height in 2000 minus height in 1999, divided by height in 1999) and relative root collar diameter increment (i.e., diameter in 2000 minus diameter in 1999, divided by diameter in 1999) were used to assess growth during the first growing season. The use of relative growth rates in seedling assessments is well documented [e.g., 18].

Table 2. Plant position assessment scores for mechanical and manual planting.

Classification	Explanation	Score	Sensitivity analysis scores	
			Eliminate too deep	Eliminate position
Ideal	Plant upright and root fully covered	10	10	10
Leaning	Plant leaning at angle of 45 degrees or more	8	8	10
High	>25 % of root mass exposed above ground	3	3	10
Mound Fall	Mound collapsed and fallen in	0	0	0
Miss	Where planter had failed to plant on a mound	0	0	0
Deep	Where 25-50% of stem was covered by soil	6	10	10
Very Deep	Where >50% of stem was covered by soil	4	10	10
Two Plants	Where two plants had been planted together	2	2	10

Table 3. Planting quality assessment scores for mechanical and manually planted seedlings.

Classification	Explanation	Score	Sensitivity analysis scores	
			Increase penalty	Decrease penalty
Firm	Plant firm in the ground	10	10	10
Acceptable	Very slight movement in root mass	7	5	9
Marginal	Movement in root mass	4	2	6
Unacceptable	Plant root very loose, easily pulled up	0	0	0

Summary of results for the reforestation site

In order to get an overview of the overall performance of each planting method/plant type combination on the reforestation site, a rating was applied to the mean plot scores for each assessment. Planting method / plant type combinations with a score above average were given a 'plus' rating, below average combinations were given a 'minus' rating, while average scores were assigned a 'zero' rating. These individual assessment ratings were then combined to produce an overall rating for each planting method / plant type combination

Statistical Methods

All statistical analyses were carried out using the plant type / planting method combinations as treatments (Table 4). The analyses were carried out using SAS software [12]. The main statistical procedures used were Analysis of Variance (Anova), followed by pairwise comparisons. Mean values per plot were used in all cases.

Table 4. Codes used for the plant type/planting method treatment combinations.

	Planting Method	
Plant Type	Mechanical	Manual
Cheviot	A1	B1
Aughrim	A2	B2
Smith	A3	B3
Tuam	A4	B4

RESULTS

Plant position (Reforestation)

The average plant position score for mechanically planted seedlings was consistently lower than that for manually planted seedlings for all four types of nursery stock (Figure 2). Mechanically planted Smith (A3) and

Tuam (A4) seedlings were scored lowest for position, with plants originating from the Smith nursery awarded the lowest average score. Statistical analysis showed that the planting method / plant type combinations had a significant impact on plant position. Pairwise comparisons showed that the means for position score were significantly lower for mechanically planted stock from the Smith (A3) and Tuam (A4) nurseries than for all other planting method/ plant type combinations. The value for mechanically planted stock from the Smith nursery (A3) was also significantly lower than that for the mechanically planted Tuam seedlings (A4).

Plant position (Afforestation)

On the afforestation site, the scores for planting position showed little variation, with the exception of the mechanically planted Smith stock (A3), which was scored lowest overall. However, this score was only 9% below the highest score for the manually planted Tuam (B4) seedlings (Figure 3). Statistical analysis indicated significant differences, with the score for A3 seedlings lower than the scores for all other planting method / plant type combinations.

