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Excavator Mound Spacing on Restocking Sites

TECHNICAL NOTE

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SUMMARY

Observations from six sites within the UK showed that trench mounding with spot brash raking by excavator improved the uniformity of spacing, machine outputs and mound to soil contact. Problematic, dense brash mats can be spot brash raked, particularly when the tops are cut into short 1 m lengths, giving improved mound spacing quality and output. Additional harvesting costs are offset by easier ground preparation giving an overall reduction in expenditure while not hampering timber extraction. Coaching improved the judgement of mound spacing. Additionally it is emphasised that a narrow (0.5 m wide) square bucket is required to achieve uniform spacing. This is shown to have a significant effect on adjacent mound spacing.

INTRODUCTION

Successful establishment is a prerequisite for producing good quality timber. Mounding provides an excellent method of ground preparation for tree establishment on many restock sites, improving the microsite for tree growth. Mounds need to be well formed and correctly spaced to ensure the development of a stable crop with good form which meets the required stocking density. Good mounding practices can also contribute to improved timber quality and reduce establishment costs.

Previous research carried out by Technical Development (TD) highlighted a need for information on mounding methods. This Technical Note focuses on best practice and suitability of mounding methods using mechanised excavators on a variety of site types. Dense brash is recognised as a major hindrance to mounding. The success of techniques for dealing with this problem and brash mats produced during mechanised harvesting are discussed as are methods of assisting an operator's judgement of mound spacing and improvements in bucket profile to reduce mound spacing across trenches.

THE IMPORTANCE OF GOOD QUALITY MOUNDING

The aim of mounding is to create a planting position free from weed competition with a microclimate conducive to growth (Tabbush, 1998). Exposing bare soil by forming a mound raises the soil temperature as more heat is absorbed during the day than by a litter or vegetation covered surface. The stored heat is released during the night, reducing the risk of frost damage.

The position of mounds determines plant spacing and must be carefully planned to ensure that the required stocking density is met. Ensuring good quality, regularly spaced mounds at the establishment stage can reduce plant mortality, improve timber quality and lower the risk of windblow (Table 1).

Recommended standards of restocking

Current research indicates that mounds should have a height of 20–30 cm and an area of 0.25 m^2 to create the ideal microsite for tree growth and root development, while suppressing weed competition. The ideal tree spacing should be between 1.5 and 2.2 m. Mound density of 2700 per hectare (1.9 m spacing) will, allowing for mortality, give a stocking of 2500 trees per hectare (ha^{-1}) at year five. This is to ensure that the trees are not so tightly spaced as to become drawn up when competing for light, or so widely spaced as to allow dense, coarse branching to develop.

Mounds may be 'spoil' mounds, which are formed from soil taken from shallow (<1 m) spoil drains, or 'hinge' mounds, where the source of the soil is immediately adjacent to the mound (Patterson and Mason, 1999).

Mounding, accompanied by the appropriate drainage, is strongly recommended on gleyed soils as it gives better root symmetry and less landscape impact than ploughing (Patterson and Mason, 1999).

Table 1 Effects of mound quality on stand development

Positive effects of well-formed mounds	Negative effects of poorly-formed mounds
Encourages a symmetrical root structure which increases tree stability	If mounds are poorly formed in terms of area, height and consolidation, unstable root architecture may develop
Creates a weed-free planting position	Mounds above 30 cm high increase the risk of desiccation by wind
Creates a microsite ideally suited to tree growth in terms of soil and air temperature and available moisture	Poor mound to soil surface contact results in root exposure and desiccation
If correctly spaced, straighter and more finely branched stems result, giving better timber quality	Wide spacing will result in heavy branching, reducing timber quality
Mound spacing which dictates plant spacing of < 2 m will minimise the amount of structurally weak juvenile wood in species such as Sitka spruce (*Picea sitchensis*)	Excessively mounding a planting site, thus exceeding the optimum stocking density, is a waste of resources

INITIAL RESEARCH

In 1999 an evaluation was undertaken to identify best practice for excavator mounding systems on restocking sites. The crucial aspects of the performance assessment were: stocking density, spacing uniformity, quality of planting position and environmental impact.

