EVALUATION OF THE CANADIAN PACIFIC FOREST PRODUCTS LTD. POWERED-CONE SCARIFIER

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ABSTRACT

The Canadian Pacific Forest Products Ltd. powered-cone scarifier was evaluated under four different site conditions in northwestern Ontario. The prime mover was a modified Koehring shortwood harvester. The implement produced from 2.2 to 7.9% mineral soil exposure distributed over 37 to 72% of the area (stocking of 2- x 2-m quadrats) and the number of plantable spots ranged from 750 to 1850/ha. Productivity varied from 1.0 to 2.3 ha/-productive machine hour at 5.5 to 8.3 furrows/20-m width. Bedrock and relatively high stoniness were responsible for lower acceptable disturbance and plantability in two of the blocks. Desirable features of the scarifier included ability to maneuver so as to treat areas that would be untreated by drag scarifiers, good productivity, ability to penetrate slash, ability to prepare seedbed in shallow mineral soil (with the flat-cone setting), ruggedness of the scarifier on rocky sites, stability on steep slopes and good ergonomic design. Some problems included the need to improve spacing by improving the tracking of the outer arms. The rakelike accumulation of slash in front of the cones and its deposition in piles reduced plantability along the furrow by approximately 10%. Pushing down residual trees or operating on moist-to-wet ground forced the raising of the scarifier's arms, and this resulted in patches of unscarified ground. Residual stands should be avoided.

RÉSUMÉ

Le scarificateur à cones motorisés de la compagnie Produits Forestiers Canadien Pacific Ltée. fut évalué sous quatre conditions de terrains différentes dans le nord-ouest de l'Ontario. Le véhicule porteur était issue d'une abatteuse-ébrancheuse-tronçonneuse de bois court modifiée Koehring. L'appareil a produit de 2.2 à 7.9% d'exposition de sol minéral distribuée sur 37 à 72% de la surface (stocking dans des quadrats de 2 x 2 m) et le nombre de microsites plantables variait de 750 à 1850/ha. La productivité variait de 1.0 à 2.3 ha par heure machine productive (HMP) avec 5.5 à 8.3 sillons/20 m de largeur. Les affleurements rocheux et la présence relativement grande de pierres sont responsable de la faible plantabilité et perturbation acceptable dans deux des bloques. Certains avantages du scarificateurs incluaient la possibilité de manoeuvrer de façon à couvrir des surfaces qui n'auraient pas été traitées avec des barrils et chaines, une bonne productivité, une habilité à pénétrer les débris ligneux, l'habilité à préparer des lits de germination même là où le sol minéral était mince (avec le cône à plat), la solidité du scarificateur dans les terrains rochailleux, la stabilité du véhicule porteur en pentes fortes et des qualités ergonomiques. Quelques problèmes furent identifiés comme le besoin d'améliorer l'espacement des sillons en controlant mieux le mouvement des bras extérieurs. L'arrangement des quatres têtes formaient un genre de râteau forestier qui accumulait les débris ligneux à l'avant des cones et le dépôt de ces débris en tas résulta en une perte d'environ 10% des microsites plantables le long du sillon. Le renversement des arbres résiduels par le véhicule porteur aussi bien que les conditions de terrain d'humides à mouillées se traduisit par des portions de sillons non scarifiées. Les îlots d'arbres résiduels devraient être évités.

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INTRODUCTION

Canadian Pacific Forest Products Ltd. (CPFP) of Thunder Bay, Ontario owns an aging fleet of Koehring shortwood harvesters that are being replaced by newer Koehring K3FF feller-forwarders. However, the chassis and drives of the shortwood harvesters remain serviceable. In 1982, the company converted one unit for use as a prime mover in scarification. The prime mover has several features that are desirable for site preparation, including a hydrostatic drive (Ryans 1986a), good visibility and comfort for the operator and the potential to pull a three- to four-row scarification unit. The first converted unit was used to pull barrels and chains. However, CPFP wanted to cut treatment costs with a more maneuverable, portable and energy-efficient scarifier than barrels and chains; i.e., they wanted to direct the energy consumed during scarification into the preparation of microsites rather than into pulling the dead weight of the drag scarifier. In 1983, with these intentions in mind, the company built a rotating powered-cone scarifier for use with the modified Koehring shortwood harvester.

In July of 1985 and May of 1986, the Mechanization of Silviculture Unit, Great Lakes Forestry Centre (GLFC), evaluated the scarifier under four site conditions. The purpose of this short-term trial was to evaluate the quantity and quality of microsites prepared by the tool.

METHODS

Location

The study area was located near CPFP Camp 603, 100 km north of Upsala, Ontario (Fig. 1) in the Central Plateau Section (B.8) of the Boreal Forest Region (Rowe 1972) in the Canadian shield. The study area was typical of terrain conditions under which site preparation with the powered-cone scarifier was routinely conducted.

Prior to harvesting, the stands had approximately equal components of jack pine (**Pinus banksiana** Lamb.) and black spruce (**Picea mariana** [Mill.] B.S.P.), with trembling aspen (**Populus tremuloides** Michx.) and white birch (**Betula papyrifera** Marsh.) in small or large pockets. Stands were 90 to 120 years old and 70 to 80% stocked.

During harvesting the jack pine and spruce were removed and the deciduous species were left as standing trees. Harvesting was conducted during the summer of 1984; a conventional tree-length cut-and-skid operation was carried out in blocks 2, 3 and 4 and full-tree Koehring (K3FF) logging occurred in block 1.

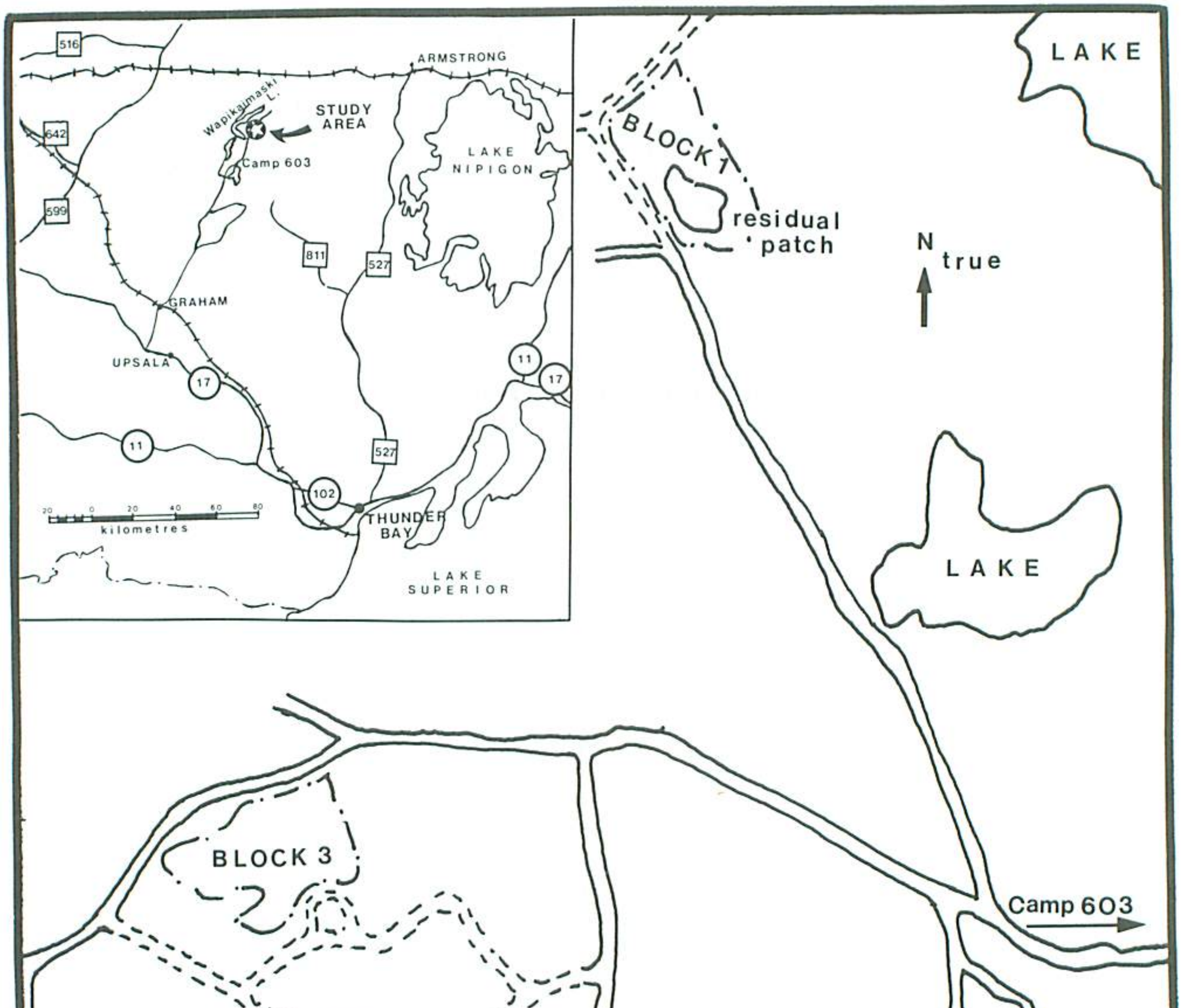

Figure 1. General location of study area and configuration of the four study blocks.

Scarifier and Prime Mover

The major modifications to the shortwood harvester to adapt it for use as a scarification unit included the elimination of the harvesting components and the positioning of the operator cabin on top of the engine compartment of the prime mover (Fig. 2); the original Koehring had the operator cabin and the engine at opposite ends of the machine. Four powered cones, each on independently controlled 3.66-m-long arms, were mounted directly at the back of the modified harvester. The operator had controls in the cab to lift the arms individually or together. Since the trial, the arms have been shortened to 3.05 m.