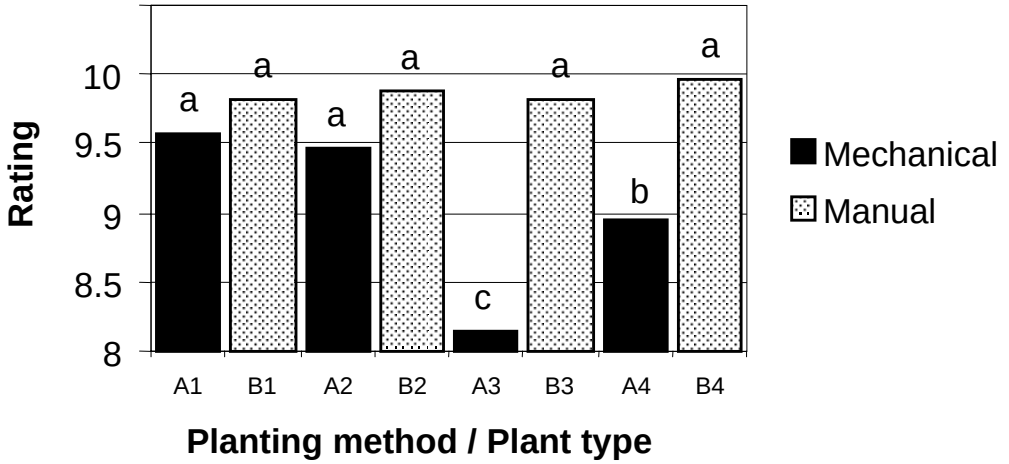

Figure 2. Plant position scores for mechanically and manually planted stock from four nurseries on the reforestation site. (Planting method/plant type combinations with different letters indicate significant differences at a = 0.05).

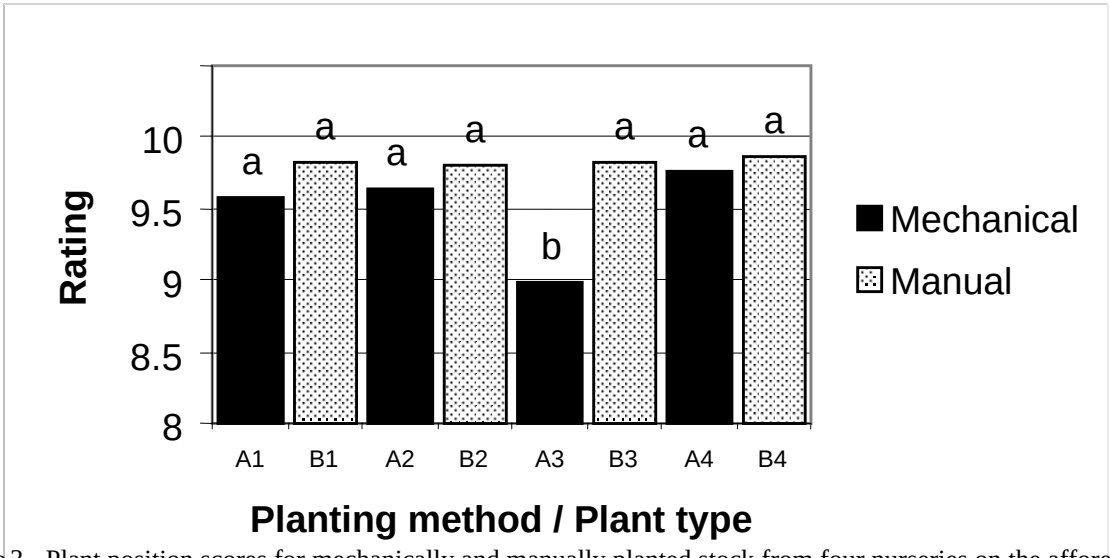

Figure 3. Plant position scores for mechanically and manually planted stock from four nurseries on the afforestation site. (Planting method/plant type combinations with different letters indicate significant differences at a = 0.05).

Planting Quality (Reforestation)

In all cases, mechanical planting was awarded lower planting quality scores than manual planting (Figure 4). This result was the same for all seedling types. Planting quality was poorest for mechanically planted 'root trainer' seedlings which were produced at the Aughrim nursery (A2). Planting quality was consistently high for manually planted seedlings. Statistical analysis showed that both planting method and plant type had a significant impact on planting quality. Pairwise comparisons showed that there were no significant differences in planting quality scores between the four manually planted plant types and the mechanically planted Smith plants (A3). The planting quality of mechanically planted Aughrim stock (A2) was significantly lower than that of most other method / type combinations, with the exception of the mechanically planted Cheviot (A1) and Tuam (A4) plants.

Planting Quality (Afforestation)

As on the reforestation site, manual planting on the afforestation site resulted in consistently higher planting quality than mechanical planting for all plant types (Figure 5). Statistical analysis confirmed the significantly higher scores for manual planting compared to mechanical planting. Significant differences were also found between the four quality scores for the mechanical operations, with the score awarded to the Aughrim plants (A2) significantly lower than all other scores.

