EVALUATION OF THE TETRA MULTIFUNCTIONAL SEMI-AUTOMATIC TREE PLANTER ON TWO SITES IN QUEBEC

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ABSTRACT

The Tetra multifunctional semi-automatic tree planter was evaluated on a full-tree logged site near Senneterre, and on a conventional tree-length logged site near La Sarre, Quebec. Overall, the proportion of trees in the "acceptable" planting quality class was 35% and 52% at Senneterre and La Sarre, respectively. The theoretical potential for planting (plantability) was slightly better, with proportions of 46% and 58%, respectively. Inadequate scarification was identified as the primary cause of unsatisfactory planting results. Modifications to improve the scarification process employed by the Tetra should result in a dramatic improvement in planting quality. Productivity was assessed at 0.36 ha (or 640 trees) per productive machine hour (PMH) at Senneterre and 0.46 ha (or 1259 trees) at La Sarre. When expressed in terms of effective productive hours (EPH), productivity increased to 0.56 ha or 962 trees/EPH for Senneterre and 0.56 ha or 1423 trees/EPH for La Sarre. When only acceptably planted seedlings are considered, planting rates decline to 324 trees/EPH at Senneterre and 655 trees/EPH at La Sarre.

RÉSUMÉ

La planteuse semi-automatique multifonctionnelle Tetra a été évaluée sur un terrain exploité par arbres entiers près de Senneterre et sur un terrain exploité de façon classique par troncs entiers près de La Sarre, au Québec. La pourcentage global de plantation acceptable a été de 35% à Senneterre et de 52% à La Sarre. La plantabilité (le potentiel théorique de plantation) était légèrement supérieur, soit de 46 et 58% aux deux endroits respectivement. Une mauvaise scarification a été jugée la principale cause des résultats insatisfaisants obtenus. Des modifications visant à améliorer la méthode de scarification employée par la machine Tetra devraient permettre une amélioration considérable de la qualité de plantation. La productivité a été évaluée à 0,36 ha ou 640 arbres par heure-machine productive (HMP) à Senneterre et à 0,46 ha ou 1 259 arbres par heure-machine productive à La Sarre. La productivité par heure effective de production (HEP) est plus élevée, soit de 0,56 ha ou 962 arbres à Senneterre et de 0,56 ha ou 1 423 arbres à La Sarre. Si l'on considère seulement les plants bien plantés, la productivité n'est plus que de 324 et 655 arbres/HEP respectivement.

TABLE OF CONTENTS

INTRODUCTION

During the summer and fall of 1986, a limited evaluation of the Tetra multifunctional semi-automatic tree planter was conducted at two locations in the province of Quebec, one near Senneterre and the other near La Sarre. The evaluation was based on the Standard Assessment Procedure (SAP) developed by the Canadian Forestry Service, and consisted of a pretreatment assessment of site conditions, a time study of equipment operation and a post-treatment assessment of planting and scarification quality (Sutherland 1986).

LOCATION AND SITE DESCRIPTION

The Senneterre study area is located approximately 50 km northeast of Senneterre in Canton Doussin-1, and the LaSarre study area is located approximately 42 km northeast of LaSarre in Canton Carqueville (Fig. 1). Both areas are in the Abitibi Temiscamingue administrative region No. 8.

The Senneterre test block consisted of a fresh loamy sand, flat to gently rolling, with surface and subsurface boulders characteristic of morainal deposits in the boreal (Gouin Sec. B3) forest region (Rowe 1972). The area was full-tree logged in the summer of 1980 with mechanical limbing at roadside. Site disturbance from logging was negligible. Prior to harvesting, the site supported a mixed softwood stand of black spruce *(Picea mariana* [Mill.] B.S.P.) and jack pine *(Pinus banksiana* Lamb.) (Fig. 2).

The La Sarre test block was characterized by flat topography, was stone free, and had a moist, silty clay soil characteristic of lacustrine deposits in the boreal (Northern Clay Sec. B.4) forest region (Rowe 1972). The area was harvested in the summer of 1985 by means of a conventional tree-length operation with limbing at the stump. Site disturbance from logging was again negligible. Prior to harvesting, the site supported a mixed softwood stand of black spruce and jack pine (Fig. 3).

PLANTER AND PRIME MOVER

General Description

The Tetra multifunctional semi-automatic tree planter is a two-row, continuously advancing dibble planter[1] for container seedlings that

[1] Mechanical planting principle described by Lawyer, J.N. 1978. Analysis of mechanized systems for planting trees for reforestation. Univ. Calif., Dep. Agric. Engin., Davis. 244 p. (unpubl.)

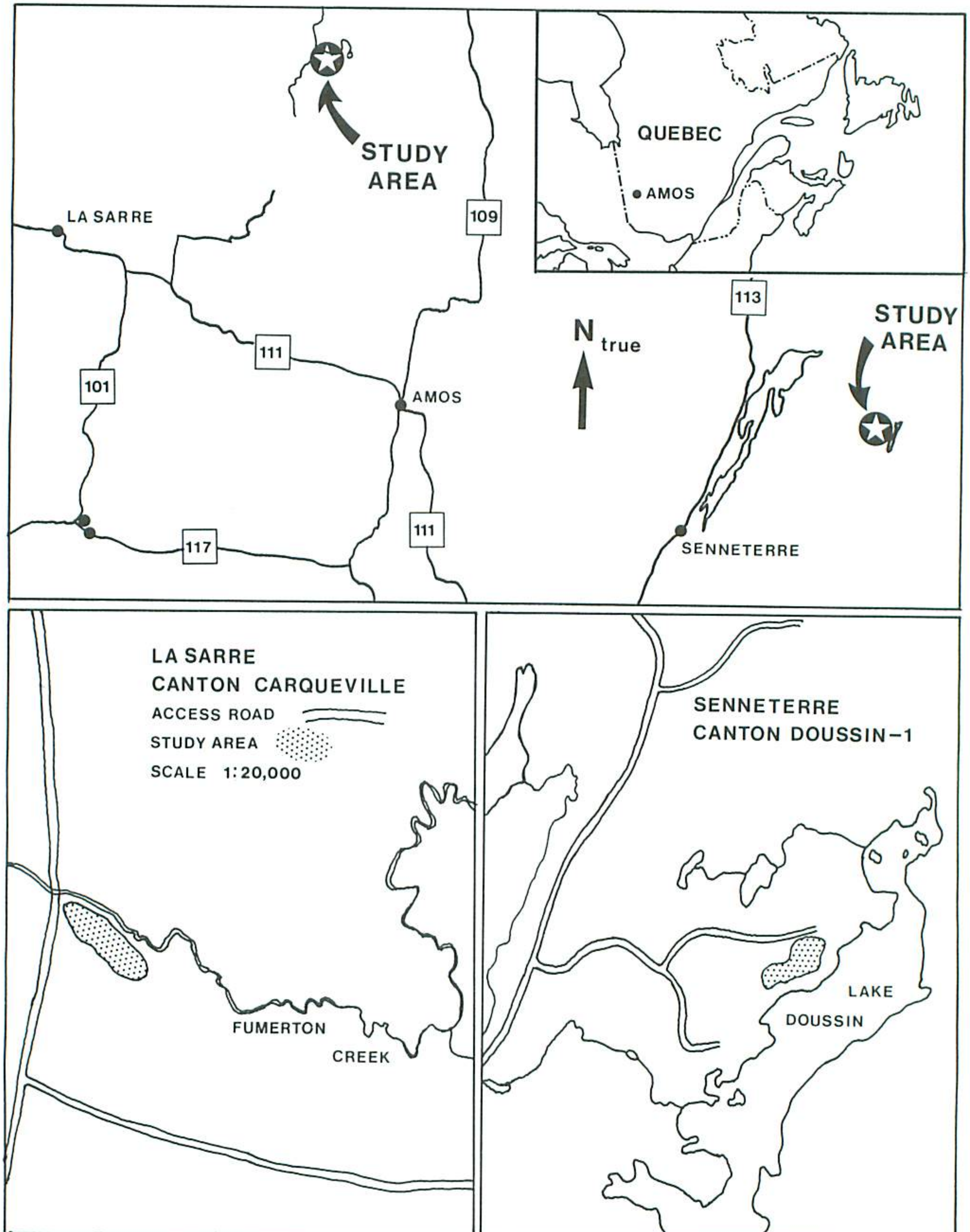

Figure 1. General location of La Sarre and Senneterre study areas.

