OPERATIONAL TESTING OF PLANTING MACHINES IN THE BOREAL FOREST OF ONTARIO

I. Reynolds-Lowther Heavy Duty Crank Axle Planter

L. F. RILEY

GREAT LAKES FOREST RESEARCH CENTRE
SAULT STE. MARIE, ONTARIO

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Director,
Great Lakes Forest Research Centre,
Canadian Forestry Service,
Department of the Environment,
Box 490, Sault Ste. Marie, Ontario.
P6A 5M7

FOREWORD

Traditionally, Crown lands in northern Ontario have been planted manually with only brief ventures into mechanical planting. Despite chronic regional shortages of labourers willing to undertake this type of work, rising labour costs and often unsatisfactory efforts from those workers who are recruited, machine planting has never become popular in the treatment of northern forests.

In recent years machine planting has become widespread in the United States and Scandinavia. Although most of the planters used are marketed commercially, limited information is available on their operational capabilities and this is often restricted to the manufacturer's promotional material. Certainly very few objective evaluations have been published and the results, even when available, often are not applicable to the sites most in need of reforestation in boreal Ontario.

Recognizing the impact that mechanization of harvesting has had on harvesting costs and seeing a parallel in the field of regeneration, the Ontario Ministry of Natural Resources (OMNR) and the Great Lakes Forest Research Centre (GLFRC) of the Canadian Forestry Service (CFS), under the aegis of the Canada—Ontario Joint Forest Research Committee, have embarked on a cooperative program to mechanize reforestation practice in Ontario. One of the major thrusts of the program has been the purchase and testing of some of the more promising planters available. The performance of each machine has been evaluated over a range of site conditions. Staff of the sponsoring organizations have played specific roles in each trial and several OMNR districts have been involved over the period of the trials, which extended from 1971 to 1974. Consequently, these trials should realistically reflect the requirements of the forest managers, make field staff aware of the types of equipment available and aid them in becoming familiar with the planting machines and the field conditions with which they can cope. It is hoped that the series of reports resulting from these trials will materially assist in the development of a viable machine planting program for Ontario.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the fine efforts and valuable assistance of F. F. Foreman, Forestry Technician, in the conduct of the field work and the preparation of this report. The cooperation provided by the Ontario Ministry of Natural Resources in Chapleau District was essential to the conduct of these trials and is greatly appreciated.

ABSTRACT

Operational machine-planting trials were carried out on a range of site conditions to determine the suitability of the Reynolds-Lowther Heavy Duty Crank Axle Planter for use in typical boreal forest conditions of Ontario. Work studies were undertaken to determine overall suitability of the unit and to relate variation in productivity and planting quality to specific site parameters. Site conditions were assessed before the trials and planting-quality assessments were conducted after planting.

The planter has proven capable of efficiently and effectively regenerating most deep-soiled, rock-free sites at costs comparable to those of hand planting. The most critical factor is the ability of the prime mover to clear a debris-free path immediately in front of the planting unit. If this is done the planter has little difficulty in planting trees well. The most important site factors handled are stumps, slash and residual trees. Other surface site conditions had little effect on either productivity or planting quality.

There are certain hazards involved in operating the planter, and these are outlined in this report. The planter is considered to be inoperable on very rocky sites and less suitable on clay sites than some other machines tested under this program.

Appendices provide detail on site assessment and work study procedures.

RÉSUMÉ

Des essais de planteuses ont été effectués dans diverses conditions de stations, afin de déterminer les qualités de la planteuse à essieu coudé à grand rendement Reynolds-Lowther, pour utilisation dans les conditions forestières boréales de l'Ontario. Les travaux consistaient à déterminer les qualités hors tout de l'unité et la variations dans la productivité et la qualité des plantages par rapport aux paramètres spécifiques de station. L'auteur a estimé les conditions de la station avant les essais, et ensuite la qualité des plantages.

La planteuse s'est avérée capable de régénérer efficacement et effectivement la plupart des stations à sol profond et non rocailleux, ceci aux coûts qui concurrencent la plantation manuelle. Sa qualité principale est d'être munie d'un engin qui peut nettoyer le terrain immédiatement en avant de l'unité de plantage proprement dite, ce qui permet sans difficulté une bonne plantation. Les principaux débris enlevés sont des souches, des rémanents et des arbres résiduels. Les autres conditions de surface de la station affectent très peu la productivité ou la qualité de la plantation.

Les quelques dangers encourus lors de l'opération de la planteuse sont soulignés dan ce rapport. Cette machine s'avère non utilisable dans des stations rocailleuses, et moins convenable dans les stations de sol argileux que d'autres machines testées lors de ce programme d'essais.

Des appendices fournissent des renseignements sur l'estimation des stations et la marche des travaux d'études.

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INTRODUCTION

Approximately 400,000 acres (162,000 ha) of forested land are cut over each year in Ontario, of which nearly 75% is regenerated naturally or artificially (Anon. 1971). The remainder, more than 100,000 acres (40,500 ha) is not regenerated and is added to a steadily increasing backlog of area in need of treatment. To date, most of the area regenerated artificially has been planted manually with bare-root stock, although a small percentage of this area was planted under the short-lived Ontario tube program in the late 1960s and some additional area is direct seeded annually. It is evident, however, that the bare-root plant is, and likely will continue to be for the foreseeable future, the mainstay of Ontario's reforestation effort.

In 1972, OMNR announced a major expansion of its silvicultural program which is designed to handle the annual cutover. As a result, and because of the labour and cost problems associated with hand planting, it is unlikely that the traditional manual methods of planting will be able to accommodate more than a small portion of the increased demand. More effective and efficient methods will have to be employed if all areas requiring re-establishment are to be treated.

The important role that mechanization can play in efforts to expand and improve regeneration practice was given early recognition by both OMNR and CFS and, as a result, a joint program in the mechanization of reforestation was established with GLFRC. It was agreed that OMNR would purchase or develop equipment for testing and conduct operational trials, and that GLFRC would be responsible for site assessment, work studies, planting quality assessment, biological and economic studies and reporting of results.

The purchasing and operational testing of planting machines that appeared suited to Ontario's boreal forest conditions was begun in 1971. The first trials conducted under the program used a Reynolds-Lowther (formerly Beloit-Lowther) Heavy Duty Crank Axle Tree Planter[1]. Trials were run in the spring of 1971, 1972 and 1973 and this report describes the results of these trials.

It should be recognized at the outset that these trials were designed to determine each planter's ability to cope with various site conditions, to point out areas where design modifications would improve performance and to determine which operating techniques would produce the best overall performance by the planters. While strenuous efforts were made by both agencies to attain maximum operating efficiency, the results of these trials can, without question, be improved upon. It is hoped that this report will enable potential users of the Crank Axle to avoid

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[1] The material in this report is provided solely for the information and use of the reader, and does not constitute endorsement by the Canadian Forestry Service of the products named.

many of the inefficiencies that invariably occur when a new piece of equipment is used by staff unfamiliar with it.

Equipment

The planting unit was made up of three distinct parts: the trailing planter, a crawler tractor drawing unit and a scarifying blade front-mounted on the tractor (Fig. 1).

Fig. 1. The complete planting unit in action, Fawn Township, 1972.

a) Planting Machine

The Crank Axle (Fig. 2) is a product of Reynolds Research and Manufacturing Corporation, McAllen, Texas. In essence, it is a descendant of the Lowther Wildland planter, which has been used off and on in Ontario for a decade or more. The Crank Axle differs from the Wildland planter in its hydraulically operated riding wheels which have a cushioning and stabilizing effect when the machine is in the planting mode (wheels partially or completely raised). The wheels, when fully lowered, transport the planter from site to site. They can be used to some extent also to control planting depth, although such practice is discouraged by the manufacturer. Figure 3 illustrates the basic planter (minus protective cab and self-contained engine for hydraulics) and identifies the major functioning parts.

Fig. 2. The Crank Axle planter in transport mode (hydraulic riding wheels in down position).

The planter is attached to the tractor by means of a sandwich hitch which allows the planter, independently of the tractor, to move vertically and laterally as the unit passes over rough ground. Side roll of the planter, which can be a safety hazard when not restricted, is limited by the hitch and the transport wheels. The transport wheels can be raised and lowered either through a direct line from the hydraulic cylinder on the planter to the hydraulic system on the tractor, or through a planter-mounted hydraulic pump and auxiliary gas engine. The latter is provided by the manufacturer as an optional accessory and was used during these trials. Operation of the planter hydraulics is controlled by the planter operator.

In operation the rolling coulter splits slash, causes the planter to ride over impenetrable objects so that the planting foot will not catch on them and opens the initial slit for the planting foot. The planting foot spreads the slit further, allowing the operator to insert the tree in the rear portion of the foot. The forward motion of the unit causes the tree to pass to the rear, whereupon soil is firmed around the roots by the packing wheels at the rear of the planter.