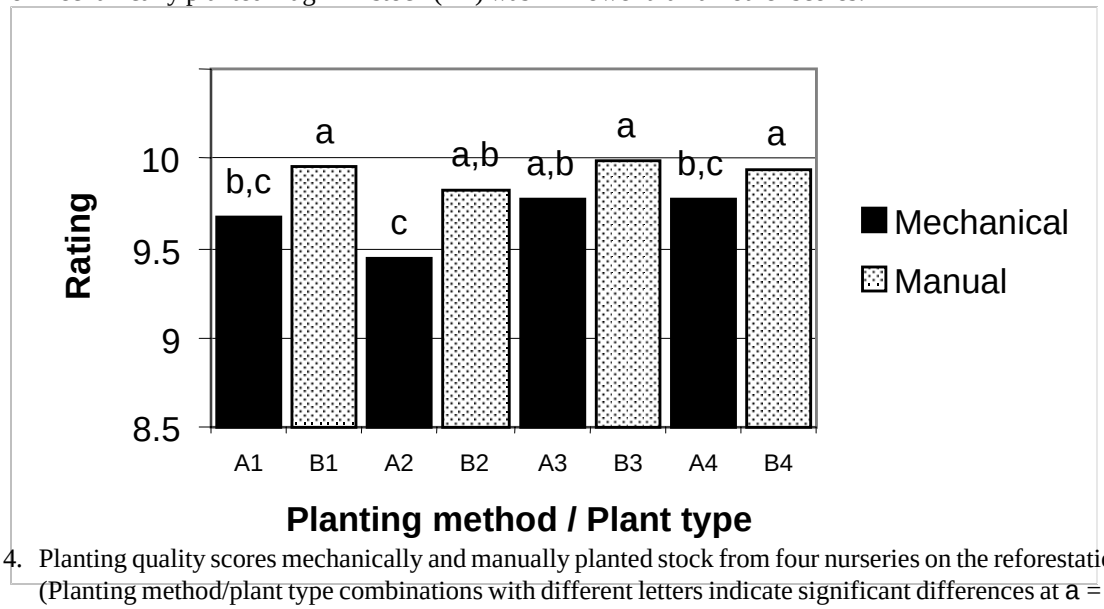

Figure 4. Planting quality scores mechanically and manually planted stock from four nurseries on the reforestation site. (Planting method/plant type combinations with different letters indicate significant differences at a = 0.05).

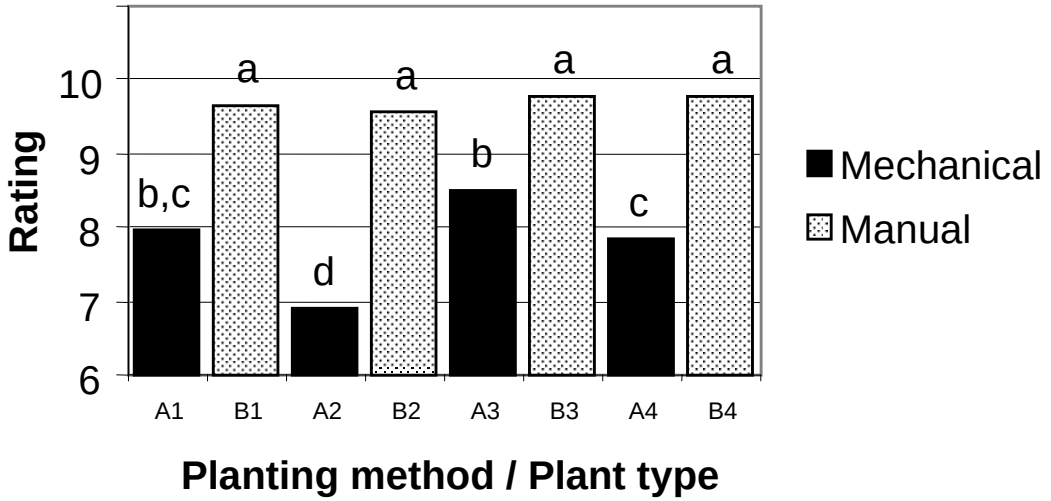

Figure 5. Planting quality scores mechanically and manually planted stock from four nurseries on the afforestation site. (Planting method/plant type combinations with different letters indicate significant differences at a = 0.05).