The prime mover's engine was scaled up from 175 to 242 kW and the two-speed gearbox was replaced with a four-speed gearbox and a variable-displacement motor that yielded 12 forward speeds. Scarifying cones received power from the prime mover's engine and the central hydraulic system. Two tandem hydraulic pumps (4 x 109 L/min. at 1200 rpm) provided hydraulic oil to a Char-Lynn 10000 motor placed on top of each cone (Fig. 3). A 4:1 gear reduction ratio resulted in a cone rotation speed of 52 rpm (Appendix A).

Penetration of the soil by the cone was a function of the weight of the cone/arm assembly combined with the digging action of the cone. The depth of penetration was limited by a hydraulic pressure-sensing system that utilized the resistance of the digging cone coupled with a double-acting cylinder that lifted the assembly slightly or completely when required (Fig. 2 and 4). Alternative mounting positions for the cylinder at the back of the prime mover were available **prior to operation** to vary the lift capability and consequently the depth of the furrow. In this trial the lift cylinder was set at the middle position and the pressure of the head on the ground was approximately 90 kPa.

The scarifier's arms were mounted at a 2-m spacing on a 6.45-m-long beam attached to the back of the prime mover. A system of restraining cylinders between the arms maintained tracking but permitted some lateral movement to enable the heads to go around obstacles (Fig. 2 and 5). Restraining cables on the outer arms were intended to prevent excessive lateral movement.

The scarifying cones each weighed 1430 kg and were 1067 mm in diameter at the top and 152 mm at the bottom, with a center-axis length of 533 mm. In all, 18 fins (six rows of three fins), each 76 mm high x 76 mm long x 25 mm thick, were placed on each cone. The cones rotated in the opposite direction to the wheels of the prime mover. The cones were mounted on flange plates that permitted manual adjustment of their angles. The ground-contact face of each cone was set at an angle of 0° (horizontal) during the trial.

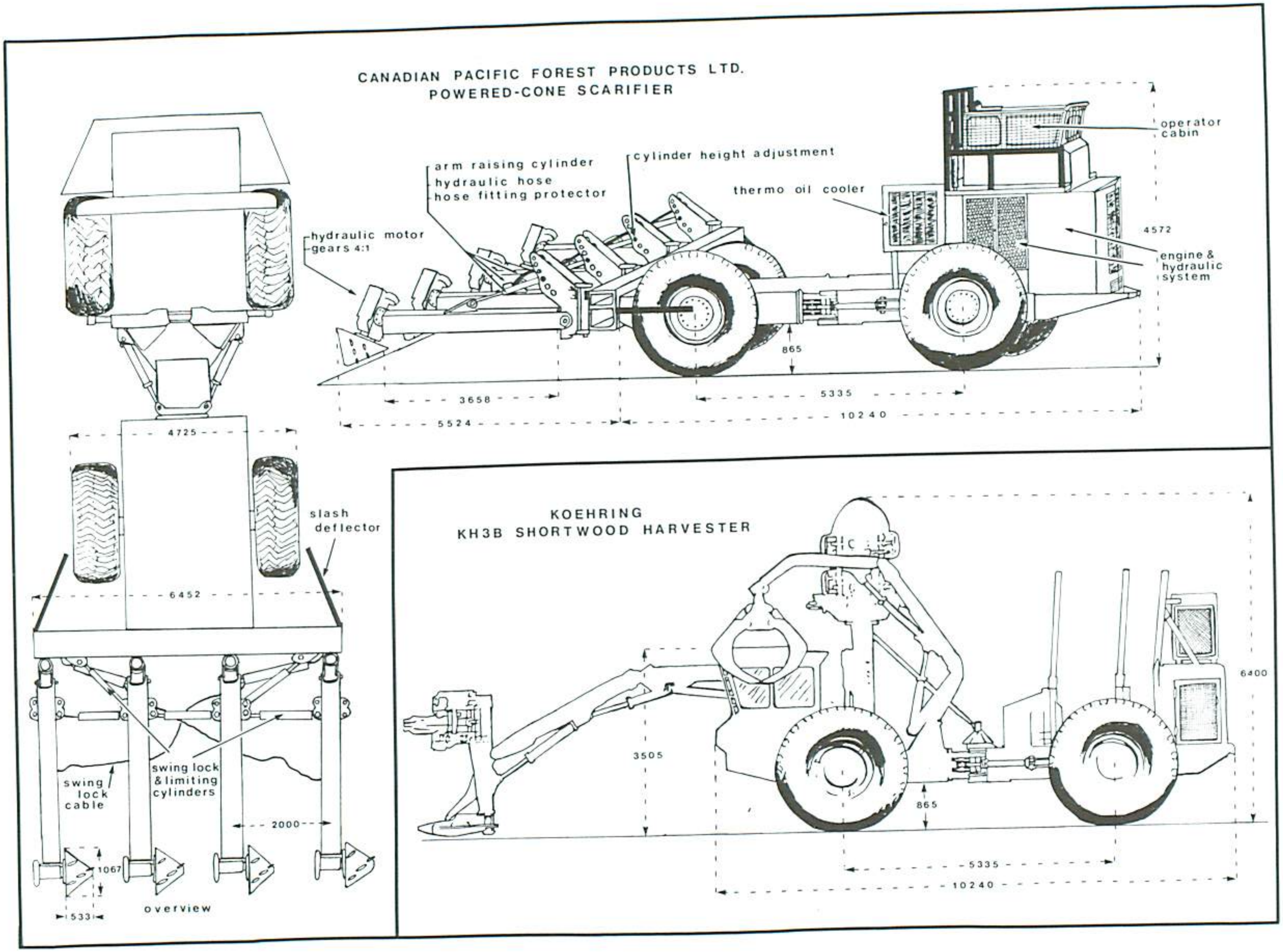

Figure 2. Major components and dimensions (mm) of the Canadian Pacific Forest Products Ltd. powered-cone scarifier and the Koehring KH3B shortwood harvester (adapted from company brochure).

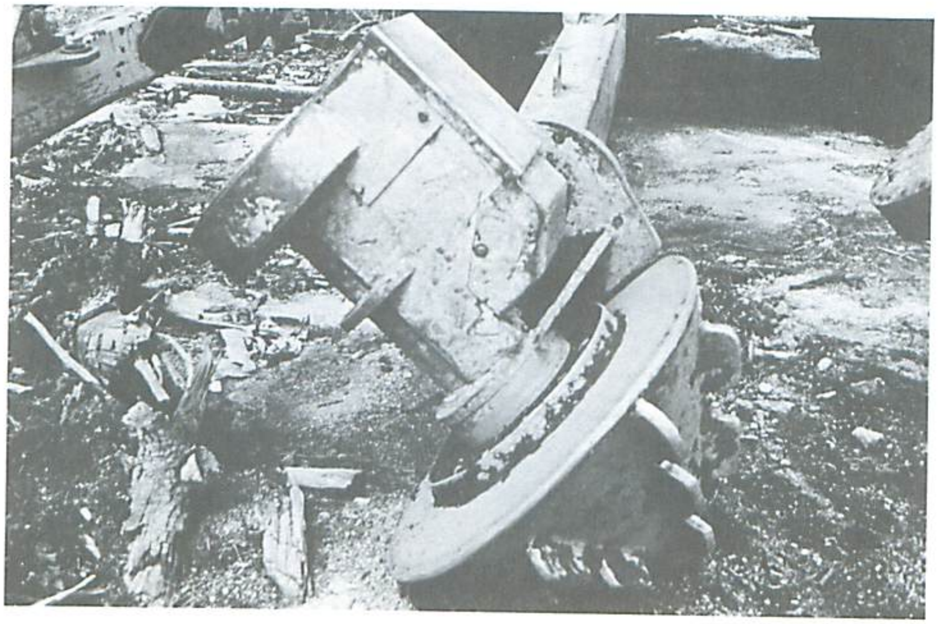

Figure 3. The powered cone used for scarification.

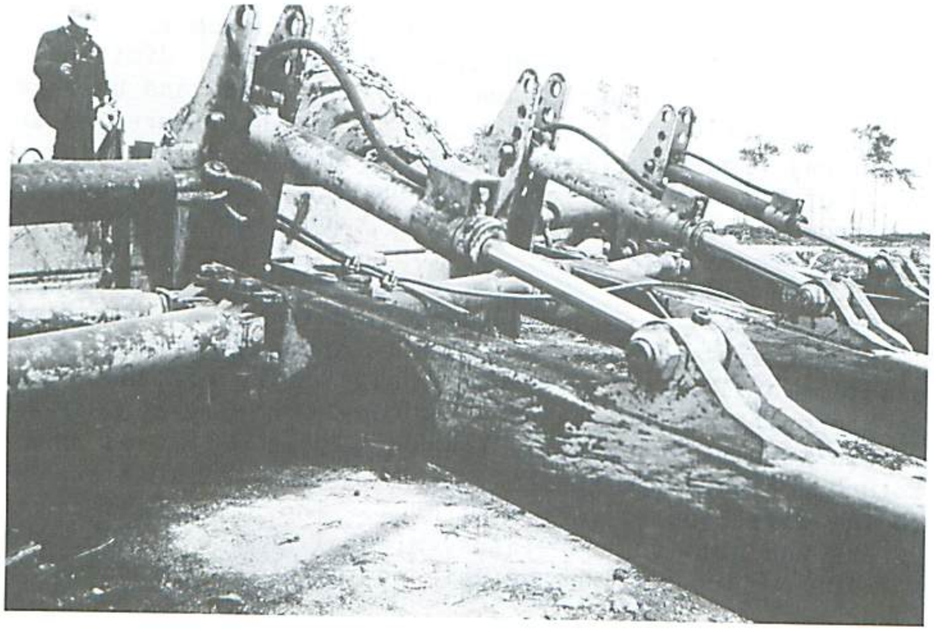

Figure 4. Cylinders used for raising the scarifier's arms.

