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# EVALUATION OF THE EFFECT OF TREE-LENGTH AND FULL-TREE HARVESTING ON THE PERFORMANCE OF THREE SCARIFIERS

A JOINT REPORT OF THE
GREAT LAKES FOREST RESEARCH CENTRE
AND THE
FOREST ENGINEERING RESEARCH INSTITUTE OF CANADA

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## ABSTRACT

The TTS-35 Disc Trencher, Leno 77 Patch Scarifier and Bräcke Cultivator (two-row) were evaluated in northeastern Ontario to determine the effects of tree-length and full-tree logging on their productivity and site preparation quality. Single passing on the full-tree areas was compared with double passing on the tree-length areas. Double coverage lowered overall productivity; however, heavy slash conditions associated with tree-length logging did not appear to influence maneuverability of the three machines on these areas. Factors such as operator experience, power of the prime mover, treatment pattern, hitch type and terrain obstacles other than slash had a much greater effect on productivity than did slash. Slash conditions on the tree-length areas clearly limited site preparation in terms of plantability and seedbed preparation, even with double coverage.

## RÉSUMÉ

Dans le nord-est de l'Ontario, les auteurs ont évalué la trancheuse à disques TTS-35, le scarificateur Leno 77 et le cultivateur double Bräcke, afin de préciser les effets de l'exploitation par troncs et par arbres entiers sur la productivité et sur la préparation des terrains. Ils ont comparé des secteurs traités une fois (arbres entiers) et d'autres traités deux fois (troncs entiers). Le double passage a fait tomber le productivité globale, mais la grande quantité de rémanents, qui est le fait de l'exploitation de troncs entiers, ne semble pas avoir joué de rôle sur la manoeuvrabilité des machines, dans ces secteurs. Des facteurs comme l'expérience du conducteur, la puissance de l'organe moteur principal, le schéma de travail, le type d'attelage et les autres obstacles avaient plus d'incidence sur la productivité. La présence de rémanents dans les secteurs exploités par troncs entiers a vraiment nui à la préparation des terrains (facilité de plantation et préparation des semis), même après deux traitements.

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Cover photo: Top left - Manual delimbing in conventional tree-length harvesting operation.

Bottom left - Site preparation with Bräcke in heavy slash resulting from tree-length harvesting.

Top right - Stroke delimber working at roadside in full-tree harvesting operation.

Bottom right - Site preparation with Leno Patch Scarifier in light slash resulting from full-tree harvesting.

# INTRODUCTION

Logging system selection is a critical forest management decision that may affect the overall profitability of the harvesting operation, the level and type of utilization, and the success of regeneration efforts.

Since its inception in Canada in the late 1960s, full-tree (FT) logging has grown to the extent that, by 1982-1983, it accounted for 26% of the total volume of wood harvested east of the Rockies (Anon. 1984). On the other hand, tree-length (TL) logging fell from 92% in 1970 to 63% in 1982-1983.

The reduction in slash loadings associated with FT logging, through the elimination of limbing and topping at the stump, has advantages for both logger and silviculturist. For the silviculturist, FT logging provides an opportunity for reducing, and possibly eliminating, slash-related regeneration problems (Haavisto 1979). The advantages, however, are tempered somewhat by the fact that some ecosystems are better able to withstand the impact of FT logging than others. Morrison (1980) cautioned that with slash removal and the consequent drain of nutrients, one might expect extremely shallow soils, coarse-textured, excessively drained soils, resistant low-base mineral soils, and soils low in organic matter, cation exchange capacity or base saturation to be sensitive to FT logging.

E.B. Eddy Forest Products Limited of Espanola, Ontario have reported an estimated 8 to 10% saving in logging costs with conventional felling, FT skidding and mechanical delimbing at roadside in comparison with conventional felling, delimbing and topping at the stump and TL skidding. In 1982 the company became interested in determining the effects of FT and TL logging on subsequent scarification operations. They requested that the Great Lakes Forest Research Centre (GLFRC) apply standardized evaluation procedures to assess the performance of three scarifiers, the TTS-35 Disc Trencher, the Leno 77 Patch Scarifier and the Bräcke Cultivator (two-row), operating under conditions resulting from the two systems. The company wished to determine how well the scarifiers could operate on FT conditions and the extent to which operations were viable on fresh TL slash. The Forest Engineering Research Institute of Canada (FERIC) was asked to participate in conducting the work studies. The company provided the sites, scarifiers, prime movers, operators, supervisors and mechanical support for the study.

Slash loading is highly dependent upon the type of harvesting system used, whereas other site variables such as terrain and ground conditions are mostly independent of the harvesting system but still affect scarifier performance. The primary objective of the trial was to identify the major site-limiting factors and by so doing isolate the effect of slash. A secondary objective was to identify quantifiable ranges of slash loadings that might limit site preparation.

A brief account of the methods, results and findings is given under **SUMMARY AND CONCLUSIONS**.

## SITE

The study area was located approximately 1 km east of Ramsay, Ontario (Fig. 1) in the Missinaibi-Cabonga Section of Boreal Forest Region B.7(2) West (Rowe 1972). Timber rights for the area are held by E.B. Eddy Forest Products Limited under a Forest Management Agreement.

Prior to harvesting, the stands were predominantly Site Class I jack pine *(Pinus banksiana* Lamb.) (Plonski 1974), with variable black spruce *(Picea mariana* [Mill.] B.S.P.), poplar *(Populus* spp.), and white birch *(Betula papyrifera* Marsh.) components. Stand age was approximately 70 years. At harvest the jack pine and spruce were removed and the hardwoods were left as standing residuals. Harvesting was conducted over a four-month period in 1982 and scarification followed almost immediately. Slash still contained foliage at time of treatment (Fig. 2 and 3). Normally, a longer delay is preferred to allow foliage to drop and slash to become more brittle.

The area is a glacial moraine with moderately frequent rock outcrops. Water- and wind-laid, very shallow to deep, silty, fine sand overlies the gently to moderately rolling terrain, which slopes up to 15%.

To compare equipment performance properly under the slash conditions resulting from the two different harvesting systems, variability in other site factors such as slope, residual stocking and soil depth must be limited. The site was in fact sufficiently variable that it was impossible to test all tools under similar conditions and therefore comparisons between tools were not made. However, it was possible to establish similar pairs of blocks so that comparisons could be made between logging systems for each tool being evaluated.

## DESCRIPTION OF THE SCARIFIERS

Working and travelling positions, including overall dimensions of the three scarifiers and prime movers, are shown in Figure 4. Additional specifications are listed in **APPENDIX A.**

### *TTS-35 Disc Trencher*

The TTS model 35 is a mechanical disc trencher designed to create two continuous furrows approximately 2 m apart. Two passive discs are mounted beneath a triangular box frame (Fig. 5). As the machine advances, the discs rotate, throwing debris and soil outward.

The angle of the discs and the weight of the scarifier determine both the ability of the discs to penetrate the soil and the width and depth of the furrow. The angle of the discs can be changed by five 6° increments or by 30° increments if the minor adjustment is insufficient to obtain satisfactory results. The weight can be increased by loading the box of the triangular frame.

The TTS was pulled by a 92-kW International S-10 grapple skidder. The disc trencher had been modified so that it could be mounted to the skidder with

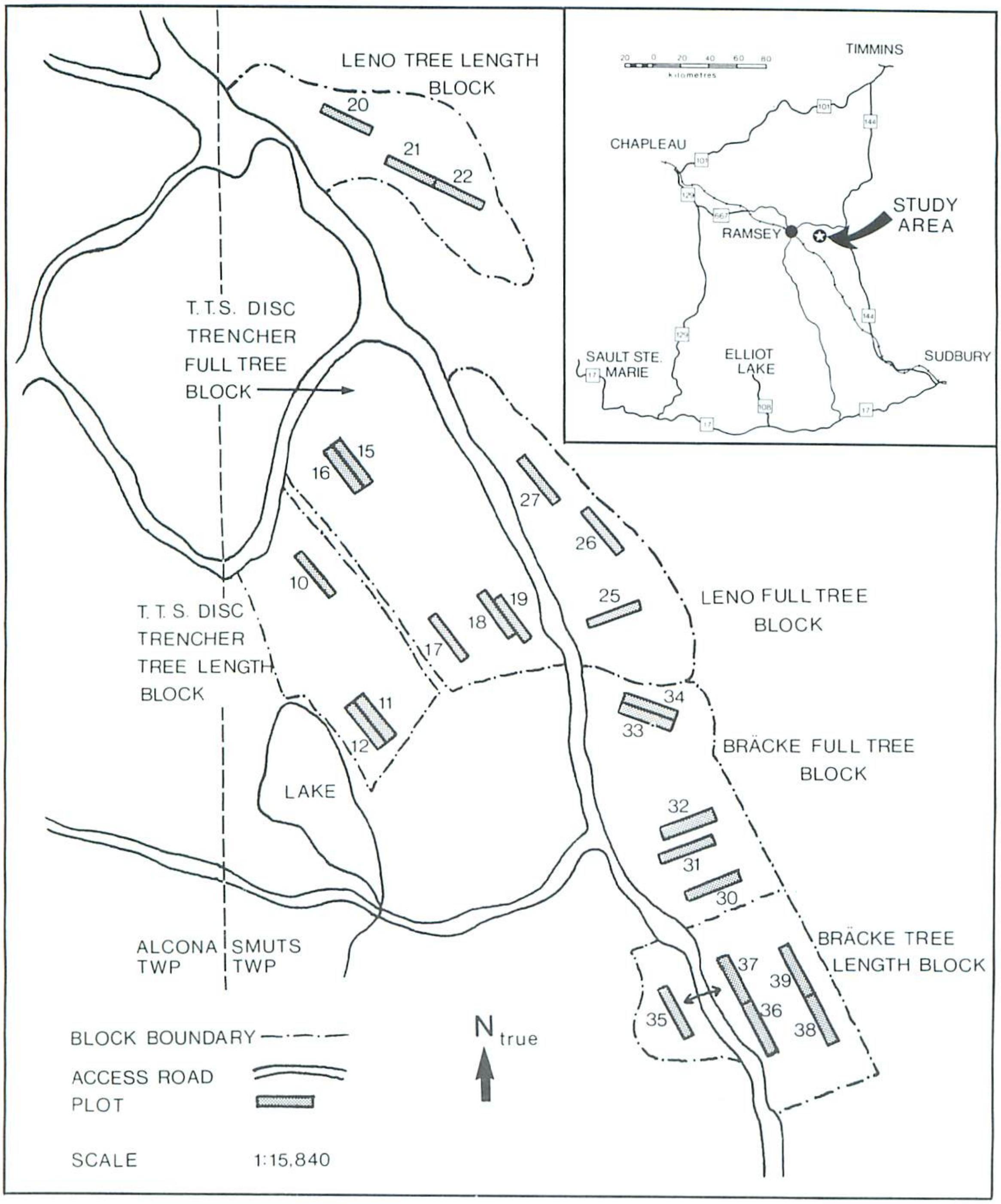



Figure 1. General location of study area and approximate location of 20-m x 100-m plots within treatment blocks in Smuts Township.

Figure 2. Characteristic slash conditions on FT harvested site.

Figure 3. Characteristic slash conditions on TL harvested site.

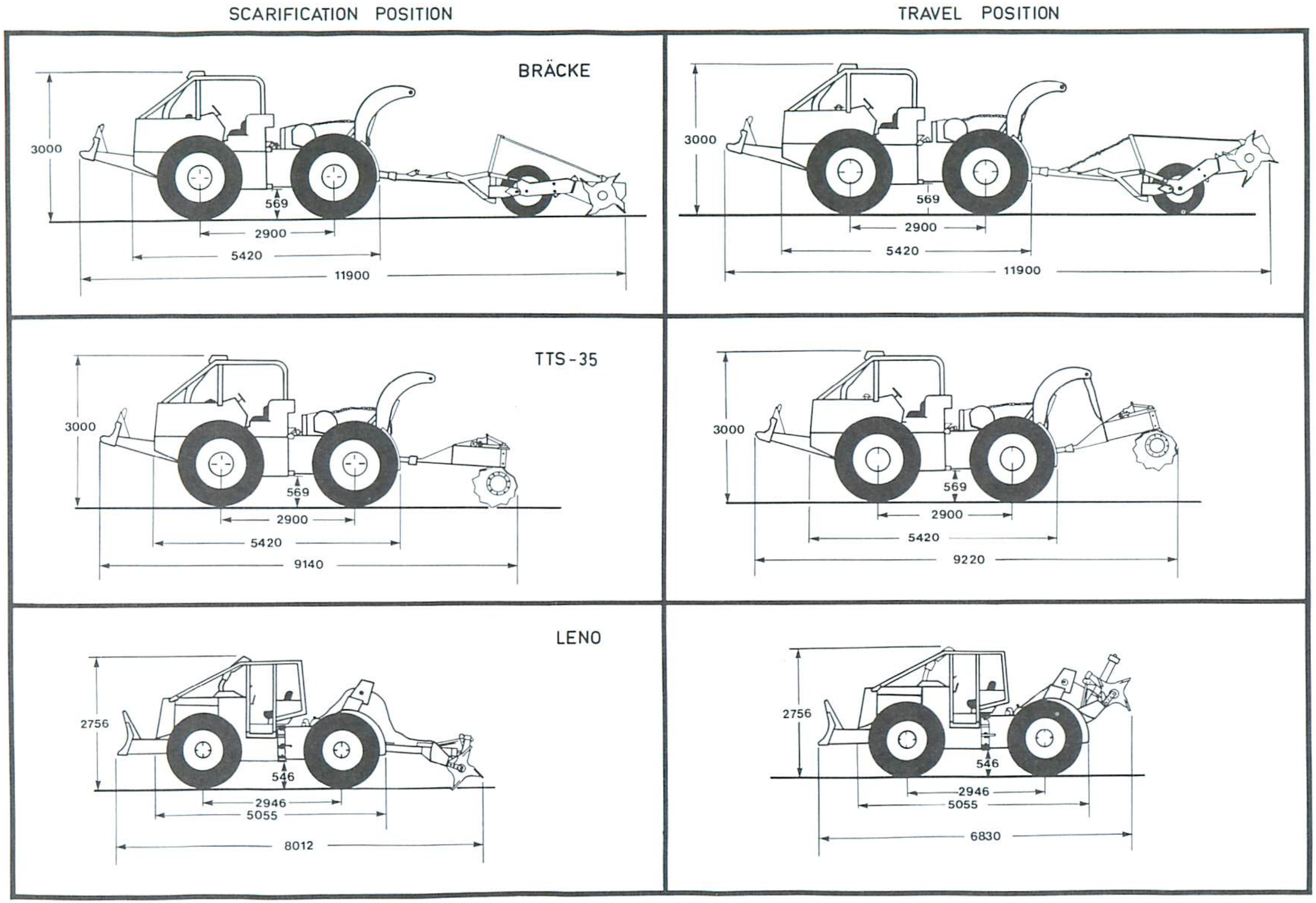



Figure 4. Overall dimensions (mm) and working positions of the scarifiers.