Relative Height Growth (Reforestation)

Considerable variation was evident in the relative height growth of the eight planting method / plant type combinations (Figure 6). The average relative height growth was generally consistent for both planting methods for each plant type. Smith planting stock (A3 and B3) produced significantly greater relative height growth than other seedling types, irrespective of planting method.

Relative Root Collar Diameter Increment (Reforestation)

As with relative height growth, large differences in relative root collar diameter increment were found (Figure 7). Mechanically and manually planted Smith plants (A3 and B3) produced the greatest increase in relative root collar diameter over the growing period. This result was statistically significant. 'Hard container' plants from the Tuam nursery (A4, B4) had negative relative root collar diameter increments, irrespective of the method of planting, and the relative root collar diameter increment of these plants was significantly lower than that of any other plant type.

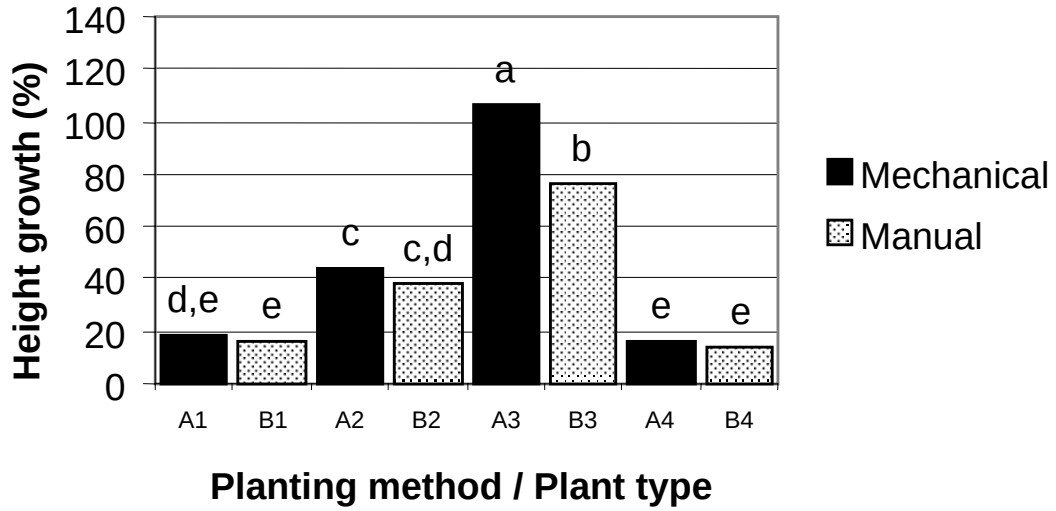

Figure 6. Relative height growth for mechanically and manually planted stock from four nurseries on the reforestation site. (Planting method / plant type combinations with different letters indicate significant differences at $\alpha = 0.05$).