Essential for operator safety is an all-steel cab for the planter (also optionally available) and a signalling device that allows the planter operator to communicate with the tractor operator. In this case a horn linked to the tractor's electrical system was installed and found

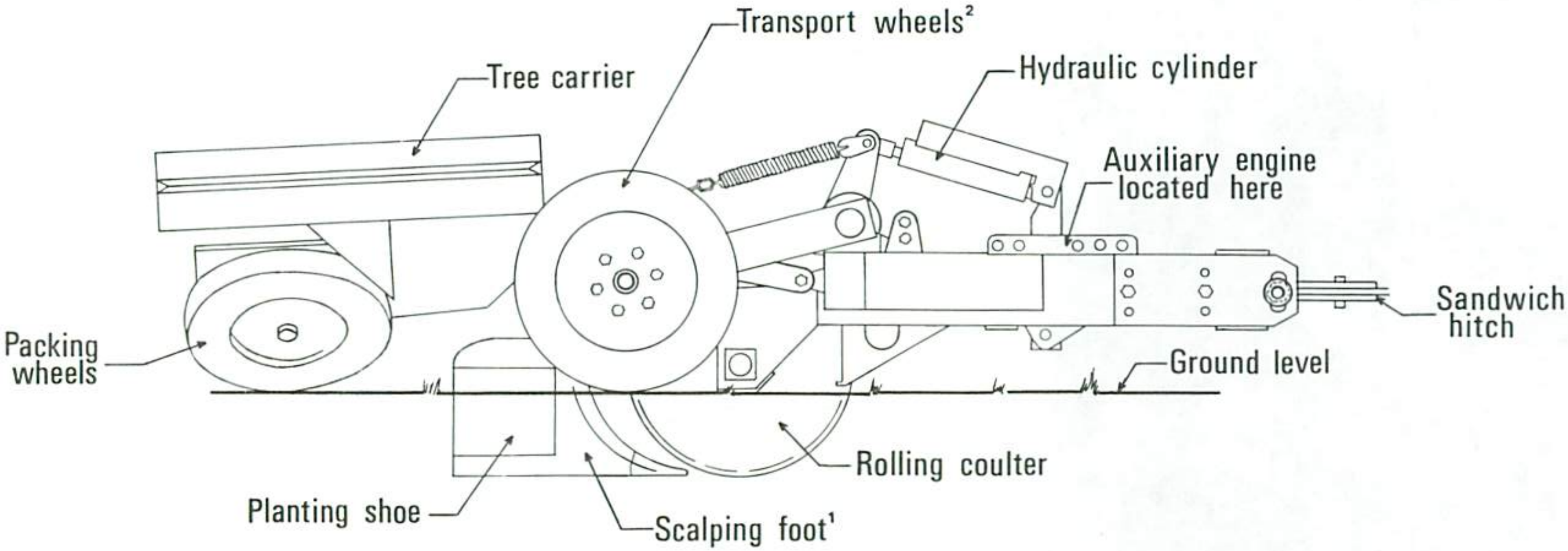

Fig. 3. The Crank Axle planter in planting mode identifying the major functioning parts.

[1] Scalping foot toe should be extended to surround edge of coulter. Coulter rides in a groove in toe.

[2] Transport wheels are lowered hydraulically to raise planting parts out of the ground for transportation of unit from one site to another.

to be highly effective. The trays on the sidewalls inside the cab hold approximately 2000 trees the size of jack pine (2-0) used in the trials.

b) Tractor

A Caterpillar D6C crawler was rented for the trials each year. Although a machine of this size is not necessary for pulling the planter alone, it is necessary in order that the slash and other impediments on the sites can be effectively and efficiently manipulated. (A D7E was also used for a very short period during one trial (1973) but the information gathered was insufficient for analysis.)

c) Scarifying Blade

A curved-faced Beloit V-blade to fit a D6C was purchased for the trials (Fig. 4). The blade is designed to fit outside the tractor's C-frame and attaches to it by means of a central pin and trunnion arms to the centre and sides of the C-frame, respectively. The bottom of the blade is fitted with a forward-projecting lip designed to assist in shearing and blade flotation. However, in stumpy areas this proved to be a major hindrance. The lip was too narrow for effective flotation and the tendency was to push stumps out rather than shear them off. This, as well as the fact that it was not possible to lift the blade to miss stumps and clear debris at the same time, greatly reduced the effectiveness of the blade and the productivity of the unit as a whole. Before the trials began, a scalping foot that projected beneath (by approximately 10 in., or 25.4 cm) and forward was added to the apex of the blade to provide a clear path immediately in front of the planter. This eliminated scarifying across the entire width of the blade and allowed the wings of the V-blade to pass over most stumps. A sole plate was added to the bottom of the scalping foot to increase blade flotation further. The scalping foot was modified for the 1972 trials giving it a greater upward tilt which provided greater flotation and less gouging of the soil. The blade is outfitted by the manufacturer with a pusher bar at the top for directing and pushing over residual trees, although it is underdesigned for sites in Ontario. (A smaller, less effective blade was used for the 1973 trial owing to the unavailability of the blade used in the previous years.)

Planting Sites

Although one of the aims of machine testing is to determine limiting site conditions, initial trials are conducted on the easier sites. Unless the planter can handle the easiest cutover sites further testing should be suspended and the machine considered unsuitable for northern Ontario. This approach allows for familiarizing staff with equipment and modifying equipment by stages, and ensures that major damage to or dissatisfaction with the machine will not occur through the accidental selection of sites beyond the planter's capabilities.

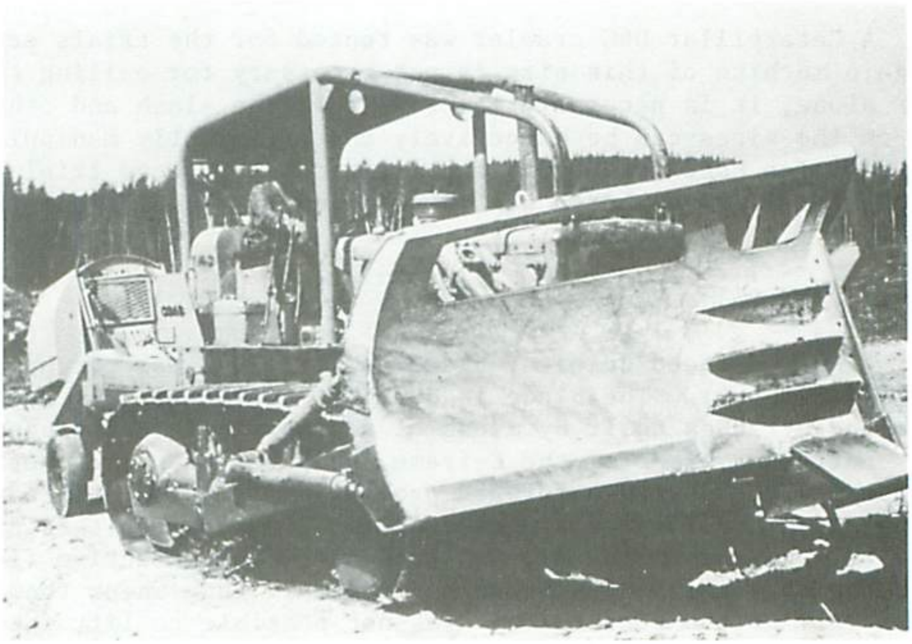

Fig. 4. The Beloit V-blade as modified for the 1972 trials.

For these reasons two flat-to-gently-rolling, relatively rock-free, sandy cutovers were chosen on which the planter could be given first trials in 1971 and 1972. A third site, more difficult and more rolling, with numerous residual trees and heavy slash, was chosen for a tougher test in 1973.

a) Fawn Township

The first area, one used for trials in 1971 and 1972, is situated some 12 miles (19.20 km) east of Sultan on the Eddy Paper Company Licence in Chapleau District. The gently rolling site is spotted infrequently by outcroppings of large boulders although there are none within the areas treated. Apart from this the soil is essentially stone-free.

An extraction road network blanketed the area, creating individual land units considered too small to use as independent planting units. Block boundaries therefore crossed these roads in several places. With the exception of one main access road, these roads were planted.

The area, typical of many jack pine (*Pinus banksiana* Lamb.) sites, had supported a good stand of that species with a minor component of spruce (*Picea* spp.). Very few cull trees were present in the stand at the time of harvest in 1970. Tree-length logging had removed most of the heavy material leaving only light slash in the form of tops and branches (Fig. 5).

Fig. 5. The Fawn Township site typical of the easiest sites requiring treatment. Note large but scattered stump occurrence.

In 1971, two rectangular blocks 10 chains x 15 chains (201.17 m x 301.75 m) were established for the trials and planted. As this was considered a familiarization trial, this configuration was deemed satisfactory, but in 1972 a 50-acre (20.25 ha) block was established adjacent to the 1971 area using roads and natural features as boundaries to bring it closer to an operational configuration.

b) Budd Lake

The second area, then in Chapleau District but now in Wawa District, and used only in the 1971 trial, is located midway between Chapleau and Wawa just south of Highway 101 in Township 24, Range XII.

Licenced to Abitibi Paper Company Limited and cut over in the spring of 1969, the area laid out for treatment was generally flat, although a hardwood mound was situated immediately adjacent to it and a "melt hole" was located within its confines. Neither was included in the planting. A more moist soil type gave rise to a heavy jack pine—spruce mixture that resulted in generally smaller stump diameters than in Fawn Township, but left much more slash for the equipment to contend with (Fig. 6). This factor shows up in the time studies. Natural boundaries and existing roads were used to delineate the trial area of 25 acres (10.12 ha).