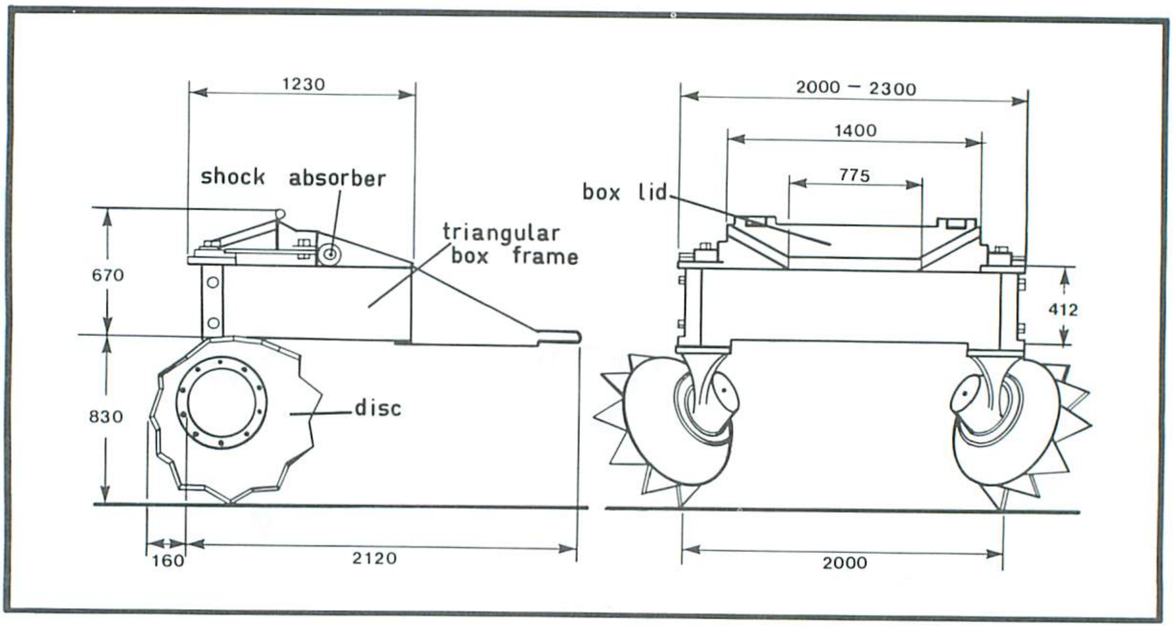



Figure 5. Major components and dimensions (mm) of the TTS-35. (Adapted from Friberg [1975]).

a 'Bräcke' type hitch (Fig. 6). The hitch allows the implement to be left behind while the winch is driven forward and free-spooled. When the slope or trouble spot has been passed, the implement can be winched in and the intervening area scarified.

The TTS was lifted from the ground for travelling long distances by means of a cable connected to the grapple arch (Fig. 7). The cylinders that raise and lower the grapple arch were used to raise the TTS. However, the TTS was unstable when raised and unbraced.

*Leno 77 Patch Scarifier*

The Leno model 77 Patch Scarifier produces two rows of scarified patches or scalps approximately 1.8 m apart. It consists of two mattock wheels mounted on a crossbeam. The crossbeam slides up and down a tubular towbar (Fig. 8). The towbar is connected to the skidder's butt plate by means of a universal joint and mounting plate (see Fig. 6).

Each mattock wheel has four pairs of scarifying tines. The tines are locked hydraulically into the scarifying position and create a scalp or patch as they are dragged through the soil by the prime mover. After a preset time has elapsed, the mattock wheel turns one quarter revolution until the next set of tines is locked into position. The timing, which is controlled by an enclosed hydraulic system, can be changed by a simple adjustment to obtain the desired patch length. An automatic overload releases the tines when an obstacle such as a boulder or stump is encountered.

Figure 6. Hitches used with the scarifiers.

Left: Bräcke hitch was used with both the Bräcke and TTS.

Right: Leno was mounted directly to skidder butt plate with a universal hitch.

Figure 7. TTS in transport position raised by grapple arch.

The Leno can be lifted off the ground by the prime mover's winch for maneuvering or travel. In the raised position, the crossbeam rests near the universal joint and is stabilized by a pin and clevis. In the scarification position, the crossbeam slides to the far end of the towbar.

The Leno was pulled by a Timberjack 350 Turbo cable skidder with a power rating of 82 kW (Fig. 9).

*Bräcke Cultivator (two-row)*

The Bräcke Cultivator, like the Leno, produces two rows of scarified patches or scalps spaced approximately 2 m apart. It consists of two machine box frames and a towbar mounted on a triangular drawbar frame (Fig. 10). Mounted within each machine frame is a rubber tire and a mattock wheel. A chain drive with an intermediate gearbox from the rubber tire rotates the mattock wheel. The Bräcke was connected to the butt plate of the prime mover through the 'Bräcke' hitch and tow chain system (see Fig. 6).

The mattock wheels rotate in the same direction as the tires, but more slowly. Therefore, each pair of tines drags through the ground until the rotation lifts it clear. This creates a series of scarified patches separated by undisturbed soil.

Patch length and the number per hectare can be varied by changing the gear ratio in the chain drive or the number of teeth from four to five per mattock wheel. The unit in the study had the standard 17-tooth sprocket setting and four teeth per mattock wheel.

The major components of the Bräcke are connected by means of pivot joints. This allows each part to move independently, both horizontally and vertically. The mattock wheels will pivot over or slide sideways when an obstacle is encountered. The pivot system also allows the mattock wheels to be lifted from the ground for transport while the Bräcke rides on its rubber tires. For transport, the mainline is connected to the liftchains and, through liftbows and liftstays, the mattocks are raised when winched in (Fig. 11). The mainline is connected to the towbar for scarification.

The Bräcke was pulled by the same International S-10 grapple skidder as the TTS.

## METHODS

The evaluation consisted of a pretreatment assessment of site conditions, work studies under operational conditions and a post-treatment assessment of the quantity and quality of site preparation produced as measured against a predetermined prescription.

The trials were run as a regular scarification operation on the basis of one 8-hour shift per day with minimal interference from the study crew. The skidder used to draw both the Bräcke and TTS was driven by the same operator. A different operator drove the skidder pulling the Leno.

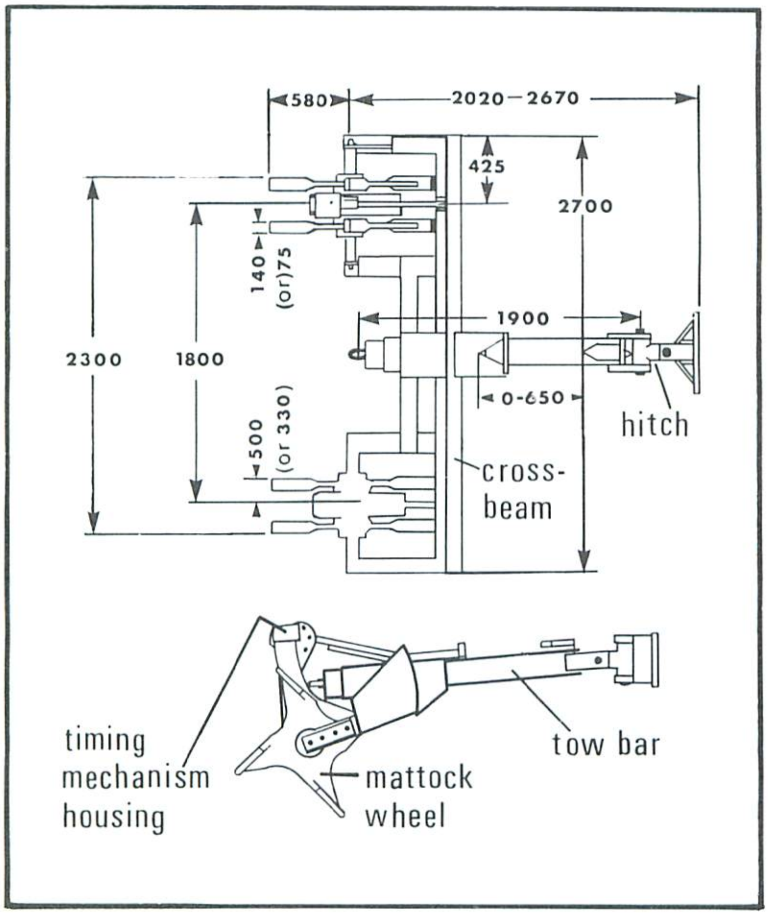



Figure 8. Major components and dimensions (mm) of the Leno 77. (Adapted from Friberg [1975]).

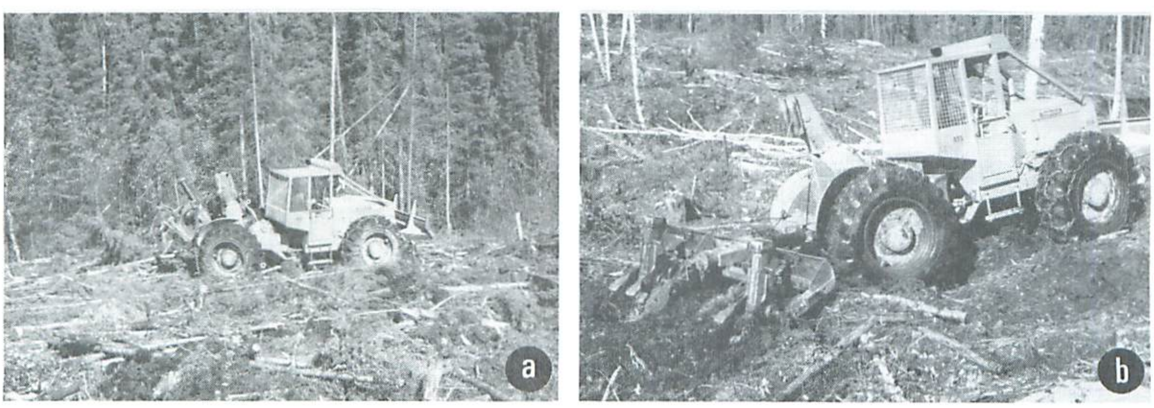
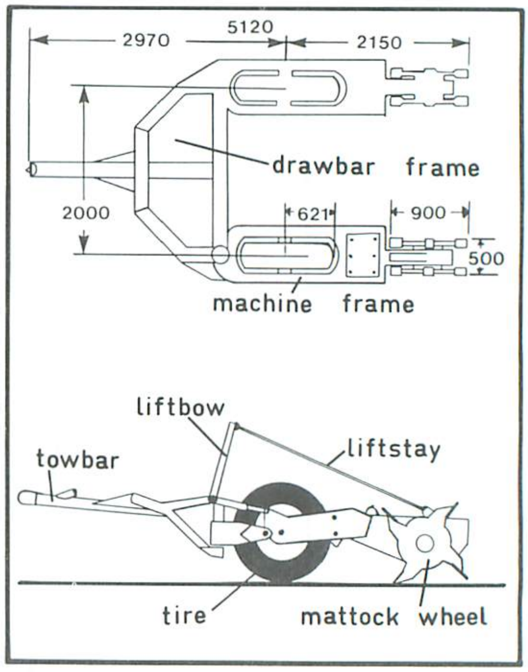



Figure 9. Working positions of the Leno.
a) Raised position for maneuvering or travelling.

b) Lowered scarifying position.

Figure 10. Major components and dimensions (mm) of the Bräcke cultivator. (Adapted from Friberg [1975]).





a) Forward scarifying position.

b) Bräcke let out when obstacle encountered or when turning, or maneuvering.

c) Raised mattocks for long distance travel.

Figure 11. Working positions of the Bräcke scarifier.

The FT blocks were scarified by means of a single-pass treatment. To achieve the best scarification possible, a double-pass treatment was applied in each of the TL blocks, except that approximately 27% of the Bräcke TL block received a single-pass treatment. This latter area consisted of a ridge with slopes of 10-30%.

The site preparation objective was to produce microsites for the operational planting of jack pine paperpot stock by using Pottiputki planting tubes.

### *Pretreatment Assessment*

Prior to scarification, three to five 0.2-ha sample plots were established in each block for both pretreatment and post-treatment assessments (see Fig. 1). Site factors likely to affect the passage of the implements and the quantity and quality of scarification achieved were assessed according to standard GLFRC methodology for equipment evaluation (see **APPENDICES** B and C).

### *Time Study*

Continuous time studies were carried out in each block to evaluate productivity, performance and operational characteristics of the three implements (see **APPENDICES** B and D). Average travel speed was determined by timing the equipment while passing through the sample plots. Fuel consumption was measured.

### *Post-treatment Assessment*

Plantability was assessed by using definitions provided by E.B. Eddy in consultation with the Ontario Ministry of Natural Resources (OMNR) and GLFRC. Receptive seedbed availability for jack pine was included in an assessment of ground disturbance (see **APPENDICES** B and E).

To assist in isolating the limiting effect of slash and in identifying quantifiable ranges of slash loadings that might limit site preparation, correlation coefficients were generated and stepwise linear regression was carried out on a subplot basis between post-treatment results and all pretreatment site variables with the exception of slope, which was not a limiting factor within the sample plots. Scatter plots were also examined. Where strong nonlinear trends were apparent, equations were developed by means of nonlinear regression.

Since an objective of the study was to evaluate the equipment under normal operating conditions, it has been assumed that the scarifiers were operated according to the prescription. Therefore, measurements used in the regression analyses have not been adjusted for possible discrepancies resulting from such factors as imprecise spacing control. (Comment on this factor is included under **RESULTS.**) Caution should be exercised in interpreting the correlation coefficients and linear regression equations provided, since the basic assumption of linearity may have been violated. In addition, the sample sizes were relatively small (15 or 25 subplots).