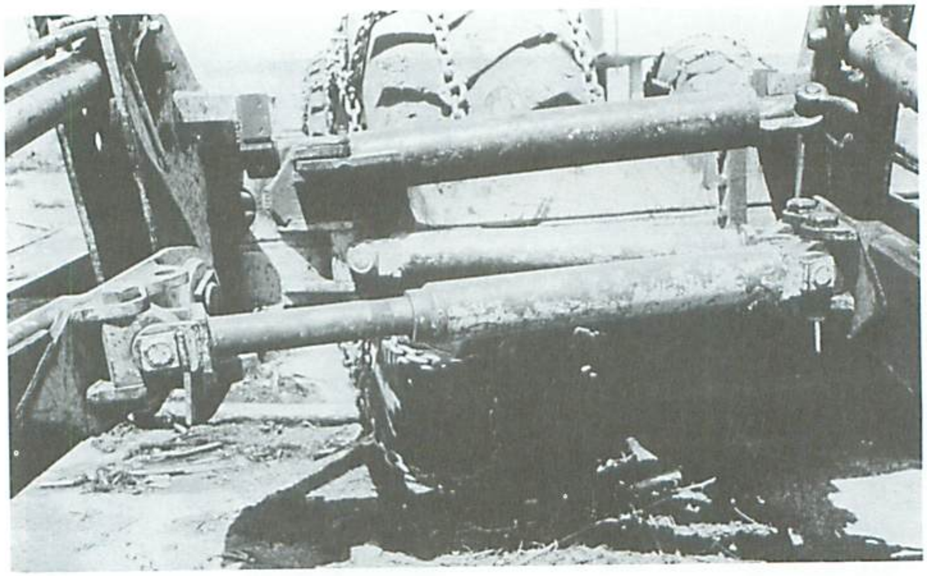

Figure 5. Swing lock and limiting cylinders and cables.

Assessment Procedure

The procedures used for the pretreatment, time study and post-treatment assessments are described in Sutherland (1986). In the pre-treatment assessment, randomly located transects consisting of 20 quadrats (each 2 x 2 m) were established in each block to measure the site variables (see Table 1).

During operation of the equipment, continuous time studies were carried out in each block to determine how time was distributed and to measure productivity per productive machine hour (PMH) and average travel speed among various activities. The study was of short duration and extent (14.4 hr and 25 ha), and was therefore useful only in determining operating characteristics of the machine and not long-term performance. Down time that resulted from active repair and service, and other delays of more than 15 minutes, are not reported.

The post-treatment assessment identified the quantity and quality of microsites. Scarification that was conducted in July of 1985 and had settled by the autumn of 1985 was assessed in the spring of 1986. The definitions of the microsite categories were provided jointly by CPFP (see pages 18 and 21). Clusters of 10 quadrats (each 2 x 2 m) were used to assess the degree of disturbance and were randomly laid out as 2- x 20-m transects perpendicular to the direction of machine travel. The same transects were used to measure gross and net furrow widths, mineral-soil exposure widths, and depths of the furrows as well as height and angle of the berms (see page 15).

Plantability was assessed on 40-m transects in the direction of machine travel. The assessment of plantable spots was made at 1.9 m plus or minus 0.4 m (no plantable spots closer than 1.5 m). The required average inter-furrow spacing was 2.1 m, with no plantable spots closer than 1.5 m for a desired density of 2500 plantable spots/ha. The best plantable spot was chosen irrespective of its microrelief position.

RESULTS AND DISCUSSION

Site Conditions

Soil and ground conditions: Mineral soil depth was one of the major distinguishing components among blocks, as indicated in Table 1 and Figure 6. Mineral soil was deeper than 35 cm in Block 1, but stoniness (49%) reduced the effective depth to 23 cm. Similarly, mineral soil in Block 2 was deeper than 35 cm, but the stoniness (54%) resulted in an effective depth of 27 cm. However, the smaller stone size in Block 2 was not considered to be a limiting factor for the penetration of the cones. Block 3 comprised a variety of conditions; average soil depth was 15 cm, and 29% of the site exhibited exposed bedrock (depth 0 cm); however, stoniness averaged 48% and 21% of the area had an effective mineral soil depth of >35 cm. The soil in Block 4 was shallow; depth averaged 9 cm.

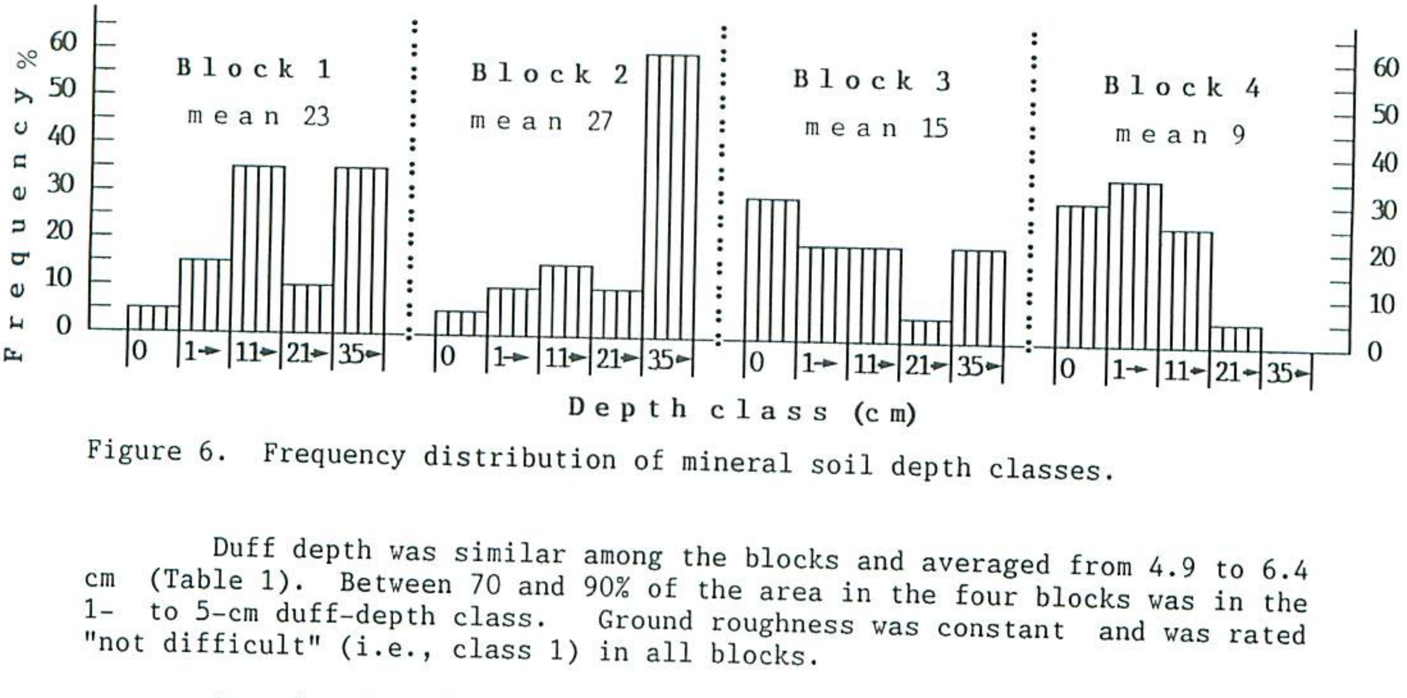

Figure 6. Frequency distribution of mineral soil depth classes.

Duff depth was similar among the blocks and averaged from 4.9 to 6.4 cm (Table 1). Between 70 and 90% of the area in the four blocks was in the 1- to 5-cm duff-depth class. Ground roughness was constant and was rated "not difficult" (i.e., class 1) in all blocks.

Ground moisture and ground condition differed among the blocks. In Block 1, loamy medium sand, 49% stoniness and a fresh moisture regime resulted in good trafficability for the prime mover in a large portion of the block. In Block 2, the deep, loamy, fine sand lay over bedrock and was wet as a result of the heavy rainfall that year; consequently, it had a low bearing capacity. Block 3 contained a large hill (up to 30% slopes), and was covered by a dry, 15-cm-deep loamy medium sand with many stones. The terrain was flat on top of the hill, with deep soil over bedrock and moist

Table 1. Pretreatment site conditions.

		Block			
		1	2	3	4
Depth of mineral soil (cm)[a]		23	27	15	9
Stoniness & bedrock presence (%)[b]		44 & 5	49 & 5	48 & 29	29 & 29
Depth to mineral soil (duff[LFH]) (cm)		6.4	4.9	5.3	5.2
Soil texture		loamy medium sand	loamy fine sand	loamy medium loamy	loamy medium sand
Ground moisture		fresh [moist]	moist	dry [moist]	fresh
Ground condition[c]		1	4	1 [4]	2
Ground roughness[c]		1	1	1	1
Slope (%)		–	–	15 (up to 30)	–
Slash:					
no.of pieces per 2 m of lineal tally	diam 1–5 cm	2.1	4.8	7.0	5.8
	diam >5 cm	.6	.6	.8	.8
volume (m^3/ha)	diam 1–5 cm	4.5	10.5	15.0	12.5
	diam >5 cm	76.4	55.6	52.7	63.1
	total	80.9	66.1	67.7	75.6
quadratic mean diam of pieces with diam >5 cm (cm)		13.2	10.8	9.8	10.7
depth (cm)		10.2	13.2	15.7	16.3
species composition, conifer/hardwood (%)		59/41	65/35	91/9	86/14
Stumps: density (no./ha)		713	358	783	720
diam (cm)		26	24	22	24
height (cm)		25	24	25	25
Brush: density (stems/ha)		2000	clumps around residual trees	–	–
stocking[d] (mainly alder) (%)		28	–	–	–
Density of residuals: (stems/ha)		103 2/3 aspen 1/3 white birch	151 1/2 aspen 1/2 white birch	2	10

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[a] Soil depths > 31 cm were recorded as 35 cm. The reported average is for the zone between 0 and 35 cm.