The amount and distribution of brash was the main factor affecting mounding success. Several variations of brash management were evaluated, including mounding on brash, windrowing, heaping brash, raking individual planting positions through brash (spot raking) and raking mounds into brash.

Both windrowing and raking brash into heaps caused irregular gaps in the mound distribution. Although closer spacing between the brash rows or heaps could achieve stocking density, the gaps could affect future timber quality and were not considered to deliver optimum performance.

The highest quality of mounding was achieved by using spot raking through brash mats to bare the ground and using trenches to obtain the spoil. Spoil to soil contact and satisfactory stocking density were achievable and the brash no longer adversely affected the uniformity of spacing. Spot brash raking proved possible in all but the deepest brash mats.

Mound spacing uniformity was affected by spoil trenches which regularly resulted in wide spacing between mounds on either side of the trench. This could be alleviated by using a shallow, stepped trench profile and also by attempting to fill in the trench with residues. In this system the mound could be placed on the 'step' to reduce the distance between mounds on either side of the trench. However, it was found to be unsuitable for wet, poorly drained sites as the mound could become waterlogged.

It was evident that the skill level of the operator affected mound density and that the ability of operators to accurately judge distances within and between rows was very variable and required investigation.

TRENCH MOUNDING WITH SPOT BRASH RAKING

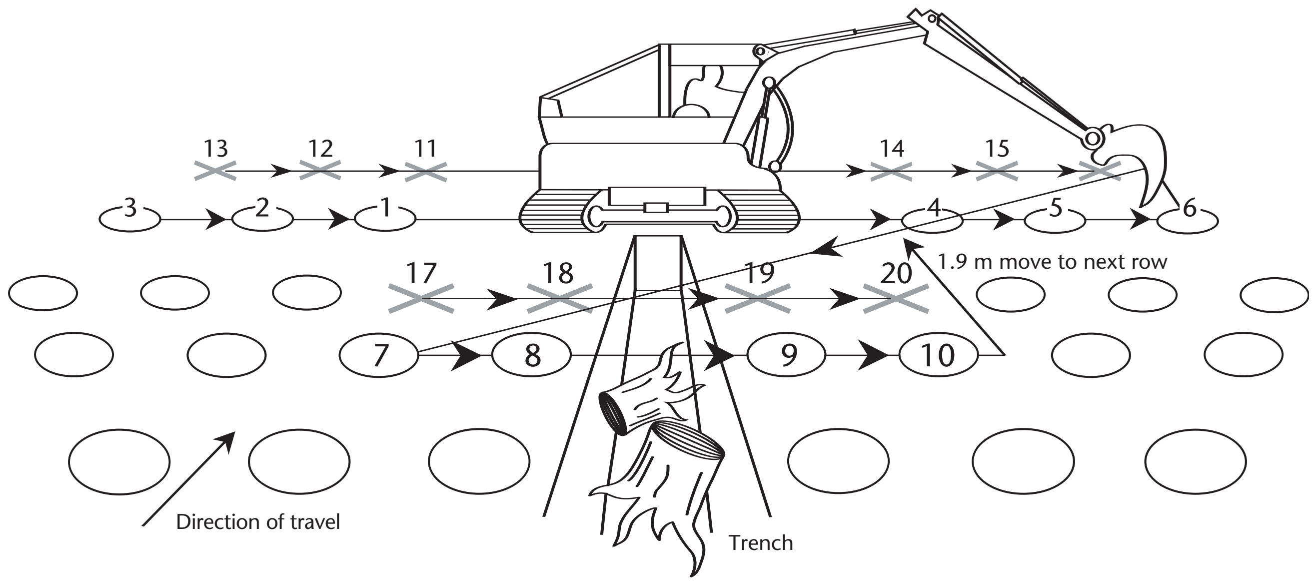
The initial research identified that trench mounding with spot brash raking is the optimum method of dealing with brash during excavator mounding operations over a range of sites. Trench mounding in rows rather than random placement enables accurate mound spacing which ensures evenly distributed planting positions, without sacrificing future site access. This also imposes order on the site, allowing in-row and between-row measurements to be used to monitor and correct operator performance.