## RESULTS

### *Pretreatment Assessment*

Tables 1 to 5 summarize pretreatment site conditions. The total volume of slash was approximately equal on the two TTS blocks (Table 1). However, slash on the TL block was primarily a relatively thick mat of coniferous branches and tops. On the FT block the smaller branch-size coniferous material was generally absent but there was a higher proportion of larger-diameter hardwood.

Total slash volumes on the two Leno blocks were quite different. The TL block was again characterized by a relatively thick mat of coniferous branches and tops, while the FT block had a relatively lighter slash loading.

Total slash volumes on the Bräcke blocks were generally similar to those on the paired Leno blocks. The proportion of hardwood was somewhat higher on the FT block than on the TL block. However, the proportion of larger hardwood stems was not as great on the Bräcke FT block as on the TTS FT block.

Stumps were fewest, and largest in diameter, on the TTS FT block, whereas stumps were most frequent and smallest in diameter on the Leno TL block (Table 2). The highest average stump height was found on the TTS TL block. The numbers and sizes of stumps were generally similar on all other blocks. Conifer stump content relative to hardwood stump content was quite uniform except for the TTS TL block where the proportion of hardwood stumps was highest.

Ground roughness[3] (Anon. 1969) was quite similar for all blocks (Table 3). Surface boulders and stones occurred infrequently.

Mineral soil depths varied considerably (Table 3). The shallowest soils were found on the TTS TL block. Soil depths of less than 2.5 cm occurred over 43% of the block. Average soil depths were similarly shallow on the Leno and Bräcke FT blocks, although percentages in the shallowest class were much lower. Soils in the remaining blocks were generally much deeper. Stoniness within the top 30 cm of soil was greater on the Leno TL and Bräcke FT blocks. The remaining blocks had less stone and were generally similar in this regard (Table 3). The average "duff" depth to mineral soil was greatest on the Leno TL block but was generally similar across all blocks (Table 3).

For the most part, ground condition[4] (Anon. 1969) was rated class 2 in all blocks; in 10% of the sample area it was rated class 3 in the TTS, Leno and Bräcke TL blocks (Table 3). The inclusion of this class 3 condition reflects

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[3]Ground roughness is measured on a scale of 1 to 5 where class 1 is a very even ground surface and class 5 is a very rough ground surface. (after the system developed by Skogsarbeten, Sweden)

[4]Ground condition gives an indication of soil trafficability and is described on the basis of soil type, ground moisture and stone or boulder content. On a scale of 1 to 5, a Class 2 site is between very good and average with respect to trafficability. (after the system developed by Skogsarbeten, Sweden)

Table 1. Slash assessment.

| Treatment | | Pieces per 20 m of lineal tally | | Diameter | | | Depth | | Volume | | | | | Areal coverage (spatial distribution) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1-5 cm (No.) | >5 cm (No.) | Avg >5 cm (cm) | Range >5 cm (cm) | Avg length (m) | Avg (cm) | Range (cm) | Avg 1-5 cm (m$^3$/ha) | Range 1-5 cm (m$^3$/ha) | Avg >5 cm (m$^3$/ha) | Range >5 cm (m$^3$/ha) | Total (m$^3$/ha) | Conifer (%) | Hardwood (%) |
| | | X | X | X | | X | X | | X | | X | | X | | |
| TTS: | tree-length | 59.0* | 14.4* | 9.2* | 6 - 26 | 5.0* | 26.2* | 0 - 200 | 12.7* | 0 - 45.1 | 75.5 | 0 - 584.9 | 88.2 | 88.5 | 11.5 |
| | full-tree | 21.0* | 10.4* | 11.1* | 6 - 46 | 3.6* | 10.4* | 0 - 115 | 4.5* | 0 - 21.5 | 79.4 | 0 - 1387.0 | 83.9 | 69.8 | 30.2 |
| Leno: | tree-length | 51.2* | 12.7* | 9.7 | 6 - 24 | 3.5 | 18.0* | 0 - 95 | 11.0* | 0 - 79.4 | 72.7 | 0 - 666.4 | 83.7* | 92.9 | 7.1 |
| | full-tree | 21.4* | 9.0* | 9.8 | 6 - 26 | 3.7 | 8.6* | 0 - 75 | 4.6* | 0 - 21.5 | 53.4 | 0 - 772.5 | 58.0* | 87.4 | 12.6 |
| Bräcke: | tree-length | 49.6* | 14.1* | 9.6* | 6 - 24 | 3.9 | 20.2* | 0 - 175 | 10.7* | 0 - 73.0 | 76.9* | 0 - 560.2 | 87.6* | 93.6 | 6.4 |
| | full-tree | 25.5* | 7.9* | 10.8* | 6 - 28 | 4.0 | 10.2* | 0 - 140 | 5.5* | 0 - 25.7 | 57.4* | 0 - 567.0 | 62.9* | 79.0 | 21.0 |

* denotes a significant difference (p = .05) between TL and FT values within each treatment for values in columns denoted (X) only.



Table 2. Stump assessment.

| Treatment | | Frequency (No./ha) | Height | | Diameter | | Species Distribution | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Avg (cm) | Range (cm) | Avg (cm) | Range (cm) | Jack pine (%) | Black spruce (%) | White birch (%) | Poplar (%) | Other or unknown (%) |
| | | X | X | | X | | | | | | |
| TTS: | tree-length | 1600 | 38.2* | 12 - 86 | 19.0* | 6 - 34 | 30.3 | 55.5 | 8.0 | 0.5 | 5.7 |
| | full-tree | 1430 | 31.6* | 10 - 86 | 21.5* | 4 - 46 | 26.6 | 57.1 | 4.8 | 0.2 | 11.3 |
| Leno: | tree-length | 1718 | 33.7* | 12 - 80 | 17.4 | 4 - 34 | 31.7 | 57.4 | 1.9 | 0.5 | 6.7 |
| | full-tree | 1683 | 30.8* | 6 - 80 | 18.5 | 6 - 42 | 38.2 | 49.8 | 2.0 | 0.0 | 10.0 |
| Bräcke: | tree-length | 1645 | 30.5 | 8 - 72 | 19.6 | 6 - 38 | 34.0 | 53.0 | 4.4 | 0.0 | 8.6 |
| | full-tree | 1710 | 32.3 | 12 - 98 | 19.7 | 6 - 38 | 30.2 | 53.4 | 3.8 | 0.0 | 12.6 |

* denotes a significant (but not strong) difference (p = .05) between TL and FT values within each treatment for values in columns denoted (X) only.

Table 3. Soil, ground moisture, ground condition and ground roughness assessments.

| Treatment | | Soil depth 0-<2.5 cm (%) | 2.5-<12.5 cm (%) | 12.5-<30 cm (%) | 30 cm+ (%) | Avg depth of mineral soil[a] (cm) | Avg depth to mineral soil (duff) (cm) | Stoniness[b] (%) | Soil texture[c] | Ground moisture[d] | Ground condition[e] | Ground roughness[e] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | X | X | | | | | |
| TTS: | tree-length | 42.9 | 7.7 | 14.0 | 35.6 | 15.7* | 11.3 | 19.7 | silty sand | fresh, fresh-moist (dry-fresh, wet) | 2(3) | 3(2) |
| | full-tree | 7.6 | 9.4 | 14.4 | 68.6 | 27.3* | 10.5 | 18.8 | silty fine sand | fresh | 2 | 2(3) |
| Leno: | tree-length | 18.3 | 14.0 | 20.0 | 47.7 | 21.4 | 13.7* | 32.0 | silty fine sand | fresh | 2(3) | 3(2) |
| | full-tree | 33.7 | 15.7 | 12.3 | 38.3 | 16.6 | 10.7* | 19.3 | silty fine sand | fresh (fresh-moist, moist-wet) | 2 | 3(2) |
| Bräcke: | tree-length | 16.2 | 13.2 | 12.2 | 58.4 | 23.6* | 10.3 | 23.6 | silty fine sand | fresh (fresh-moist, moist-wet) | 2(3) | 3(2) |
| | full-tree | 31.6 | 16.0 | 15.0 | 37.4 | 17.0* | 11.7 | 26.2 | silty fine sand | fresh | 2 | 3(2) |

[a]Soil depth >35 cm was recorded as 35 cm. Average is for a zone from 0 to 35 cm.

[b]A steel rod was shoved into the soil every 2 m along transects in each subplot. If a stone or boulder was encountered within the first 30 cm of mineral soil, it was recorded and a % occurrence figure was provided for each subplot.

[c]According to Belisle's (1980) field manual for describing soils.

[d]Categories within parentheses account for ≥10% of the sample area.

[e]Categories within parentheses account for ≥10% of the sample area. Ground roughness includes stumps as well as surface rocks, boulders, overturned stumps and depressions.

*denotes a significant difference (p = .05) between TL and FT values within each treatment for values in columns denoted (X) only.

the presence of pockets of moist to wet ground at the time of equipment operation.

The terrain within the sample plots was generally flat to gently pitching. Except in the Bräcke FT block, > 75% of the travel of the scarifiers within the plots was on slopes of -5 to +5% (Table 4). On that block only 52% of travel was on such gentle slopes.

Residual tree stocking was highest on the TTS FT block and on parts of the TTS TL and Bräcke FT blocks (Table 5). On the latter, stocking was significantly higher than on the Bräcke TL block. However, the relative numbers in each case were low. It is believed that the values tend to underestimate the average conditions in these blocks. Residual brush and minor vegetation occurred infrequently and had no significant impact on equipment performance.

*Time Study*

Each block took from 1½ to 4 days to treat depending upon delays and productivity. Double passing most of the TL blocks resulted in a much longer trial in these areas. **APPENDIX D** gives a breakdown of the total scheduled time for each block into shift-level time elements including major delays and repairs (>15 min). Time elements are defined according to Bérard et al. (1968). Machine time formulae are also listed in **APPENDIX D.**

Table 6 provides a summary of the elemental times within the productive machine hours (PMH) of the continuous time study, as well as the average number of minutes per hectare for each time element in the six areas. Elemental times are defined in **APPENDIX D.** The effective productive time (EPT) ranged from 53 to 68% of the PMH. On the Bräcke and TTS operations, part of this time was devoted to winching in the implement.

Maneuvering, or turning between passes, took from 13% of the time with the Leno on the TL area to 21% of the time with the Bräcke on the FT site.

A further breakdown of maneuver time into types of turns and average times per turn is presented in Table 7. Average times per turn were similar with all three machines despite the Leno's advantages of being shorter and readily raised from the ground. However, the operator was slow with the winch, often taking up to 25 cmin to raise the Leno. The frequency of turns was highest with the Leno on the FT site. This was because of a shorter distance per pass and the operator's tendency to cover small untreated patches in a run-by-run pattern. The Bräcke on the FT site also had a high frequency of turns because of the irregular topography. This produced a high percentage of total time in 'maneuver', and a shorter period of EPT before another turn.

'Obstacle' times (i.e., delays caused by the implement encountering an obstruction) were not frequent (Table 8), and almost nonexistent with the Leno. Delays of the obstacle-implement type occurred more frequently with the TTS but still fewer than three times per ha.

Table 4. Slope assessment[a].

| Treatment | | -25 to -11 (%) | -10 to -6 (%) | -5 to -1 (%) | 0 to +5 (%) | +6 to +10 (%) | +11 to +25 (%) | Total (%) | No. of 20 m segments sampled[b] |
|---|---|---|---|---|---|---|---|---|---|
| TTS: | tree-length | 0 | 1 | 43 | 52 | 2 | 2 | 100 | 109 |
| | full-tree | 1 | 1 | 34 | 50 | 6 | 1 | 100 | 100 |
| Leno: | tree-length | 3 | 3 | 37 | 39 | 14 | 4 | 100 | 145 |
| | full-tree | 3 | 2 | 37 | 52 | 3 | 3 | 100 | 90 |
| Bräcke: | tree-length | 0 | 2 | 32 | 56 | 9 | 0 | 100 | 205 |
| | full-tree | 8 | 14 | 24 | 28 | 16 | 10 | 100 | 135 |

[a]Percentage of 20 m long passes of implements within six classes of slope. Slopes refer to forward direction of travel.

[b]The number of segments in the TL blocks is higher than in the FT blocks, because of double passing of the implements. The TTS TL block had three plots with double passing while the FT block had five plots with single passing.

Table 5. Residual stocking assessment.

| Treatment | | Density[a] (no./ha) | Stocking[b] (%) | Avg DBH (cm) | DBH range (cm) |
|---|---|---|---|---|---|
| TTS: | tree-length | 57.5 | 1.7 | 11.3 | 6 - 14 |
| | full-tree | 85.0 | 2.2 | 18.2 | 6 - 34 |
| Leno: | tree-length | 25.0 | 0.7 | 9.0 | 6 - 12 |
| | full-tree | 0.0 | 0.0 | - | - |
| Bräcke: | tree-length | 15.0 | 0.2* | 10.5 | 6 - 14 |
| | full-tree | 55.0 | 1.8* | 16.2 | 8 - 20 |

[a]Stems >5 cm DBH and >1.5 m in height.
[b]Stocking based on 4-$m^2$ quadrats.
*Denotes a significant difference ($p = .05$) between TL and FT values within each treatment.

The two main obstacles encountered by the TTS were stumps and residuals. For a delay to occur, each disc had to snag an obstruction at the same moment. As there was no way to raise the TTS with the Bräcke hitch mounting, freeing the implement once it was stuck was difficult; the operator had to turn the skidder around while free-spooling, then push at the stump or disc to free it.

The Bräcke was not severely affected by obstacles. The tines would periodically hook under a boulder or stump, causing the prime mover's wheels to spin. However, the implement came free easily when winched in after forward free-spooling. The longest delays with the Bräcke were caused by residuals, windfalls, or logs falling across the mattock wheels simultaneously, so that the operator was required to remove the obstruction manually. Delays caused by these obstacles are included in Table 8 to illustrate the total time lost as a result of all obstacles.

Delays caused by obstacles were more frequent than those affecting the implements. Positive slope was the major obstacle on all blocks. The International S-10 pulling the TTS was the machine most sensitive to positive slopes. It accounted for over 7 minutes' delay per hectare, and such delays occurred more than 17 times/ha on each block. The same skidder was also affected by slope when pulling the Bräcke, but less so than with the TTS.