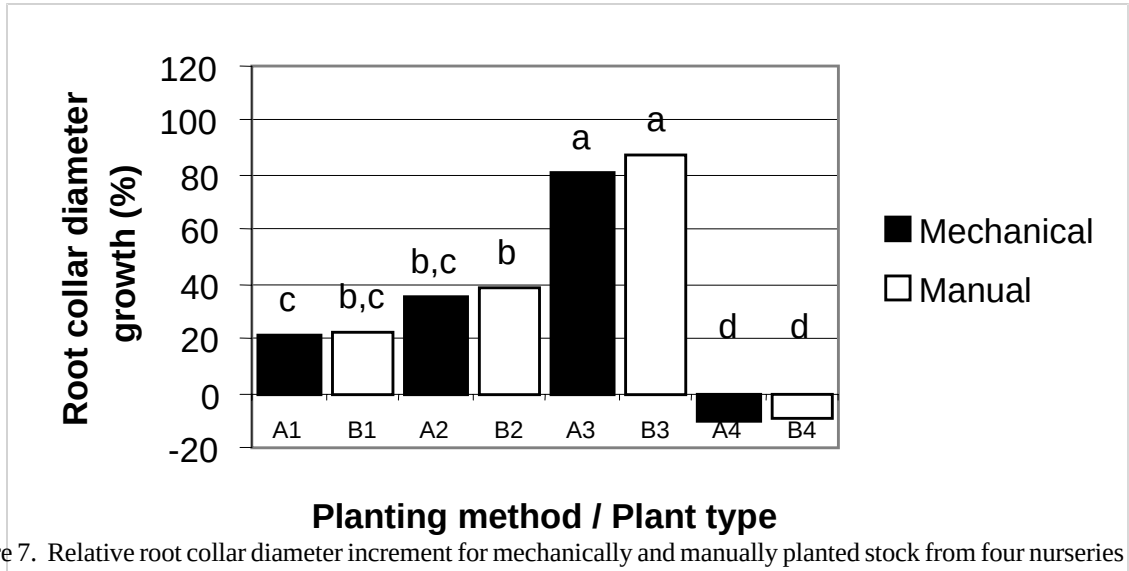

Figure 7. Relative root collar diameter increment for mechanically and manually planted stock from four nurseries on the reforestation site. (Planting method / plant type combinations with different letters indicate significant differences at $\alpha = 0.05$).

Plant Mortality (Reforestation)

Plant mortality was generally low and on average ranged from 0.56% (B1) to 7.54% (A1) (Figure 8). For each type of planting stock used, mortality was higher when seedlings were mechanically planted than when they were manually planted. Many of these differences were statistically significant.

Summary of results for the reforestation site

The results indicated that all the manually planted treatments (i.e. the B's) rated higher than their mechanically planted equivalents (Table 5). Manually planted Smith stock (B3) had the highest overall rating, followed by mechanically planted Smith stock (A3) and manually planted Aughrim seedlings (B2). Mechanically planted Tuam stock (A4) had the lowest overall rating.

Sensitivity Analysis

Sensitivity analysis was carried out on the results for plant position and planting quality using modified scoring systems (as shown in Tables 2 and 3). The first sensitivity analysis scoring system for plant position eliminated planting depth as a factor in the evaluation. The results for the reforestation site were very similar to those obtained using the original scoring system, with the mechanically planted Cheviot (A1) and Aughrim (A2) seedlings joining the mechanically planted Smith (A3) and Tuam (A4) seedlings with scores significantly lower than those for all manually planted seedlings (Table 6). The results for the afforestation site were similar to those obtained using the original scoring system, with the exception of the elimination of the significant difference between the scores for the mechanically Smith plants (A3) and those for all other planting method / plant type combinations (Table 7).