Fig. 6. The Budd Lake site. Slash concentration noticeably heavier than in Fawn Township.

c) Township 12H

The area for 1973, again in Chapleau District and chosen mainly because by this time the district staff were becoming very familiar with the planter and its operation, was on the Island Lake Lumber Company Licence south of Chapleau. It was rolling with short, relatively steep pitches. The soil was again sandy and stone-free, ranging from dry on the hilltops to quite moist in the depressions. The previous stand had been a heavy jack pine—spruce mix with poplar (*Populus* spp.)—birch (*Betula* spp.) clumps on the knolls and scattered hardwood stems throughout much of the remaining portion. It is typical boreal forest mixedwood type (Fig. 7), one that is common to that general area and that makes hand planting somewhat difficult because of the residuals and downed material. Natural features and existing roads formed the block boundary for the 40-acre (16.20-ha) trial area.

Fig. 7. The Township 12H site with heavy slash and residual concentrations. The most difficult site successfully treated.

Planting stock each year was provided by OMNR from the allocation for the District's planting program. Species were selected according to the requirements of the site. "Nursery run" planting stock was used for the general planting operation although some graded stock being used for the biological assessments was machine planted during the operations. Jack pine and spruce (2-0 or 3-0) were planted. Only excessively large or excessively small stock caused difficulty as the planter seemed able to cope with average nursery-stock sizes with little effect on productivity or planting quality.

Site Assessment

To evaluate planting machine performance in a meaningful way it is necessary to quantify the site factors that might have an effect on machine operation. Shortly before planting was scheduled to begin each year, sample plots were established and the site conditions in each trial area assessed according to the methods outlined in Appendices A and B. Experience gained during 1971 indicated that plots must be positioned to facilitate machine travel through them and to minimize interference during planting.

The following are the results of the site assessments on each of the four areas treated.

a) Stumps

Table 1 gives pertinent stump data. Major differences occurred at Budd Lake where stump frequency was more than double that on any of the other sites. All other stump factors were lower. Average stump height on the Township 12H site was much higher than on the other sites. It was anticipated that stump frequency and particularly stump height would be major obstacles to progress during planting whereas stump diameter would be less of a hindrance because of a general decrease in frequency with increase in diameter. As a result the planting unit would be better able to avoid large stumps by slight meandering.

Table 1. Stump assessment

Location	Frequency (per acre)[a]	Avg ht (in.)[b]	Ht range (in.)[b]	Avg diam (in.)[b]	Diam range (in.)[b]
Fawn Township ('71)	239	7.0	1-14	9.9	2-18
Budd Lake ('71)	521	4.8	1-13	7.6	2-14
Fawn Township ('72)	163	5.6	2-20	9.6	2-19
Township 12H ('73)	206	16.5	9-42	8.9	2-17

[a] 1 acre = 0.40 ha

[b] 1 in. = 2.54 cm.

b) Slash

Slash was measured using a slightly modified version of the line-intersect method and volumes were calculated according to the formula provided by van Wagner (1968). This method does not allow for a measure of pieces per acre but provides only pieces intersected for a given length of lineal tally. Hence, frequencies indicated in Table 2 do not relate to any specific area size. Volume per acre and all other calculated slash information is based upon slash 3 in. (7.62 cm) in diameter.

Table 2. Slash assessment

Location	Pieces (per 66 ft[a] of tally)		Avg diam (in.)[b]	Diam range (in.)[b]	Avg length (ft)[a]	Length range (ft)[a]	Vol/acre[c] (cu. ft)[d]
	<3 in.[b]	3 in. +[b]					
Fawn Twp ('71)	2	2	3.2	3-10	20.0	2-42	240
Budd Lake ('71)	3	8	3.7	3-11	18.5	3-49	800
Fawn Twp ('72)	12	2	4.5	3-18	21.8	4-66	220
Twp 12H ('73)	11	10	5.0	3-15	23.2	1-75	1410

[a] 1 ft = 30.48 cm

[b] 1 in. = 2.54 cm

[c] 1 acre = 0.40 ha

[d] 1 cu. ft = 28,316.85 cu. cm

Slash volumes at Budd Lake were much greater than in the Fawn Township area, although the slash component was otherwise quite similar on the two sites. The effect of this greater slash volume on the planting operation will be described later. The slash volumes in Township 12H were greater still, owing mainly to the largely unused hardwood component of the previous stand. However, volume was much less important to operational efficiency in Township 12H than it was at Budd Lake because of modifications made to the planter between the 1971 and 1972 trials.

c) *Residual Trees*

Few stems were left from harvesting operations in the Fawn Township area. They appeared as isolated individuals or as small groups although the trees in groups were often quite young. Although relatively more numerous at Budd Lake, residual stems per acre remained low and could still be expected to have little effect on the planting trials. In both areas all standing stems were counted as residuals, whether dead or alive, whole or broken. This helps to explain the apparent discrepancy between the low average height figures and the corresponding high average diameter figures shown in Table 3. By contrast, the high frequency of residuals encountered in Township 12H seemed, from casual observation, to affect progress markedly.

Table 3. Residual tree assessment

Location	Frequency (per acre)[a]	Avg dbh (in.)[b]	Diam range (in.)[b]	Avg ht (ft)[c]	Ht range (ft)[c]	Gross total vol/acre[a] (cu. ft)[d]
Fawn Twp ('71)	11	2.7	2- 4	16.5	15-20	3
Budd Lake ('71)	25	5.6	2-10	20.2	10-40	43
Fawn Twp ('72)	7	4.8	2-11	16.1	10-30	14
Twp 12H ('73)	142	6.4	2-14	37.3	14-70	654

[a] 1 acre = 0.40 ha

[b] 1 in. = 2.54 cm

[c] 1 ft = 30.48 cm

[d] 1 cu. ft = 28,316.85 cu. cm

d) Slope

Slopes were measured in the direction of machine travel. Thus, upslope data of Table 4 indicate only slopes that are positive for the tractor whereas downslope data represent only those that are negative for the tractor. From experience it was considered that side slope would be a problem only where it exceeded 20%. None occurred on any of the trial areas.

Utilization of this information was quite straightforward for the Fawn Township and Budd Lake operations where the planting unit made all its passes in the same direction through a concentric planting pattern. This was complicated somewhat at Township 12H because a parallel planting pattern was used. Therefore, each positive or negative slope on one pass was matched by its opposite on the subsequent pass. The average slope for the last area can therefore not be given a positive or negative notation.

Of greater importance in considering the effect of slope on productivity are average and maximum slopes and lengths, both positive and negative.

Table 4. Slope assessment

Location	Level (±2%) (lineal tally %)	Avg up-slope (%)	Avg up-slope length (chains)[a]	Max up-slope (%)	Length max up-slope (chains)[a]	Avg down-slope (%)	Avg down-slope length (chains)[a]	Max down-slope (%)	Length max down-slope (chains)[a]
Fawn Twp ('71)	54	7.4	0.55	14	0.40	6.9	0.53	14	0.30
Budd Lake ('71)	95	3.0	1.00	3	1.00	3.0	1.00	3	1.00
Fawn Twp ('72)	31	7.0	0.50	22	0.20	8.2	0.54	22	0.20
Twp 12H ('73)	31	9.0	0.75	60	1.00	b	b	b	b

[a] 1 chain = 20.12 m

[b] Same as for "upslope". See text for explanation.

e) Stones and Boulders

In the assessments at Budd Lake, the only area in which stones were frequent, soil was sieved through a 1-in. (2.54 cm) grate (See Fig. 8). Stones passing through the grate were ignored whereas those with an average dimension of up to 12 in. (30.48 cm) were included for the measurement of stone volume in the soil (Table 5).

Assessment was restricted to the top 12 in. (30.48 cm) of mineral soil since this was considered the maximum depth of planter penetration. The stone concentration at Budd Lake appeared to have little influence on the ability of the planter to treat the area.

Boulders, or rocks with an average dimension of more than 12 in. (30.48 cm), would also be included in this part of the assessment. However, except for one inconsequential outcropping encountered during the 1972 Fawn Township trial, none occurred on the planting sites.

Fig. 8. The Budd Lake site showing degree of stoniness in soil. This concentration did not adversely affect planting quality.

Table 5. Assessment of stoniness

Location	Max piece size, avg of 3 dimensions (in.)[a]	Avg piece size, avg of 3 dimensions (in.)[a]	Vol of stone in sample (%)
Fawn Twp ('71)	--	nil	--
Budd Lake ('71)	4	1.3	18.5
Fawn Twp ('72)	One small outcrop of rocks occurred in the trial area.		
Twp 12H ('73)	--	nil	--

[a] 1 in. = 2.54 cm

f) Soils and Minor Vegetation

Table 6 gives general soil and ground cover characteristics of the sites. All sites were sandy and ideal for this machine. Because of the planting method of the Crank Axle it is doubtful that it would be efficient in the heaviest soil conditions of the boreal forest. As a result, the Crank Axle was not tested on clay soils during these trials.