[b] Determined by inserting a steel rod into the soil every 2 m along transects. The presence of stones was recorded if a stone or boulder was encountered within the first 35 cm of mineral soil. The percentage of bedrock applied when the depth of mineral soil equaled "0 cm".

[c] Swedish terrain classification system (Anon. 1969). Square brackets refer to a % occurrence > 10 % of the sample area. Ground roughness includes stumps as well as surface rocks, boulders, overturned stumps and depressions.

[d] Based on the presence or absence of at least one stem in a 2- x 2-m quadrat.

conditions that resulted from a perched water table similar to that in Block 2. The bearing capacity of the soil was good over most of Block 3. The soil in Block 4 was a shallow, fresh, loamy medium sand over bedrock that provided good support for the equipment. Blocks 1 through 4 were classified 3.1.1, 4.1.1, 2.1.3 and 2.1.1, respectively, under the Canadian Pulp and Paper Association's system of terrain classification for Canadian forestry (Mellgren 1980).

Logging slash: Block 1 (full-tree logged) had a low count of slash in the 1- to 5-cm diameter class throughout the block (Table 1 and Fig. 7). Block 2 (tree-length logging) had more small-diameter (1-5 cm) coniferous slash than Block 1, but because of the high proportion of deciduous trees in the original stand, the counts of slash in both blocks were still low. The counts of slash in the >5 cm diameter class were the same in blocks 1 and 2 with few aspen and white birch windfalls. Block 3 had a higher component of jack pine slash whereas Block 4 had more black spruce slash; both blocks had more slash than did blocks 1 and 2. The slash conditions in blocks 3 and 4 were considered medium.

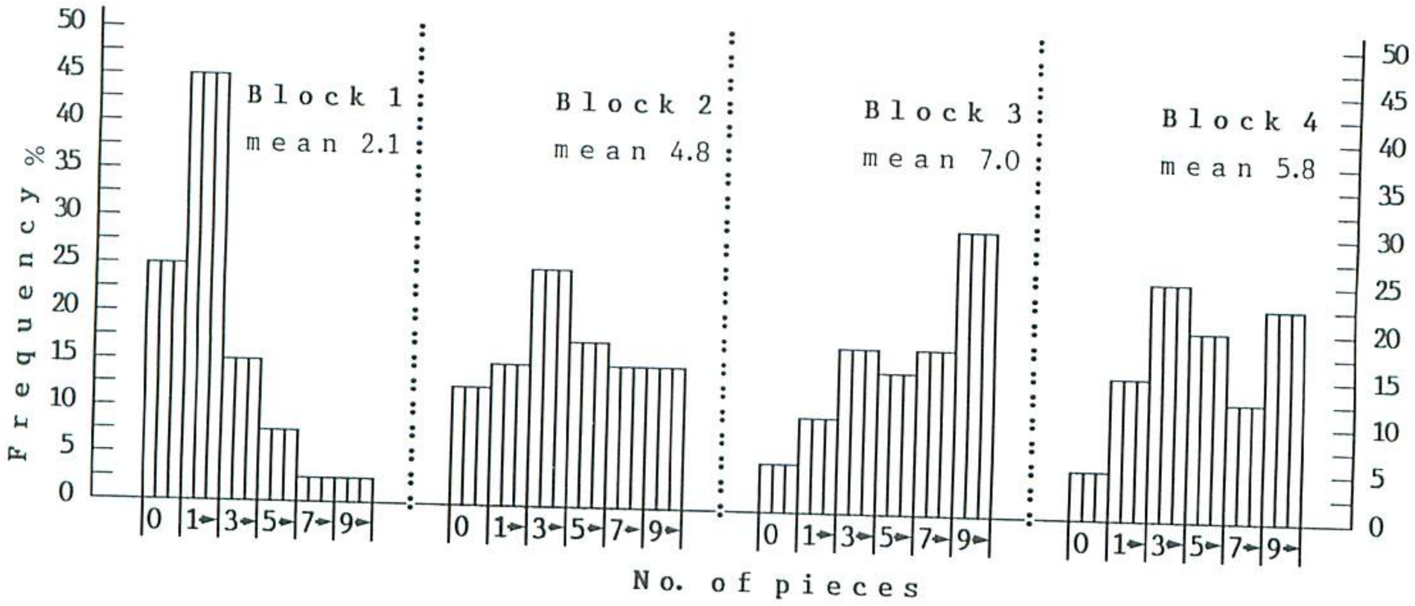

Figure 7. Frequency distribution of the number of pieces of slash per 2 m of lineal tally (for pieces 1-5 cm in diameter).

Stumps, brush, minor vegetation, and residual trees: Block 2, with its higher number of residual trees, had only half the stump density of the other blocks. Stump heights were relatively low in all four blocks (Table 1).

Brush was almost absent in the open areas of each block, but clumps of alder (**Alnus** sp.) grew in association with the residual trees in blocks 1 and 2. Minor vegetation was composed of various ericaceous species, including blueberry (**Vaccinium angustifolium** Ait.), and covered less than 10% of the area.

Residual trees were almost absent in blocks 3 and 4. In Block 1, a pocket of approximately 90 stems/ha (two-thirds poplar, average DBH 30 cm, and one-third white birch, average DBH 26 cm) covered 1.3 ha (26%) of the 5-ha block (Table 1). In Block 2 residual trees were mostly grouped in clusters of almost twice the density of residuals than in Block 1, i.e., 160 stems/ha. The largest trees were mainly poplar (average DBH 26 cm), and the smallest were white birch (average DBH 20 cm).

Work Study

The machine worked during two scheduled shifts per day with two operators. Operator 1 had two years' experience with the machine and worked for most of the trial (20 out of 25 ha, or 80%) while Operator 2 treated almost all of Block 2 and part of Block 4. Operator 2 had experience with the Koehring for harvesting but little with the scarification unit, and as he was hesitant to use second gear, he did his work in first gear. It would have been difficult to use second gear among the residual trees of Block 2 but Block 4 could have been treated in second gear. Block 3, in which the greatest slopes were encountered, was treated in first or second gear, depending on the requirements of specific areas. Block 1 was also treated in first or second gear, depending on whether the machine was operating within or outside the patch of aspen, respectively. On the whole, travel speed was approximately 2.1 km/hr (forward scarification with no stops) in blocks 1 and 3, 1.6 km/hr in Block 2 and 2.5 km/hr in Block 4.

In Block 1, stops were required for cooling down or changing gear in connection with hydraulic and cooling problems; this accounted for 10.8% of PMH (Fig. 8). Maneuvering to treat patches that would be missed because of the use of a concentric-circle pattern of treatment accounted for 6.9% of PMH. The raising of scarifying heads over pushed-down residuals in the patch of residuals accounted for 3% of PMH. Productivity was 1.54 ha/PMH.

In Block 2, the equipment encountered major problems as a result of soft ground, boulders and residuals. A lack of power that resulted from hydraulic system problems caused delays when the prime mover tried to push over isolated large aspen trees and finally had to back up to go around them. The moist or wet soil conditions caused delays for the prime mover that amounted to 18.1% of PMH; over all, obstacles caused delays of 42.6% of PMH (Fig. 8). Productivity was 1.02 ha/PMH, with only 45.7% effective productive time (EPT) and 5.5 furrows/20-m width. Narrower and lighter prime movers and implements would have been affected less by those conditions, i.e., smaller machines could have maneuvered more easily around residuals and would have pushed fewer trees to the ground (where they might impede scarification). Leblanc and Sutherland (1987) reported that light, wheeled