Spoil for mounding is dug from a trench excavated in the centre of the clear ground between the brash mats with the mounds placed either side of the trench. The trench is then backfilled with stumps and residual debris. Brash-free areas to promote mound to soil contact are created within the brash mats by spot brash raking before spoil is placed.

The most effective sequence of work for trench mounding with spot brash raking is (Figure 1):

- The operator lays down three 'outer' mounds either side of the trench (positions 1–6).
- The operator then lays two mounds either side of the trench in front of the machine, two rows prior to the current row (positions 7–10).
- The operator then moves back 1.9 m and repeats this process. When the method is completed the operator is always laying out 5 mounds either side of the trench

Figure 1 Sequence of work for trench mounding with a 9 m reach boom



when using an excavator with a 9 m reach boom and 4 mounds either side of the trench when using an 8 m reach boom (positions 11–20).

Bucket profiles

Excavator bucket shape influences stocking as a wider trench profile is created with a larger bucket and results in mounds on either side of the trench having wide spacing. Generally, the narrower the excavator bucket diameter, the narrower the trench and the closer the mounds on either side. Initial trials indicated that a V-shaped bucket (1.3 m wide x 1.3 m deep) gave mound spacing of 2.3 m across the trench (Figure 2). With the longer reach excavators (9 m), two rows of mounds out of ten (20%) are affected, while with shorter reach excavators (8 m), two rows out of eight (25%) are affected by wide spacing across the trench.

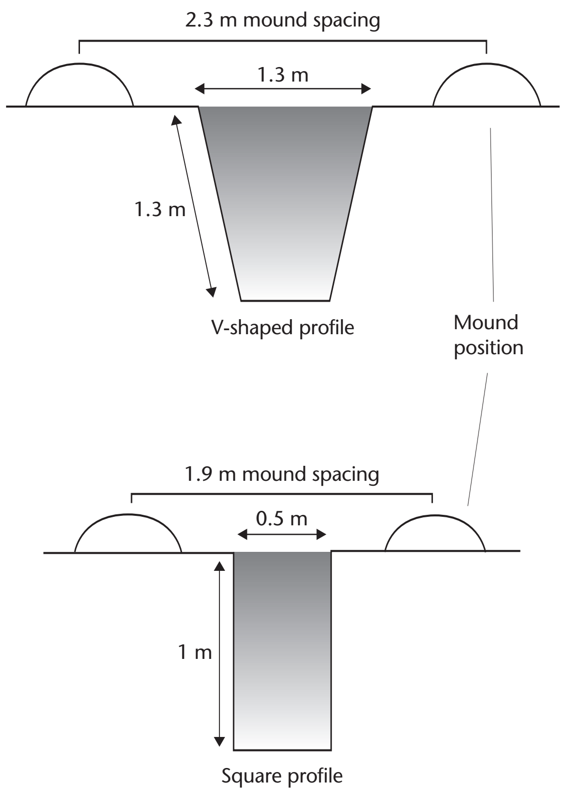
More recent trials with a square bucket profile (0.5 m wide x 1.0 m deep) achieved a more uniform and narrower spacing across the trench (1.9 m) while still allowing a sufficient volume of soil to be dug for mound construction (Figure 2).

Method comparisons

A comparison between existing excavator mounding methods and trench mounding was made on six sites, which had previous crops of predominantly Sitka spruce and had been felled within 3 years of the start of the trial. The resultant brash zones ranged from 3.3 m to 4.0 m wide with the cleared brash-free zone *c.* 80 m wide. The area of the sites covered in brash mats was between 33% and 40%. In order to assess mound stocking density and spacing uniformity, both in-row and between-row distances were measured during the trials. Optimum mound spacing is considered to be between 1.5 m and 2.2 m; any mounds with a between-mound measurement less than 1.5 m were excluded form the unit area count.

Three method comparisons were made. The methods used and summary of results are given in Table 2.

Figure 2 Trench and mound width variation



Comparison 1 Assess the efficacy of trench mounding, comparing spot brash raking with scratch/hinge mounding on a dry mineral site (Table 2).