Table 6. Soil and vegetation assessment

Location	Minor vegetation	Depth to mineral soil (in.)[a]	Texture	Soil depth (ft)[b]	Soil moisture
Fawn Twp ('71)	light-heavy	<1-5	sand	>3	dry
Budd Lake ('71)	light	1-4	sand	>3	dry-fresh
Fawn Twp ('72)	light-medium	1-2	sand	>3	dry
Twp 12H ('73)	light-medium	1-6	sand	>3	dry-fresh

[a] 1 in. = 2.54 cm

[b] 1 ft = 30.48 cm

Operating Procedure

In conducting these trials we worked very closely with OMNR staff in Chapleau District and at Head Office in Toronto. The District staff was responsible for all operational planting equipment and procedures including initial preparation of the planter, provision of tractor, blade, planting stock, operating staff and supplies and conduct of the planting operation. Trees were planted in a manner and at a spacing determined by the Unit Forester in charge. District shop staff assisted whenever repairs or maintenance were required.

Staff of the GLFRC were responsible for work studies and the assessment of site conditions, planting quality and survival. They were instructed to keep interference with normal operations to a minimum but to assist in nonoperational matters wherever help was needed and would not influence the results of the work studies. With the exception of the 1972 work studies and planting assessments done under contract to M. B. Price, R.P.F., all field work assigned to the CFS was conducted by GLFRC staff.

Although not all planting machines are adapted to such a technique, usually because of restricted sideways movement, the trials in 1971 and 1972 were carried out with the machine travelling in a concentric pattern using an ever-decreasing perimeter. This pattern can be used most successfully on more or less rectangular areas. Turning time, which can be a major time factor in parallel planting, is at a minimum because turns are wide and planting continues through most turns. Because of the irregular shape of the area treated in 1973, parallel planting was used.

Generally trees were to be planted at 6-ft (1.83-m) spacing within the rows, although for Township 12H spacing was set at approximately 4 ft (1.22 m) to account for an expected wider inter-row spacing. Inter-row spacing was to be as close to 8 ft (2.44 m) as possible. Because of the risk of slash damage to trees planted on previous passes it is extremely difficult to attain a tighter inter-row spacing. Inter-row spacing was the responsibility of the tractor operator while intertree spacing was determined by the planter operator. No spacing aids were given to the planter operator. He was allowed to develop his own rhythm although this was frequently broken by non-plantable distances due to stumps and slash. As the operator's speed of planting became evident, the tractor operator was instructed to reduce or increase forward speed to attain the prescribed intertree spacing efficiently. Whenever necessary, such instructions were given to the various operators and the time gained or lost was recorded in the work studies.

Because it is strenuous and sometimes hazardous work, two planter operators were always on site to spell each other off. The idle operator would spend his time at the many small jobs that always need doing on such operations.

For safety and operational efficiency a direct communications link between planter and tractor is essential. Therefore, a horn was installed on the tractor by which the planter operator could signal the tractor operator to stop, move forward or reverse. The tractor operator must be prepared to act almost instantaneously upon a signal from the planter. This is particularly true if debris passes up through the planting shoe opening and the planter must be stopped immediately to avoid injury to the operator. With this machine the tractor operator must have an overriding concern for the men in the planter.

Work Studies

To evaluate machine performance properly, to assess its ability to cope with various site conditions and to provide sufficient data against which the performance of other machines can be compared, detailed work studies must be conducted on each operational trial. An explanation of the work study method used, time element designations and definitions are given in Appendix C.

Work studies were carried out at two levels. To gain an impression of the machine's overall capability in relation to general site descriptions, planting rates, design and structural limitations, and operational improvements required, general time studies were conducted. This involved timing the operations for virtually the full period of each trial. To determine how the various site factors affect productivity, careful timings were made as the unit passed through the plots on which site assessments had been conducted. Each 0.1-acre (0.04-ha) subplot formed a timing unit. Time of entry and exit were precisely noted using the hitch on the planter as the reference point. Time elements were recorded in the prescribed manner. This portion of the study provided a basis for comparing planter productivities and for relating productivity, either in linear or areal terms, to the specific pretreatment operating conditions in each plot as well as to planting quality, which was assessed immediately after planting (see next section).

The motion of the scarifying-planting unit was broken down into one productive and six nonproductive classes. The designation "forward" represented productive effort. The designations "stop" or "reverse", initiated by either the planter or tractor operators (recorded separately), "manoeuvring" and "personal" were used to signify nonproductive effort. Since the horn signals were audible to the observer, stops or reversals initiated by the planter operator could be distinguished from those initiated by the tractor operator. This technique was not fail-safe. On occasion the tractor operator was able to predict when the planter would run into difficulty. In such instances he directed the planter operator with a hand signal to raise the planter until he passed over or by the obstacle. Such signals were evident to the person conducting the time study. The term "manoeuvring" refers mainly to efforts made while turning corners in the blocks or making turns at the ends of runs in the case of the 1973 trials. The former delays were caused by the fact that plots were often quite close to the block corners and consequently the tractor had to be manoeuvred into position to enter and leave the plot in a preset manner. Lunch breaks and rest periods constituted most of the personal nonproductive time. In all cases lunch breaks were attributed to the tractor operator up to the point at which the operator was ready to go. When more time was required because the planting crew was still eating, it was charged against "personal" delay and forms part of the evaluation.

Post-treatment Survey

The assessment of planting quality was also carried out in two stages. The bulk of the data was collected row by row after the planter made each pass through the subplot. The influence of each pass through the subplot on the previous row was assessed at the same time.

Some evaluations were subjective. However, in evaluating planting depth, a variation of up to 1 in. (2.54 cm) above or below the root collar was regarded as satisfactory. Measurements in excess of this were rated as deep or shallow. Owing to the presence of a ridge of loose soil in which the trees were planted it was necessary to visualize the general ground level extended to the base of the tree in estimating the position of the root collar. The loose soil could not be interfered with because the measurements of planting quality taken in a concurrent and more detailed study would have been affected.[2]

The assessment of tree packing was based on how the tree responded to a firm tug on its stem. If it was loose, it yielded quite readily to this tug and was so rated. A tree was regarded as covered by debris when interference was judged sufficient to jeopardize its survival. If a tree was surrounded by debris yet still had a good chance of growing through, it was not regarded as debris-covered. To evaluate the extent of the debris interference caused by subsequent passes, trees so affected were totalled anew in the second stage of assessment and the difference between this new total and the previous figure was recorded.

In the second part of the quality assessment, the failure of the scarifying–planting unit to plant a tree was measured in terms of the lineal distance and probable cause of failure, i.e., stumps, debris, or miscellaneous, undetermined causes. Intertree distances up to 9 ft (2.74 m) (representing the 6-ft (1.83-m) standard set by OMNR plus an allowance of one-half this distance) were considered to be acceptable and no tally was taken. Intertree distances greater than 9 ft (2.74 m) were measured, the 6-ft (1.83-m) standard was deducted and the difference was recorded as fail area.

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[2] A more detailed study of the biological significance of mechanical planting is being conducted by R. F. Sutton of the Great Lakes Forest Research Centre.

All trees in each plot were assessed during both of the post-treatment evaluations.

Results

a) Work Studies

The detailed overall work studies clearly identified those operational factors which most affected productivity and machine availability. Accumulated times by each work study element, as recorded in the field, are given in Table 7 for each of the four trials. Investigation of these data enabled us to pinpoint and determine the significance of the factors responsible for decreased productivity. For example, it is evident that "reverse planter", "reverse tractor", "manoeuvring" and "personal" times are acceptably small on all four jobs with the possible exception of "manoeuvring" in Township 12H, the result of planting in a parallel pattern rather than a concentric one. Since most of the time under "stop tractor" is not paid for, this section also can be largely ignored. Thus the greatest single factor affecting productivity is the "stop planter" category and here is where the greatest gains can be made when attempting to reduce nonproductive effort.

In 1971 clearing debris that was fouling planter operation was a major problem and, as can be seen, the time consumed in this operation increased almost 150% in the move from Fawn Township to Budd Lake where measured slash volume was also much greater. An increase in measured slash usually signals a roughly parallel increase in light slash. This was the case in the 1971 trials as most of the difficulty arose from branches and other light slash accumulating in the coulter and planting foot areas and not from the larger pieces which were measured to determine slash volume. Modifications made to operating procedure and to the planter during that year and the following winter were mainly responsible for the reduction of time in this element in the 1972 and 1973 trials.

In 1971 and 1973, time-consuming breakdowns occurred. These can be expected from time to time with any mechanical device; however, proper repair or modification should confine each of them to a single occurrence. Obviously these trials were not long enough to identify all the problem areas but the data gathered should be of use in the development of a durable machine relatively free of major mechanical difficulty. Changes in the auxiliary engine's throttle/hydraulics arrangement reduced motor stalling to an insignificant level. Other problems, e.g., long delays in supplying stock and refuelling, can be minimized through a high degree of organization. Delays attributed to the CFS are considered to be atypical and are not considered in the evaluation of the planter.