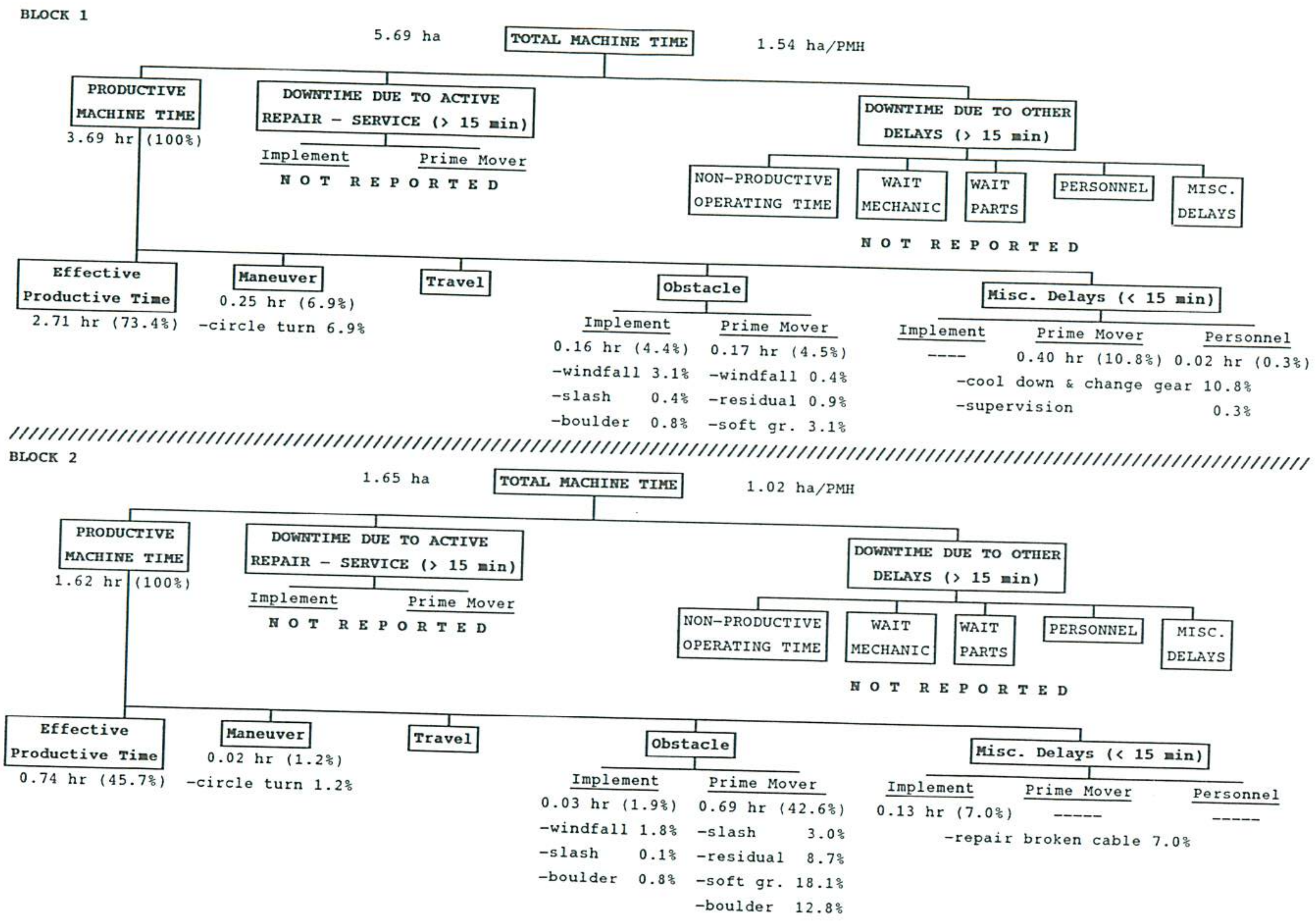

Figure 8. Results of short-term continuous time study in blocks 1 and 2.

skidder-mounted tools achieved an average of eight furrows per 20-m width in residual stands with 120 to 150 stems/ha.

The distribution of time elements was similar among blocks 3 and 4, with 74% EPT and 12-13% obstacle delays (Fig. 9). Maneuvering to treat patches missed as a result of the concentric-circle pattern accounted for 13 and 9% in blocks 3 and 4, respectively. However, it is important to note that the ability to treat these patches is a desirable feature of the unit in comparison with the much less maneuverable tractor/drag or even Koehring/drag scarification units. One minor delay in Block 4 resulted from the repair of restraining cables in the outside arms (arms 1 and 4). Regular inspection of the cables is necessary to ensure that they function properly in maintaining the desired spacing.

Productivity was 25% higher in Block 4 than in Block 3 (2.33 vs 1.79 ha/PMH) because of the steeper slopes in Block 3. The advantage of having an experienced operator was evident in Block 3; it is doubtful that the inexperienced operator would have been very successful in treating the steeper slopes.

Long-term productivity figures provided by CPFP personnel (G.J. Garner, CPFP, Thunder Bay, Ontario, personal communication) are 1.5-1.7 ha/PMH and 1.2 ha/scheduled machine hour (SMH). Long-term productivity for most two-row mechanical disc trenchers or patch scarifiers with a skidder as a prime mover averages from 1.00 to 1.05 ha/SMH[1,2].

Table 2 documents the frequency with which the scarifier's arms had to be lifted by the operator to avoid problems with obstacles. One, two or four arms were raised at one time (raising three arms was very rare). In blocks 1 and 2 only one or two arms were raised to avoid the pushed-down trees where the density of residuals was low. Where the density was higher, four arms were raised together. In Block 3, the major reason for raising the arms was an accumulation of slash. As a result of their counter-rotation and the heavy weight of the long arms that supported them, the cones "burrowed" beneath the slash, causing a buildup of slash in front of the cones. The four arms did not work independently of each other in slash; they acted as a giant rake that dragged a slash pile as wide as the machine up to the point at which the arms were raised to clear the slash accumulation. Lifting of four arms at a time was most common. In Block 4, slash was also the main reason for lifting, but residuals, even if present only occasionally in pockets, necessitated a large number of lifts.

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[1] Fortin, Y. and Pacquet, G. 1985. Reboisement et travaux connexes sur les forêts publiques, statistiques et coûts d'opération 1984-85. Min. Energie Ressour. Qué., Serv. Pépin. Reboise. Rap. intern. 64 p.

[2] Fortin, Y. and Paquet, G. 1986. Statistiques et coûts sur les opérations de plantation et les travaux connexes (Forêts publiques) 1985-1986: Min. Energie Ressour. Qué., Serv. Régén. For. Rap. intern. 58 p.

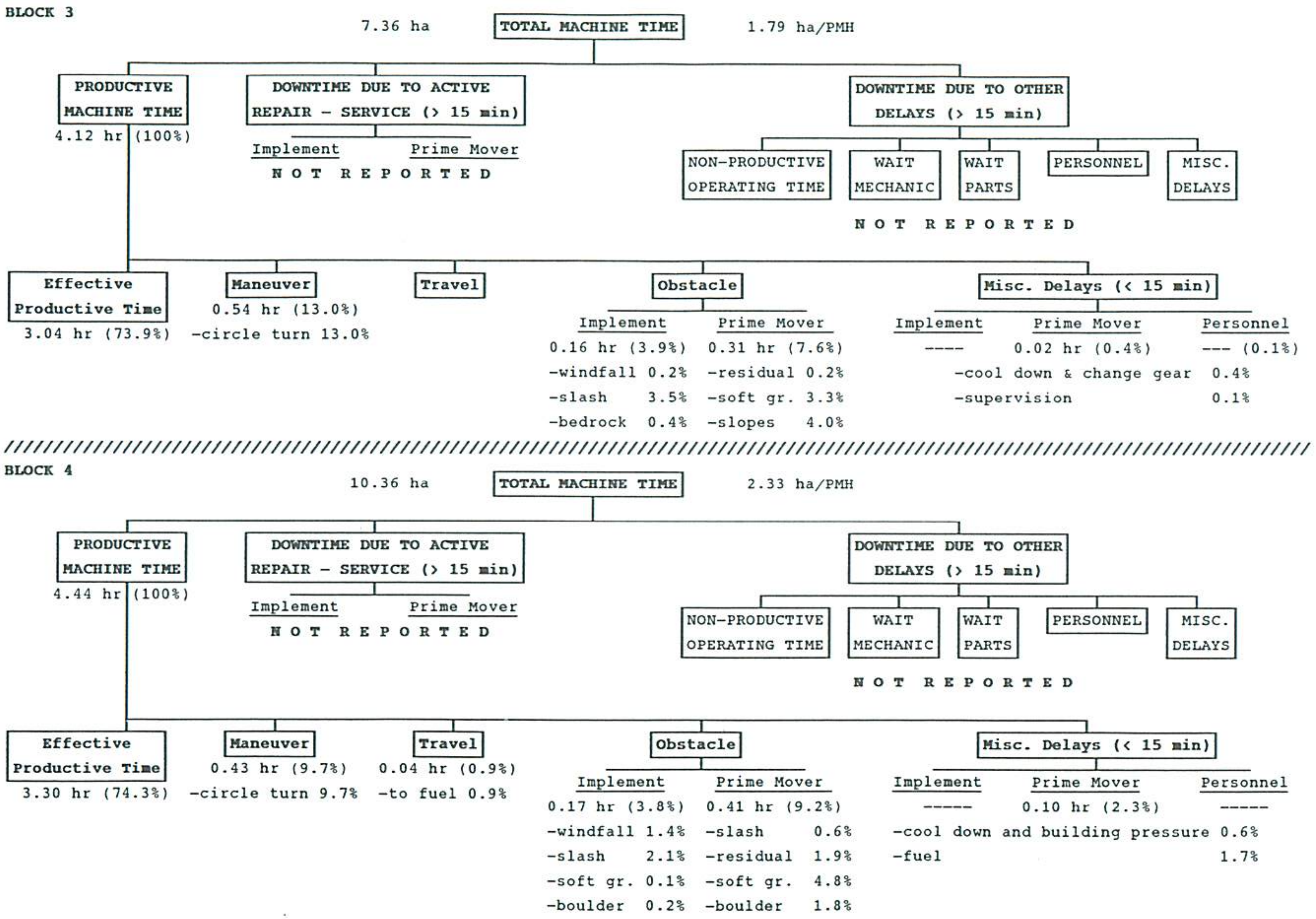


Figure 9. Results of short-term continuous time study in blocks 3 and 4.

Table 2. Frequency of arm lifts as a result of various obstacles.