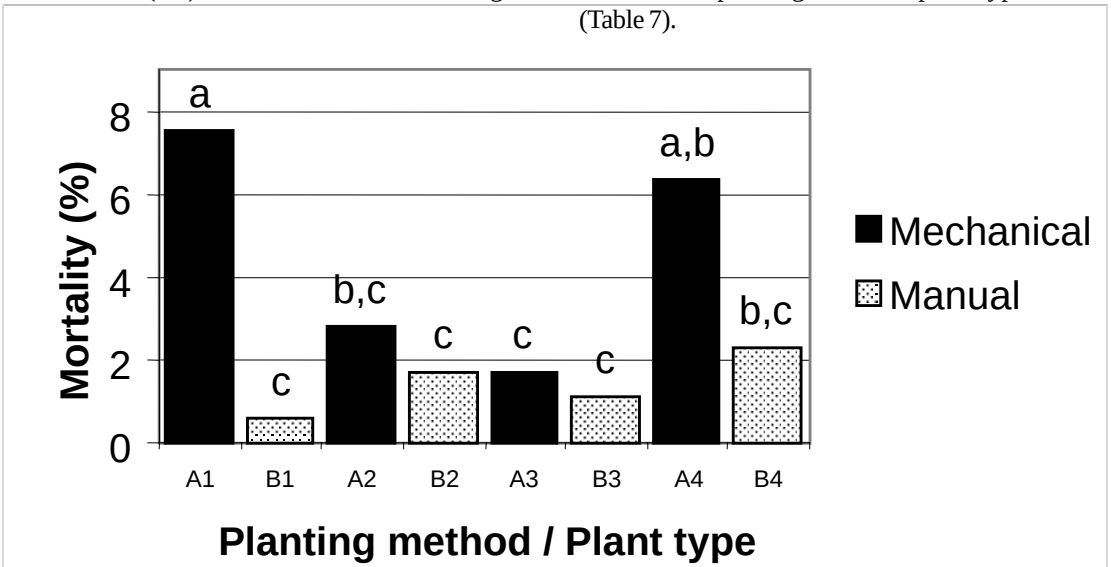

Figure 8. Mortality for mechanically and manually planted stock from four nurseries on the reforestation site. (Planting method / plant type combinations with different letters indicate significant differences at $\alpha = 0.05$).

Table 5. Summary of results for the reforestation site (+ = above average; - = below average; 0 = average).

	Cheviot		Aughrim		Smith		Tuam	
	A1	B1	A2	B2	A3	B3	A4	B4
Planting position	+	+	+	+	-	+	-	+
Planting quality	-	+	-	+	+	+	-	+
Relative height incr.	-	-	0	-	+	+	-	-
Relative root collar incr.	-	-	0	+	+	+	-	-
Mortality	-	+	+	+	+	+	-	+
Total	-3	+1	+1	+3	+3	+5	-5	+1

The second sensitivity analysis scoring system for plant position reduced the analysis to an evaluation of the presence of seedlings at each planting spot. The results for the reforestation site were again very similar to those obtained using the original scoring system, with the scores for mechanically planted Smith (A3) and Tuam (A4) seedlings still significantly lower than those for the manual treatments (Table 6). The results for the afforestation site were similar to those obtained using the first sensitivity analysis scoring system (Table 7).

The first sensitivity analysis scoring system for planting quality was used to evaluate the impact on the results of an increase in the penalty associated with low quality planting. For the reforestation site the results were very similar to those obtained using the original scoring system (Table 8), while the statistical differences for the afforestation site were identical to those obtained using the original scoring system (Table 9). The second sensitivity analysis scoring system was used to evaluate the impact of a reduction in the penalty associated with low quality planting on the analysis. The results for the reforestation site showed scores that were statistically less distinct than those found using the original scoring system (Table 8). The results for the afforestation site were very similar to those obtained using the original scoring system and the first sensitivity set, with the scores for all manually planted seedlings still significantly higher than those for mechanical planting (Table 9).

Table 6. Sensitivity analysis of the scoring system for plant position on the reforestation site. (Planting method/plant type combinations with different letters for the same scoring system indicate significant differences at α = 0.05).

Scoring system	A1	B1	A2	B2	A3	B3	A4	B4
Original scores	9.58	9.82	9.47	9.88	8.15	9.82	8.96	9.98
	a	a	a	a	c	a	b	a
Sensitivity set 1	9.60	9.83	9.53	9.91	9.48	9.92	9.11	9.98
	b	a	b	a	b	a	b	a
Sensitivity set 2	9.83	10.0	9.72	10.0	9.56	10.0	9.44	10.0
	a,b	a	a,b,c	a	b,c	a	c	a

Table 7. Sensitivity analysis of the scoring system for plant position on the afforestation site. (Planting method/plant type combinations with different letters for the same scoring system indicate significant differences at α = 0.05).

Scoring system	A1	B1	A2	B2	A3	B3	A4	B4
Original scores	9.59	9.84	9.61	9.82	8.98	9.84	9.77	9.87
	a	a	a	a	b	a	a	a
Sensitivity set 1	9.76	9.84	9.72	9.82	9.69	9.89	9.83	9.88
	a	a	a	a	a	a	a	a
Sensitivity set 2	9.89	10.0	9.94	9.94	9.89	10.0	9.94	10.0
	a	a	a	a	a	a	a	a

Table 8. Sensitivity analysis of the scoring system for planting quality on the reforestation site. (Planting method / plant type combinations with different letters for the same scoring system indicate significant differences at α = 0.05).