The scratch mounding method resulted in erratic spacing without a defined trench. The operator was forced to place mounds where they could be scratched, rather than placing spoil from a trench. Stocking levels of 2500 trees spaced >1.5 m apart were not achieved using this method, based upon the stocking density of the plots surveyed.

Output almost doubled when trench mounding with spot brash raking was replaced by scratch mounding with brash raking. However, stocking performance was reduced due to limitations in mound position selection opportunities.

Comparison 2 Assess the efficacy of existing trench mounding with spot brash raking on steep peaty gley soils, and repeat the method with the operator focusing more on mound spacing (Table 2).

The changed method was the spot brash rake method with the operator focusing more accurately on spacing by using the techniques described in the spacing uniformity trials section. This resulted in an extremely marginal increase in stocking compliance of trees between 1.5 m and 2.2 m inclusive.

Comparison 3 Compare the existing method of trench creation in the brash mat and mounding into the brash-free zone with trench creation in the brash-free zone and spot brash raking in the brash zone. Additionally the operator was to focus more on mound spacing (Table 2).

The method was changed from creating the trench in the brash mat to creating the trench in the centre of the brash-free zone with the operator focusing on spacing. The results show that with the existing method, the proportion of cyclic time spent on mounding was 65% due to the operator having to prepare the brash mat. As a result of the changed method this proportion of the cyclic time spent on mounding was increased by 19% to 84%. This indicates that productive mounding time was being lost due to backfilling in the brash zone. One key observation was the effect of the trench on spacing, with mound centre to centre distances as great as 3.7 m.

When the method was changed and the operator was asked to focus on mound spacing, the average centre to centre mound distance was reduced. The greatest advance in reducing mound centre to centre spacing was due to the narrower mound placement across the trench. In addition, the number of mounds with less than 1.5 m spacing was significantly reduced.

Outputs and therefore costs were similar on both the current and changed methods. The trial was conducted in conditions where there was a great deal of woody residue, which made mounding time-consuming.

SPACING UNIFORMITY TRIALS

Having compared the effectiveness of trench mounding with spot brash raking on a range of site conditions, further trials were carried out to develop the method and identify best practice, with particular emphasis on developing and enhancing operator skill levels.

Table 2 Comparisons 1, 2 and 3: results

Comparison method	Method in use	Output (ha sh^{-1}*)	Total mounds ha^{-1} excluding mounds at spacing < 1.5 m	Overall stocking ha^{-1}	Number of mounds < 1.5 m
Method 1					
Existing	Trench mound with spot brash rake	0.047	2715	3509	794
Changed	Scratch mound with brash rake	0.086	1903	2719	816
Method 2					
Existing	Trench mound with spot brash rake	0.064	2519	3272	753
Changed	Trench mound with spot brash rake – operator focusing on spacing	0.069	2528	3161	633
Method 3					
Existing	Trench mound on the brash mat	0.059	2745	3169	424
Changed	Trench mound with spot brash rake – operator focusing on spacing	0.057	2638	2806	168

* sh = standard hour which includes an allowance for rest and other work.

In order to assess mound spacing uniformity during the trials, both in-row and between-row distances were measured and an overall uniformity performance calculated. The numbers of mounds were counted within plots to give the number of mounds per hectare. Mounds were counted as acceptable only if their centre to centre distance was between 1.5 m and 2.2 m. Any with a between-mound measurement either less than 1.5 m or greater than 2.2 m was excluded.

Two trials were carried out using operators of varying experience; the first used an experienced operator, while the second used a very inexperienced operator. The first trial evaluated the operator's ability to judge uniform mound spacing of 1.9 m by eye and investigated the use of mechanical aids and coaching techniques to assist spatial judgement. The second trial evaluated the ability of an inexperienced operator to achieve correct uniform mound spacing following coaching in spatial judgement.

Developing skills in spatial judgement

The first trial involved the experienced operator initially trench mounding an area containing a marked plot. When the area was completed, the mounds within the plot were counted and the between-mound distances measured with the assistance of the operator. The measurements showed the operator the variation in between-mound distances and the effect on uniformity. Further measurements were made outwith the plot to demonstrate the correct between-mound spacing of 1.9 m and where other between-mound distances varied. This provided the operator with a means to calibrate his spatial judgement performance by subsequent measurement, similar to other operations such as thinning control and the harvesting of different product lengths. The results of this coaching were tested by mounding another area which was followed by further discussion and measurement of the resultant mound spacing.