Figure 2. Senneterre test block.

Figure 3. La Sarre test block.

combines scarification and planting in one operation. Imported into Canada from Finland as the Serlachius automatic tree planter in 1985 by Équipements Denis Inc. of St. Hyacinthe, Quebec, the unit was mounted on a Bombardier Valmet BT-12 forwarder (Fig. 4), and tested [2,3,4] in New Brunswick and eastern Quebec to evaluate its possible use, under a variety of site conditions, for planting IPL 45 and IPL 67 containers (similar to Multipot and CanAm containers). As a result of these tests, modifications were made to the planter and feed system during the winter of 1985. It was renamed the Tetra multifunctional semi-automatic tree planter, and the major changes involved removing and simplifying some electronic controls, replacing existing hydraulic components with more commonly available hydraulics, rebuilding the planting heads, and converting the fully automated tree-feed system to a semi-automatic manually fed system.

The Scarifying and Planting Cycle

Appendix A provides technical specifications for the planting machine components. The tree planting unit is mounted on the rear chassis of the forwarder, and the scarification equipment (developed specifically for this planter) is attached to a frame ahead of the bogie (Stjernberg 1985). Two operators are required: one to operate the prime mover and one to handle seedlings and load them into the rotating carousels (i.e., one carousel for each planting head). A diesel power plant located in the planting unit provides power via hydraulic pumps to the planter and scarifier components.

The scarifiers, on each side of the machine, consist of two driven discs (with teeth) that produce a continuous planting bed ahead of the planting device (Fig. 5). Mounted on pendulum-type arms on a horizontal axle, the discs exert downward pressure by their weight only. The arms can be lifted by hydraulic cylinders (Fig. 6). Each of the four discs can be operated at two different speeds in both directions. The first (or largest-diameter) disc removes logging debris and the second disc forms the planting bed, which consists of an inverted humus layer with mineral soil on top (Fig. 7). The bogie wheels then pass over the bed and compress the overturned layer to provide the final planting microsites.

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[2] Arsenault, J. and Brunelle, A. 1986. Rapport sur les essais de la planteuse Tetra. (Report on the trials of the Tetra planter). Ministère de l'Energie et des Ressources du Québec. Région Bas-St-Laurent-Gaspésie. Unité de Gestion 13, Baie-des-Chaleurs. 68 p. (unpubl.)

[3] Côté, B. and Gendron, N. 1986. Essai de la planteuse mécanique de plants en contenants "Tetra" dans le Grand-Portage (1985). (Report on the mechanical treeplanter for containers, Tetra). Ministère de l'Energie et des Ressources du Québec. Région Bas-St-Laurent-Gaspésie. Unité de Gestion 11, Grand Portage. 23 p. (unpubl.)

[4] Frechette, L. and Côté, F. 1986. Plantation mécanique avec la planteuse "Tetra", Region 04. Ministère de l'Énergie et des Ressources, Trois-Rivieres, Region 04. 8 p. (unpubl.)

Figure 4. Tetra multifunctional semi-automatic tree planter mounted on a Bombardier BT-12 forwarder.

Figure 5. Scarifying discs operating.

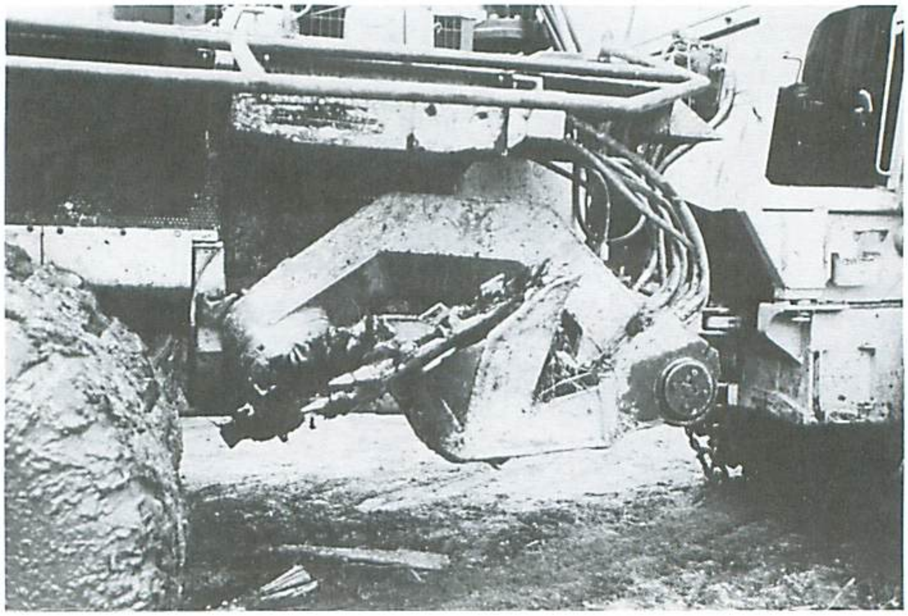

Figure 6. Scarifying arms in a raised position.

Figure 7. Disc configuration.

The planting cycle begins with the two rotating carousels, which are loaded manually in a continuous process by the planter operator (Fig. 8). These feeder or reserve carousels each contain 44 cavities and rotate on a table to release one seedling at a time to the transfer system. Synchronization of the carousel with the remainder of the planting cycle is fully automatic. The transfer system consists of a chain conveyor that is indexed by a photocell located at the lower end. A seedling is held at this position for transfer to the planting mechanism.

Each planting mechanism moves on rollers along a pair of bars mounted on a guide at the rear of the planting unit (Fig. 9). During the actual planting of a seedling, the planting devices are stationary on the ground while the prime mover continues forward. The devices are then pulled back along the bars by a chain drive while still in contact with the ground. The devices can be lifted for turns and are set to lift automatically if the forward pull exceeds a certain preset limit, as could occur during contact with large obstacles such as stumps or boulders. The bar guides are attached to the rear of the prime mover to allow lateral movement of the planting mechanism. This helps to isolate the planting device from the prime mover when they encounter rough terrain.

The planting mechanism consists of a square tube that is pressed downward by a hydraulic cylinder. A pair of wedge-shaped jaws (hydraulically operated) is attached to the bottom of this tube (Fig. 10). When closed, they take the shape of a blunt chisel that creates the planting hole. When opened, they allow the seedling to fall into the hole. The seedling is placed at the proper depth by two pushing arms located inside the planting head tube. The compaction of the microsite around the seedling is accomplished by two flaps, one on each side of the planting head tube.

Two sensors located on either side of the planting tube are used to control planting depth and assess the density of the planting substrate. Both are activated by the packing flaps. Planting depth is established by deflection of a flap as the planting tube and dibble are extended from the planting head into the ground. If the packing flap is not deflected sufficiently, as in the case in which the dibble strikes a hard object or soft mud, then the planting attempt is aborted. To sense the planting substrate, a second spring deflector coupled with a preprogrammed computer memory reads the density (mechanical resistance) of the substrate. The computer either rejects the substrate as being too hard or too soft and aborts the attempt or it accepts the substrate and allows completion of the planting cycle.

A sensor on the drive shaft of the prime mover gives the signal for planting at a preselected distance. If the planting cycle is not completed the machine then makes additional attempts until a successful planting is accomplished. Any potential increase in distance between plants is automatically compensated for by planting the next seedling a shorter distance away. A planting cycle takes approximately three seconds (Stjernberg 1985).