	Block 1	Block 2	Block 3	Block 4
		(no./ha)		
One arm only				
residual tree	13	2	-	3
conifer slash	2	-	7	2
boulder	-	-	-	-
Arms 1 and 2 or 3 and 4 together				
residual tree	4	6	-	6
conifer slash	1	-	6	3
boulder	-	-	-	-
Four arms together				
residual tree	12	11	-	5
conifer slash	1	2	16	9
boulder	1	1	1	-
Count of individual raises per ha				
residual tree	70	57	3	23
conifer slash	7	10	83	42
boulder	4	2	3	2
total	81	69	89	67

There was no great difference among blocks in the total frequency of individual arm lifts (81, 69, 89 and 67 lifts/ha in blocks 1, 2, 3 and 4, respectively). The lift time was normally longer when a downed residual tree rather than the accumulation of conifer slash necessitated the lift.

Scarification

Furrow characteristics: In blocks 1, 3 and 4, the profile of the furrow was flat, with a slightly higher elevation under the cone-tip side, because stoniness or shallow soil prevented deeper penetration. Furrow depth sometimes approached zero (i.e., ground level). When soil sufficiently deep and relatively free of stones was encountered, there was a well defined side slope of approximately 45°. In all three blocks, the berm was composed of slash and duff. In Block 2, where the mineral soil was deep and moist, a side slope was produced and the berm often contained mineral soil or mineral over duff (Table 3 and Fig. 10).

Use of the same treatment for all sites was necessary because the implement settings had to be preset and could not be varied from the cab during operation. The weight of the cones and their rotation speed ensured that slash and duff were removed and mineral soil exposed under the more

Table 3. Furrow characteristics.

	Block			
	1	2	3	4
Inter-furrow width (cm)	131	265	166	174
Gross furrow width (cm)	107	99	98	96
Net furrow width[a] (cm)	53	40	49	46
Mineral furrow width[b] (cm)	33	25	13	22
Depth of furrow[b] (cm)	17	15	15	10
Berm height[b,c] (cm)	19	13	14	11
Berm angle[b] (degrees)	58	48	54	51

[a] including net width = 0
[b] excluding net width = 0
[c] berm created at the small end of the cone

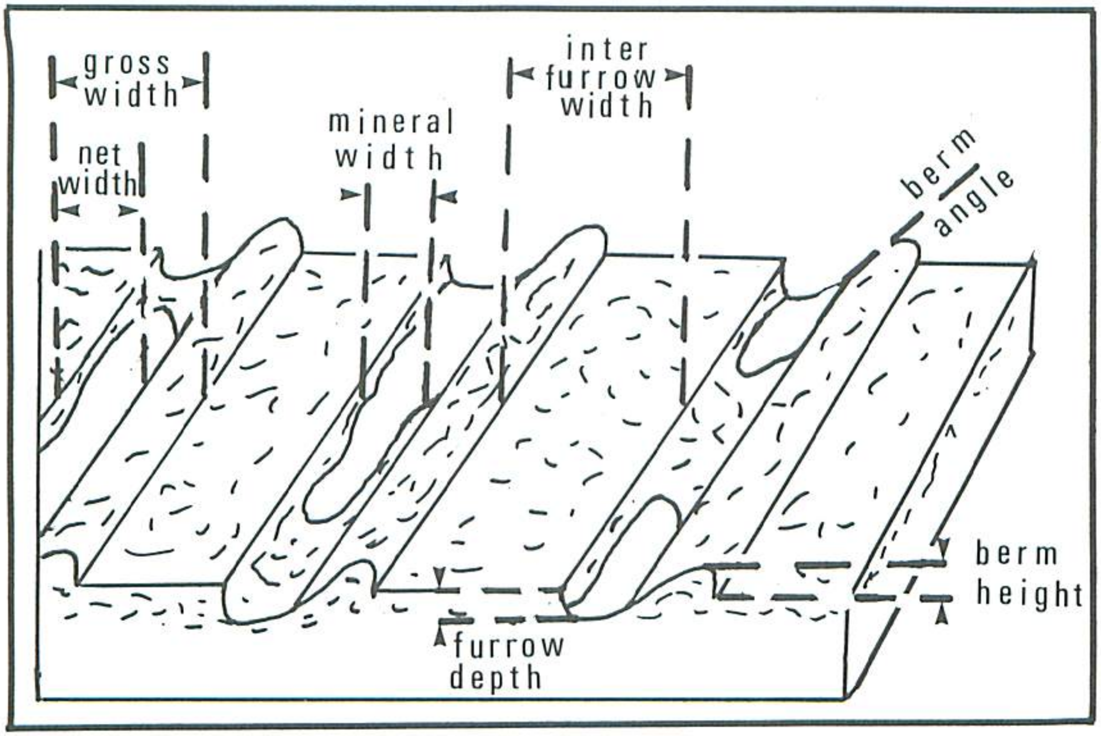


Figure 10. Parameters measured to describe the characteristics of the furrow created by the implement.

difficult conditions in the area. Because the cones operated aggressively, they displaced mineral soil to form a side slope in stone-free soil even if they were set at a flat angle with the ground. The flat cone setting used during the trial was a good choice for the shallow-soil areas because an angled cone setting would have produced a narrower, more discontinuous furrow.

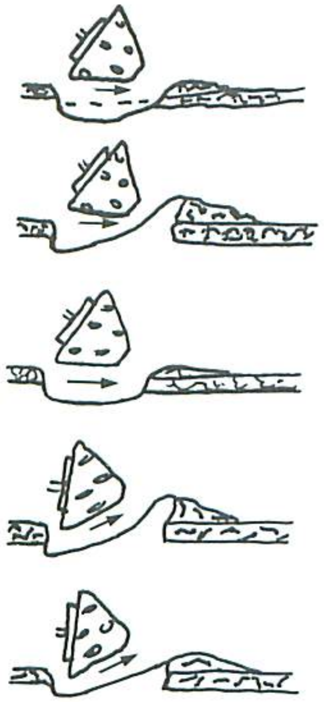
Because the cone angle and rotation speed and the height of the cylinder arm were not varied during the trial, it is difficult to predict the range of furrow types that could be produced by the implement. In any event, if long-term microsite/site-specific information eventually becomes available, it may be advisable to equip future versions of the CPFP scarifier with controls in the cab for cone angle, rotation speed and/or down pressure to enable the operator to achieve a variety of results more easily. Such controls on the Swedish Silva-Wadell cone scarifier increase its versatility. For example, with appropriate adjustments, when the cones were operated in deep soil at a flat angle with the ground, a flat profile could be obtained, in contrast with that obtained by the CPFP scarifier (Adelsköld and Hallonborg 1987) (Fig. 11). Since the trial, modifications to the CPFP scarifier have allowed the amount of pressure on the ground applied by the cones to be changed from the cab during operation.

The forward travel speed of the prime mover was an additional key variable that could affect the degree of disturbance. In stony soil or shallow soil over bedrock (i.e., where cone penetration was restricted), forward speed had little effect on the furrow profiles. However, for the cylinder height used in the trial in the deeper, stone-free or moist soils, the slower the forward speed, the larger the amount of mineral soil moved to the side and the berm.

Operating speeds generally used to maintain an acceptable quality of microsite and mechanical efficiency vary between 3.0 and 3.6 km/hr (forward with no delays) for most skidder-drawn two-row scarifiers (Ryans 1986a). The highest speed achieved in this trial with the CPFP scarifier was 2.5 km/hr in Block 2. It is believed that it would not be realistic to operate at a higher speed, as this would increase the susceptibility of the scarifier to damage or accident. Hence, the range of possible travel speeds is limited and varying travel speed is an impracticable way of controlling scarification. With in-cab control of pressure of the scarifying heads on the ground, added since the evaluation in this report took place, the travel speed can be changed in relation to the operating site conditions because the operator can adjust the pressure to keep the prescribed degree of scarification constant.

Overall disturbance by microsite category and microrelief:

The amount of disturbance created by the scarifier was the result of inter-furrow spacing and the effectiveness of scarification along the furrow. The operators kept the inter-pass spacing tight wherever possible. However, although the restraining cylinders kept the two inner arms at nearly constant spacing despite some lateral movement, they were less effective in restraining the two outside arms. Spacing was tighter (10 furrows/20-m width) only on the corners because of restricted lateral movement of the outer arms when turning.



(1) flat cone angle
shallow and fresh mineral soil

(2) flat cone angle
deep and moist mineral soil

(3) flat cone angle
deep and fresh mineral soil

(4) larger cone angle
deep and moist mineral soil

(5) larger cone angle
fresh mineral soil

Figure 11. Characteristic furrow profiles created by the CPFP scarifier in this trial and by the Silva-Wadell scarifier (3, 4, 5), according to Adelsköld and Hallonborg (1987).

The total amount of mineral soil disturbed was greatest in Block 1. Because exposed bedrock was almost absent (5% by area) and furrow spacing was tightest (8.3 furrows/20-m width), the total surface coverage was 7.9% and the distribution (percentage of the quadrats with at least 1% of their surface covered by the microsite category) was 72% (Table 4). High subsurface stoniness (44%) reduced the amount of disturbed mineral soil but the distribution of this soil was affected to a lesser degree. Exposed mineral soil was most frequently present at the bottom (44%) of the furrows in Block 1 (Table 4), but the distribution of exposed mineral soil on the shallow microrelief and loose mineral soil on the side microrelief were moderately frequent (22%) in Block 1. Block 1 also had the highest berms (Table 3) and the greatest surface coverage (1.9%) and distribution (37%) of mineral soil deeper than 5 cm over organic mounds (Table 4).

In Block 2, mineral soil accounted for only 3.3% of the total, with a distribution of 37%; this was mainly because the equipment had to maneuver around residual clumps and soft ground, producing a density of 5.5 furrows/20-m width. Another reason for the lower disturbance value was the number of residuals pushed over by the prime mover; these obstacles forced the raising and lowering of the heads. The frequency of net furrow width equal to "0 cm" was 20% in Block 2 and 10% in Block 1.