Use of boom dimensions to assist judgement

Before starting a third area, the operator fully extended the boom and then brought it in by an estimated 1.9 m to assess if boom configuration could be used to improve spatial judgement. This action was carried out a number of times and achieved an average spacing of 1.76 m. Other boom movements were investigated but only those where the boom was fully extended or fully into the side of the machine were considered to assist the spatial judgement of the operator.

Other measuring aid trials

Measuring aids such as chains or paint marks on the boom and bucket were investigated but found to be impractical due to the boom configuration.

Minimising trench width

The effect of the trench width on mound spacing was also discussed and the operator attempted to maintain a narrow trench by careful and methodical digging.

Results

The results of the trials are given in Table 3. A comparison of the results from areas 1 and 2 shows that when asked to focus on improving uniformity the operator increased the percentage of mounds spaced between 1.5 m and 2.2 m from 89% to 94%. The results also show there was a reduction in output of *c*. 20% and overall mound density increased significantly.

The results from the third area, where the trench was narrowed and spacing was assisted by the measurements on the boom, show an increase in the acceptable number of mounds at 3231 ha^{-1}. There was also an increase in the number of mounds at less than 1.5 m apart but a decrease in the mounds greater than 2.2 m apart.

High proportions of mounds were produced within the target range of 1.5 m to 2.2 m. However, overall average spacing reduced and stocking density increased. Further consolidation to improve spacing is therefore necessary.

To test the effect of coaching on a novice operator, the work of an operator who had only been working with the excavator for *c*. 1 month was studied. Initially the operator's existing spacing uniformity was assessed, and this was then followed by a coaching session. This was similar to the coaching given to the experienced operator, resulting in a greater focus on mound spacing and uniformity.

The results showed that the number of mounds placed at the required spacing (1.5–2.2 m) improved from 70% to 90%, giving greater accuracy of mound placement. The excavator used had an 8.3 m maximum boom reach which allowed the placement of only four mounds rather than the standard five either side of the trench which may have contributed to the overall mounding accuracy. It is important to note that this was a series of short studies and that the probability of sustaining the operator performance improvements over a long time period is unknown.

Table 3 Experienced operator trial results

Method in use	Output (ha sh^{-1}*)	Number of mounds ha^{-1} between 1.5–2.2 m	Overall stocking ha^{-1}	Mounds between 1.5 and 2.2 m inclusive (%)	Number of mounds < 1.5 m	Number of mounds > 2.2 m
1. Standard spot brash rake trench mound system	0.110	2486	2826	88	154	166
2. Standard spot brash rake trench mound system with operator focusing more on spacing uniformity	0.086	3055	3255	94	107	93
3. Standard spot brash rake trench mound system but with measured reference points painted on machine boom and narrow trench	0.088	3231	3589	89	337	61

* sh = standard hour which includes an allowance for rest and other work.

EVALUATION OF BRASH MAT CONSTRUCTION METHOD ON HARVESTING AND GROUND PREPARATION

The trench mounding with spot brash raking system can be used on sites with a high percentage of woody residues. However, the presence of these residues can make mounding time consuming and also reduces the quality of mound to soil contact. In particular, where felled tops of 4–5 m long are present, there are problems when trying to spot brash rake. It was postulated that if harvested tops were cut into shorter sections (1 m) this should make the ground preparation operation easier although it could make the brash mat less robust for flotation.

Trial description

Two conventionally felled trial areas were selected on adjacent sites. One area had random length tops incorporated into the brash mats and the other had all tops cut into *c.* 1 m lengths. Both areas were subsequently trench mounded. At both sites information on the harvesting and forwarding was collected to assess:

- The operational time difference caused by cutting up the tops.
- The flotation performance during forwarding to establish whether cutting tops to 1 m lengths would cause flotation on the brash mat to be adversely affected.