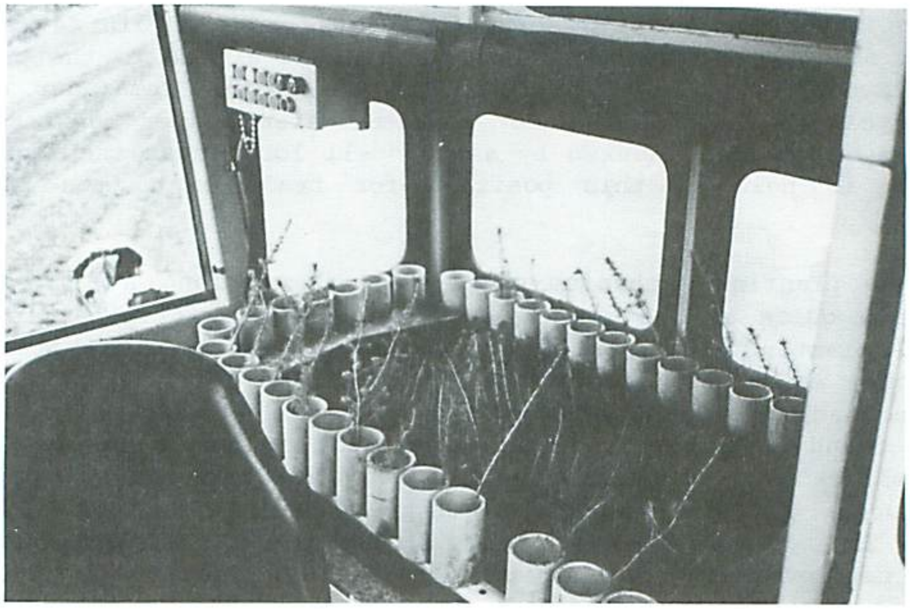

Figure 8. Rotating feed carousels in cab.

Figure 9. Planting mechanism on guide bars.

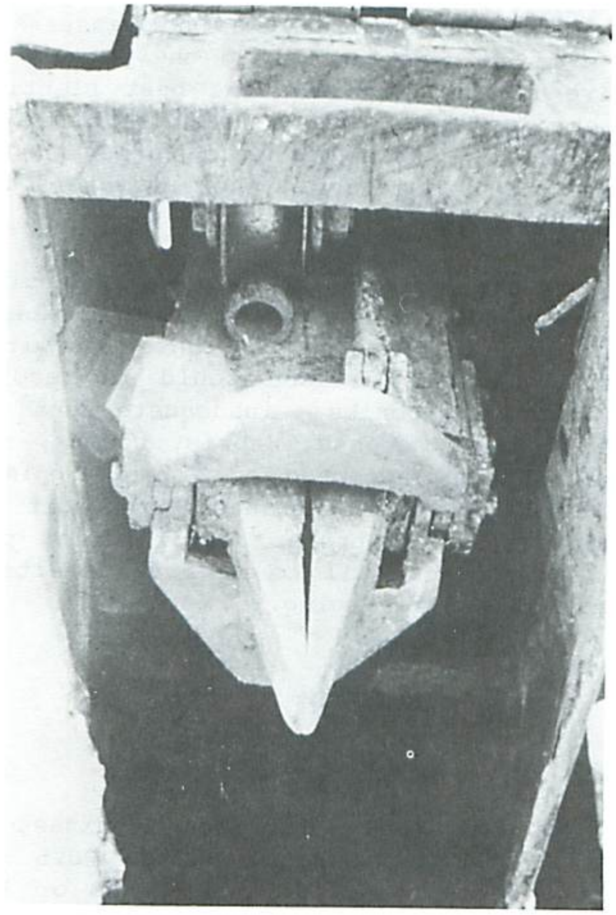

Figure 10. Planting jaws (dibble) and packing flaps.

METHODS

The SAP provides a description of the pretreatment assessment, time study and post-treatment assessment. In the post-treatment assessment the planting job performed by the Tetra was assessed for planting quality and plantability. The actual quality of each planting attempt made by the Tetra along a series of 40-m strips was rated according to a list of parameters specified in Appendix B. In addition to the physical parameters of planting depth and compaction, the quality of scarification at each plant location was rated as to microsite category[5] (Appendix C). The spacing between planting attempts was also recorded.

Along the same 40-m strips used for planting quality the potential for planting (plantability) was assessed within the path followed by the planting head and involved rating microsites on the basis of the quality of scarification and according to whether there was microsite penetration by a handplanting tool. This tally was separate from that of planting quality and was based on a prescribed spacing of 2 m between

[5] refers to a soil/duff modification description

trees (plus or minus 0.4 m) or 2,500 trees/ha, as specified by the province. The entire scarified furrow width was not assessed because the planting head was in a fixed position behind the prime mover and hence did not test the entire furrow width for the best planting microsite. The method of assessment employed in this trial involved evaluation of the potential for planting by the Tetra head rather than the overall plantability of the entire furrow width. The parameters for plantability are listed in Appendix B.

Finally, one of the primary goals of conducting the Tetra assessment was to identify reasons for unsatisfactory planting quality, i.e., either of "fair" quality, improperly planted or with trees missing. A primary and a secondary reason could be recorded for each attempt under the following categories: inadequate depth of scarification, caused by either bedrock, stones, debris, stumps, roots, duff or unknown factors; planting head accepted an improper planting medium, i.e., bedrock, roots, stumps, debris, stones, soil soft and too deep, duff, hard clay, or others; and improper scarification process, which occurs when the scarifying discs fail to make an inverted humus layer with 2 cm or more of mineral soil capping.

RESULTS

Pretreatment Assessment

The presence of surface and subsurface stoniness at Senneterre limited average mineral soil depth soundings to 20.5 cm (Table 1). Approximately 32% of the depth soundings were 10 cm or less at Senneterre. All depth soundings at La Sarre were ⩾ 30 cm; however, the compact silty clay soil was difficult to penetrate and could pose a problem to hand planters during periods of low soil moisture (Fig. 11).

Table 1. Average soil and ground conditions.

	Mineral soil depth[a] (cm)	Duff depth (cm)	Stoniness (avg % areal coverage)[b]	Ground roughness class
Senneterre	20.5 (1.5)[c]	8.7 (.56)	29	1 (2%)[d]
La Sarre	35.0[e]	14.6 (.68)	0	1

[a] measured to a maximum depth of 30 cm of mineral soil
[b] proportion of quadrats in which the presence of surface or subsurface stones (up to a depth of 30 cm) is detected with the soil probe (assessed at same time and location as mineral soil depth)
[c] Values within parentheses are confidence intervals at the 10% level of significance.
[d] % occurrence on 40% of the sample
[e] depth of mineral soil exceeded 30 cm on majority of soundings

Ground roughness is one aspect of terrain difficulty that can be used to determine machine trafficability and is based on the height/ depth and frequency of obstacles on the site such as stumps and boulders. Classes range from 1 to 5 in ascending order of severity. The ground roughness for both Senneterre and La Sarre averaged class 1 (Table 1), which is described as a very even ground surface. However, at Senneterre, the presence of surface boulders resulted in a class 2 (intermediate) rating on 40% of the area sampled.

Average duff[6] depth was greater at La Sarre (14.6 cm) than at Senneterre (8.7 cm). The distribution of duff depths shown in Figure 12 indicates that La Sarre had a higher proportion of readings (85%) in the 6- to 20-cm range than did Senneterre, where 70% of the readings fell within the 1- to 10-cm range.

Slash depth averaged 3.4 cm at Senneterre and 9.2 cm at LaSarre (Table 2). Figure 13 shows the distribution of slash depth readings, which indicates that there was no slash depth to record on 65% of the sampled area at Senneterre. As with slash depth, the number of slash pieces per 2 m of linear length of sample and slash volume was higher at La Sarre than at Senneterre. The distribution of the number of slash pieces > 5 cm per 2 m (Fig. 14) indicates that 74% of the quadrats at Senneterre and 57% at La Sarre contained no large slash pieces. This was also reflected in slash volume, in which the distribution of slash volumes > 5 cm showed no volumes on a majority of quadrats (Fig. 15). At La Sarre, 41% of the quadrats had a slash count of 6-10 pieces per 2-m quadrat in the ⩽ 5-cm category and an additional 39% had a count of 1-5 pieces per 2-m quadrat in the ⩽5-cm category (Fig. 16). At Senneterre, 74% of quadrats contained from one to five pieces of small-diameter slash.

Average slash diameter in the > 5 cm-category, and the distribution of diameters was similar on the two sites, with the majority of slash in the 6- to 10-cm diameter class (Fig. 17).

Table 2. Slash.

	Pieces per 2 m of linear tally		Diameter	Depth	Volume		
	1-5 cm (no.)	>5 cm (no.)	Avg >5 cm (cm)	Avg (cm)	Avg 1-5 cm (m³/ha)	Avg > 5 cm (m³/ha)	Total vol (m³/ha)
Senneterre	1.8 (.21)[a]	.32 (.05)	8.3 (.85)	3.4 (.47)	3.8 (.30)	20.4 (1.9)	24.2
La Sarre	6.7 (.28)	.54 (.06)	9.3 (.41)	9.2 (.63)	13.7 (.59)	34.4 (5.2)	48.1

[a]Values within parenthesis are confidence intervals at the 10% level of significance.