On the Bräcke TL site, there was a high frequency of positive slope 'obstacle' time because a long, steep slope made up 2.3 ha (27%) of the total scarified area. The slope was treated and the scarification operation on the slope was timed separately from that on the flat area. Delays on the slope comprised 79% of the total 'obstacle-prime mover' time for the entire TL site despite the fact that it accounted for only 27% of the area and was being treated in a single-pass operation. On a time-per-area basis, delays in the

Table 6. Summary of time elements.

| Treatment | | Observed productive time | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Effective productive time | | | | Travel | | Maneuver (turn) | | Obstacle | | | | Sub-total | Delay[a] | | Total | |
| | | Scarify | | Forward | Winching | | | | | Implement | | Prime Mover | | | | | | |
| | | (%) | (min/ha) | (%) | (%) | (%) | (min/ha) | (%) | (min/ha) | (%) | (min/ha) | (%) | (min/ha) | (%) | (%) | (min/ha) | (%) | (min/ha) |
| TTS: | tree-length | 54.7 | 56.5 | (84) | (16) | 1.9 | 1.9 | 17.1 | 17.7 | 3.2 | 3.3 | 12.0 | 12.4 | 88.9 | 11.1 | 11.5 | 100 | 103.3 |
| | full-tree | 53.3 | 49.3 | (82) | (18) | 2.9 | 2.7 | 13.5 | 12.4 | 3.1 | 2.8 | 15.7 | 14.5 | 88.5 | 11.5 | 10.6 | 100 | 92.4 |
| Leno: | tree-length | 67.8 | 88.7 | (100) | - | 1.4 | 1.8 | 13.0 | 17.0 | 0.2 | 0.2 | 4.9 | 6.5 | 87.3 | 12.7 | 16.6 | 100 | 130.8 |
| | full-tree | 54.9 | 80.9 | (100) | - | 2.8 | 4.2 | 17.2 | 25.4 | <0.1 | <0.1 | 7.4 | 10.9 | 82.3 | 17.7 | 26.1 | 100 | 147.5 |
| Bräcke: | tree-length | 58.5 | 68.3 | (87) | (13) | 2.2 | 2.6 | 14.6 | 17.1 | 0.5 | 0.6 | 10.8 | 12.6 | 86.6 | 13.4 | 15.7 | 100 | 116.9 |
| | full-tree | 54.9 | 46.4 | (87) | (13) | 3.5 | 3.0 | 21.4 | 18.1 | 0.3 | 0.3 | 8.2 | 7.0 | 88.3 | 11.7 | 9.9 | 100 | 84.5 |

[a]Only delays between 0.05 min and 15 min are included here. Those less than 0.05 min were included in the element in which they occurred, while those over 15 min were not considered productive time and were therefore excluded from the sample.

Table 7. Breakdown of maneuver times.

| Treatment | | Type of turn | | | No. of turns per hectare | | | | Time per turn | | | | Avg duration of effective productive time between turns |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Run-by-run (%) | Lands pattern (%) | Broken pattern (%) | Run-by-run (No./ha) | Lands pattern (No./ha) | Broken pattern (No./ha) | Total (No./ha) | Run-by-run (cmin) | Lands pattern (cmin) | Broken pattern (cmin) | Avg (cmin) | (cmin) |
| TTS: | tree-length | 44 | 1 | 55 | 6.5 | 0.2 | 8.2 | 14.9 | 119 | 93 | 118 | 119 | 378 |
| | full-tree | 29 | 24 | 47 | 3.1 | 2.6 | 5.0 | 10.7 | 93 | 77 | 151 | 116 | 463 |
| Leno: | tree-length | 45 | 21 | 34 | 8.0 | 3.8 | 6.0 | 17.8 | 114 | 60 | 93 | 95 | 498 |
| | full-tree | 79 | - | 21 | 17.6 | - | 4.7 | 22.3 | 110 | - | 130 | 114 | 363 |
| Bräcke: | tree-length | 28 | 46 | 26 | 5.0 | 8.4 | 4.8 | 18.3 | 112 | 88 | 83 | 93 | 373 |
| | full-tree | 79 | - | 21 | 13.9 | - | 3.7 | 17.6 | 102 | - | 103 | 102 | 263 |

Table 8. Summary of obstacle time. (Delays for cleaning debris from implement are included.)

| Treatment | | Prime Mover | | | | | | | | | | Implement | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Positive slope | Negative slope | Side slope | Stump | Residual windfall | Boulder bedrock | Wet ground | Debris | Unknown | Total | Stump | Debris | Boulder bedrock | Residual windfall | Clean implement | Total |
| TTS: | tree-length (no./ha) | 20.0 | 0.8 | 0.2 | 1.3 | 3.3 | 1.0 | 3.0 | 0.5 | 0.5 | 30.6 | 0.8 | - | 0.2 | 1.4 | - | 2.4 |
| | (cmin/ha) | 773 | 40 | 9 | 113 | 152 | 29 | 96 | 7 | 20 | 1249 | 38 | - | 5 | 290 | - | 333 |
| | full-tree (no./ha) | 17.9 | 0.7 | 0.5 | 2.2 | 5.7 | 0.9 | 2.9 | 0.3 | 0.9 | 32.1 | 1.6 | - | - | 1.0 | - | 2.6 |
| | (cmin/ha) | 740 | 28 | 18 | 115 | 321 | 35 | 151 | 10 | 31 | 1454 | 239 | - | - | 45 | - | 284 |
| Leno: | tree-length (no./ha) | 8.3 | 0.8 | 0.8 | 1.6 | 0.5 | 0.3 | 0.2 | 0.8 | - | 13.4 | - | 0.2 | - | - | 0.2 | 0.3 |
| | (cmin/ha) | 468 | 15 | 28 | 90 | 7 | 14 | 2 | 26 | - | 649 | - | 23 | - | - | 31 | 54 |
| | full-tree (no./ha) | 5.7 | - | 0.2 | 1.8 | 1.3 | 1.1 | 0.2 | 0.3 | - | 10.5 | - | - | - | 0.2 | 0.2 | 0.3 |
| | (cmin/ha) | 617 | - | 2 | 117 | 90 | 207 | 11 | 43 | - | 1086 | - | - | - | 3 | 26 | 29 |
| Bräcke: | tree-length (no./ha) | 24.6 | 1.4 | 0.2 | 0.7 | 0.5 | 0.5 | 1.4 | 0.9 | - | 30.2 | 0.1 | - | 0.7 | 0.2 | 1.3 | 2.3 |
| | (cmin/ha) | 1005[a] | 71 | 22 | 63 | 22 | 16 | 32 | 30 | - | 1262 | 1 | - | 22 | 40 | 393 | 456 |
| | full-tree (no./ha) | 16.3 | 0.3 | - | 0.4 | 0.3 | 0.4 | 1.1 | - | - | 18.8 | - | - | - | 0.6 | 0.6 | 1.1 |
| | (cmin/ha) | 590 | 14 | - | 8 | 28 | 15 | 37 | - | - | 693 | - | - | - | 28 | 145 | 173 |

[a]High value result of long, steep slope comprising 27% of treated area. Frequency of "positive slope" obstacles was 79 times/ha on this area but only 12 times/ha on remainder of block.

'obstacle-prime mover' category accounted for 37 min/ha on the slope and 4 min/ ha on the flat area. Seventy percent of the total 'obstacle' delays affecting the prime mover, and 80% of the positive slope 'obstacle' delays occurred on the slope (Table 8).

The average lengths of delay per 'obstacle-prime mover' caused by positive slope were 40, 78 and 39 cmin for the TTS, Leno and Bräcke, respectively, for the TL and FT blocks combined. Although delays were fewer with the Leno, there was a longer delay before scarification was resumed.

Stumps and boulders were the second most frequent cause of delays in the 'obstacle-prime mover' category when the Leno was used, and there was a longer period during which the machine was stuck under such circumstances. Larger stumps also caused delays on the TTS operation.

Birch and trembling aspen *(Populus tremuloides* Michx.) residuals were greatest in number on the two TTS areas and therefore contributed to the 'obstacle-prime mover' delays. Wet spots were also numerous on the TTS FT and TL sites.

Minor 'delay' ( $< 15$ min) times ranged from 11.1 to 17.7% of the productive machine time (Table 9). Delays for personal reasons and for supervision made up the main portion of 'delay' time with the TTS and Bräcke operations. Service delays were longer with the Leno because the trials involved a greater number of shifts owing to low utilization, and the implement was leaking hydraulic oil which had to be replenished periodically. The Leno also had to have the hydraulically controlled mattock wheel timing adjusted because hydraulic oil changes viscosity with changing temperature. As previously noted, the Bräcke was more prone to picking up a log or tree length which the operator would sometimes have to remove manually.

Minor breakdowns were few on the skidders. However, most repair time was used to fix the mainline which broke at the place of attachment to the implement or became twisted in the winch. Cable repairs are charged against the implement since cables are used to lift up or winch-in the scarifier.

The productivity of the three machines ranged from 0.41 ha/PMH with the Leno on the FT site to 0.71 ha/PMH with the Bräcke on the FT site (Table 10). The productivity was expected to be low on the TL cut areas since the TTS and Leno made double passes on nearly 100% of the area.

The Bräcke's productivity was only 0.28 ha/PMH on the slope section of the TL site. On the flat section, the productivity was 0.73 ha/PMH despite double passing.

When only EPT is used, the productivity increases to 1.23 and 1.29 ha/hr for the TTS and Bräcke, respectively, on the FT sites. The Leno's productivity still remains below 0.75 ha/hr, an indication of lower average travel speed for the entire block.

Measured travel speeds are presented in Table 10. These speeds were recorded within the sample plots only, and for passes without delays. On all blocks, the operators kept the skidders in first gear.

Table 9. Breakdown of minor (<15 min) delays within productive machine time.

| Treatment | | Personal | Supervision and operator reconnaissance | Removal of debris from prime mover | Engine stall | Preparation of implement for scarification or travel | Adjustment of implement | Removal of debris from implement | Breakdown | | Service | | Warm up | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Prime mover | Imple-ment | Prime mover | Imple-ment | | |
| TTS: | tree-length (cmin/ha) | 194 | 255 | - | - | 234 | - | - | - | 256 | 103 | 103 | - | 1146 |
| | (%) | 17 | 22 | - | - | 20 | - | - | - | 23 | 9 | 9 | - | 100 |
| | full-tree (cmin/ha) | 456 | 240 | - | - | 11 | - | - | - | 136 | 102 | 102 | 18 | 1065 |
| | (%) | 43 | 22 | - | - | 1 | - | - | - | 13 | 10 | 10 | 1 | 100 |
| Leno: | tree-length (cmin/ha) | 404 | 92 | - | 6 | 299 | 262 | 31 | 35 | 34 | 256 | 228 | 33 | 1660 |
| | (%) | 24 | 6 | - | 0.3 | 18 | 16 | 2 | 2 | 1 | 15 | 14 | 2 | 100 |
| | full-tree (cmin/ha) | 742 | 71 | - | - | 42 | 358 | 27 | - | 409 | 394 | 529 | 39 | 2610 |
| | (%) | 28 | 3 | - | - | 1 | 14 | 1 | - | 16 | 15 | 20 | 2 | 100 |
| Bräcke: | tree-length (cmin/ha) | 332 | 514 | - | - | 81 | - | 183 | - | 127 | 118 | 200 | 15 | 1569 |
| | (%) | 21 | 33 | - | - | 5 | - | 12 | - | 8 | 7 | 13 | 1 | 100 |
| | full-tree (cmin/ha) | 5 | 215 | 15 | - | 297 | - | 152 | - | 231 | - | 73 | - | 988 |
| | (%) | 1 | 22 | 2 | - | 30 | - | 15 | - | 23 | - | 7 | - | 100 |

Table 10. Productivity summary.

| Treatment | | Total PMH (hr) | Area (ha) | Productivity per PMH (ha/hr) | Productivity per effective productive time (EPT) (ha/hr) | Travel speeds[a] (km/hr) | Fuel consumption (L/engine hr) |
|---|---|---|---|---|---|---|---|
| TTS: | tree-length | 10.85 | 6.3 | 0.58 | 1.06 | 3.7 | 12.7 |
| | full-tree | 8.93 | 5.8 | 0.65 | 1.23 | 3.9 | 13.8 |
| Leno: | tree-length | 13.36 | 6.1 | 0.46 | 0.68 | 3.6 | 17.0 |
| | full-tree | 15.19 | 6.2 | 0.41 | 0.74 | 3.8 | 15.9 |
| Bräcke: | tree-length | 16.61 | 8.5 | 0.51 | 0.88 | 3.9 | 13.3 |
| | full-tree | 10.14 | 7.2 | 0.71 | 1.29 | 4.5 | 11.5 |

[a]Travel speeds were recorded in the plots and include those without stops.

The average fuel consumption was 13.2, 16.4 and 12.6 L/hr for the TTS, Leno and Bräcke, respectively, on the TL and FT sites combined.

*Post-treatment Assessment*

Table 11 summarizes the number of plantable and marginally plantable planting spots. A total of 2,500 spots/ha represents a potential stocking of 100%. Table 12 describes the microsite conditions of the planting spots, and also provides an indication of the site factors contributing to an assessment of the planting spot as unplantable. The quality of soil disturbance at the point of planting spot selection only is described in Table 13. Table 14 describes overall soil disturbance including the creation of receptive seedbed by the implement, prime mover and/or logging activity. Disturbance of plantable soil (hereinafter abbreviated to 'plantable disturbance') is synonymous with the creation of a receptive seedbed. Soil disturbance classes are listed in **APPENDIX E**. Table 15 describes the overall distribution and size of individual patches of disturbance. Table 16 shows the dimensions of the scarified scalps/furrows and soil disturbance within the scalps/furrows for the FT blocks only.

Though not included in the analyses, adjustments for discrepancies in plantability as a result of inter-row or within-row spacing have been made for the FT blocks only (Table 17). Because of overlapping furrows and heavy slash conditions, similar measurements and adjustments were not possible for the TL blocks. As a result of the adjustment, the change in plantability was greatest for the TTS, and accounted for a 16% increase in stocking. This was a result of the wider than optimum inter-row spacing which may have been a function of the higher incidence of residuals. The actual number of furrows/scalps as a percentage of the potential output was highest for the TTS.