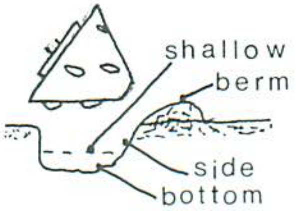
Table 4. Overall soil disturbance created by the implement, by microsite category and microrelief.

		Surface coverage (%)				Distribution[a] (%)			
	Microsite categories	Block 1	Block 2	Block 3	Block 4[b]	Block 1	Block 2	Block 3	Block 4[b]
Plantable and/or seedable	Exposed mineral soil, firm base (bottom)[c]	4.4	1.3	0.9	1.2	44	20	26	20
	Exposed mineral soil, firm base (shallow)	1.8	1.0	0.5	1.2	22	15	12	20
	Loose mineral soil (side < 45°)	1.2	0.3	0.3	0.2	22	5	12	5
	Loose mineral soil (berm)	–	0.4	–	–	–	7	–	–
	Subtotal mineral soil > 5 cm deep	7.4	3.0	1.7	2.6	70	37	42	42
	Mineral soil 1-5 cm deep (bottom-shallow)	0.5	0.3	0.5	0.9	13	5	17	16
	Total mineral soil	7.9 (1.1)[d]	3.3 (1.3)	2.2 (.4)	3.5 (.5)	72	37	49	53
	Mounding (mineral soil on duff) (side or berm)	1.5	0.3	0.2	0.4	25	5	9	7
	Shallow mounding (mineral soil 1-5 cm on duff)	0.3	0.2	0.1	0.1	7	7	7	8
	Total mounding	1.8	0.5	0.3	0.5	37	17	17	16
	Total mix (mineral soil + duff) (bottom)	0.3	0.1	–	0.3	8	3	–	8
	Total duff 1-5 cm on mineral soil	0.3	0.3	0.2	0.2	6	8	8	5
	Total	10.4 (1.3)	4.2 (1.4)	2.7 (.4)	4.5 (.6)	81	42	56	65
Not acceptable	Mineral soil or mix on duff + slash (berm)	0.2	0.1	0.2	0.6	7	3	7	15
	Other not acceptable (duff > 5 cm, bedrock, water etc.)	28.8	13.7	25.4	24.0				
	Total disturbance (implement)	39.4	18.0	28.3	29.1	88	45	71	86
	Number of furrows/20-m width	8.3 (.4)	5.5 (1.3)	7.4 (.5)	8.3 (.4)				

[a] Refers to the proportion of 2- x 2-m quadrats in which the indicated microsite category accounted for at least 1% of the area of the quadrat.

[b] All values in this column were mathematically adjusted from 7.4 to 8.3 to account for breakage of the restraining cable.

[c] Microrelief categories: bottom, shallow < 5 cm below original ground level of the mineral soil, side angle < 45°, and berm.



[d] Values within parentheses are confidence intervals at the 10% significance level.

In comparison with blocks 1 and 2, the total mineral soil disturbed in Blocks 3 and 4 was lower as a result of the higher frequency of bedrock. Although soils were deeper in Block 3 than in Block 4, the 20% more stoniness in Block 3 limited the amount of overall mineral soil disturbance (2.2 vs 3.5% in blocks 3 and 4, respectively) (Table 3).

Slopes of up to 30% (an average of 15%) in Block 3 made it difficult to keep a constant inter-pass spacing and the chronic problem of lateral movement of the arms caused a reduction in the number of furrows (7.4 furrows/20-m width). The distribution of mineral soil (49% in Block 3 and 53% in Block 4) was relatively efficient when the pre-scarification exposure of bedrock and the lower-than-prescribed furrow spacing that was achieved are considered.

The "mounding" and the "duff 1-5 cm on mineral soil" acceptable disturbance categories contributed to less than 1% of the surface coverage in blocks 2, 3 and 4. Although the amount of mineral soil loosened by the turning action of the cones ranged from 0.2 to 1.2%, depending on soil depth, the mixed mineral soil/organic category was almost absent. This was because the organic layer (duff) was shallow and the small quantity of mixture that was produced was pushed aside and loosely scattered in the berm, which normally had a high content of slash. Disturbance caused by the prime mover was greatest in blocks 2 and 3, in which moist ground conditions resulted in rutting (Table 5).

Table 5. Overall soil disturbance created by the prime mover, by microsite category and microrelief.

	Surface coverage (%) in block				Distribution[a] (%) in block			
Microsite category	1	2	3	4	1	2	3	4
Mineral soil	0.3	0.7	0.2	0.3	5	8	2	3
Duff 1-5 cm on mineral soil	0.1	0.1	–	0.1	1	2	–	2
Total acceptable	1.1	0.8	0.2	0.4	6	8	3	6
Not acceptable	2.1	5.9	5.7	1.3				
Total exposure	3.2	6.7	5.9	1.7	8	13	14	8

[a] Refers to the proportion of 2- x 2-m quadrats in which the indicated microsite category accounted for at least 1% of the area of the quadrat.

Puttock and Smith (1986) reported that the Donaren 180D powered-disc trencher obtained 7.2% surface coverage by mineral-soil disturbance with 10 furrows/20-m width under site conditions similar to those in Block 1 of this trial. Mathematical adjustment of the 8.3-furrow width obtained in Block 1 to 10 furrows/20-m width gives 8.9% surface coverage by mineral-soil exposure.

Mechanical disc trenchers and patch scarifiers usually produce less mineral exposure than hydraulically downpressured and/or powered disc trenchers (Fleming 1982, Pyke 1982, Ryans 1982, Hedin 1985, Smith et al. 1985, Puttock and Smith 1986, Ryans 1986b, Gibbard and Sutherland 1987, Leblanc and Sutherland 1987, Sidders[3], Veitch 1987) and, by inference (e.g., the Donaren 180D), probably less than the powered-cone scarifier.

__Plantability along the furrow by microsite category__: The highest number of plantable spots **along the furrow** (84%) was recorded in Block 1 (Table 6). Exposed mineral soil provided 40% of the plantable spots followed by the "duff 1-5 cm on mineral soil" (25%) and "loose mineral soil" (17%) categories. Because of stoniness, the "loose mineral soil on the side" microrelief was of insufficient volume and was not selected as often as the exposed mineral soil between the stones (mainly on the bottom-shallow microrelief) (Table 7). The high percentage of spots in the "duff 1-5 cm on mineral soil (incomplete removal of duff)" category in Block 1 was related to the difficulty of continuously exposing mineral soil as a result of the high subsurface stoniness.

In Block 1, the plantability **along the furrow** was 89% outside the patch of residual trees, but was 66% inside the patch; a similar value (69% plantability) was obtained in Block 2, where the operator avoided the denser clumps of trees so that the residual conditions actually treated by the machine were more or less similar to those in the **residual patch** in Block 1 when plantability along the furrow was considered.

In Block 2, 28% of the plantable spots were on exposed mineral soil, i.e., 12% less than in Block 1. The proportion of plantable spots on loose mineral soil was 21%, i.e., 4% more than in Block 1. The relatively high percentage of spots in the "duff 1-5 cm on mineral soil" category (17%) was related to very light disturbance by the cones when downed residuals were residuals were under the arms. In all, Block 2 had 15% fewer plantable spots along the furrow than Block 1, mainly as a result of downed residuals.

Plantability **along the furrow** was 61% in Block 3 but only 39% in Block 4. Plantability in exposed mineral soil was 29% in Block 3 and 13% in Block 4. Plantability in the loose mineral soil category, on the side of the furrow, represented only 9% in Block 3 and 10% in Block 4; i.e., cultivation was restricted by stoniness and shallow soils.

The situation in Block 3 was similar to that in Block 1 in that it was easier to plant between the stones on the bottom-shallow microrelief than on the side. In Block 4 and in parts of Block 3, shallow mineral soil was the major reason for the small number of plantable spots. As well,

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[3] Sidders, D. 1987. Pre- and post-data analysis, powered disc trencher trial, 1986-87 Dore Mountain Camp 2. Canada-Saskatchewan Forest Resource Development Agreement. Gov't of Can., Can. For. Serv. Intern. Rep. 50 p.

Table 6. Plantability along the furrow, by microsite category.

Microsite category	Block 1 (%)	Block 2 (%)	Block 3 (%)	Block 4 (%)
Exposed mineral soil	12	15	7	1
Exposed mineral soil (stones or bedrock)[a]	28	13	22	12
Subtotal (exposed mineral soil)	40	28	29	13
Loose mineral soil	3	9	3	1
Loose mineral soil (stones or bedrock)[a]	14	12	6	9
Subtotal (loose mineral soil)	17	21	9	10
Total mineral soil	57	49	38	23
Total mound	1	3	1	1
Total duff 1-5 cm on mineral soil	26	17	22	15
Total plantable spots	$\boxed{84}$	$\boxed{69}$	$\boxed{61}$	$\boxed{39}$
Total shallow mineral soil	2	3	5	13
Total stones-bedrock	1	1	1	
Total mixed on slash + duff		3	1	1
Total shallow mound		1	1	2
Total conifer slash pile	4	4	9	12
Total pushed-down residuals	3	3		
Total duff 1-5 cm on 1-5 cm mineral soil	1	3	2	6
Total duff > 5 cm on mineral soil	5	14	20	26
Total non-plantable spots	$\boxed{16}$	$\boxed{31}$	$\boxed{39}$	$\boxed{61}$

[a] "Stones or bedrock" indicates that the mineral soil is not deeper than 35 cm on those plantable spots.

slash accumulation under the arms reduced the amount of mineral-soil exposure in blocks 3 and 4, and this resulted in the high percentage of spots in the "duff 1-5 cm on mineral soil" category. Piles of conifer slash created by the raking action of the cones were partly responsible for the fact that 9% of the spots in Block 3 and 12% in Block 4 were not plantable (Table 6). The loss of plantable spots occurred from the point at which the cones were raised until they contacted the ground again (approximately 2.6 m). The arms could not be dropped fast enough (for fear of damaging the heads) or were not raised often enough; these factors forced the operator to raise the arms higher and for a longer period, to clear a greater accumulation of slash.