6 This refers to the uppermost organic horizons in a soil profile and is made up of litter, fermentation and humus (L, F, H) layers.

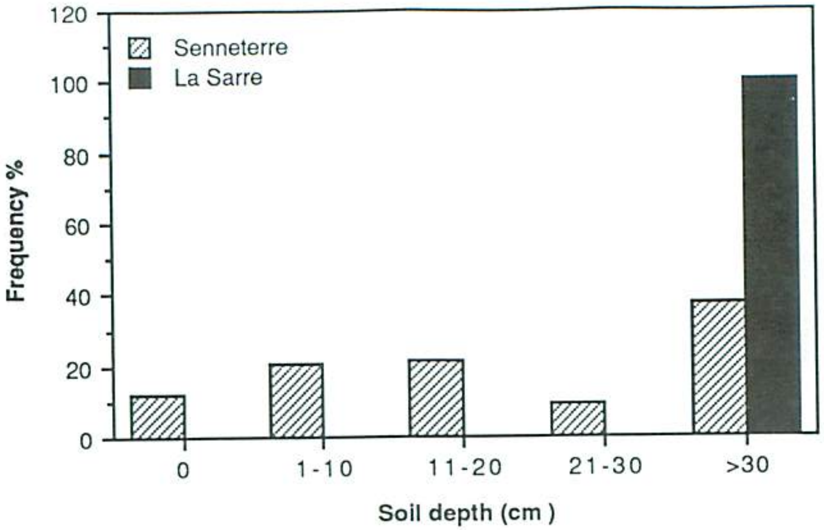

Figure 11. Frequency distribution of soil depth.

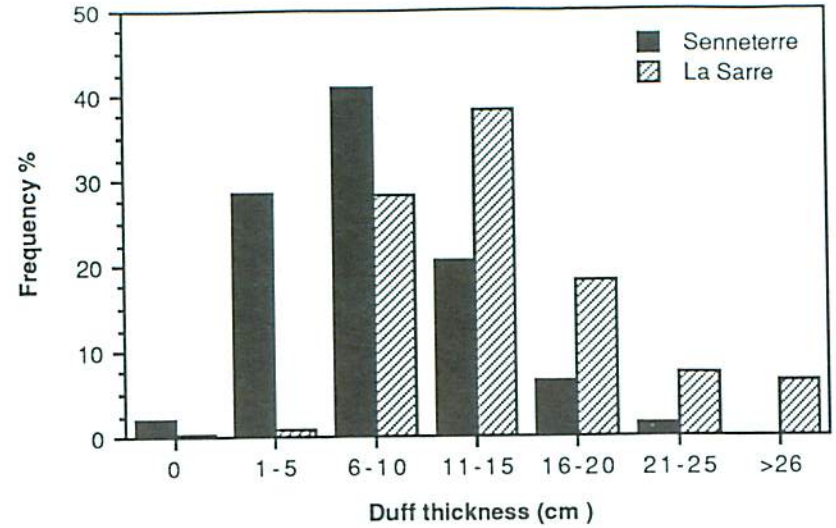

Figure 12. Frequency distribution of duff depth.

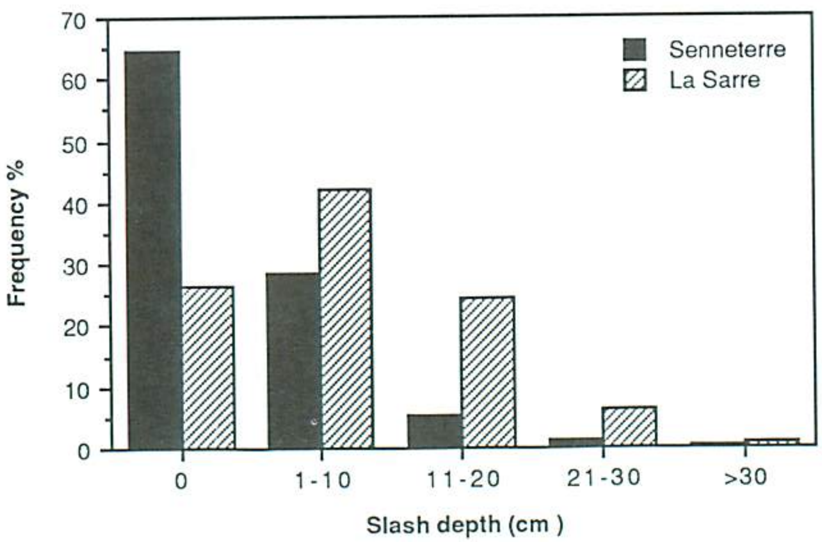

Figure 13. Frequency distribution of slash depth.

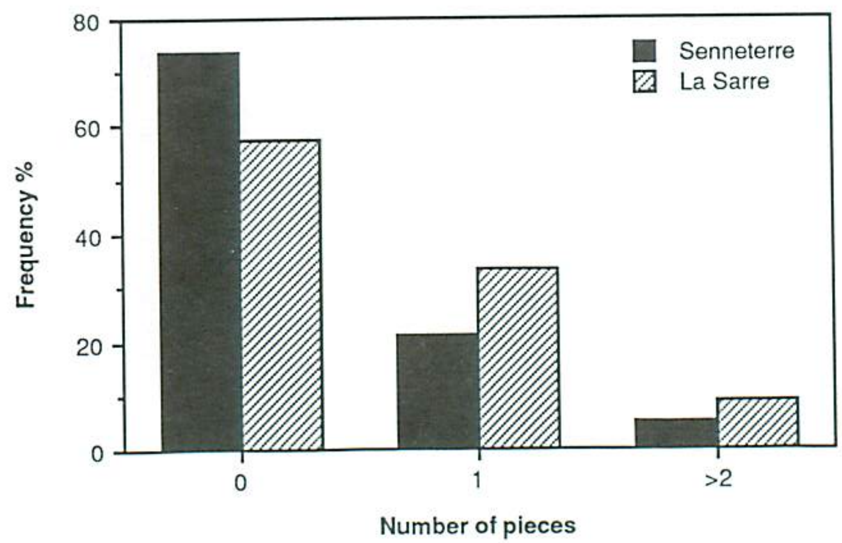

Figure 14. Frequency distribution of slash pieces per 2 m of lineal tally (for pieces >5 cm in diameter).

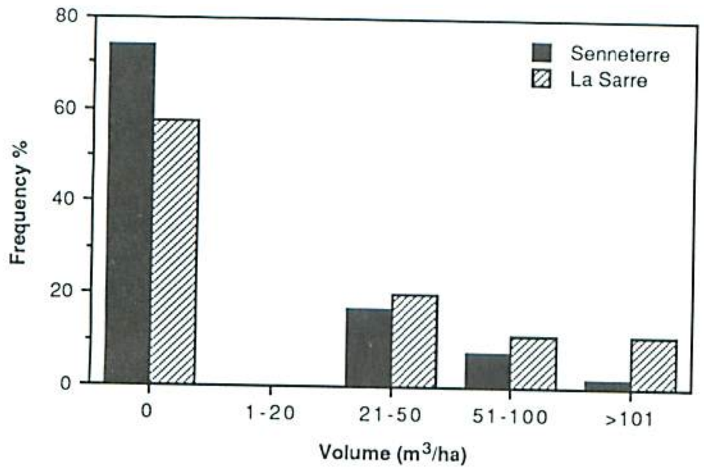

Figure 15. Frequency distribution of volume of slash >5 cm in diameter.

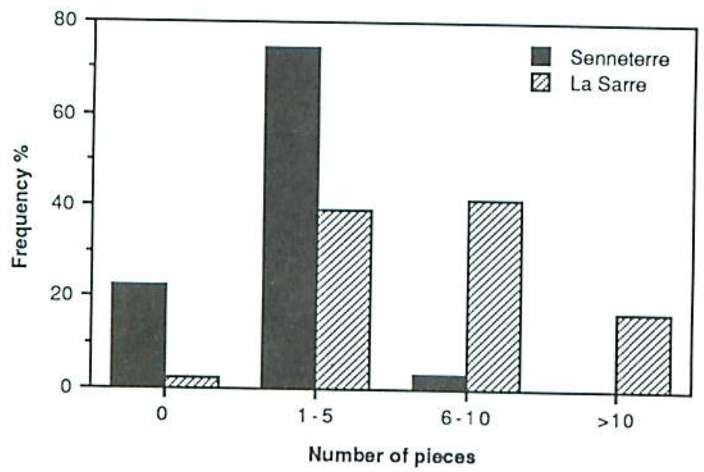

Figure 16. Frequency distribution of slash pieces per 2 m of lineal tally (for pieces 1-5 cm in diameter).