TTS Disc Trencher: The TTS produced approximately double the number of plantable spots and about the same number of marginal spots on the FT as compared with the TL block (Table 11). The occurrence of unplantable spots as a result of impenetrable conditions was higher on the TL

Table 11. Assessment of plantability[a].

| Treatment | | Plantable spots (%) | Plantable spots (No./ha) | Marginally plantable spots (%) | Marginally plantable spots (No./ha) | Plantable + marginally plantable spots (%) | Plantable + marginally plantable spots (No./ha) | Unplantable spots (%) | Unplantable spots (No./ha) | Total (%) | Total (No./ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TTS: | tree-length | 26.3 | 658 | 10.0 | 250 | 36.3 | 908* | 63.7 | 1592 | 100.0 | 2,500 |
| | full-tree | 54.2 | 1,355 | 11.0 | 275 | 65.2 | 1,630* | 34.8 | 870 | 100.0 | 2,500 |
| Leno: | tree-length | 36.0 | 900 | 14.3 | 358 | 50.3 | 1,258 | 49.7 | 1242 | 100.0 | 2,500 |
| | full-tree | 47.3 | 1,183 | 12.4 | 310 | 59.7 | 1,493 | 40.3 | 1007 | 100.0 | 2,500 |
| Bräcke: | tree-length | 30.4 | 760 | 28.2 | 705 | 58.6 | 1,465* | 41.4 | 1035 | 100.0 | 2,500 |
| | full-tree | 64.2 | 1,605 | 17.8 | 445 | 82.0 | 2,050* | 18.0 | 450 | 100.0 | 2,500 |

[a] Based on 4 $m^2$ quadrats. Not adjusted for spacing. See Table 17 for effect of spacing.

* Denotes a significant difference (p = .05) between TL and FT values within each treatment for values in this column only.

Table 12. Microsite conditions on selected planting spots.

| Treatment | | Soil penetration | | | | Debris | | | Duff depth | | | Vegetative competition | | | Microrelief | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Penetrable[a] (%) | Rock[b] (%) | Debris[b] (%) | Water[b] (%) | None[a] (%) | Light[c] (%) | Heavy[b] (%) | < 1.5 cm[a] (%) | 1.5 - 3 cm[c] (%) | > 3 cm[b] (%) | None[a] (%) | Herbaceous[c] (%) | Woody[b] (%) | Level (%) | Raised (%) | Side (%) | Hollow (%) |
| TTS: | tree-length | 77.4 | 13.3 | 4.3 | 5.0 | 64.0 | 30.0 | 6.0 | 40.0 | 8.3 | 51.7 | 98.7 | 0.0 | 1.3 | 44.0 | 6.3 | 12.0 | 37.7 |
| | full-tree | 96.6 | 1.8 | 0.2 | 1.4 | 86.8 | 13.0 | 0.2 | 65.4 | 6.2 | 28.4 | 93.4 | 0.0 | 6.6 | 34.6 | 3.4 | 15.0 | 47.0 |
| Leno: | tree-length | 89.3 | 3.0 | 1.7 | 6.0 | 72.3 | 26.7 | 1.0 | 50.3 | 7.7 | 42.0 | 100.0 | 0.0 | 0.0 | 44.0 | 1.7 | 18.0 | 36.3 |
| | full-tree | 90.7 | 7.3 | 1.0 | 1.0 | 89.0 | 10.3 | 0.7 | 56.0 | 7.3 | 36.7 | 100.0 | 0.0 | 0.0 | 40.0 | 1.3 | 14.7 | 44.0 |
| Bräcke: | tree-length | 95.8 | 0.2 | 0.2 | 3.8 | 61.0 | 30.8 | 8.2 | 50.2 | 13.6 | 36.2 | 99.8 | 0.0 | 0.2 | 57.2 | 1.8 | 26.0 | 15.0 |
| | full-tree | 99.4 | 0.6 | 0.0 | 0.0 | 89.8 | 9.8 | 0.4 | 70.0 | 12.2 | 17.8 | 99.8 | 0.2 | 0.0 | 55.0 | 0.8 | 25.0 | 19.2 |

[a]Plantable condition

[b]Unplantable condition

[c]Marginally plantable condition

Table 15. Distribution and area of plantable and marginally plantable soil disturbance.

| Treatment | | Frequency[a] (%) | Avg area[b] $(cm)^2$ |
|---|---|---|---|
| TTS: | tree-length | 39.4 | 2380 |
| | full-tree | 67.6 | 3348 |
| Leno: | tree-length | 53.4 | 3664 |
| | full-tree | 61.4 | 2452 |
| Bräcke: | tree-length | 70.4 | 2064 |
| | full-tree | 86.8 | 2796 |

[a]Percentage of 4-$m^2$ quadrats with $\geq 400$ $cm^2$ plantable or marginally plantable soil disturbance.

[b]Average area of above disturbance classes in quadrats with $\geq 400$ $cm^2$ of disturbance.

higher on the FT block but not significantly so (p = .05) (Table 11). Soil penetration conditions were similar on both blocks. Wetter conditions on the TL block offset rockier conditions on the FT block (Table 12). A slightly higher percentage of the planting spots fell within the higher-quality, plantable, soil disturbance classes on the FT block (Table 13).

Implement-caused plantable (receptive seedbed) disturbance was similar on both blocks (Table 14). There were 20% fewer patches of desirable disturbance on the TL block, but the patches tended to be larger (Table 15).

On the FT block, the scalps averaged 7,200 $cm^2$ of subsurface soil disturbance (Table 16). The total plantable and marginally plantable soil disturbance created by the implement within the scalps was 35% of the subsurface area. This relatively low percentage indicates that although the mattock wheel tines were disturbing large areas of the duff overburden, they were not effectively penetrating the duff layer.

On the TL block, in the absence of moist-to-wet ground conditions, there was a negative relationship between plantability and the volume of small slash and soil depth ($R^2$ = 0.79) (Fig. 12). Similarly, with the effect of moist-to-wet ground conditions removed, there was a relatively strong nonlinear relationship (S = 0.64) between the volume of small slash and receptive seedbed (Fig. 13).

On the FT block, if soil depth and the volume of small slash are plotted against plantability (Fig. 14), it can be seen that, where soil depth is not a limiting factor (average depth $>10$ cm), there is a relatively strong relationship ($R^2$ = 0.71) between plantability and the volume of small slash. Significant correlations between receptive seedbed and a) soil depth (R = 0.62) and b) stump diameter (R = 0.60) were evident. However, from the available data

Table 16. Dimensions of furrows/scalps and amount of plantable and marginally plantable soil disturbance within furrows/scalps[a].

| Treatment | Overall | | | Subsurface[b] | | | Plantable soil disturbance | | Marginally plantable soil disturbance | | Plantable + marginally plantable soil disturbance | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Length (cm) | Width (cm) | Area ($cm^2$) | Length (cm) | Width (cm) | Area ($cm^2$) | Total area ($cm^2$) | Percentage of subsurface area (%) | Total area ($cm^2$) | Percentage of subsurface area (%) | Total area ($cm^2$) | Percentage of subsurface area (%) |
| TTS: full-tree | 200 | 93 | 18,600 | 113 | 36 | 4068 | 2640 | 64.9 | 792 | 19.5 | 3432 | 84.4 |
| Leno: full-tree | 175 | 65 | 11,375 | 112 | 64 | 7168 | 1840 | 25.7 | 692 | 9.6 | 2532 | 35.3 |
| Bräcke: full-tree | 181 | 74 | 13,394 | 78 | 45 | 3510 | 1344 | 38.3 | 584 | 16.7 | 1928 | 55.0 |

[a]Area on which implement has broken through duff and/or soil surface.

[b]Hollowed-out depression.

Table 17. Adjustment of plantability.

| Treatment | Actual and potential output | | | | | | | Adjusted output | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spacing | | No. of furrows/scalps | | | Total plantability | | Spacing adjustment | | | Total plantability[c] | |
| | Inter-row (no. of rows/100-m wide sample) | Within-row (no./100 m of lineal travel)[a] | Potential[b] (no./ha) | Actual (no./ha) | Actual as % of potential (%) | Planting spots (no./ha) | Stocking (%) | Inter-row (no. of rows/ 100-m-wide-sample) | Within-row (no./100 m of lineal travel)[a] | No. of furrows/scalps (no./ha) | Planting spots (no./ha) | Stocking (%) |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| TTS: full-tree | 40.0 | 50.0 | 2000 | 1980 | 99 | 1630 | 65.2 | 50.0 | 50.0 | 2500 | 2038 | 81.5 |
| Leno: full-tree | 53.5 | 44.0 | 2354 | 2075 | 88 | 1493 | 59.7 | 50.0 | 50.0 | 2500 | 1586 | 63.3 |
| Bräcke: full-tree | 45.0 | 48.6 | 2187 | 2065 | 94 | 2050 | 82.0 | 51.5 | 48.6 | 2500 | 2333 | 93.0 |

[a]No. of contiguous 2-m-long segments within the rows for the TTS and no. of scalps for the Leno and Bräcke.

[b]Potential = column 1 x column 2.

[c]Adjusted total plantability = column 10 x $\frac{\text{column 6}}{\text{column 3}}$

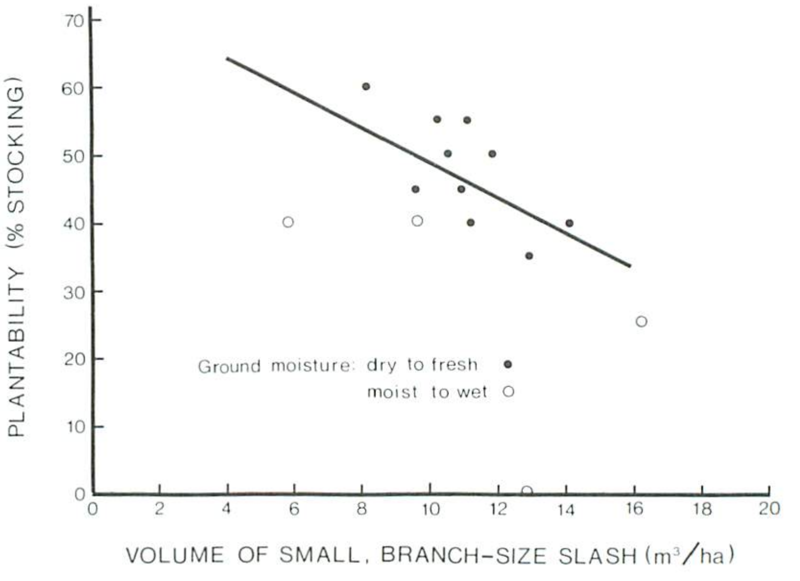


Figure 12. Leno TL block. Stocking of 4-$m^2$ quadrats with plantable and marginally plantable planting spots *vs* volume of slash pieces 1-5 cm in diameter. The line shown is from the equation:

Plantability (%) = 60.17-(2.94 x vol. of small pieces of slash ($m^3$/ha)) + (0.19 x soil depth (cm))

where $R^2$ is 0.79. Soil depth is assumed to be 21.4 cm (average for block). For soils >30 cm deep, use 30 cm in the equation.

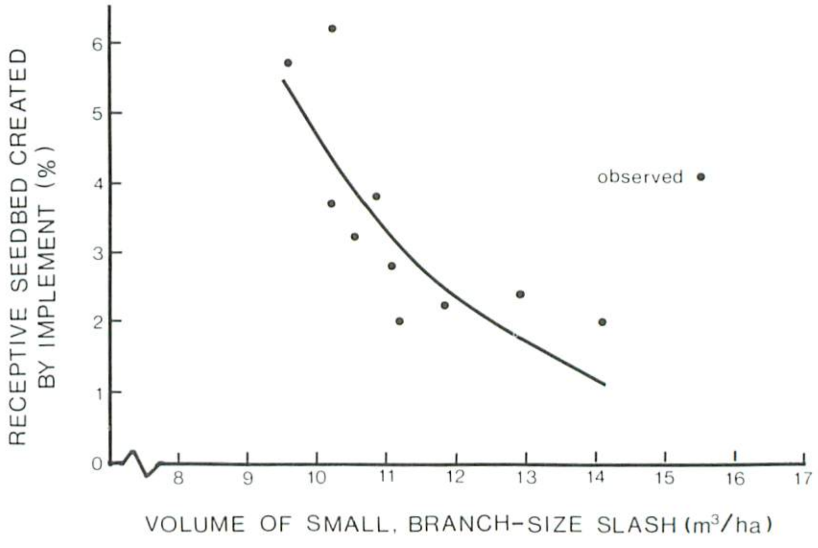


Figure 13. Leno TL block. Plot of receptive seedbed created by implement *vs* volume of slash pieces 1-5 cm in diameter. Derived through non-linear regression using the equation,

Receptive Seedbed (%) = 160.93e (0.35 x vol. of small pieces of slash ($m^3$/ha))

Does not include subplots with moist to wet ground moisture conditions. Coefficient of determination (S) is 0.64.

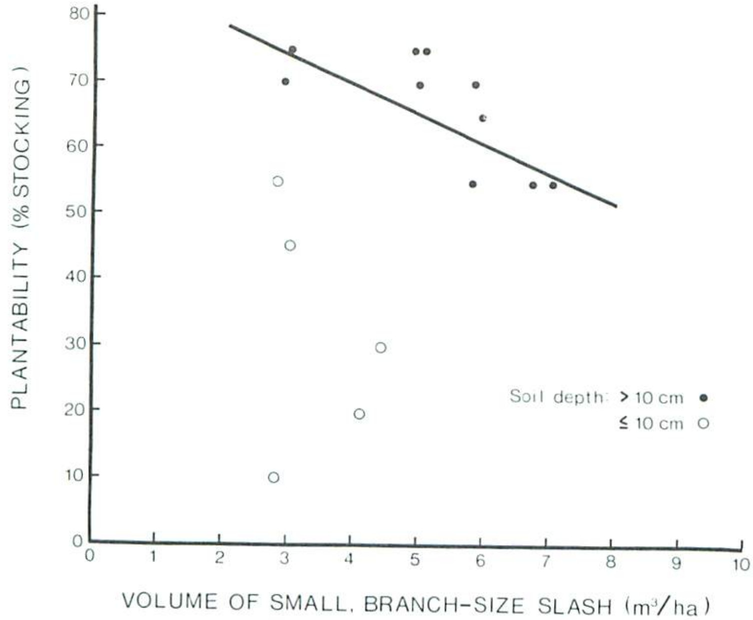


Figure 14. Leno FT block. Stocking of 4-$m^2$ quadrats with plantable and marginally plantable spots *vs* volume of slash pieces 1-5 cm in diameter. The line shown is from the equation:

Plantability (%) = 63.42-(4.28 x vol. of small pieces of slash ($m^3$/ha)) + (0.23 x soil depth (cm))

where $R^2$ is 0.71. Soil depth is assumed to be 20.0 cm. The equation is for soils >10 cm in depth. For soils >30 cm deep, use 30 cm in the equation.

it was not possible to develop a satisfactory predictive equation for receptive seedbed with respect to the single-pass treatment.