Table 7. Percentage of plantable and non-plantable spots, by microrelief and microsite category along the furrow.

Microsite category	Block 1 (%)	Block 2 (%)	Block 3 (%)	Block 4 (%)
Subtotal, exposed mineral soil	89 bo-sh[a] 11 side	93 bo-sh 5 side	95 bo-sh 4 side	86 bo-sh 14 side
Subtotal, loose mineral soil	22 bo-sh 73 side	7 bo-sh 70 side 23 berm	17 bo-sh 83 side	26 bo-sh 60 side
Total mineral soil	73 bo-sh 27 side	55 bo-sh 34 side	77 bo-sh 23 side	61 bo-sh 34 side
Total duff 1-5 cm on mineral soil	22 side	15 side	7 side	10 side
Total plantable spots	77 bo-sh 21 side 2 berm	60 bo-sh 28 side 12 berm	82 bo-sh 16 side 2 berm	68 bo-sh 26 side 6 berm
Total non-plantable spots	72 bo-sh 23 side 5 berm	77 bo-sh 8 side 15 berm	83 bo-sh 6 side 11 berm	78 bo-sh 8 side 14 berm

[a] bo-sh = bottom-shallow

Most of the plantable spots were on the highest point within the bottom-shallow microrelief, usually on the edge of the furrow; i.e., 70-80% of the spots in blocks 1, 3 and 4. In Block 2 this proportion was reduced to 60% because of the greater availability of side and berm microrelief than in the other blocks (Table 7).

For the achieved furrow densities and plantable disturbance created along the furrows, plantability was 1850, 1000, 1200 and 750 plantable spots/ha in blocks 1 through 4, respectively.

SUMMARY AND RECOMMENDATIONS

The CPFP powered-cone scarifier, mounted on a converted Koehring shortwood harvester, was assessed on sites with deep, stony soil or shallow soil over bedrock or subsurface boulders; on residual-free sites or those with moderate to dense residuals; and on sites with light to moderately thick conifer slash and slopes of up to 30%.

On the basis of a short-term study, the productivity of the scarifier ranged from 1.0 to 2.3 ha/PMH. Long-term productivity figures provided by CPFP were approximately 1.5-1.7 ha/PMH and 1.2 ha/SMH.

The cone angle was set so that the side surface was flat on the ground. With relatively high subsurface stoniness and shallow soil on bedrock, the typical furrow profile generally had a flat bottom. In deeper mineral soil, a well defined side slope with an angle less than 45° was created on the side of the furrow nearest the cone tip. The berm was generally composed of duff and slash in shallow mineral soil, but was occasionally mostly mineral soil or mineral soil on duff in areas with deep mineral soil.

Exposed and loose mineral soil were the main acceptable categories of disturbance and plantable microsite created by the implement. The largest amount (7.9%) and best distribution (72%) of exposed mineral soil and the highest plantability along the furrow (57%) in the mineral soil categories were achieved in deep soils free of residual trees, and of less than 50% stoniness.

Unscarified furrows occurred when residual trees were pushed down by the prime mover. Wider furrow spacing resulted when residual clumps were avoided instead of being pushed down. The amount (3.3%) and distribution (37%) of exposed mineral soil, and plantability along the furrow (47%) in the mineral soil categories, were less when the unit faced site conditions characterized by excessive numbers of residual trees.

Shallow to very shallow soil, in combination with low to high stoniness, exposed bedrock and/or slash accumulation under the arms, severely limited the ability of the heads to prepare exposed and loose mineral soil (surface coverage of 2.2 to 3.5%, distribution of 50%, and plantability along the furrow between 23 and 38%). However, because of the flat angle setting of the cone, the implement was able to create furrows of exposed mineral soil of an acceptable width, and this can be considered desirable seedbed preparation in shallow mineral soil.

A high percentage of spots had to be located in slightly (1-5 cm, plantable) or moderately (>5 cm, nonplantable) disturbed duff on mineral soil because stoniness, downed residual trees and slash under the arms prevented the cones from digging deeper into the ground.

In deep, stony soil, and in shallow soil, most available plantable spots were located in the bottom of shallow furrows (70-80%). In deep, moist and mostly stone-free soil, plantable spots were located in the bottom of the furrow (60%) and the side slope and berm of the furrow (40%) microreliefs.

Furrow spacing ranged from 5.5 to 8.4 furrows/20-m width, whereas the prescribed average spacing was 9.5 furrows/20-m width. Inter-pass spacing was lowest during operation in dense residuals and moist soil, areas that possibly could be avoided and treated with lighter and narrower machines. Where trees were less dense and more evenly distributed, the machine functioned adequately; however, residuals generally had to be pushed over because of the width of the machine, and this resulted in ground obstacles that interfered with the production of plantable microsites. As well, inter-furrow and inter-pass spacings were generally wider than those prescribed because of the failure of the restraining controls on the outer arms to maintain tracking.

Desirable features of the implement and prime mover include the ability to maneuver into and treat areas that would be left untreated by drag scarifiers, good productivity, ability to penetrate slash, ability to prepare seedbed in shallow mineral soil (with a flat angle setting for the cones), ruggedness of the scarifier on rocky sites, stability on steep slopes and good ergonomic design.

Some problems that have been identified include the need to improve spacing by improving the tracking of the outer arms. The rakelike accumulation of slash in front of the cones and its deposition in piles reduced plantability along the furrow by approximately 10%. It is not clear to what degree this offsets the slash-penetrating ability of the cones. The pushing down of residual trees as well as moist-to-wet ground conditions forced the raising of the arms and resulted in unscarified ground. Residual stands should be avoided and possibly treated with lighter, narrower machines. The CPFP scarifier should be used in open areas where its desirable features can be used to best advantage.

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APPENDIX A. TECHNICAL DATA FOR THE SCARIFIER AND PRIME MOVER

POWERED-CONE SCARIFIER

cone diameter: 1067 mm at top, 152 mm at bottom
cone length: 533 mm (center axis)
cone weight: 1430 kg
number of fins per cone: 18
length and thickness of fins (new): 76 mm x 25 mm
hydraulic motor on each head: Char-Lynn 10000 (5710 cm^3 displacement)
two dual hydraulic pumps, 109 L/min for each head at 1200 rpm
cone angle adjustment: manual
scarifier directly mounted
two gears provide 4:1 reduction from hydraulic motor to cone (52 rpm freeload)
arm length: 3658 mm (trial 1985), 3048 mm (1987)
cabin controls for raising arms
pressure release if turning resistance of the cone becomes too high

PRIME MOVER (KOEHRING K3HB SHORTWOOD HARVESTER)

Specifications

overall length (less implement): 10240 mm
(with implement): 15764 mm
overall width (less implement) (953 mm x 991 mm tires): 4725 mm
(less implement) (1105 mm x 991 mm tires): 5030 mm
(with implement): 6452 mm
height (over cabin protectors): 4572 mm
ground clearance: 865 mm
wheelbase: 5335 mm

Power and drive train

engine: Cummins NTA 855 - 243 kW
drive: variable displacement pumps and motors with four-speed gearbox, double reduction differentials and planetary wheel hubs both front and rear
travel speed: 0.8 to 5.6 km/hr

Hydraulic system

reservoir capacity: 820 L
total system capacity: 1000 L
cooling: separate oil cooler and fan with cold-temperature bypass
pumps: two gear pumps

APPENDIX B. DEFINITION OF TIME STUDY ELEMENTS[a]

Definition of Long-term Study Time Elements

TOTAL MACHINE TIME: The sum of Scheduled Machine Hours and Overtime. It is the time associated with the machine for a given shift.

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

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

ACTIVE REPAIR/SERVICE: Repair consists of mending or replacement of parts as a result of failure or malfunction. It includes modifications or improvements to the machine, and routine and preventive maintenance performed to ensure that the machine is in satisfactory operating condition.

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

NON-PRODUCTIVE OPERATING TIME: The portion 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 MECHANICS: The portion of in-shift time during which the machine is broken and is not under repair because of the unavailability of mechanics.

WAITING FOR PARTS: The portion of in-shift time during which the machine is broken and is not under repair because of the unavailability of parts.

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

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[a] Definitions are based on those reported in Folkema et al. (1981) and Smith et al. (1985).

Definition of Short-term Study Time Elements

The PMHs recorded during 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. Does not include delays.

MANEUVER (TURN): Occurs from the time the scarifier has finished a pass until the scarifier begins the next pass. This element may include raising the implement from the ground, turning and then lowering the implement.

OBSTACLE DELAY: Occurs from the time the scarifier stops (or scarifies over an area already scarified) because of an obstruction until scarification resumes.

TRAVEL: Is the time spent a) traveling in the block or to the roadside between breaks, and b) on repairs. It includes traveling (if $\leq$15 min) between sites.

MISCELLANEOUS DELAYS ($\leq$15 MIN): Same as delays >15 min but includes those times $\leq$15 minutes. Short-term delays are part of productive machine time whereas delays >15 minutes are not considered part of productive time.