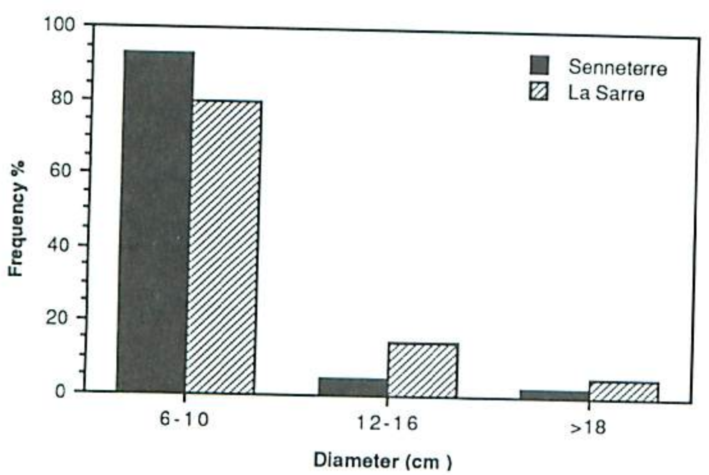

Figure 17. Frequency distribution of slash with a diameter >5 cm.

Table 3. Stumps.

	Frequency (no./ha)	Avg height (cm)	Avg diameter (cm)
Senneterre	1283	18.8 (1.2)[a]	17.4 (.60)
La Sarre	925	22.3 (1.1)	23.5 (.93)

[a] Values within parenthesis are confidence intervals at the 10% level of significance.

Stump density was higher at Senneterre, but both stump height and diameter were higher, on average, at La Sarre (Table 3).

There were virtually no residual trees or brush at either location. Senneterre had a 10% cover of minor vegetation made up primarily of the families Ericaceae and Gramineae.

Both sites were in the 0-5% slope class, which indicates that the terrain was flat.

In summary, La Sarre contained more debris, higher stumps and deeper duff, whereas Senneterre was stonier and rougher, and had more stumps. According to the Canadian Pulp and Paper Association's Terrain Classification system (Mellgren 1980), Senneterre is rated 2.1.1 and La Sarre 3.1.1.

Time Study

Continuous time studies of the Tetra were conducted at both locations to determine machine productivity and to identify any problems or sources of downtime.

The results, including sources and cumulative time of delays, are shown in Figure 18 for both sites. The only major sources of downtime due to active repair at Senneterre were repairs to the planting head, feed system and planter power supply, which amounted to 21.5% of total machine time. A series of other short-term delays caused by overheating hydraulics, repairs to the planting head, loading of seedlings and other miscellaneous factors accounted for an additional 13.4% of total machine time. At La Sarre miscellaneous delays accounted for 6.2% of total machine time and were caused by the same factors as at Senneterre. Turning with the planting head in a raised position averaged 1.42 min at Senneterre and 1.31 min at La Sarre.

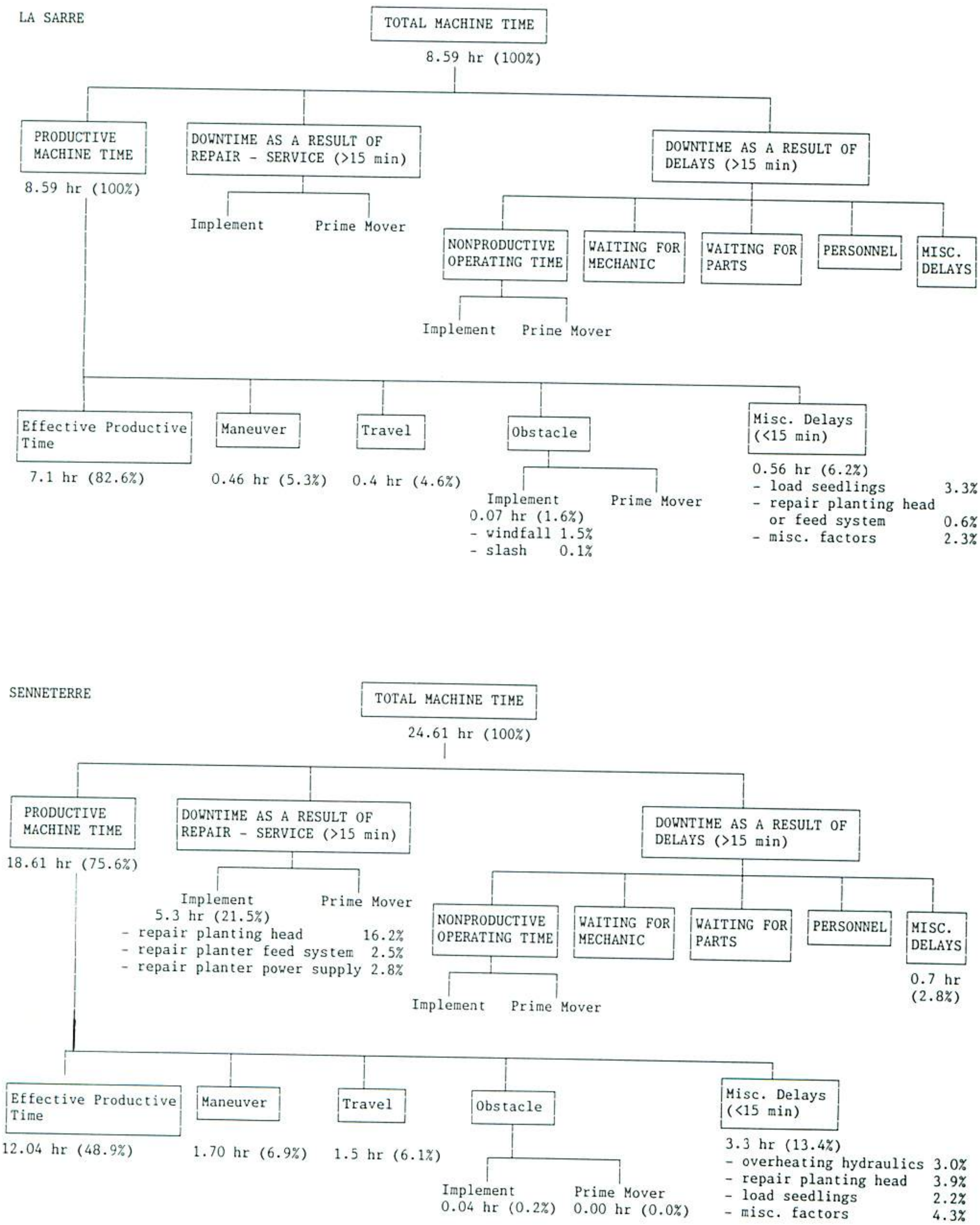

Figure 18. Results of continuous time study at Senneterre and La Sarre.

Average travel speed differed slightly (1.56 and 1.40 km/hr for Senneterre and La Sarre, respectively). Machine productivity was assessed at 0.36 ha (or 640 trees) per productive machine hour (PMH) at Senneterre and 0.46 ha (or 1259 trees) per PMH at La Sarre. When expressed in terms of effective productive hours (EPH), productivity increased to 0.56 ha (or 962 trees) per EPH at Senneterre and 0.56 ha (or 1,423 trees) per EPH at La Sarre. When only these seedlings in the "satisfactory" and "fair" planting categories are considered, planting rates decline to 324 trees/EPH at Senneterre and 655 trees/EPH at La Sarre. In a Swedish study of the Serlachius planting machine, productivity averaged 0.68 ha/EPH, travel speed averaged 1.5 km/hr and the planting rate was 1,200 *acceptably planted*[7] seedlings/EPH (Adelsköld 1983). These values are summarized in Table 4.

Table 4. Productivity summary.