The crop on the trial areas was a non-thin Sitka spruce with an average tree size of 0.27 m^3 and a standing volume of 420 m^3 ha^{-1} on a shallow peat (10–20 cm deep) over a mineral soil. To produce a thick brash mat containing a large proportion of stem-wood residue, the harvester (an excavator based Daewoo 250 LC-V fitted with a Ponnse H 60 harvesting head) cut the tops off at 12 cm top diameter (Figure 3).

Figure 3 Harvester working in 'short-top' drift

Results

Harvesting and forwarding

The results of the harvesting trial are detailed in Table 4. Although there was only a difference of *c.* 0.02 m^3 in the average tree size between the trial areas the average time difference to cut up the tops increased by 47% to 0.08 standard minutes. This gave an average cost difference of £0.06 per tree when based on a harvester cost of £45 per hour. With an average tree size of 0.28 m^3 and a standing volume of 313 m^3 ha^{-1}, the cost increase for cutting short tops was £67.07 ha^{-1}. This represents an increase of 3.6% in the total harvesting cost for the conventionally felled area (£1878 ha^{-1} assuming £6 per m^3).

Forwarding was carried out with a Ponnse Buffalo H16 medium class forwarder with 700 mm tyres and wheel chains fitted on the front wheels of the front bogie. The forwarder carried a 15 m^3 load (58 x 4.9 m long) of sawlogs. It travelled both brash mat specifications 12 times to simulate 180 m^3, equivalent to extracting 0.5 ha

Table 4 Comparison trial results

Outputs	Long tops 4–5 m	Short tops 1 m
Area cut (ha)	0.068	0.091
Total standing volume (m^3 ha^{-1})	526	313
Average tree volume (m^3)	0.26	0.28
Number of live trees	134	99
Time to cut up and place top per live tree (standard minutes per tree)	0.17	0.25
Cost per tree at £45 per hour (£ per tree)	0.13	0.19

from a crop of 360 m^3 ha^{-1}. The distance travelled was considered representative for typical felling coupe sizes based upon TD forwarder extraction work in Scotland.

There was little difference in the performance of the four brash mats and no additional thatching was required to sustain forwarder movement, although the 1 m length tops allowed slightly deeper ruts to be formed.

Ground preparation

The excavator used in the trial was a Fiat Hitachi EX 120 12 tonne excavator with a boom reach of 8.0 m and a V-shaped bucket of dimensions 1 m deep, 0.8 m wide (top) and 0.3 m wide (bottom).

The trench mound system was used to place four mounds either side of the excavator, with the trench in the centre of the brash-free zone and spot brash raking into the brash mats. As the area of the brash mats relative to the brash-free zone was less in the 'short top' trial site, five mounds were placed in the brash-free zone and three in the brash mats. The ground preparation operation carried out in both trial sites was assessed and the results are given in Table 5.

Table 5 Results of long and short tops trial

Outputs	Long tops 4–5 m	Short tops 1 m
Stocking (mounds ha^{-1})	2625	2709
Area (ha)	0.064	0.062
Mound time in the stump zone (bmin*)	10.88	15.41
Mound time in the brash zone (bmin)	20.78	7.70
Output in the stump zone assuming 2700 ha^{-1} (ha per bh*)	0.170	0.150
Output in the brash zone assuming 2700 ha^{-1} (ha per bh)	0.088	0.182
Output: stump and brash zone assuming 2700 ha^{-1} (ha per bh)	0.120	0.160

*bmin (basic minute) and bh (basic hour) do not include any allowance for rest or other work.

A comparison between the 'long top' and 'short top' trials shows that the effect on the operation is most apparent in the brash zone which has increased the output for this aspect of the operation by over 100% in the 'short top' brash zone. The overall output when cutting the 'short tops' has increased from 0.12 ha bh^{-1} to 0.16 ha bh^{1} (33%). Therefore, when based on contractor mounding costs of £300 ha^{-1}, the theoretical costs could reduce by 25% or £75 ha^{-1}.

Evaluation of the ground preparation operation showed that the quality of mound to soil contact was better in the 'short top' brash mats. Mounding uniformity was more easily achieved in the 'short top' site as it was easier to spot brash rake and the degree of boom and bucket movement was reduced. Mound uniformity, given as mean in-row and between-row spacing, over the ground preparation site (Table 6) shows that mounding performance was more consistent in the 'short top' site especially for in-row spacing in the 'short top' brash zone.