Bräcke Cultivator (two-row): On the FT block, the Bräcke produced more than double the number of plantable spots while the percentage of marginal spots was significantly lower than on the TL block (Table 11). Figures 15 and 16 illustrate the results achieved under light and heavy slash conditions. Overall plantability and potential stocking were 40% higher on the FT block. Planting tool penetrability was relatively high on both blocks. Wetter conditions on the TL block reduced plantability slightly (Table 12). A much higher percentage of the planting spots could be located on the higher-quality plantable soil disturbance classes on the FT block (Table 13).

Implement-caused plantable disturbance (creation of receptive seedbed) was 47% higher on the FT block (Table 14). The patches of desirable disturbance were both more frequent and larger in area on the FT block (Table 15).

On the FT block, the scalps averaged close to 3,500 $cm^2$ of subsurface soil disturbance (Table 16). The total plantable and marginally plantable soil disturbance created by the implement within the scalps was 55% of the subsurface area, an indication of moderately high duff-reducing effectiveness.

Figure 15. Successful Bräcke scalp made in light slash conditions on FT block.

Figure 16. Unsuccessful Bräcke scalp made in heavy slash conditions on TL block.

On the TL block, with the exclusion of subplots with moist-to-wet moisture conditions, there was a linear relationship ($R^2$ = 0.31) between the volume of small slash and plantability (Fig. 17) and a nonlinear relationship (S = 0.49) between the volume of small slash and receptive seedbed (Fig. 18).

On the FT block, soil depth was significantly correlated with plantability, but the relationship was not strong (R = 0.41). All of the slash variables had low correlations with plantability. There was a significant but weak negative correlation (R = -0.49) between the number of stumps and receptive seedbed. This would be expected since the amount of potentially treatable soil surface would be decreasing with increasing numbers of stumps. Also, the stumps inhibit the maintenance of working contact between the mattock tines and the soil surface. All of the slash variables had low correlations with receptive seedbed. No single variable or combination of variables produced strong equations for predicting site preparation output on the FT block.

## DISCUSSION

### *Time Studies*

TTS Disc Trencher: Despite double passing, PMHs and EPTs per hectare were only 12% and 15% greater, respectively, on the TL block. The small difference in EPT indicates a slower travel speed on the FT block if it is assumed that spacing between passes was similar on the two blocks.

As indicated by the 'obstacle-prime mover' time, obstacles had a greater influence on the FT block. Hence, stopping and starting, and a rougher ride, could have resulted in the slower average travel speed.

The prime mover was slightly underpowered according to the TTS manufacturer's specifications, and as a result was sensitive to obstacles, especially positive slope. Since the unit was underpowered, it appeared to be advantageous that it was equipped with a "Bräcke"-type hitch with the TTS rather than a towbar or universal hitch when slopes were encountered.

There were some 'obstacle-implement' delays caused by residuals and stumps. If both discs encountered stumps at the same time, the TTS became snagged. The delay was often long because there was no easy means of lifting the TTS over stumps. The operator's habit of letting out the winch as soon as he felt a small resistance to the implement may have increased the number of delays.

Travel speeds within the plots were similar for both blocks. Since plots were located so as to minimize stand and terrain obstacles other than slash, there was no apparent effect of debris on travel speed or productivity.

Leno 77 Patch Scarifier: EPT per hectare was only 10% higher on the TL block despite double passing, and productivity per PMH was actually lower on the FT block. This was a result primarily of the initial inexperience of the operator, who had the habit of attempting to treat every small patch within the FT block (the first block treated). As the FT

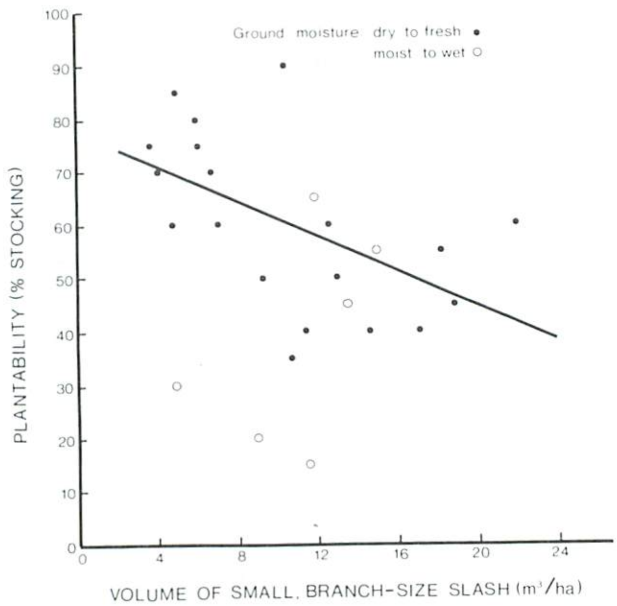


Figure 17. Bräcke TL block. Stocking of 4-$m^2$ quadrats with plantable and marginally plantable planting spots vs volume of slash pieces 1-5 cm in diameter. With moist-to-wet conditions excluded, equation for line is,

Plantability (%) = 77.57 - (1.66 x vol. of small pieces of slash ($m^3$/ha))

where $R^2$ is 0.31.

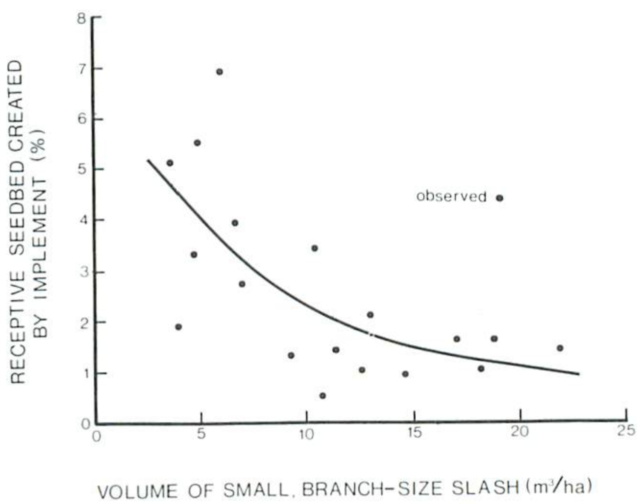


Figure 18. Bräcke TL block. Plot of receptive seedbed created by implement *vs* volume of slash pieces 1-5 cm in diameter. Derived through non-linear regression using the equation,

Receptive Seedbed (%) = 0.57 + 6.89e $^{(-0.14 \times \text{vol. of small pieces of slash (m}^3\text{/ha))}}$.

Does not include subplots with moist-to-wet ground moisture conditions. Coefficient of determination (S) is 0.49.

block was somewhat more difficult to treat anyway, such delays resulted in a low average travel speed and high proportion of maneuver time. There was an obvious improvement over time, and consequently a better overall operation on the TL block.

Slash had no apparent effect on travel speeds within the plots, or on productivity. Obstacles had little effect on the Leno, as is shown by the low incidence of 'obstacle-implement' times. However, the average duration of an 'obstacle-prime mover' delay was greater than with the other implements. This may have been because of the different operators but the "Bräcke"-style hitch used with the TTS and Bräcke appeared to influence the duration of delays as well. With the "Bräcke" hitch, the implement can be dropped and then winched in, so that 'obstacle-prime mover' delays are shorter and more of the site can be treated.

Bräcke Cultivator (two-row): PMHs and EPTs per hectare were 38% and 47% greater respectively, on the TL site. 'Obstacle' time, including both prime mover- and implement-caused delays, was 84% greater on the TL site. These differences were a result of double passing on 73% of the TL blocks and of very lengthy 'obstacle-prime mover' delays on positive slopes on the 2.3-ha ridge.

The travel speed was slightly lower on the TL block. In only one instance did slash directly affect the Bräcke. However, slash may have affected travel speed indirectly because the operator sometimes appeared to slow down and look through the slash for other obstacles that might affect his riding comfort. Travel speed may also have been higher on the FT plots because there were more runs on negative slopes of 10-25%.

It would appear that double passing does not require twice the number of PMHs to treat the same area. This may be due to the fact that the operator is more familiar with obstacles and can achieve a higher travel speed on the second pass. Also, maneuvering and turning on the second pass are automatic and do not require a decision about where to make the next pass.

### *Post-treatment Assessment*

TTS Disc Trencher: On the TL block, double passing produced poor plantability and receptive seedbed results. Soil depth and, to a lesser extent, ground moisture conditions significantly limited site preparation. The severe limiting effect of heavy slash is reflected in the high number of planting spots that had to be selected in thick duff, even though the duff was not notably thicker on this block, i.e., the implement was not able to penetrate the thick mat of slash. It is quite evident that the heavy average loading of 13 $m^3$/ha of small slash and 76 $m^3$/ha of large slash severely hampered the effectiveness of the TTS, despite double passing.

The discs were successful in penetrating and reducing the duff layer on the FT block. None of the pretreatment site variables had a major limiting effect on planting spot or receptive seedbed production. With allowances made for differences in plantability between the TL and FT blocks as a result of shallow and wet soil conditions, the single-pass treatment yielded 56% more plantable and marginally plantable planting spots on the FT block than on the TL block.

There is an indication that slash in the form of large hardwood stems had a measurable limiting effect on the FT block. However, it is important to note that the same total volume but different type of slash on the TL block had a far more serious undesirable effect upon equipment performance.

The fact that the actual number of furrows/scalps as a percentage of the potential output was highest for the TTS reflects an advantage inherent in continuous as opposed to patch-type scarification. Continuous scarification also leaves a continuously marked pathway for tree planters to follow.

Leno 77 Patch Scarifier: On the TL block, double passing produced poor results over all. Because of the combined effect of several factors, results were good where slash loadings were least severe. First, the operator was very conscientious in ensuring that the second pass overlapped the first pass. Second, the Leno was set to produce long scalps and therefore to maintain good contact with the ground. The net effect was that areas in which the slash was not heavy were well treated; hence, the scattering of relatively large, well treated patches of disturbance on the TL block.

A relatively high percentage of the planting spots was rejected on the TL block because of thick duff. This is primarily evidence of the Leno's inability to penetrate the thick mat of slash. The somewhat thicker duff layer on this block may have compounded the problem slightly. Slash penetration may have been affected by the fact that the mattock tines were several centimetres shorter than normal owing to previous wear.

When encountered, moist-to-wet conditions significantly limited site preparation on the TL block but the overall effect was small. From Figure 14 it appears that, on dry-to-fresh sites with deep soils and more than 6 to 8 $m^3$/ha of green, branch-size coniferous slash, plantability cannot be expected to exceed the 60% stocking level if a double-pass treatment is used with the Leno.

As with plantability, the amount of branch-size slash was a major factor limiting the production of receptive seedbed on the TL block. From Figure 15 it is apparent that, with more than 10 to 11 $m^3$/ha of fresh, branch-size coniferous slash on dry-to-fresh sites with deep soils, receptive seedbed production cannot be expected to exceed 3% when a double-pass treatment is used with the Leno.

The single-pass treatment on the FT block achieved slightly better results than double passing on the TL block.

Duff depth was apparently a limiting factor affecting plantability on the FT block, as was evidenced by the large number of planting spots that had to be selected in deep duff. The scalps created by the Leno on the FT block were relatively large but the proportion of area within the scalps in which the mattock tines actually penetrated through the duff layer down to or close to the mineral soil was small. Hence, it is apparent that while the mattock tines maintained good contact with the ground they were not able to cut through the duff, which averaged 10.7 cm in depth. This is most likely because of the combined effect of their angle of penetration, bearing pressure as determined by the weight of the implement, and wide nonaggressive design (14 cm wide vs 10 cm on the Bräcke).

When work was being done on those areas within the FT block with shallow soils, site preparation was significantly limited. However, the overall effect was minor.

From Figure 16 it appears that, on dry-to-fresh sites with deep soils and more than 6 to 8 $m^3$/ha of branch-size coniferous slash, plantability cannot be expected to exceed 60% when a single-pass treatment is used with the Leno. It is apparent that 6 to 8 $m^3$/ha of small slash is a critical amount, since at or above this level even double passing did not yield better results. This amount of slash fell within the upper and lower ranges of conditions on the FT and TL blocks, respectively (Fig. 14 and 16).

Bräcke Cultivator (two-row): The double-pass treatment produced generally poor results on the TL block. The amount of slash was probably the major limiting site variable on the TL block. The high number of spots that could not be planted because the duff layer was so thick was due to the difficulty the scarifier had in penetrating the heavy slash.

From results on the TL block (Fig. 17), it appears that on dry-to-fresh sites with deep soils and more than 10 to 12 $m^3$/ha of fresh, branch-size coniferous slash, plantability can be expected to fall off sharply and have little chance of exceeding 60% even when a double-pass treatment is used with the Bräcke. This amount of small slash fell approximately midway in the range of conditions on the TL block, an indication that double passing was a successful prescription on those areas on which slash was not as heavy. Similarly, Figure 18 indicates that on dry-to-fresh sites with deep soils and about 8 to 10 $m^3$/ha of fresh, branch-size, coniferous slash, the production of receptive seedbed can be expected to fall off sharply and have little chance of exceeding 3% when a double-pass treatment is used with the Bräcke.

On the FT block, site preparation was successful. If we allow for differential losses in plantability between the two blocks as a result of shallow and wet soil conditions, the single-pass treatment increased total plantability over that on the TL block by 35%. Implement-caused plantable soil disturbance or receptive seedbed was 47% greater on the FT block than on the TL block.

The average duff depth of 11.7 cm was not a limiting factor on the FT block, as is evidenced by the low percentage of planting spots that had to be selected in thick duff. The proportion of area within the Bräcke scalps in which the mattock tines penetrated the duff layer down to or close to the mineral soil was high, and this suggests that the mattocks coped well with the duff conditions.

With the exception of minor influences such as soil depth and the number of stumps, none of the site variables on the FT block greatly limited plantability or receptive seedbed production, and no single variable or combination of variables produced strong equations for predicting site preparation output. The relatively light average slash loading of 6 $m^3$/ha of small slash and 63 $m^3$/ha of large slash did not limit the effectiveness of the implement.

## SUMMARY AND CONCLUSIONS

The TTS-35 Disc Trencher, Leno 77 Patch Scarifier and Bräcke Cultivator (two-row) were evaluated during the fall of 1982 to determine the effects of TL and FT harvesting on operational productivity and site preparation. Testing was carried out cooperatively by GLFRC, FERIC and E.B. Eddy Forest Products Limited on sites located in the boreal forest near Ramsay in northeastern Ontario.