Site	Total machine time (hr)	Productive machine hours (PMH)[a]	Travel speed[b] (km/hr)	Area (ha)	Productivity per productive machine hour (ha/hr)	Productivity per effective productive hour (ha/hr)	Productivity per effective[c] productive hour (trees/hr)
Senneterre	24.2	18.74	1.56	6.76	0.36	0.56	962
La Sarre	8.59	8.59	1.40	3.96	0.46	0.56	1,423

a includes delays less than 15 min, turns and maneuvers for obstacles

b without stops, i.e., during effective productive time

c involves forward travel and functioning only

Utilization and mechanical availability are measures that reflect both the reliability and the effectiveness of equipment. Because of the short duration of the trials at both Senneterre and La Sarre, calculations of these two parameters were thought to be non-representative and consequently are not presented. However, it was noted that mechanical availability was improved beyond what was achieved by the Serlachius version of the Tetra in the 1985 Quebec trials (see footnotes 2,3 and 4 on page 4 of this report). Mechanical delays were related to the modifications made to the planter and feed system during the winter of 1985 (e.g., sizing of hydraulic cylinders).

Post-treatment Assessment

(a) Planting quality: Planting quality (including the attempts rated as satisfactory and fair[8]) was 35% on the basis of 511

7 Planting criteria may not be comparable in the two studies.

8 An attempt was rated as fair if the tree was considered to have at least a 50% chance of survival.

attempts assessed at Senneterre and 46% on the basis of 434 attempts assessed at LaSarre (Table 5).

Table 5. Actual planting quality and plantability of scarified row.

	Actual planting quality			Plantability of scarified row		
	Satisfactory + fair (%)	Improperly planted (%)	Total no. of attempts assessed	Yes (%)	No (%)	Total no. of potential planting spots
Senneterre	35 (6.1)[a]	65	511	46 (7.2)	54	494
La Sarre	46 (6.2)	54	434	58 (6.3)	42	429

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

Thirty-one percent of all planting attempts at Senneterre were made in either mineral soil or ⩽ 4 cm of duff over mineral soil. Another 64% of the attempts were made in a combination of the microsite categories: >4 cm of duff, mineral soil over inverted duff, or inverted duff over undisturbed mineral soil.

At La Sarre, 64% of all planting attempts were made in either mineral soil or ⩽4 cm of duff over mineral soil and 33% of the attempts were made on >4 cm of duff over mineral soil.

At Senneterre, in 35% of the cases, less than satisfactory planting was attributed to an improper scarification process, which resulted in failure to produce suitable microsites (Table 6). In a further 40% of the cases, less than satisfactory planting was attributed to the planting heads accepting an improper planting medium that consisted primarily of stones, roots, or stumps or that was improper because of unknown causes. Such obstacles provided a false ground reference reading. The remaining 25% of the reasons were divided between inadequate depth of scarification as a result of interference from logging debris and/or duff, and a series of other minor reasons attributable to either the planting process or the scarification process.

At La Sarre, 70% of the primary reasons for less than satisfactory planting were attributed to inadequate depth of scarification as a result of interference primarily from debris and to a lesser extent from duff. The balance of the reasons (30%) was divided between the planting head accepting an improper medium, primarily because of roots and stumps, and for a series of other minor reasons attributable to either the planting or scarification heads.

Table 6. Reasons for less than satisfactory planting quality.

	Senneterre		La Sarre	
	Primary reason (%)	Secondary reason (%)	Primary reason (%)	Secondary reason (%)
Improper scarification process	**35.5**[a]	0.0	0.0	0.0
Planting head accepting an improper planting medium caused by:				
- roots	6.1	0.0	5.0	0.0
- stumps	4.6	0.0	5.8	0.0
- stones	16.6	0.0	0.0	0.0
- debris	0.0	1.4	0.0	**51.5**
- unknown factors	13.2	**86.5**	1.9	0.0
Inadequate depth of scarification caused by: - debris	3.0	0.0	**48.0**	0.0
- duff	7.7	0.0	21.9	0.0
Miscellaneous other reasons	13.8	12.1	17.4	**48.5**
TOTAL	100.0	100.0	100.0	100.0

[a]Arrows indicate a direct association of a secondary reason with a primary reason.

The most common secondary reason (87% of the cases) for less than satisfactory planting at Senneterre was acceptance of an improper planting medium by the planting head. This was associated with improper scarification as a primary reason, an indication that the planting head sensing device would often accept an improper planting medium and complete the planting attempt in duff or shallow mineral soil over duff.

Likewise, at La Sarre, the most common secondary reason for less than satisfactory planting was acceptance of an improper planting medium by the planting head because of debris. This resulted in seedlings that were planted in duff between slash. Representing 52% of all secondary reasons, this was associated with inadequate depth of scarification as the primary reason. The remaining secondary reasons were also associated with inadequate depth of scarification as the primary reason.

Two other physical attributes that were assessed for each planted seedling were compaction and depth of planting.

Compaction was rated as loose on 35% of the planted seedlings assessed at Senneterre and 37% at La Sarre. Expressed in terms of reasons for less than satisfactory planting, 40% of all attempts in which compaction was loose were associated with an improper scarification process at Senneterre, an indication that seedlings planted in duff or thin mineral soil over duff could not be packed adequately. At La Sarre, 63% of attempts in which compaction was loose were associated with inadequate depth of scarification as a result of interference by debris, which also prevented adequate packing of seedlings.

Planting depth was rated shallow (with root collar above the mineral soil surface) for 68% of the planted seedlings assessed at Senneterre and 41% at La Sarre. The remaining seedlings, with some minor exceptions, were firmly planted at both locations. When expressed in terms of reasons for less than satisfactory planting, 44% of all attempts considered shallow were associated with an improper scarification process at Senneterre. This means that the seedlings were planted in either duff or shallow mineral soil over duff. At La Sarre, 63% were associated with inadequate depth of scarification as a result of interference by duff or debris.

(b) Plantability: The number of plantable microsites (plantability) along the furrow was slightly higher than the actual number of seedlings planted, planting quality being deemed acceptable on 46% of the 494 spots assessed and 58% of the 429 spots assessed at Senneterre and La Sarre, respectively (Table 5).

At Senneterre, plantable microsites (which consisted of those in the categories "mineral soil" and "⩽4 cm of duff over mineral soil") constituted 35% of all attempts that were assessed and accounted for the majority (77%) of plantable attempts. Where attempts were made on non-plantable microsites, 85% of the microsite categories consisted of >4 cm of duff, inverted duff over mineral soil or, to a lesser extent, mineral soil over inverted duff.

At La Sarre, plantable microsites (which consisted of those in the categories "mineral soil" and "⩽4 cm of duff over mineral soil") constituted 56% of all attempts that were assessed and accounted for the majority (97%) of plantable attempts. Where attempts were made on non-plantable microsites, 75% of the microsite categories consisted of >4 cm of duff over mineral soil.

The ability of a planting tool to penetrate the substrate was assessed with a soil probe bar during each planting attempt. At Senneterre, the substrate was penetrable in 85% of the attempts whereas this figure was 78% at La Sarre. The presence of stone was the primary cause of lack of penetration at Senneterre, whereas debris inhibited penetration at LaSarre in 12% of the attempts.

There was no debris on microsites at Senneterre that were rated for plantability. The presence of debris on microsites was predictably higher at La Sarre because of a heavier slash loading, but in only 13% of the planting attempts at this location was there a heavy debris cover.

At both locations, microrelief was considered level on over 99% of the planting attempts, and vegetative competition was nil.

(c) Spacing of planted seedlings and of plantable microsites: The inter-tree spacing measured along the furrow and between planted seedlings (good and fair only) averaged 4.3 m at Senneterre and 3.6 m at La Sarre (Table 7). When compared with the provincial requirement of 2 m ± .4 m, the resulting stocking along the furrow was 47% and 56% for Senneterre and LaSarre, respectively. Under the plantability assessment (plantable microsite spots only) spacing between attempts was closer at 3.9 m and 2.9 m, with the result that stocking was slightly higher (52% at Senneterre and 69% at La Sarre) along the row.

Table 7. Average spacing between actual planting attempts and between plantable microsite spots.