Table 7. Work study time summary for Reynolds-Lowther Crank Axle trials in terms of basic motions and function on four sites of differing difficulty

Function	Fawn Township, 1971 Minutes	%[a]	Budd Lake, 1971 Minutes	%[a]	Fawn Township, 1972 Minutes	%[a]	Township 12H, 1973 Minutes	%[a]
Forward	1144.46		1026.60		2420.75		1217.82	
	1144.46	52.3	1026.60	61.7	2420.75	75.1	1217.82	45.6
Stop planter								
clearing debris	113.19		314.03		52.23		35.59	
breakdown	459.07		47.87		34.12		249.17	
motor stall	28.83		24.48		7.29			
refuelling	44.31		22.78					
servicing	13.82				105.57		90.51	
supplying stock	16.53		20.98		225.20		77.02	
change operators			13.20					
instruction (CFS)	2.83							
instruction (OMNR)			2.98		3.43			
CFS experiment	0.20		9.20		55.70			
out of stock							39.53	
other	27.17		1.50		7.24		34.28	
	705.95	32.3	457.02	27.5	490.78	15.2	526.10	19.7
Stop tractor								
clearing debris	14.30		1.87		3.68		14.42	
breakdown	30.80				1.12		14.97	

(continued)

Table 7. Work study time summary for Reynolds-Lowther Crank Axle trials in terms of basic motions and function on four sites of differing difficulty (continued)

Function	Fawn Township, 1971		Budd Lake, 1971		Fawn Township, 1972		Township 12H, 1973	
	Minutes	%[a]	Minutes	%[a]	Minutes	%[a]	Minutes	%[a]
Stop tractor								
refuelling			35.62					
servicing	42.74		1.08				22.72	
instruction (CFS)	5.75		1.00		4.25		14.69	
instruction (OMNR)			3.72		0.12		8.42	
rest	11.68							
stuck					0.23			
CFS delay	0.20						104.24	
other	6.25		0.77				7.25	
lunch	103.24		38.53		234.48		360.00	
cross road	2.31							
	217.27	9.9	82.59	5.0	243.88	7.6	546.71	20.5
Reverse planter								
clearing debris	49.84		49.25		10.47		1.35	
other			5.57					
	49.84	2.3	54.82	3.3	10.47	0.3	1.35	0.1
Reverse tractor								
clearing debris	28.39		4.64		2.95		71.76	
stuck					12.03			
other	0.29		1.18					
	28.68	1.3	5.82	0.3	14.98	0.5	71.76	2.7

(continued)

Table 7. Work study time summary for Reynolds-Lowther Crank Axle trials in terms of basic motions and function on four sites of differing difficulty (concluded)

Function	Fawn Township, 1971			Budd Lake, 1971			Fawn Township, 1972			Township 12H, 1973		
	Minutes		%[a]	Minutes		%[a]	Minutes		%[a]	Minutes		%[a]
Manoeuvring												
clearing debris	3.15			5.57						6.30		
turn										88.84		
instruction (CFS)	3.95						15.52					
instruction (OMNR)	0.68						0.55					
other	24.42			3.75						77.26		
		32.20	1.5		9.32	0.6		16.07	0.5		172.40	6.5
Personal												
lunch				14.97						99.31		
rest	7.49			10.18			17.71			11.62		
instruction (CFS)										2.06		
instruction (OMNR)										0.26		
other	1.29			2.55			5.56			16.64		
injury	1.75						1.81			4.73		
		10.53	0.5		27.70	1.7		25.08	0.8		134.62	5.0
TOTAL		2188.93	100.1		1663.87	100.1		3222.01	100.0		2670.76	100.1

[a] Percentages may not add up to 100% because of rounding.

Minor improvements can also be made by a thorough investigation of delays in other areas. With proper attention paid to each problem area, the overall result can be a highly efficient operation with a minimum of unnecessary delay.

Time data from Table 7 have been reorganized in Table 8 into a form that more readily indicates operational efficiency in terms of productive and nonproductive effort. These data have been converted to hours for the calculation of the planting production information given in Table 9. Machine availability (operating time) was very high at Budd Lake in 1971 (91.5%) and in Fawn Township in 1972 (87.2%). The two major breakdowns noted above resulted in decreased availability in each of the other two trials, but even so, only the Fawn Township 1971 trial was much below the industrially accepted norm of 80% availability. The lower "operating time" percentage for the 1971 trial in Fawn Township is explained largely by the fact that this was the first trial with the Crank Axle and all staff were unfamiliar with machine planting in general and the use of this machine in particular. Total productive time was high in 1972 as a result of improvements made after 1971 to operational procedure of the type noted above and to the machine. As the 1972 trial was conducted on a site very similar to the 1971 site we benefited from our earlier experience. Decreased productive time in 1973 was the result of the breakdown, inefficient organization of stock supplies and a worn-out auxiliary engine on the planter. As noted, this trial was conducted on a parallel strip basis and considerable nonproductive time was consumed in making turns at the ends of the rows. "Personal" time was also higher but still within acceptable limits.

The reduction in trees planted per acre in 1972 (Table 9) reflects the tractor operator's tendency to stay further away from the previously planted row than had been the case in 1971, despite low slash volumes and few topographical impediments. In 1973 inter-row spacing was relatively narrow despite the large number of residual trees present and the heavy slash volume in the area.

The number of trees planted per productive hour was highly consistent over three of the four trials. The much lower number recorded in 1972 was due to a tractor operator who tended to be slow, cautious and methodical. This tendency is reflected in the relatively low average forward speed and in reduced net area planted per productive hour. On the other hand, in 1973, a higher forward speed allowed the rate of planting to be maintained despite greater obstruction by site conditions. Coupling this higher forward speed with a moderately wide inter-row spacing resulted in a higher planting rate per hour as well.

Table 8. Time breakdown in terms of productive and nonproductive effort[a]

	Fawn Township 1971		Budd Lake 1971		Fawn Township 1972		Township 12H 1973	
	Minutes	%	Minutes	%	Minutes	%	Minutes	%
Productive time (1)	1144.46	57.8	1026.60	65.1	2420.75	83.5	1217.82	56.8
Work-oriented nonproductive time (2)	263.74	13.3	388.48	24.6	80.67	2.8	338.48	15.8
Personal time (2)	10.53	0.5	27.70	1.8	25.08	0.9	132.30	6.2
Nonoperating time (3)	562.56	28.4	134.88	8.5	372.18	12.8	456.23	21.3
Nonavailable time (tractor) (4)	194.71	9.8	76.00	4.8	247.86	8.6	404.94	18.9
Nonavailable time (other) (4)	12.93	0.7	10.20	0.6	75.47	2.6	120.99	5.6
Total elapsed time (1 + 2 + 3 + 4)	2188.93	110.5	1663.86	105.5	3222.01	111.2	2670.76	124.5
Available time (1 + 2 + 3)	1981.29	100.0	1577.66	100.0	2898.68	100.0	2144.83	100.0
Operating time (1 + 2)	1418.73	71.6	1442.78	91.5	2526.50	87.2	1688.60	78.7

[a] Definitions for terms in this table are provided in Appendix C.

Table 9. Planting production summary

	Fawn Twp 1971	Budd Lake 1971	Fawn Twp 1972	Twp 12H 1973
Total trees planted	16,240	15,250	26,450	17,800
Area planted (acres)[a] - gross	30	25	49	40
- net	26	23	46	32
Trees planted/acre[a] - gross	541	610	540	445
- net	625	663	575	556
Duration of trial (total elapsed time - hr)	36.5	27.7	53.7	44.5
Available time (hr)[b]	33.0	26.3	48.3	35.7
(%)	100.0	100.0	100.0	100.0
Operating time (hr)[b]	23.6	24.0	42.1	28.1
(%)	71.6	91.5	87.2	78.7
Productive time (hr)[b]	19.1	17.1	40.3	20.3
(%)	57.9	65.1	83.5	56.9
Trees planted/available hour	492	580	508	499
Trees planted/operating hour	688	635	628	633
Trees planted/productive hour	850	892	656	877
Net area planted (acres)[a]/ available hr	0.79	0.87	0.95	0.90
Net area planted (acres)[a]/ operating hr	1.10	0.96	1.09	1.14
Net area planted (acres)[a]/ productive hr	1.36	1.35	1.14	1.58
Avg forward speed (miles[c]/hr)	1.22	1.40	0.89	1.47
Avg intertree spacing (ft)[d]	7.6	8.3	7.2	8.8
Avg inter-row spacing (ft)[d]	9.2	7.9	10.5	8.9
Avg spacing (ft)[c]	8.3	8.1	8.7	8.9

[a] 1 acre = 0.40 ha

[b] Any time differences (%) between this table and Table 8 are the result of conversion from centiminutes to hours and are not greater than ±0.1%.

[c] 1 mile = 1.61 km

[d] 1 ft = 30.48 cm

b) Planting Quality

Results of the postplanting assessments are provided in Table 10. Planting depth is almost entirely under the control of the planter operator. It is his positioning of the tree and operation of the riding wheels which determine the depth to which each tree is planted. The majority of trees were planted to an acceptable depth. Deep planting, except where excessive burying occurred, was not considered seriously detrimental to tree survival. However, shallow planting often left roots exposed and it is felt that these trees constitute a high percentage of those expected to be dead after one year. Preliminary results from the more detailed biological assessments indicate that survival and growth of the machine-planted trees are as good as or better than those of control trees planted by hand at the same time. More information on the biological performance of the machine-planted trees will be available when the results of these assessments have been analyzed.

In general trees were firmly packed. In the worst case, just over 21% were considered poorly packed, indicating that the planter's ability to pack on deep, relatively light soils is good. In many cases failure to pack well was the result of interference by debris on the site or abrupt irregularities in microsite relief.