Prior to scarification, site conditions dependent on the method of harvesting, e.g., slash volume and depth, were assessed along with site conditions independent of harvesting, e.g., soil depth, duff depth and ground roughness.

Since harvesting occurred during the same year, slash still bore foliage at the time of treatment. To ensure a valid operational comparison and the most efficient use of each scarifier, a single-pass operation was undertaken on all FT areas. Double passing was used on the TL areas with the exception of approximately one quarter of the Bräcke TL area, which was given single-pass treatment.

Double coverage lowered overall productivity; however, heavy, fresh slash conditions did not appear to influence the ability of the three machines to travel over the area. Factors such as operator experience, power of the prime mover, treatment pattern, hitch type and terrain obstacles had a much greater effect on productivity than did slash.

Site preparation success was measured against a prescription to produce plantable spots in which Pottiputki planting tubes could be used to plant jack pine paperpot stock. Though not included in the prescription, receptive seedbed availability for jack pine was also assessed.

Analysis included a screening of both the harvesting-dependent and harvesting-independent site parameters to determine which factors were most limiting to microsite production. Since many of the site factors interact to limit the efficiency of the implements, linear stepwise and, where appropriate, nonlinear regression analyses were used. In some of the treatments, data were sufficient to identify trends and to generate equations specifying the range of conditions--particularly with respect to slash volume--that limit the scarifiers.

Soil depth <10 cm, and moist-to-wet ground moisture conditions, severely limited the production of plantable spots and receptive seedbed regardless of slash conditions. Other factors such as the stocking and density of residuals and ground roughness were not generally encountered at levels severe enough to have a major limiting effect on scarification.

In the absence of shallow soils and moist-to-wet ground conditions, the amount and type of slash, particularly the thick mat of mostly fresh, foliated, coniferous branch-size slash associated with TL havesting, clearly limited plantability and receptive seedbed production for each scarifier. The effects are summarized as follows.

### *TTS Disc Trencher*

Single-pass coverage on the FT area yielded 80% more plantable spots than the unsuccessful double-coverage treatment on the TL area. Receptive seedbed production was also much higher. Although the volume of slash was high on the FT block, this slash consisted, for the most part, of large hardwood stems which did not limit scarification to the extent that the branch-size coniferous slash did on the TL block. The data were insufficient to permit prediction of the range of volumes of slash within which the TTS would perform successfully.

### *Leno 77 Patch Scarifier*

Single-pass coverage yielded roughly the same site preparation results on the FT block as double coverage achieved on the TL block. A volume of 6 to 8 $m^3$/ha of fresh branch-size slash, the upper limit on the FT area and the lower limit on the TL area, is critical. Above this amount, plantability, according to the criteria used herein and on the sites examined, cannot be expected to exceed the 60% stocking level with either single or double coverage. Above 10 to 11 $m^3$/ha of fresh, branch-size slash, receptive seedbed cannot be expected to exceed 3% with double coverage.

### *Bräcke Cultivator (two-row)*

Single-pass coverage on the FT area yielded a 35% improvement in plantability over the TL block. Double coverage was marginally successful on the TL area and may be a feasible treatment on freshly cut TL sites on which the volume of branch-size slash is less than 10 to 12 $m^3$/ha. Above this amount, plantability cannot be expected to exceed 60% stocking with double coverage. Receptive seedbed production was also much higher on the FT block. Above 8 to 10 $m^3$/ha of fresh, branch-size slash, receptive seedbed cannot be expected to exceed 3% with double coverage.

In conclusion, the TTS, Leno and Bräcke could not cope with the slash conditions associated with TL-harvested cutovers less than a year old, even with double coverage. Examination of the effect of slash age on scarifier efficacy is required to determine at what time and in what manner the three scarifiers may be used successfully for treating TL harvested sites.

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# APPENDICES

# APPENDIX A

## TECHNICAL DATA ON THE SCARIFIERS AND PRIME MOVERS

### SCARIFIERS

*TTS-35 DISC TRENCHER*

| | |
|---|---|
| disc type . . . . . . . . . . . . . . . . | Canadian |
| disc diameter . . . . . . . . . . . . . . | 120 cm |
| no. teeth/disc . . . . . . . . . . . . . | 9 (square-end) |
| length of teeth . . . . . . . . . . . . | 28 cm |
| recommended power of prime mover . . | 97 kW + |
| weight . . . . . . . . . . . . . . . . . | 1750 kg |
| - maximum loaded weight . . . . . . . | 3500 kg |
| angle adjustment: minor . . . . . . . | 5 x 6° per major setting |
| major . . . . . . . | 30° setting |
| maintenance . . . . . . . . . . . . . . | 6 greasing points |
| hitch options . . . . . . . . . . . . . | pin and draw |
| . . . | 3-way swivel (universal joint) |
| . . . | modified Bräcke hitch |
| price . . . . . . . . . . . . . . . . . | $26,500 with 'O' ring hitch, Nov. 1984 |

| *Manufacturers* | *Distributors* |
|---|---|
| Työtehoseura Ry<br>Metsäkoeasema<br>SF 05200 Rajamäki<br>FINLAND | KBM Forestry Consultants Inc.<br>360 Mooney Street<br>Thunder Bay, Ontario<br>P7B 5R4 |
| Tyovaline Oy (Finnish Agent)<br>Karapellontie 10<br>P.O. Box 7<br>02611 Espoo 61<br>FINLAND | Hakmet Litée<br>P.O. Box 248<br>Dorion, Québec<br>J7V 7J5 |

*LENO MODEL 77 PATCH SCARIFIER*

| | |
|---|---|
| mattock wheels . . . . . . . . . . . . . | 2 mattock wheels with 4 pairs of tines per wheel |
| tine width . . . . . . . . . . . . . . . | 14 cm |
| distance between mattocks . . . . . . . | 180 cm |
| weight . . . . . . . . . . . . . . . . . | 1,800 kg |
| recommended power of prime mover . . . | 60 kW + |
| patch length . . . . . . . . . . . . . . | time of scalping continuously adjustable with control knob |
| options . . . . . . . . . . . . . . . . | seeder attachment |
| overload protection . . . . . . . . . . | Hydraulic control will release mattock wheels at a load of approximately 1,700 kP on the teeth |
| hitch type . . . . . . . . . . . . . . . | universal joint, bolted to butt-plate |
| price . . . . . . . . . . . . . . . . . | $37,000, May 1984 |

| *Manufacturer* | *Distributor* |
| --- | --- |
| System Svedlund AB<br>Box 445<br>S-701 06 Örebro<br>SWEDEN | Canadian Forestry Equipment Ltd.<br>90E Brunswick Blvd.<br>Dollard des Ormeaux, Québec<br>H9B 2C5<br>(offices in Edmonton, Toronto and Fredericton) |

*BRÄCKE CULTIVATOR (TWO-ROW)*

| | |
| --- | --- |
| mattock wheels . . . . . . . . . . . . . . | 2 mattock wheels with 4 pairs of tines per wheel |
| tine width . . . . . . . . . . . . . . . . | 10 cm |
| weight . . . . . . . . . . . . . . . . . . | 3,000 kg |
| tires . . . . . . . . . . . . . . . . . . | 30.0 x 60.0 cm, 16-ply |
| recommended power of prime mover . . . | 97 kW+ |
| drive sprocket . . . . . . . . . . . . . . | 17 teeth/sprocket |
| options . . . . . . . . . . . . . . . . . | 1, 2 and 4-row models |
| . . . . . . . . . . . . . . . . . . | seeders |
| . . . . . . . . . . . . . . . . . . | travel trailer |
| . . . . . . . . . . . . . . . . . . | 15- and 19-toothed sprockets for changing patch length |
| . . . . . . . . . . . . . . . . . . | mattock wheel with 5 pairs of tines |
| hitch . . . . . . . . . . . . . . . . . . | Bräcke type |
| price . . . . . . . . . . . . . . . . . . | $34,590 including hitch, Nov. 1984 |

| *Manufacturer* | *Distributor* |
| --- | --- |
| Robur Maskin AB<br>Gränsgatan 42<br>S-84060 Bräcke<br>SWEDEN | KBM Forestry Consultants<br>Inc.<br>360 Mooney St.<br>Thunder Bay, Ontario<br>P7B 5R4 |

## PRIME MOVERS

*TIMBERJACK 350 TURBO CABLE SKIDDER*

engine . . . . . . . . . . . . . . . . . . GM 3-53N/3 cylinders
. . . . . . . . . . . . . . . . . . power rating - 82 kW SAE flywheel
power train . . . . . . . . . . . . . . torque converter - single-stage
. . . . . . . . . . . . . . transmission - powershift, 3-speed forward and reverse

maximum travel speeds (24.5 x 32 tires):

| 1st gear | 2nd gear | 3rd gear |
|---|---|---|
| 5.8 km/hr | 12.4 km/hr | 33.4 km/hr |

tires . . . . . . . . . . . . . . . . . . 24.5 x 32 - chains on front during trial

*INTERNATIONAL S-10 GRAPPLE SKIDDER*

engine . . . . . . . . . . . . . . . . . . International DT-358
. . . . . . . . . . . . . . . . . . power rating - 92.5 kW SAE flywheel
power train . . . . . . . . . . . . . . torque converter - single-stage
. . . . . . . . . . . . . . transmission - powershift, 4-speed forward, 3-speed reverse

maximum travel speeds (standard 23.1 x 26 tires):

| 1st gear | 2nd gear | 3rd gear | 4th gear |
|---|---|---|---|
| 5.1 km/hr | 10.0 km/hr | 17.9 km/hr | 33.6 km/hr |

tires . . . . . . . . . . . . . . . . . . 23.1 x 26 - chains on front during trial

## APPENDIX B

### ASSESSMENT PLOTS

A plot system modified from that described by Riley (1975) for the testing of planting machines was used in this trial. The purpose of the plot/subplot system is to provide a means of relating equipment performance, in terms of both productivity and site preparation production, to pretreatment site conditions. Each plot is 100 m long by 20 m wide (0.2 ha) with five 20-m by 20-m (0.04 ha) subplots as indicated in Figure B1. The smaller subdivisions facilitate data analysis and the timing of equipment operations in the plots. Three plots were established in each of the Leno TL and FT blocks and the TTS TL block. Five plots were established in each of the other blocks.

Since all of the assessments with the exception of the overall time study are conducted on the plots, plot corners on one side are marked by semi-permanent cornerposts and all subplot boundaries are marked by flagged chaining pins to facilitate relocation after equipment operation.

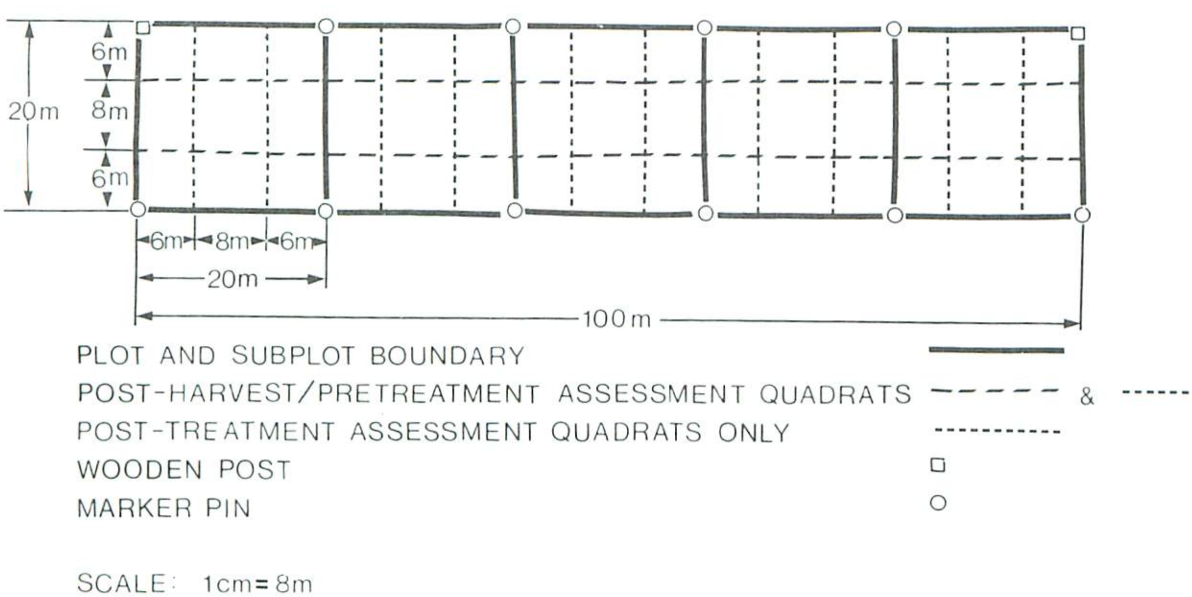


Figure B1. Plot layout for pretreatment and post-treatment assessments.

# APPENDIX C

## PRETREATMENT ASSESSMENT

Physical factors that may affect the forward progress of the implements and their ability to create plantable and/or seedable micro-sites were recorded in the pretreatment assessment.

### *Slash*

Slash was measured by means of a modified version of the line intersect method. Volumes were calculated according to the formula provided by Van Wagner (1968, 1982) and related to the physical properties of slash in Ontario (McRae 1982). The frequency of material 1-5 cm in diameter was tallied. The sound portion of material >5 cm in diameter was tallied in 2-cm classes. Volumes were calculated separately for material 1-5 cm in diameter and >5 cm in diameter. The frequency of 1- to 5-cm-diameter material was recorded on 200 2-m lengths of line intersect in each plot while larger pieces were recorded on 100 2-m lengths. Slash length was recorded for all stems >5 cm in diameter at the point of intersection on the line intersect tape. Length was recorded on 100 of the 2-m lengths of line intersect in each plot. Slash depth was measured by recording the highest intercept within 15 cm of a metre stick placed at the center of the 2-m length of line intersect. The intercept must be ≥ 1 cm in diameter at the point of interception. One hundred samples were taken in each plot. At the point of depth measurement, it was recorded whether the slash was predominantly softwood or hardwood.

### *Stumps*

The species, average diameter outside bark, and height of all stumps ≤1.5 m in height were recorded in 2-cm classes on 100 2-m x 2-m quadrats in each plot.