	Actual planting attempts		Plantable microsite spots (m)
	Satisfactory and fair (m)	All attempts (m)	
Senneterre	4.3 (.43)[a]	1.9 (.04)	3.9 (.39)
La Sarre	3.6 (.38)	1.8 (.04)	2.9 (.24)

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

The spacing, along the furrow, of seedlings in the "satisfactory" and "fair" planting categories combined with the average spacing between furrows of 2.1 m for both sites resulted in a density of 1118 trees/ha for an overall stocking of 45% at Senneterre and 1305 trees/ha for an overall stocking of 52% at La Sarre (Table 8).

Table 8. Density and stocking based on planting quality.

	Satisfactory + fair planting[a]		Prescribed	
	(No./ha)	(%)	(No./ha)	(%)
Senneterre	1118	45	2500	(100%)
La Sarre	1305	52	2500	(100%)

[a] based on 4.3 m and 3.6 m average inter-tree spacing for Senneterre and La Sarre, respectively, and 2.1 m average inter-row spacing on both sites

DISCUSSION

The scarification objective of the Tetra, that is, of mineral soil deposited on top of inverted duff, was not achieved under the site conditions that existed at Senneterre (Fig. 19). Often the inverted duff layer was produced but with no mineral soil or < 2 cm of mineral soil on top; hence, the term "improper scarification process". This duff/mineral soil sandwich was then compressed by the bogie wheel assembly and the planting cycle was executed, and as a result, seedlings were often planted shallowly (i.e., 68% had the root collar above the original humus/mineral soil interface) and loosely (i.e., 35% did not have sufficient packing). In an attempt to improve the scarification process at La Sarre the scarifier was operated with the secondary discs rotating passively (i.e., with no hydraulic power) so as to reduce the amount of material thrown up by the secondary discs. This adjustment was successful in reducing the mounding of duff material but planting quality improved only from 35% to 46% at La Sarre. The greater duff depth and slash loading at La Sarre were more limiting factors, causing inadequate depth of scarification, which accounted for 70% of the cases in which planting quality was less than satisfactory.

The planting cycle of the Tetra includes sensors that control the depth of penetration of the dibble and either accept or reject the ground medium or substrate being planted. The fact that the planting head accepted an improper medium was an important primary and secondary reason for less than satisfactory planting quality on both sites. At Senneterre, stoniness was the most common primary reason for acceptance of an improper medium by the planting head; the secondary reasons were not known. When the planting dibble is inserted adjacent to surface stones the packing flaps can be deflected by one or more stones. The planting cycle is then completed, even though there has been a false reading of ground reference and, as a result a seedling has been planted either too shallowly or on a microsite adjacent to the stone that may be too soft. At La Sarre roots and stumps were the most common primary reason for acceptance of an improper medium by the planting head, and debris was the most common secondary reason. Although it is clear that the scarification process was less than adequate, part of the problem is related to the inability of the planting sensors to reject readings of pressure resistance from debris, stones, roots, stumps and excessive humus layers.

Plantability (the potential for planting along the path of the planting head within the scarified furrow) was slightly better than planting quality at both Senneterre and La Sarre but fell far short of acceptable standards. In a study of the Serlachius tree planter in Sweden, Adelsköld (1983) assessed an area of 0.5 m radius around each planting attempt for alternate planting sites in mineral soil. He found nearly twice as many mineral soil locations as were utilized by the planting machine. Similarly, the fact that at both Senneterre and La Sarre many more suitable planting microsites existed outside the path of the planting head supports the statement of Adelsköld that "higher demands for site preparation are set for mechanical planting because the

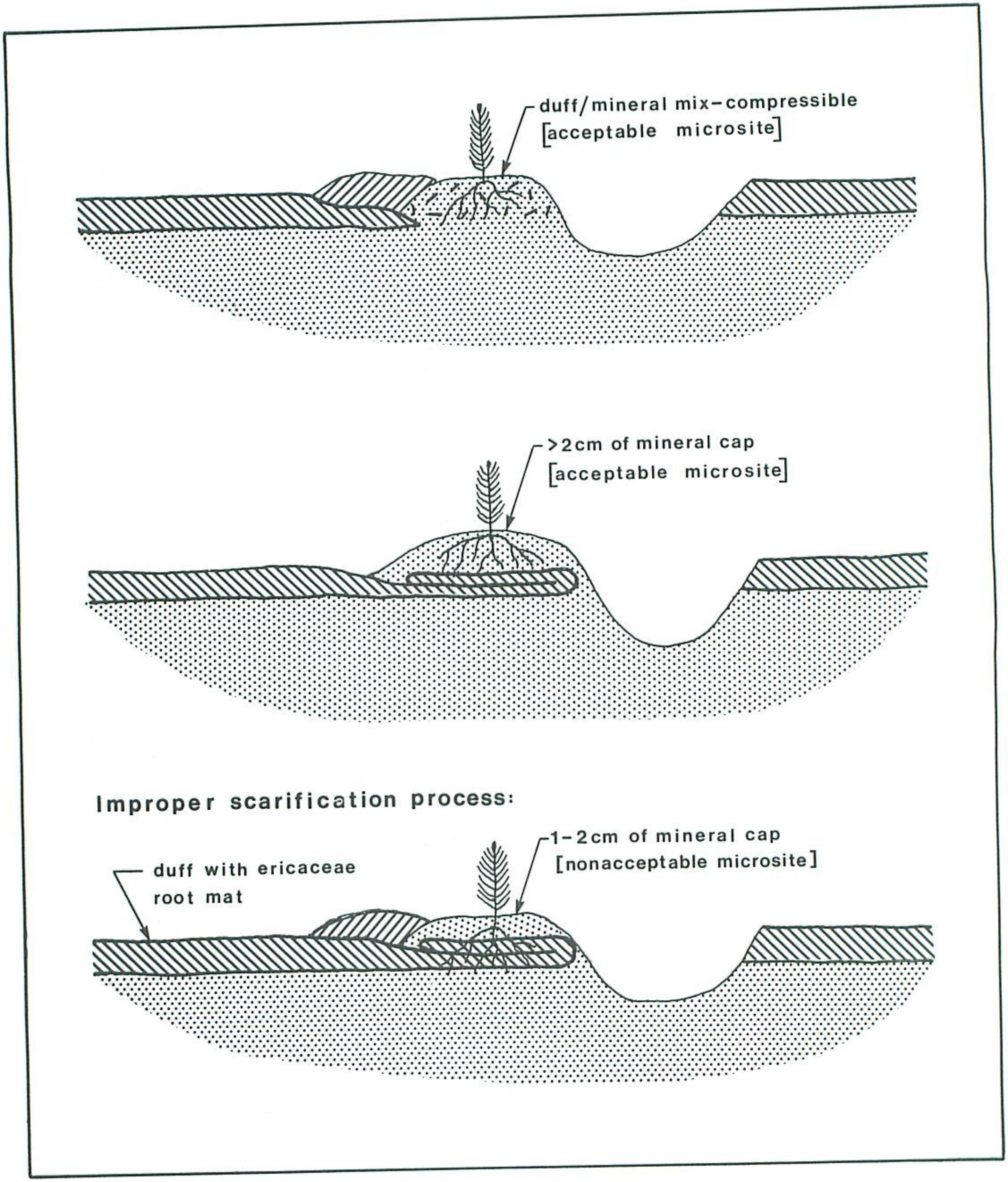

Figure 19. Scarification profiles of the Tetra scarification discs.

machines can still not choose planting spots in mineral soil". At Senneterre and La Sarre a high percentage of unsuitable microsites was created along the path followed by the planting head. Meanwhile, acceptable microsites were often found adjacent to the unsuitable sites. This reveals that scarification is not uniform or continuous in these site conditions. Moving the planting heads laterally to plant along a different path where there are more suitable microsites is one possible solution for improving planting quality without modifying the equipment. This does not, however, solve the overriding problem of the inability of the scarifiers to give consistent results.

Possible causes of the poor scarification results at Senneterre are ineffective tooth length on the scarification discs, and disc arms that are not hydraulically weighted to increase penetration force. A similar conclusion was drawn from the Swedish study. At La Sarre the combination of thicker duff and more debris prevented a proper scarification result.

Penetration in each planting attempt, assessed with a hand tool, was high--85% and 78% for Senneterre and La Sarre, respectively. Such results demonstrate that soil density and subsurface obstacles were not a major impediment to planting by hand and hence would not present a major impediment to the tree planting dibble.