Very few trees received injury either from the pass during which the tree was planted or from the subsequent pass. Debris covering, sufficient to jeopardize survival, occurred mainly as a result of the planting of the next row when trees were then knocked down in the previous row or debris pushed onto the previous row. The severity of the problem is directly related to slash volume and size (particularly length), residual tree density, inter-row spacing and the tractor operator's assessment of the problem. It can be minimized by careful consideration of each of these factors. Generally a wider inter-row spacing overcomes the problem.

The incidence of exposed roots, generally indicating shallow planting, can be controlled largely through proper planting procedure by the planter operator. Virtually no additional exposure of roots resulted from a subsequent pass.

The main factor in the decrease in the number of trees planted per acre or per hour is the inability of the planting machine to cope with certain unameliorated microsite conditions. The reasons for failure of the machine to plant trees are outlined in Table 11. In all cases logging debris is the main cause although the numerous stumps at Budd Lake were also a major factor. Since the planter is supported by and rides on the rolling coulter, the tendency is for the planting foot to be lifted out of the ground whenever surface or subsurface debris is encountered through which the coulter cannot penetrate. At such times

Table 10. Planting quality in terms of the number and percentage of trees affected

Quality class	Fawn Township, 1971		Budd Lake, 1971		Fawn Township, 1972		Township 12H, 1973	
	No. of trees	%[a]	No. of trees	%[a]	No. of trees	%[a]	No. of trees	%[a]
Planting depth								
deep	237	19.4	171	13.5	217	13.2	58	3.1
satisfactory	715	58.5	878	69.4	1150	69.9	1593	86.0
shallow	271	22.2	217	17.1	279	17.0	201	10.9
	1223	100.1	1266	100.0	1646	100.1	1852	100.0
Packing								
firm	1021	83.5	1024	80.9	1470	89.3	1452	78.4
loose	202	16.5	242	19.1	176	10.7	400	21.6
	1223	100.0	1266	100.0	1646	100.0	1852	100.0
Other								
injury during planting	15	1.2	19	1.5	18	1.1	10	0.5
trees covered by debris during planting	34	2.8	4	0.3	49	3.0	160	8.6
trees with exposed roots	126	11.1	116	9.2	106	6.4	66	3.6
trees injured from planting of adjacent row	9	0.1 (1.3)[b]	----	----- (1.5)	7	0.4 (1.5)	16	0.9 (1.4)
trees covered by debris from planting of adjacent row	186	15.2 (18.0)	136	10.7 (11.0)	49	3.0 (6.0)	218	11.8 (20.4)
roots exposed from planting of adjacent row	----	----- (11.1)	2	0.2 (9.4)	----	----- (6.4)	1	0.1 (3.7)

[a] Percentages may not add up to 100% because of rounding.

[b] Figures in parentheses represent combined totals for both passes.

the operator will refrain from inserting a tree and an unplanted distance results. A similar situation occurs for other obstacles such as stumps, roots, rock, frozen ground, etc. Terrain irregularity was the greatest factor under "other causes" although in 1973 frozen ground was also a cause of unplanted distance.

The very high incidence of unplanted distance in 1973 was related to the high slash and residual volume, a V-blade that was not suited to efficient handling of this volume, and the stumps that occurred. Despite the relatively good results achieved in 1971 and 1972, it was quite apparent in all cases that a more effective scarifying device mounted on the front of the tractor would have reduced the amount of unplanted distance and resulted in a more efficient and productive operation.

c) Costs

Costs for the trials include those normally accounted for by OMNR in their operations, i.e., all operational costs except permanent staff salaries. However, the experimental nature of the trial resulted in prolonged stoppages for modification during which time charges for tractor standby, extra float time, etc., were included in OMNR's overall cost. Under normal operating conditions such charges would have been minimized. In addition, other extraneous costs were included so that the costs recorded were often inflated. Such charges were removed from the final cost calculations, the results of which are shown in Table 12 along with the actual costs recorded. The revised costs are those which one could more reasonably expect to incur and which, with improvement in operational efficiency, could undoubtedly be reduced still further. All costs are in 1971 dollar values (discounted to 1971 at 8% where necessary) and have been rounded to the nearest dollar. The average district cost per acre for site preparation and hand planting is provided for comparison. Average district cost per thousand trees planted was calculated on an arbitrarily chosen figure of 800 trees per acre (1975 trees/ha).

DISCUSSION

Over the course of the trials it became quite apparent that, with certain qualifications, site conditions per se were not the major factors affecting high productivity and quality of planting. Provided that major immovable subsurface obstacles are scattered (e.g., boulders, frost, etc.) and slopes do not become excessive (i.e., greater than approximately 25%), the Crank Axle is capable of planting most light-soiled sites. The determining factor is the ability of the prime mover to provide a clear strip at ground level along the path followed by the scalping foot/planting foot portion of the planting machine. The prime

Table 11. Failure of machine to plant, by cause, in terms of fail length along the planting row

Cause	Fawn Twp, 1971		Budd Lake, 1971		Fawn Twp, 1972		Twp 12H, 1973	
	Fail length/ plot (ft[a]/chain[b])	Fail %	Fail length/ plot (ft[a]/chain[b])	Fail %	Fail length/ plot (ft[a]/chain[b])	Fail %	Fail length/ plot (ft[a]/chain[b])	Fail %
Stumps	3.1	4.7	6.9	10.5	2.3	3.5	6.1	9.2
Logging debris	4.0	6.1	7.0	10.6	8.2	12.4	20.5	31.1
Other causes	0.6	0.9	4.0	6.1	3.3	5.0	4.9	7.4
Total fail length	7.7	11.7	17.9	27.1	13.8	20.9	31.5	47.7

[a] 1 ft = 30.48 cm

[b] 1 chain = 20.12 m

Table 12. Costs for machine planting in 1971 dollars

Trial	District avg[a]		Calculated district cost[b]		Revised cost[c]	
	per acre[d]	per M	per acre[d]	per M	per acre[d]	per M
Fawn Twp, 1971 / Budd Lake, 1971	54.00	67.50	47.00	69.00	37.00	54.00
Fawn Twp, 1972	54.00	67.50	50.00	86.00	42.00	72.00
Twp 12H, 1973	54.00	67.50	62.00	112.00	46.00	83.00

[a] Cost established by the district for site preparation and hand planting based on experience from previous years.

[b] Total cost for the trial as reported by the district exclusive of permanent salaries.

[c] Total cost exclusive of expenses incurred because of the experimental nature of the trials and other costs not directly related to the conduct of the trial.

[d] 1 acre = 0.40 ha

mover and frontal attachment must be able to remove slash, stumps, residuals, etc., from this pathway. If this is done successfully, the unit functions as an effective and efficient means of planting bare-root stock. Therefore, if there are no limiting site conditions (and there were none on these trials with the exception of a few short slopes that exceeded 25%), the major considerations are a well-designed frontal clearing attachment (e.g., a V-blade) and a prime mover of sufficient power to handle the site conditions encountered.

Unplantable distances, particularly in Township 12H and at Budd Lake, emphasize this need for effective front clearing. Most of this distance was not unplantable in the sense that it could not be machine-planted but was in the sense that the tractor unit did not render it suitable for planting. Thus, much of this unplanted distance could have been stocked if the tractor unit had done its work effectively. Unplanted distances are not, then, a fault of the planting machine. It should be pointed out that they are highly dependent on the tractor operator as well and are not solely a problem of equipment. With better preclearing, productivity in terms of trees per acre and per hour would have been much improved.

The following site conditions, if not adequately prehandled by the prime mover, created the greatest impediments to productivity and quality planting.

1. Stumps

Stump height is the principal concern. Stumps higher than approximately 12 in. (30.48 cm) come into contact with the blade across its width and generally must be pushed out to permit the tractor to pass over them without danger of hangup. Wherever possible the tractor operator should attempt to avoid hitting and removing stumps with the blade. This slows down the machine and the stumps often roll under the blade and tractor to interfere eventually with the planter and create unplanted distance. In general, stumps become increasingly problematic as their frequency increases. Larger diameter stumps are not a major problem provided they are sufficiently scattered that they can be avoided by both tractor and planter.

2. Slash

This is less of a problem for the tractor than stumps but if not handled adequately it is of much greater significance in reducing productivity and increasing unplanted distance. The blade must clear all debris from the path of the planter, a width of 2-3 ft (60.96 - 91.44 cm), down to ground level. If this is not done properly larger debris will interfere with planter operation, causing unplanted distance, and smaller debris may foul the planting mechanism, resulting in stoppages.

3. Residual Trees

The main difficulty in the initial instance occurs if residuals are so numerous that the tractor cannot avoid them and must push them down. This slows productivity but once the tree is on the ground it has much the same effect as noted under "slash" above. However, each of these problems can be largely eliminated if a proper combination of blade, tractor and operator ability is employed.

In each case, the revised costs per acre are lower than those normally incurred by Chapleau District for site preparation and follow-up manual planting. However, cost per thousand trees planted is slightly higher for the 1972 and 1973 trials. Increasing the number of trees planted per acre through better selection of equipment and better field organization will reduce considerably the cost per thousand. This will undoubtedly occur under normal field operations in the future. In most cases "revised" cost differences are not major, and may be perfectly acceptable if there are local labour shortages or if additional area could be regenerated through complementary use of manual and machine planting techniques.