Scoring system	A1	B1	A2	B2	A3	B3	A4	B4
Original scores	9.68	9.97	9.49	9.83	9.74	9.98	9.62	9.93
	b,c	a	c	a	a,b	a	b,c	a
Sensitivity set 1	9.56	9.94	9.27	9.76	9.65	9.97	9.50	9.90
	b	a	b	a	a	a	b	a
Sensitivity set 2	9.77	9.98	9.62	9.89	9.79	9.98	9.69	9.95
	a,b	a	b	a	a,b	a	a,b	a

Table 9. Sensitivity analysis of the scoring system for planting quality on the afforestation site. (Planting method / plant type combinations with different letters for the same scoring system indicate significant differences at $\alpha = 0.05$).

Scoring system	A1	B1	A2	B2	A3	B3	A4	B4
Original scores	7.99	9.64	6.90	9.57	8.49	9.77	7.87	9.79
	b,c	a	d	a	b	a	c	a
Sensitivity set 1	7.44	9.57	6.18	9.43	7.99	9.71	7.36	9.72
	b,c	a	d	a	b	a	c	a
Sensitivity set 2	8.42	9.69	7.43	9.66	8.84	9.81	8.27	9.84
	b	a	c	a	b	a	b	a

DISCUSSION

Plant position

Mechanically planted seedlings were assigned lower scores than manually planted seedlings in the plant position assessment (as well as in the planting quality assessment), on both the reforestation and the afforestation sites. This may be partly explained by the experimental nature of the operations. In the establishment of the specific experimental plots, the manual planting crew may have introduced a level of care not normally present under operational planting conditions. This was not the case with the Bräcke operator, as the experimental plots were incorporated in large scale planting operations.

On the reforestation site, all four manually planted seedling types were assigned consistently high scores, resulting in a variation of only 1.6%. The variation in the scores awarded to mechanically planted seedlings was substantially greater at 17.5%. On the afforestation site, manual planting again resulted in consistently high scores for all four plant types, with the variation between the highest and lowest scores of only 0.5%. The scores associated with mechanical planting operations on the afforestation site followed a similar trend to the results obtained on the reforestation site, with lower and less consistent scores than those awarded to manual planting operations. The variation between the highest and lowest scores associated with mechanical planting on the afforestation site was 8.8%. These overall trends agree with findings in Sweden [7, 17] and the U.K. [3].

The sensitivity analysis of the scoring system for plant position on the reforestation site produced results indicating the robustness of the original statistical differences, with significantly lower values for the mechanical treatments using each of the three scoring systems. The absence of significant differences in the analysis of plant position on the afforestation site using the original scoring system was maintained when the sensitivity analysis scoring systems were used, demonstrating the insensitivity of the results to changes in the scoring system.

Planting Quality

Planting quality scores assigned to mechanical and manually planted seedlings showed a similar trend as the planting position scores. On the reforestation site, the scores awarded to mechanically planted seedlings displayed a variation of 3.5%, while manually planted seedlings were scored with a variation of only 1.5%. This indicated a greater level of consistency in planting quality resulting from manual planting operations. However, for mechanical planting the extent of variation in planting quality between the plant types was much lower than it was for planting position.

On the afforestation site, relatively low scores were awarded for planting quality after mechanical planting, while much higher scores were associated with manual planting. The poor results for mechanical planting can be (partly) attributed to the soil type on the afforestation site [2]. The soil was very dry and stony, and as a result, the machine had difficulty in properly firming the plants in the ground.

The sensitivity analysis of the scoring system for planting quality, on both the reforestation and afforestation sites, produced results very similar to the ones obtained using the original scoring system, indicating the robustness of the original statistical differences between planting quality scores for the different planting method / plant type combinations.

Growth Assessments

The growth assessments were based on relative values to compensate for differences in plant size at time of planting. It would have been illogical to expect a plant of 20 cm height to put on an equal height increment in one growing season as a plant of 40 cm [18]. An alternative way of dealing with this problem would have been to include initial plant size as a covariate in the statistical analysis [13]. It is recognised that in longer-term assessments of growth differences between planting methods and plant types, the initial plant size will rapidly become insignifi-

cant.