The lower planting rate experienced at Senneterre, 962 tree seedlings/EPH versus 1,423/EPH at La Sarre, is the result of a higher degree of soil stoniness at Senneterre, which prevented planting at the optimum spacing. The spacing problem was further aggravated by overheated hydraulics, which tended to slow down the response time of the planter components and thus increased the spacing between attempts. The density of seedlings in the "satisfactory" and "fair" planting categories totalled 1,118/ha at Senneterre--much lower than the provincial requirement of 2,500/ha. Although the planting rate was higher at La Sarre, the density of seedlings tallied in the "satisfactory" and "fair" planting categories was still low at 1,305/ha. When planting rates are adjusted to include only seedlings in the "satisfactory" and "fair" categories the productivity drops to 337 acceptably planted seedlings/EPH at Senneterre and 655/EPH at La Sarre. These values are far below the 1,122 acceptably planted seedlings/EPH achieved in the Swedish study (Adelsköld 1983).

A comparison of test results with those achieved in Quebec in 1985 with the Tetra shows that planting quality was lower at Senneterre and La Sarre. Changing the automatic magazine feed system to a manual feed system during the winter of 1985-1986 appears to have resulted in a considerable reduction in downtime related to the magazine feed system. As observed in 1985, there are still problems with the scarifier in clearing debris, stones and duff effectively and with the ground sensing mechanism that identifies and avoids planting microsites that are too soft, i.e., compressible, debris, or duff.

SUMMARY AND CONCLUSIONS

The Tetra multifunctional semi-automatic tree planter was evaluated at two locations, one each near Senneterre and La Sarre, Quebec. The Senneterre location was a full-tree logged clearcut of spruce and pine with limbing carried out at roadside. The topography was flat to gently rolling with surface and subsurface boulders present. The La Sarre location was a conventional tree-length logged clearcut of spruce and pine and the topography was flat and stone free. The La Sarre location contained more debris, higher stumps, deeper duff and denser soil whereas the Senneterre site had impediments to soil penetration in the form of stoniness, greater ground roughness and higher stump density. Senneterre would be considered an easy site to machine plant while La Sarre would be rated easy to moderate.

The proportion of trees that were rated as being in the satisfactory or fair planting quality classes was 35% at Senneterre, for an overall stocking of 45% based on a prescription of 2 m x 2 m. The primary reasons for less than satisfactory planting were an improper scarification process, that resulted in trees planted in >4 cm of duff or <2 cm of mineral soil over duff, and acceptance by the planting head of an improper medium because of interference from stones.

The proportion of trees in the satisfactory and fair planting quality classes was slightly higher at La Sarre (46%) and overall stocking was 52%. The primary reasons for less than satisfactory planting were inadequate depth of scarification because of debris and duff and, to a lesser extent, acceptance by the planting head of an improper medium because of interference from roots and stumps.

Plantability (the potential for planting), assessed along the path of the planting head, was only slightly better than planting quality, at 46% and 58% for Senneterre and La Sarre, respectively. These results indicate that, although there is a problem with the automatic sensing of planting substrate by the planting head, the greatest concern is lack of proper scarification. Inadequate length of scarifier teeth and the lack of downward pressure on the scarifying discs were felt to be largely responsible for this shortcoming.

Results of a brief time study indicate that modifications carried out in 1985 to convert the planter from a fully automatic to a manual magazine-feed system (see footnotes 2, 3, and 4 on page 4 of this report) were successful in reducing downtime associated with that part of the cycle. However, overall mechanical availability of other components, namely the planting head and hydraulics, needs to be improved. Machine productivity was assessed at 0.36 ha (or 640 trees) per productive machine hour (PMH) at Senneterre and 0.46 ha (or 1,259 trees) per PMH at La Sarre. When expressed in terms of effective productive hours (EPH), productivity increases to 0.56 ha or 962 trees/EPH at Senneterre and 0.56 ha or 1,423 trees/EPH at La Sarre. When only acceptably planted seedlings are considered, planting rates decline to 324 trees/ EPH at Senneterre and 655 trees/EPH at La Sarre.

The results of this study indicate that the Tetra tree planter is still in the developmental stage and not yet suitable for operational use under the site conditions described herein. Modifications to improve the scarification process alone should result in a dramatic improvement in planting quality.

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APPENDICES

APPENDIX A

Planter and Prime Mover Specifications

a) Planter and Prime Mover

Overall length: 12.92 m
Width: - single wheels 3.05 m
- double wheels 3.96 m
Height: - transport 3.5 m
- work 4.11 m
Weight: - 26,000 kg

b) Planter

Length: 7.8 m
Weight: 8,000 kg
Engine: - make--Valmet
- model--611CSH
- power--121 kw (163 HP) @ 2,200 RPM

Hydraulic System: Circuits controlling the scarifying heads and the lifting and movement of the planting devices:

Two pumps - make--Vickers
- model--TA1919 V20, maximum volume of 2 X 80 L/min @ 2,000 RPM and a pressure of 10-14 megapascals (100-140 bars)

One pump - make--Vickers
- model--PVE 21, maximum volume of 90 L/min @ 2,000 RPM and a pressure of 10-18 megapascals (100-180 bars)

One pump - make--Valmet
- model--B22-16D, volume of 32 L/min @ 2,000 RPM and a pressure of 7 megapascals (70 bars)

Scarification motor (one per disc) - make--SISU
- model--600 with a maximum speed of 60 RPM

Pneumatic System: two air compressors - make--Clayton
- volume capacity--2 X 340 L/min @ 2,000 RPM and a pressure of 0.6 megapascals (6 bars)

Ground speed during planting: 12-30 m/min
Designed planting rate: 1,000-1,500 seedlings/hr
Seedling storage capacity: approximately 6,000 plants (depends on container type)

c) Prime Mover--Bombardier Valmet BT-12

Engine:
- make--John Deere
- model--740 A
- power--13 KW SAE flywheel (152 HP)

Power train: transmission
- type--Clark Powershift
- model--13/1 HR28460
- ratios--1st 4.80
  2nd 2.27
  3rd 1.31
  4th 0.95

Hydraulic system: Circuits controlling the steering, the loader and the inverted grapple. Two hydraulic pumps connected parallel and driven by the transmission

Pump capacity @ 2,000 RPM = 114 L/min
Relief valve setting: 13,800 kPa

Suspension: gear driven bogie type

Wheels: six
- front--two tube-type
  16-ply 62.2 x 81.3
- rear --four tube-type
  16-ply 40.6 x 60.9

Electrical: voltage--12 V
battery capacity--204 amps
alternator capacity--72 amps
ground--negative

d) Distributor: Equipment Denis Inc.
5110, rue Beaudry
St. Hyacinthe, Quebec
J2S 8A2

APPENDIX B

Assessment Parameters[1] for Planting Quality and Plantability

	Planting Quality	
	acceptable	unacceptable
Tree Insertion	- satisfactory - firm, root collar at mineral soil level - fair, root collar up to 1/3 top height above firm mineral soil; tree considered to have a 50% chance of survival	- improperly planted - tree missing
Tree angle	- less than 15° angle from vertical	- exceeds 15° angle from vertical
Planting depth	- root collar at mineral soil level - root collar up to 1/3 top height above or below firm mineral soil	- too deep, too shallow, or roots exposed
Compaction	- firm	- loose, yields to a firm tug
Planting microsite	- see Appendix C for a description of soil/duff modification classes	
	Plantability	
Penetration by planting tool	- full	- less than full because of bedrock, stones, roots, debris, stumps, or hard clay
Microrelief	- level, raised or side	- hollow
Debris	- none or partial coverage	- heavy (requires removal for planting)
Vegetative competition	- none or competing herbaceous	- competing woody
Microsite	- see Appendix C	

[1] adapted from Sutherland (1986)

APPENDIX C

Microsite or Soil/Duff Modification Categories

acceptable

- mineral soil
- 0-4 cm of duff over mineral soil
- 2 cm or more of mineral soil over inverted duff
- mineral soil/duff mix over mineral soil (compressible)

non-acceptable

- >4 cm of duff
- <2 cm of mineral soil over inverted duff
- mineral soil over noninverted duff
- mineral soil over duff over bedrock
- mineral soil/duff mix over mineral soil (non-compressible)
- inverted duff over undisturbed duff
- debris, i.e., no scarification