Modifications

A major delay was experienced in the 1971 Fawn Township trial when the cab portion of the planter was lifted up and over the guides that keep it free to move vertically but hold it from moving more than several inches laterally. The cab became caught in this position and took several hours to free. This difficulty can be overcome by extending the side guides upwards or, better still, joining them at the top by an arch which would prevent the cab from being caught at the extreme end of its upward travel.

One other major delay occurred when the hydraulic pump on the planter failed, but this could not have been avoided by any modification or by a different operating procedure.

In the 1971 trials, the clearing of minor slash from the coulter/scalping foot area was a continuing cause of stoppage. Even though the coulter was adjusted so as to be as close as possible to the tip of the scalping foot, debris would pass into the space above (between coulter and arc of scalping foot) and foul the unit. This problem was overcome by extending the tip of the scalping foot forward so that it projected beyond the rear edge of the coulter and the coulter rode in a small groove in the scalping foot tip (See Fig. 3). Consequently, the time for clearing debris in the "stop planter" function was much reduced in 1972 and 1973.

In 1973 the main delay under "stop planter" resulted from the tearing off of a hydraulic hose. Adequate protection of hoses and electrical wiring will virtually eliminate downtime in this area.

As noted above and in the SUMMARY, well-organized operational procedures will do much to overcome most other delays and will tend to maximize productivity.

Safety

Despite the fact that this planter can be modified to make it safer, it has some features that will continue to be hazardous to the operator in Ontario's boreal forest conditions. For example, it affords a very harsh ride, with the operator being continually thrown around inside the cab as the coulter, scalping foot, packing wheels or transport wheels pass over obstacles. It is a very tiring ordeal, and such treatment may cause injury to the operator. Prolonged exposure to jarring, particularly as the planter rolls over stumps, could result in back injury. Several minor injuries did occur on the trials. Some of these difficulties can be overcome by providing hand grips, heavy padding in the cab and some shock-absorbing features. The rough ride can also be considered a major reason for inefficiency in planting since the time the operator spends protecting himself or holding on reduces the time he has for putting trees into the planting foot. In addition, there is the problem of debris passing up through the opening in the planting foot area. This material is generally driven into the cab as it moves forward and, with the operator sitting astride this area, the possibility of being speared or otherwise injured is very real. As a result, the operator must be continually on the watch for debris entering the cab. This, of course, detracts from his ability to concentrate on doing a good planting job.

Some close calls occurred on the trials. Unfortunately, while some closing of the gap may be possible, there must be some space for the planting foot to travel vertically with respect to the cab and the problem would be extremely difficult to eliminate entirely by this means. (Some additional protection can be provided by placing a low shield immediately in front of the operator to ward off incoming material.) It should be noted that, in areas of high minor slash volumes or where green slash was prevalent, the men who worked in the planter were most apprehensive about the dangers presented by debris passing up through the opening in the planting foot area.

Although it has been stated that the planter will effectively and efficiently regenerate certain sites, users of the Crank Axle should be aware of and take all necessary precautions against these safety hazards.

Limiting Sites

A trial was initiated on a boulder till site in 1974 to test the machine's capabilities under such conditions. Surface conditions were little different from those of the other trial sites. The trial was terminated with less than 1 acre (0.40 ha) covered because of the severe pounding given to operator, machine and equipment and it was concluded that the Crank Axle is not suited to soils with more than minimal rock content.

Although the unit was not tested on clay soils, it was felt that it was generally too light for proper planting foot penetration or follow-up packing in this condition. There appeared to be little need for such a test since trials of another planter, the Taylor Drum Colter, have shown that machine to be excellent for heavy, rock-free soils.

SUMMARY AND CONCLUSIONS

Four operational trials of a Reynolds-Lowther Crank Axle Planter with self-contained hydraulic power were conducted in the Chapleau area in cooperation with staff of the OMNR's Chapleau District. Site assessments and work studies were undertaken to evaluate the ability of the planter to cope with certain site conditions and to pinpoint areas of work that are the greatest source of nonproductive time. The assessments were also designed to indicate which features of machine design were possible sources of breakdown, malfunction or extended downtime. Stumps, slash and residual trees were determined to be the primary sources of reduced productivity or poor planting quality. However, all of these can be overcome as serious impediments by judicious selection of a suitably powered tractor, a well-designed front-mounted clearing device and a good operator. Other major sources of downtime can be largely reduced or eliminated by well-organized operational procedures.

Output in terms of trees planted per acre was moderate and somewhat below what might be expected for hand planting. Planting in terms of trees per hour was less than desired but not critically so. Because of a need for wide inter-row spacing (a minimum of 8 ft, or 2.44 m), trees must be spaced more closely within rows if a high level of planting per acre and per hour is to be achieved. Several modifications to the planter are required if major causes of stoppage are to be eliminated.

Planting quality is quite high with most trees being placed at a satisfactory depth and well packed. Some injury results when debris is thrown over trees from a subsequent pass of the planter. Considerable unplanted distance occurs from stumps and logging debris on site if adequate frontal clearing is not achieved by the prime mover.

Some of the major points to be considered in the setting up of a Crank Axle planting operation are summarized below.

1. The field crew, including the tractor operator, should be thoroughly familiar with the functioning of the planter, the requirements of the job and the potential safety hazards of the operation.

2. The crew should be thoroughly familiar with planter maintenance procedures and have an established maintenance schedule. A full tool kit should be on hand and there should be ready access to shop facilities for repairs, welding, modifications, etc.

3. The most suitable planting pattern (i.e., parallel or concentric) should be determined in advance and the most suitable long axis of planter runs established.

4. There should be two planter operators to provide relief.

5. The tractor must have sufficient power to handle most site conditions. Sizes will range from the D6C for the easier areas to the D7E for the more difficult ones.

6. A well-designed, well-fitted V-blade is necessary to clear a minimum path at ground level. Through either design or operation, effort should be made to avoid skipping or excessive scalping. A scalping foot is essential.

7. Restocking and refuelling points should be strategically located to keep downtime for these purposes to a minimum. If necessary, these operations should be done each time the unit passes one of the points so that it does not run out of trees or fuel at a remote point.

8. Periodic discussion with and instructions to crew members are desirable to maintain correct operating procedure.

9. Pushing out of stumps should be avoided. High stumps are a major operational impediment.

10. A signalling device operated from the planter cab is essential.

11. The gap between the coulter and the tip of the scalping foot must be closed.

12. All exposed hosing and wiring should be protected.

Although it has some features which constitute safety hazards, the Crank Axle is capable of effectively and efficiently regenerating most rock-free, light-soiled sites at reasonable cost.

REFERENCES

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Plonski, W. L. n.d. Standard volume tables. Ont. Dep. Lands For., Timber Br.

van Wagner, C. E. 1968. The line intersect method in forest fuel sampling. For. Sci. 14(1): 20-26.

APPENDICES

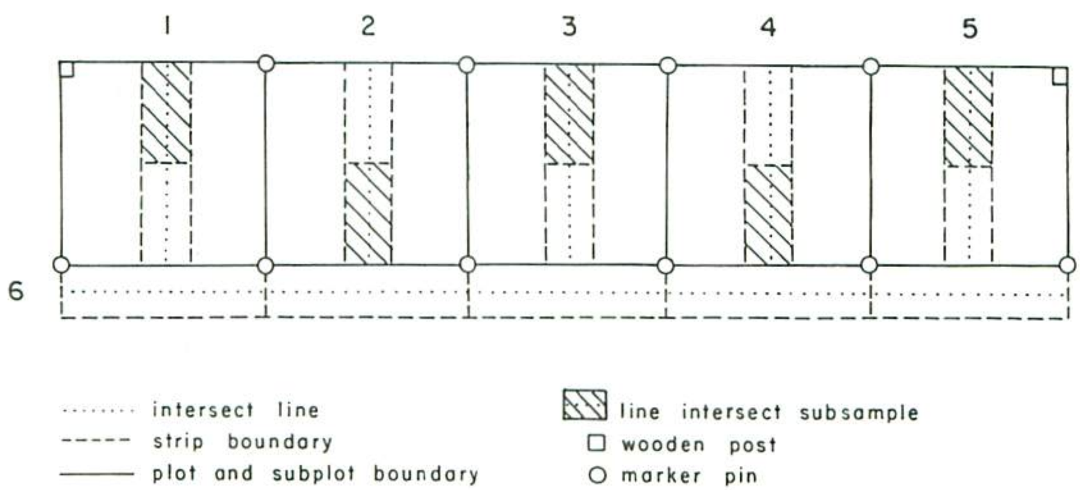
APPENDIX A

ASSESSMENT PLOT ESTABLISHMENT

A typical trial area is approximately 50 acres (20.24 ha) in size. Prior to machine planting, the area is traversed and boundaries are marked. Plots are established to sample the area to determine slash volume, stumps, residual trees, minor vegetation, humus depth, soil texture, soil depth, moisture regime, rock, slope, etc., as a pretreatment survey. Once this has been completed, a time study of the planting operation is carried out recording all elements present in the operation. Delays are individually time, identified and analyzed later. A post-treatment survey is carried out to record planting quality, nonplantable distance and spacing.