### *Residual Trees*

All living and dead residual stems (including trees and brush) > 5 cm DBH and ≤ 1.5-m tall were recorded by species in 2-cm DBH classes on 100 2-m x 2-m quadrats in each plot.

### *Brush*

The frequency of stems (including trees and brush) ≤5 cm DBH and > 1.5-m tall and the major species were recorded on 100 2-m x 2-m quadrats in each plot.

### *Minor Vegetation*

The percent coverage to the nearest 10% of all woody stems (including trees, brush and shrubs) ≤1.5-m tall and the major species were recorded on 100 2-m x 2-m quadrats in each plot.

### *Ground Roughness*

Ground roughness, a measure based on the frequency, height and depth of surface obstacles and depressions, was recorded on five 80-$m^2$ units in each plot. Stumps were measured separately but were included in the calculation of ground roughness. The method of ground roughness assessment was adapted from the Swedish terrain classification system (Anon. 1969).

### *Mineral Soil Depth*

Soil depth was measured in 5-cm classes to a maximum of 35 cm at the center point of 100 2-m x 2-m quadrats in each plot.

### *Duff Depth (L, F, H layers)*

Duff depth was measured in 1-cm classes to a maximum of 30 cm at 20 representative locations in each plot.

### *Stoniness*

When mineral soil depth was being measured, it was recorded whether stones or boulders were encountered in the top 30 cm of mineral soil.

### *Ground Condition*

Ground condition (Anon. 1969) is a composite measurement of soil type, ground moisture and stone or boulder content. At least one soil pit was dug in a representative location adjacent to each plot. Soil texture was determined according to Belisle (1980). Ground moisture was estimated at the time of equipment operation.

### *Slope*

Percent slope was measured along five 20-m sections on the long axis of each side of each plot.

## APPENDIX D

## SUMMARY OF OPERATING ELEMENTS

### *Operational Summary*

See Table D1 for operational summary of time studies.

### *Major Repairs*

TTS - weld crack in hitch tube of Bräcke hitch (1.66 hr - TL site)

Leno
- repair bent strut that holds the timing mechanism housing to the main frame (0.32 hr - FT site)
- repair broken fitting caused by debris (1.04 hr - TL site)
- remove lift chains entangled in implement (0.41 hr - TL site)

Bräcke
- cable entangled in winch (0.29 hr - FT site)
  (0.79 hr - TL site)
- replace cable (0.50 hr - TL site)
- remove log jammed between Bräcke wheel and machine frame (0.30 hr - TL site)

Timberjack
- repair winch (1.17 hr - FT site)
- repair blade cylinder (3.01 hr - TL site)
- repair tire chains (0.36 hr - TL site)
- repair transmission hose (0.73 hr - TL site)

International - repair hose fitting on logging arch (1.05 hr - Bräcke - FT site)

### *Nonproductive Operating Time*

Nonproductive operating time consisted primarily of travelling to the garage or fuel tank for major repairs and service. The one exception was the Leno on the FT site when it was stuck in a gully and the operator attempted to free it for 20 min.

### *Miscellaneous Delays*

Personal delays were the main cause of miscellaneous delay time except for a 19-min wait for a skidder to pull the Leno out of a gully on the FT tree site.

Table D1. Operational summary of time studies.

| Treatment | | Scheduled time (hr) | Machine: Repair I[a] (hr) | Machine: Repair PM[b] (hr) | Machine: Service I (hr) | Machine: Service PM (hr) | Operation: Nonproductive operating time (hr) | Operation: Awaiting parts I (hr) | Operation: Awaiting parts PM (hr) | Operation: Awaiting mechanic I (hr) | Operation: Awaiting mechanic PM (hr) | Operation: Misc. delay (hr) | Machine & operation: Productive (PMH) (hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TTS: | tree-length | 13.95 | 1.66 | – | 0.24 | 0.38 | 0.52 | – | – | – | 0.30 | – | 10.85 |
| | full-tree | 9.53 | – | – | – | 0.23 | 0.11 | – | – | – | – | 0.26 | 8.93 |
| Leno: | tree-length | 22.84 | 1.45 | 4.10 | – | 0.08 | 1.05 | 0.83 | 0.57 | 0.62 | 0.27 | 0.50 | 13.36 |
| | full-tree | 19.37 | 0.32 | 1.17 | – | 0.30 | 1.21 | – | 0.42 | – | 0.16 | 0.32 | 15.19 |
| Bräcke: | tree-length | 27.49 | 1.59 | – | 0.22 | 0.40 | 0.77 | 1.70 | – | 0.32 | – | 0.88 | 16.61 |
| | full-tree | 12.90 | 0.29 | 1.05 | 0.20 | 0.40 | 0.31 | – | – | – | 0.49 | – | 10.14 |

Machine time formulas (%)

| Treatment | | Mechanical availability: I (%) | Mechanical availability: PM (%) | Mechanical availability: Combined I + PM (%) | CPPA[c] availability (%) | Utilization (%) |
|---|---|---|---|---|---|---|
| TTS: | tree-length | 85.1 | 96.6 | 82.6 | 81.5 | 77.8 |
| | full-tree | 100 | 97.5 | 97.5 | 97.5 | 93.7 |
| Leno: | tree-length | 90.2 | 76.2 | 70.3 | 65.3 | 58.5 |
| | full-tree | 96.2 | 91.1 | 88.0 | 86.3 | 78.4 |
| Bräcke: | tree-length | 90.2 | 97.7 | 89.2 | 81.2 | 73.9 |
| | full-tree | 95.2 | 87.5 | 83.8 | 83.6 | 78.6 |

[a]I = implement
[b]PM = prime mover

*Definition of Machine Time Elements*

SCHEDULED MACHINE HOURS (SMH): Nominal statement of intent for regular machine activity (e.g., 8-hr shift). It usually corresponds to operator's paid on-job time.

PRODUCTIVE MACHINE TIME or PRODUCTIVE MACHINE HOURS (PMH): That part of total machine time during which the machine is performing its primary function.

ACTIVE REPAIR: Repair consists of mending or replacement of part(s) in consequence of failure or malfunction. It also includes *modifications* or *improvements* to the machine.

SERVICE: Service is routine and preventive maintenance performed to maintain the machine in satisfactory operational condition.

DELAY: That portion of SMH during which the machine is not performing its primary function for reasons other than active repair and service. Delay time is divided into:

NONPRODUCTIVE OPERATING TIME: Period of in-shift time during which the machine's engine is running but the machine is doing something other than performing its primary function.

WAITING FOR MECHANIC(S): That in-shift time during which the machine is broken and is not under repair because of the unavailability of mechanic(s).

WAITING FOR PART(S): Period of in-shift time during which the machine is broken and is not under repair because of the unavailability of part(s).

MISCELLANEOUS DELAY: Period of in-shift time during which the machine engine is not running for reasons other than for active repairs and service and/or waiting for repairs and service.

## *Total Machine Time Model*

<table>
<tr><td rowspan="7">total machine time (normal shift length plus overtime)</td><td colspan="2">productive machine time[a]</td></tr>
<tr><td colspan="2">active repair</td></tr>
<tr><td colspan="2">active service</td></tr>
<tr><td rowspan="4">delay</td><td>nonproductive operating time</td></tr>
<tr><td>awaiting mechanics</td></tr>
<tr><td>awaiting parts</td></tr>
<tr><td>miscellaneous delay</td></tr>
</table>

[a]breakdown of time elements for short-term timing is given in Table D1.

## *Machine Time Formulas*

$$\text{Utilization} = \frac{\text{PMH (in shift)}}{\text{SMH}} \times 100$$

$$\text{Total time utilization} = \frac{\text{PMH (in shift and outside of shift)}}{\text{SMH + overtime}} \times 100$$

$$\text{Mechanical availability} = \frac{\text{PMH}}{\text{PMH + repairs + service}} \times 100$$

(PMH, repairs and service include both in- and out-of-shift activities.)

$$\text{CPPA availability} = \frac{\text{SMH - (repair + service + wait [parts + mechanic])}}{\text{SMH}} \times 100$$

(Repairs and service include only in-shift activities.)

CPPA availability, by definition, is influenced not only by machine characteristics but also by operational factors (i.e., waiting for parts, or waiting for mechanic). Mechanical availability excludes these operational factors.

For details regarding definitions of machine time elements refer to Folkema et al. (1981).

*Definition of Short-term Study Time Elements*

The PMHs recorded in the continuous timing were broken down into the following elements.

EFFECTIVE PRODUCTIVE TIME (EPT) (SCARIFICATION): Begins when the implement is in the soil and the prime mover begins *forward* travel. The EPT can include *winching* if the implement is equipped with a quick disconnect hitch and there is effective scarification during winching.

MANEUVERING (TURNING): Occurs from the time the scarifier has finished a pass to begin a turn until it begins the next pass. For the Leno, this element includes raising the implement from the ground, turning, and then lowering the implement. For the Bräcke and TTS, because the implement is kept on the ground, the element includes the time from when the pass is completed until the scarifier is aligned to the next pass. If the winch is used, the time involved in free-spooling and winching is included, especially if these activities are performed over a previously scarified area and at a narrow angle.

Maneuvering is broken down into the type of turn: run-by-run, operation in lands pattern, or broken pattern.

OBSTACLE: Is the time between stopping because of an obstacle and resumption of scarification. It includes various elements, depending upon the scarifier. In the operation of the Leno, it includes 'stuck' time, time to raise the implement from the ground, and time moving forward and/or reversing until the Leno has been dropped and forward movement has begun. With the Bräcke hitch-attached implements, obstacle time includes 'stuck' time, moving forward while free-spooling the mainline, and any reversing after free-spooling. The obstacle time ends when the implement begins to be winched in. Depending upon the cause, the obstacle time is charged against the implement or the prime mover.

TRAVEL: Is the time spent travelling in the block or to the roadside between breaks, repairs, lunch, and start and end of shift. It also includes travelling between sites if less than 15 min.

DELAY: Includes delays between 0.05 min and 15 min. Delays over 15 min were not considered part of productive time. Delay is any downtime and non-productive operating time.

## APPENDIX E

### POST-TREATMENT ASSESSMENT

The quantity and quality of site preparation were assessed in terms of the production of plantable spots for jack pine in Japanese paperpots and receptive seedbed for jack pine. The basic sample unit was a 2-m x 2-m quadrat. Ten transects of 10 contiguous quadrats each were aligned perpendicular to the direction of scarification across each sample plot. Each quadrat was considered to be discrete and, therefore, unaffected by conditions in the adjacent quadrats. Whether or not a quadrat lay within a scarified row was recorded. The number of scalps or furrows with at least half their area inside the quadrat was also recorded.

**Plantability**

On each quadrat, the best plantable microsite was selected, tested for plantability and described. The assessment method used was a modified version of a system developed by Greenwood (1982). A plantable microsite was defined as a spot approximately 30 cm square meeting the best conditions for each of the following four categories. Note: 'P' denotes a plantable condition, 'M' marginal and 'P' unplantable.

*Depth of duff (L, F, H layers)*

P $\leqslant$ 1.5 cm

M > 1.5 cm $\leqslant$ 3 cm

NP > 3 cm

*Debris (needles, bark, twigs, stems, roots, etc.)*

P None. No debris or debris insignificant with respect to hand planting or survival.

M Light. Partially covered with debris, so that the planter is required to displace a slight amount of material prior to planting.

NP Heavy. Mostly or completely covered with debris, so that the planter is required to alter the microsite prior to planting.

*Vegetative Competition*

P None.

M Competing herbaceous vegetation only.

NP Competing woody vegetation.

*Soil/Duff Modification Type*

P 1. Exposed mineral soil with a firm base, or

2. Thin (≤1.5 cm) duff/mineral soil mix which would readily settle to a firm base, or

3. Thin (≤1.5 cm) duff on firm mineral soil.

M 1. Mounded mineral soil on firm mineral soil, or

2. Moderately thick (> 1.5 cm ≤ 3 cm) duff/mineral soil mix on a firm base, or

3. Moderately thick (>1.5 cm≤ 3 cm) duff on firm mineral soil.

NP 1. Excessively deeply exposed mineral soil; i.e., 'C' horizon, or

2. Mounded mineral soil on thick duff or debris, or

3. Thick ( > 3 cm) duff/mineral soil mix, or

4. Thick ( > 3 cm) duff, or

5. Inverted sod layer, or

6. Other, includes mounded duff, exposed rock, water, etc.

If a microsite meeting all of the above criteria for plantability were not available, a microsite with marginal or, if necessary, unplantable conditions would be designated the best planting spot. A Pottiputki planting tube was used to test whether the selected planting spot was penetrable. If not penetrable, another spot was selected.

The final spot selected was described according to the P, M or UP classes listed for the conditions above. In addition, the following were recorded:

*Penetration*

P Full penetration

NP Rock
Root mat
Debris
Water

*Origin of Planting Spot*

Created by implement
Created by prime mover (logging or scarification)
Natural disturbance
No disturbance

*Microrelief of Planting Spot*

Level
Raised
Side
Hollow

Spots created by the implement were given first priority for selection as plantable spots. If only marginally acceptable conditions were created by the implement, plantable conditions created by other means would be selected if available. Similarly, marginal conditions created by the implement were given higher priority over marginal conditions originating from other sources. In terms of microrelief, the preferred location was in plantable quality soil disturbance on the side of the scalp or furrow close to the mineral soil-humus interface.

## Disturbance

*Quantity*

The total percentage (to the nearest 5%) of soil and/or duff disturbed by the implement in each quadrat was recorded. The combined disturbance from logging, implement prime mover and natural causes was also recorded. Disturbance was defined as:

1. Exposed or dislocated mineral soil
2. Reduced, compressed (less than half undisturbed depth) or dislocated duff
3. Exposed rock previously covered by duff and/or mineral soil

Note: Dislocated slash, vegetation and rock were not included.

*Quality*

The total percentage of area to the nearest 1% in each of the P and M soil disturbance categories listed under 'Soil/Duff Modification Type' was recorded on every second quadrat. A distinction was made between disturbance created by the implement and disturbance from other sources. The P disturbance class corresponded closely to the definition of receptive seedbed given by Riley (1980).

## Dimensions of Scalps/Furrows

On the FT blocks, 10 scalps were measured in each plot to determine the average length and width of the hollowed-out part of the scalp as well as the overall length of the total scalp including the hollowed-out and mounded sections. For the furrows created by the TTS, ten 2-m lengths of furrow were measured in each plot to determine the average width of the subsurface disturbance as well as the overall width, including the mounded portion.