The main feature in relation to relative height growth was the consistency of increment values for the same plant type after mechanical and manual planting. Relative root collar diameter increment followed a similar pattern, in that increases in relative root collar diameter were consistent across individual plant types. As with relative height growth, Smith plants (both mechanically and manually planted) had the greatest increase in relative root collar diameter. Tuam seedlings (both A4 and B4) performed poorly and had both the smallest increase in relative height growth and in root collar diameter increment. This poor performance may be linked to the fact that the plants were pot-bound at time of planting [9]. Three of the mechanically planted seedling types (i.e. Cheviot, Aughrim and Smith) achieved higher relative height increments than their manually planted equivalents, while for relative root collar diameter increment the opposite was the case. The higher height increments for the three mechanically planted seedling types is noteworthy because (as discussed previously) all mechanically planted seedling types were awarded poorer scores in the planting position and planting quality assessments than their manually planted equivalents. The fact that these mechanically planted seedlings appear to have been less well planted, seems to have had no negative effect on their relative height growth in the first growing season. The sensitivity analyses clearly indicated that these results were not sensitive to changes in the scoring systems used. It is possible that the growth performance of these containerised seedlings, during the first growing season, was influenced more by the rooting and the growth medium within the containers than by the results of the planting operation [9]. It will be interesting to monitor the performance of the mechanically planted seedlings during subsequent growing seasons, to see if the low scores for plant position and planting quality result in future growth reductions when compared to the manually planted seedlings.

Plant Mortality

The failure rate after manual planting was very low for all four plant types, with the average for the four manually planted seedling types at 1.41%. The same level of consistency was not achieved after mechanical planting. The average failure rate for the four mechanically planted seedling types was 4.60%, reaching a high of 7.54% for Cheviot plants. It was difficult to identify any clear reason for this high incidence of plant mortality after mechanised planting of these seedlings, apart from some localised rabbit damage in one of the five Cheviot plots, resulting in 11% mortality in this plot. However, even a mortality rate of 7.54% one year after planting would be acceptable in operational planting contracts, where the maximum rate is set at 10-15%, depending on the quality of the site.

The Bräcke Planting Machine

The Bräcke planter is a relatively cheap planting head that can be fitted to most excavators. Preliminary productivity studies that were part of this project indicated that the Bräcke planter was capable of planting 180 to 200 plants per hour on reforestation sites and 250 to 300 plants per hour on afforestation sites. Studies on reforestation sites were based on the planting machine carrying out the windrowing of slash, mounding and planting (including the application of insecticide). These productivity values are very similar to those obtained in trials carried out by the British Forestry Commission (0.07 ha or 175 plants per hour (at 2 x 2 m spacing)) [3] and by Skogforsk in Sweden (between 254 and 262 plants per hour) [17].

Reforestation costs in Ireland are currently higher when using this machine than for traditional mechanised ground preparation and manual planting methods using bare-root plants. However, other benefits of mechanised planting have to be considered in the overall evaluation process. First, mechanised planting will involve a reduction in management planning and supervisory input. Second, the fact that the operator is protected from poor weather conditions will result in improved operator working conditions and an increase in the available work window. Third, the possible integration of the insecticide application in the planting operation will reduce operator contact with chemically treated trees.

CONCLUSIONS

This study has demonstrated that the Bräcke planting machine is capable of planting a range of containerised plant types to acceptable standards on both reforestation and afforestation sites. Mechanical planting did not score as well as manual planting in the plant position and planting quality analyses. The sensitivity analysis of the scoring systems showed that these results were very robust. It must be borne in mind however, that greater care may have been taken with manual planting in this research project than would be possible under operational planting conditions. The Bräcke planter had some difficulty in firming the plants on the afforestation site where the soil was very dry. Results from the mortality assessment following mechanised planting on the reforestation site showed survival rates to be acceptable.

Evaluation of growth rates indicated clear differences between plant types. Both manually and mechanically planted Smith plants, which were grown in peat containers, produced the best overall relative height growth and

relative root collar diameter increment over the first growing season. Further research should be carried out on the combination of the Bräcke planter and the containerised plants, in order to optimise the plant / container type / machine interactions, to streamline the planning and execution of the planting operations, and to see if the high early growth rates observed in this study will be sustained in the long term.

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