Basing harvesting costs on £6 per m^3, the cost penalty for cutting up the tops into shorter lengths is £67.07 ha^{-1}. However, ground preparation costs of £300 ha^{-1} can be reduced by £75.00 ha^{-1} giving an overall cost benefit of £7.93 ha^{-1}. It is likely that, as the harvester operator becomes more accustomed to the method, harvesting cost penalty could reduce, which would increase the overall cost benefit.

EFFECT OF ACCURATE SPACING AND STOCKING DENSITY

As previously stated, a robust ground preparation method, with uniformly correctly spaced mounds, will result in improved final crop quality. Incorrectly spaced mounds will give over- or understocking which will affect establishment costs and is likely to adversely affect the volume, stability and quality of the final crop.

Table 6 Mean in-row and between-row spacing results

Mound spacing	Brash mat zones: target mound spacing of 1.9 m	
	Long tops	Short tops
Overall average in-row spacing (m)	2.1	2.0
Overall average between-row spacing (m)	2.0	1.9
Average in-row spacing in the brash mat zone only (m)	2.1	1.9
Average between-row spacing in the brash mat zone only (m)	1.8	1.8

Assuming that the correct density of uniformly spaced mounds is 2700 ha^{-1}, when comparing the costs with an overstocking of 3500 ha^{-1}, the likely cost difference is £270 ha^{-1} at year five. This is based on Forestry Commission costs of operations such as ground preparation, planting, weevil control, beating up and chemical weeding to establish both crop densities. Where stocking is correct, using a robust ground preparation method such as the trench mound system, it is likely that beating up, pathogen and weed control costs will reduce compared to other ground preparation methods.

Given a hypothetical restocking programme of 1000 ha per annum, restocking at 3500 trees ha^{-1} rather than 2700 trees ha^{-1} would result in an additional cost of £270 000 per annum. Although an unlikely scenario, this does illustrate the importance of achieving accurate stocking densities. There are also the implications of the impact on nursery stocks and the requirement of more chemical application. Conversely understocking is likely to reduce costs at the establishment stage, but may have an adverse effect on timber quality and value, which will have implications for future harvesting operations.

Where sites are stocked at a target uniformity of 1.9 m x 1.9 m then overall and green sawlog percentage is likely to increase and small roundwood percentage decrease which may lead to increased revenue when thinning and clearfelling. Additionally, on sites where a uniform crop has been harvested, subsequent ground preparation should be easier, thus reducing costs.

CONCLUSIONS

- Trench mounding with spot brash raking achieves the best results of spacing performance, acceptable outputs per hour and mound to soil contact when compared to other existing mounding methods on steep peaty gley sites. The method also imposes an order on the site, allowing within-row and between-row measurements to be used to monitor and correct operator performance.

- Operator coaching, through discussion of uniform stocking density and measurement of the 1.9 m spacing requirement, improved overall mound spacing and uniformity with an experienced operator and was particularly noticeable with an inexperienced operator.

- Cutting up the tops into short, *c.* 1 m, lengths increased the time element of the operation by 47%, which resulted in a harvesting cost increase of *c.* £67 ha^{-1}. The operator was unaccustomed to the new method and with further practice using this method the time penalty may be reduced. A medium class forwarder performed well on the ‘short top’ brash mat with no significant degrade in the route after 12 passes.

- Ground preparation in the ‘short tops’ trial gave outputs 33% greater than the ‘long tops’ trial and resulted in a cost reduction of £75 ha^{-1}. The quality of mound to soil contact and uniformity of spacing also improved.

- The overall cost benefit of reducing the tops to short 1 m lengths was £7.93 ha^{-1}.

- Bucket specification has an effect on overall mound spacing as a wide bucket (1.3 m) can increase the spacing between 20% and 25% of the mounds depending on boom length. The width of the trench can be reduced by using a bucket with a narrower profile (0.5 m) while still making sufficient soil available for mounding.

- There are clear indications that accurate mound spacing and correct density will reduce establishment costs and improve timber quality.

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