Up to eight plots are established within the trial area, one for each 5-6 acres (2.02-2.43 ha) to be planted. Each plot is 5 chains (100.6 m) long by 1 chain (20.12 m) wide with an extra strip 1/4-chain (5.03-m) wide added to the side of the plot. (The latter is needed to meet the requirements of the line intersect survey method used for assessing slash volume.) These in turn are broken down into five square subplots, each 0.1 acres (0.04 ha) in size. This breakdown simplifies the collection of site data.

In order that the plot/subplot system may also be used for the detailed investigation of the effect of site factors on planter productivity and for the assessment of planting quality, plot corners on one side are marked by semipermanent cornerposts and all subplot boundaries are marked by flagged chaining pins. Figure A1 outlines the method of establishment and how the plots are used for assessment purposes. Plots are numbered and pertinent information is recorded on plot corner posts. With the exception of the overall time studies, all assessments are conducted on these plots.



SCALE: 1 INCH = 1 CHAIN
(1 centimetre = 7.92 metres)

Fig. A1. Plot layout for mechanization of reforestation (pre- and post-treatment assessment).

APPENDIX B

PRETREATMENT SURVEY

Factors that may affect the forward progress of the machine, its ability to plant or the suitability of the site for planted trees are recorded in the pretreatment survey.

a) Stumps

Stumps are tallied by 1-in. (2.54-cm) diameter classes outside bark along 10 chains (201.17 m) of 1/4-chain (5.03-m) wide strip within and alongside the plot. Two cross-sectional measurements are taken on each stump and an average diameter calculated. Stump height is tallied in inches on 2 1/2 chains (50.3 m) of this strip (shown by hatched area in Fig. A1) with a maximum of four heights per diameter class being recorded. All heights are measured from the general ground level around the stump to the estimated average stump face level.

b) Slash

Slash is measured using a slightly modified version of the line intersect method and volumes are calculated according to the formula provided by van Wagner (1968). Slash volumes are based upon cross-sectional diameters measured at the point where the chain intersects the slash on the cruise line; hence the name "line intersect". For these trials, volumes are calculated only for slash in the 3-in. (7.62-cm) diameter class or greater at point of intersection. Diameters are tallied in 1-in. (2.54-cm) classes. Material smaller than this is tallied on a frequency basis only. As noted in the text the method is useful only for volume determination and not for frequency per unit area.

A 10-chain (201.17-m) sample is taken in each plot wherein all pieces encountered are tallied according to the above. Slash length is tallied on one-quarter of the larger sample.

c) Residual Trees

All residuals within the 10-chain (201.17-m) sample are tallied by 1-in. (2.54-cm) dbh classes and distinguished as either dead or alive. Heights of all residuals are estimated to the nearest 5 ft (1.52 m). Volumes are calculated using standard volume tables commonly used in Ontario (Plonski, n.d.).

d) Slope

Slope is measured in percent in the direction of machine travel and the distances are recorded in chains. Two 5-chain (100.6-m) lines are traversed, one along each side of the plot. The slope is taken to each break in topography and started at the beginning of each subplot. Side slope is measured only if it is greater than 20%.

e) Stoniness

A hole 2 ft x 2 ft x 1 ft (0.61 m x 0.61 m x 0.30 m) deep is made in the mineral soil and the contents sieved through a 1-in. (2.54-cm) mesh. Stones passing through the sieve are ignored. All material larger than 1 in. (2.54 cm) is subjected to a water displacement method of measuring volume. If the range in size is considered significant, rough estimates of frequency and percent volume by 3-in. (7.62-cm) size class are given (e.g., 1 in. - 3 in. (2.54 - 7.62 cm), 4 in. - 6 in. (10.16 - 15.24 cm), 7 in. - 9 in. (17.78 - 22.86 cm), 10 in. - 12 in. (25.40 - 30.48 cm). The measurements are in cubic feet and fractions thereof. One soil pit per plot is measured.

f) Boulders

Three dimensions are taken of the observable volume (i.e., to a soil depth of 1 ft, or 0.30 m) and the volume is calculated in cubic feet and recorded. Boulders are considered to be rocks greater than 12 in. (30.48 cm) in average dimension.

g) Minor Vegetation

A general impression of minor vegetation conditions is obtained for each plot, i.e., with respect to their effect on the physical planting operation rather than their biological effect on the tree. They are recorded as nil; light, medium or heavy density; tall, medium or low shrub; or grass; or herbaceous.

h) Soils

One tally is taken per subplot giving soil texture, soil depth and duff layer depth.

i) Moisture Regime

On the basis of general impressions each subplot is recorded as being very dry, dry, fresh, moist or wet.

APPENDIX C

WORK STUDIES

To obtain a complete event record for the entire planting operation and to relate site factors to productivity, work efficiency studies are conducted on each trial. As nearly as possible a 100% time study is conducted and all time elements as indicated below are recorded and coded.

Equipment required includes a clipboard with three stopwatches set up in sequence for the timing of each element plus a 30-minute stopwatch for recording total elapsed time.

When plots are being traversed by the planter, the time spent in each subplot on each pass is recorded. In assessing the planted subplots, an equal number of equidistant passes for each plot is taken so that the same travelled distance is recorded for each plot within a block. Coverage intensity is worked out from inter-row and intertree spacing.

Times are tallied in minutes and centiminutes (1/100 of a minute) in seven primary categories:

Forward

Stop (planter-caused)

Stop (tractor-caused)

Reverse (planter-caused)

Reverse (tractor-caused)

Manoeuvring

Personal

Categories 2-7 are further broken down and coded as shown later in this Appendix.

In the case of breakdown, delays are recorded as to time of day and duration, including (if necessary) removal time to the shop and return and the mechanic's time to the field from the shop. Breakdowns of the tractor or other tractor-caused delays are not included in the assessment of the capabilities of the planter. Account is taken of this factor when assessing the planting operation as a whole.

DEFINITIONS

Total elapsed time:

The entire time period for the trial.

Available Time:

The total time available for operating during the day as dictated by tractor availability, i.e., the time over which the tractor and its operator are available for operation within the accepted working day. Time lost due to tractor breakdown, operator absenteeism or CFS timing of the operation is considered *Nonavailable Time*.

Operating Time:

The total time for which the planting unit is functionally available[a] (operable) during the working period or *Available Time* minus delays due to breakdown, servicing, etc., of the *planter* (*Non-operating Time*).

Productive Time:

The total *Operating Time* minus all delays other than those occasioned by *inoperability* of the planter or *Available Time* minus all delays encountered during the working period.

Nonproductive Time:

This is divided into three categories:

(a) *Personal nonproductive:*

Nonworking time (of the planter) due to the on-the-job personal requirements of the workers directly involved in the planting operation excluding the tractor operator and those involved in time studies.

(b) *Work-oriented nonproductive:*

All nonworking time (of the functionally available planter) occurring during the normal working day other than (a) above.

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[a] The condition existing when the planter is capable of performing in the intended manner, i.e., is capable of planting trees, has trees available to plant and is in good mechanical repair. This is exclusive of the planter operator and other external influences such as site factors, weather or supervision.

(c) *Nonoperating:*

The time during which the planter is not functionally available.

Nonavailable Time:

Time during which the tractor is not available for operation or during which the operation is halted for a reason not related to the planting machine, operational organization, etc.

The categorization of each time element into productive, nonproductive or nonavailable units for the purposes of the tables in the body of this report is set out below. The diagram illustrates the relationships among these units.

<table>
<tr><td rowspan="2">PRODUCTIVE TIME
for planting machine</td><td colspan="3">NONPRODUCTIVE TIME</td><td rowspan="4">NONAVAILABLE
(Tractor)

-servicing
-personal</td><td rowspan="4">NONAVAILABLE
(CFS and other)</td></tr>
<tr><td>(a)
PERSONAL</td><td>(b)
WORK-ORIENTED
-clearing debris
-reverse
-lift planter
-etc.</td><td rowspan="2">(c)
NONOPERATING
-servicing
-breakdown
-loading
-etc.</td></tr>
<tr><td colspan="3">OPERATING TIME
for planting machine</td></tr>
<tr><td colspan="4">AVAILABLE TIME
for tractor (100% base)</td></tr>
<tr><td colspan="6">TOTAL TIME (>100%)</td></tr>
</table>

P = productive time
Pe = personal (nonproductive)
WO = work-oriented nonproductive

NO = nonoperating
NA = nonavailable (tractor)
NA (b) = nonavailable (CFS)

P = FORWARD

STOP PLANTER

WO	raise and lower
WO	clearing debris
NO	breakdown
NO	motor stall
NO	horn wires
NO	refueling
NO	planting cab, blade
NO	servicing
NO	supplying stock
NO	changing planters
WO	instruction - OMNR
NA (b)	- CFS
WO	other
NA (b)	CFS experiment

REVERSE PLANTER

WO	clearing debris
WO	other

PERSONAL

NA	lunch
Pe	rest
Pe	other

STOP TRACTOR

WO	clearing debris
NA	breakdown
NO	scalper
NA	servicing
NA	inspect problem
NA	refueling
WO	instruction - OMNR
NA (b)	- CFS
NA	other
NA	stuck

REVERSE TRACTOR

WO	clearing debris
NA	stuck

MANOEUVRING

WO	clearing debris
WO	turn
WO	wet
NA/NA (b)	stuck
NA/NO	servicing
WO	instruction - OMNR
NA (b)	- CFS
WO	other