SWEDISH SILVICULTURAL TECHNOLOGY: A WESTERN CANADIAN PERSPECTIVE

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Abstract

In June 1989, Séamus Parker and Patrick Forrester of the Forest Engineering Research Institute of Canada (FERIC) toured Sweden for two weeks to observe current silvicultural activities. The tour was jointly funded by the Canadian Department of External Affairs under the Technology Inflow Program (TIP), and FERIC. The report documents the observations made and information gathered by the authors. Current Swedish silvicultural practices and methods, particularly those employed by the larger forest companies, are discussed. The activities addressed are site preparation, planting, stand cleaning, pruning, and commercial thinning, with some comments on ergonomics and forest/machine interactions.

Acknowledgements

The authors thank Lynda Watson of the Canadian Department of External Affairs for her assistance in obtaining funding, and Jan Fryk of Forskningsstiftelsen Skogsarbeten for his help in organizing the tour. Our thanks also to the companies and personnel in Sweden (Appendix I) for their hospitality and cooperation during this informative tour.

We also thank Ingrid Hedin, Jennifer Tan, Kathi Patton, and Kathy Prochnau of FERIC for their help in the production of this report.

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Disclaimer

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Summary

In June 1989, two researchers from the Forest Engineering Research Institute of Canada (FERIC) visited Sweden for two weeks to observe silvicultural developments and operations. The study trip was funded in part by the Canadian Department of External Affairs under the Technology Inflow Program (TIP).

In Sweden, site preparation is a highly mechanized forestry activity that employs machine attachments such as rotating discs and cones, patch scarifiers, and non-powered units (plows and harrows). Patch scarifiers have been modified over the past decade and they are now capable of creating mounds of mineral soil. The current trend is towards site-specific scarification, which has led to development of multipurpose implements. As well, mounding treatments have become an option in site-adaptive scarification.

Several mounding implements were viewed in Sweden, i.e. the Donaren 870H mounder, the Bräcke three-row hydrostatically powered mounder, and the Öje Högen mounder. All have potential in Western Canada.

Planting is the main method of regeneration in Sweden. Of the area clearcut, 85% is planted, 14% is regenerated naturally, and 1% is seeded. Seeding is carried out only on thin rocky soils that cannot be manually planted. Current and anticipated labour shortages in the forest industry in Sweden have fuelled interest in mechanical planting. For many years, a consortium of forest companies has been working to develop an effective planting machine, i.e. the Silva Nova tree planter. The Silva Nova is still in the prototype stage of development; an operational machine will not be available for several years.

Seedling distribution methods are closely related to the nursery systems used. Swedish stock-production systems have been developed to provide efficient handling techniques. The production lines of the Hiko and Planta 80 containerized systems are almost totally automated; the greenhouse and artificial aging systems are computer controlled to provide optimum seedling growth and condition.

The most common tools for planting this containerized stock are the tube types where soil conditions permit their use. "Carrot extractors" or dibbles (hole pipes) are also employed.

Stand cleaning and spacing operations in Sweden currently treat 350 000 ha annually. In some areas, two or three hardwood and brush cleanings are required to bring a coniferous plantation to the free-growing stage. The large area requiring treatment has made alternatives to manual and motor-manual methods necessary. Two methods of cleaning and spacing in established conifer plantations prevail: modified or purpose-built prime movers with cleaning heads, or motor-manual clearing saws. Clearance and ground pressure are very important factors in the design and application of cleaning machines.

One-quarter of Sweden's 65 million m^3 annual cut is made up of commercially thinned wood. Of the total area thinned, 60% is "first thinnings," yielding an average of 50 m^3/ha. The large forest companies are highly mechanized, and 50% of their total volume produced is harvested mechanically by shortwood systems.

Numerous makes of single-grip harvesters and processing heads are available. The heads are powered hydraulically and perform four functions: holding, felling, delimbing, and bucking. Though little commercial thinning is done at present in Western Canada, Swedish equipment may have potential in the harvesting of small-diameter lodgepole pine stands.

Since the 1970s, Swedish equipment designers and manufacturers have emphasized the importance of ergonomics. Improvements to the operator's work space and machine controls have increased machine and operator productivity. Also, increased accessibility to the machine's components has improved ease of maintenance and has reduced costs. Incorporating similar ergonomic principles into North American equipment design would result in similar benefits. In particular, Swedish-style suspension seats with joy stick controls offer great potential to the North American forest industry and have been incorporated into some North American equipment.

Work is now being done at the Swedish University of Agricultural Sciences to solve the problems of soil compaction and rutting caused by forestry machines. To prevent rutting, the university is developing an electronic system to control slip and torque, with possibilities of adapting the wheel forces to the strength properties of the forest floor. In addition to this work, the university is investigating the strength characteristics of various soil types to determine what loads and shear forces may be applied without causing severe soil compaction. This information can then be used in conjunction with the slip and torque control to optimize operations.

Sweden and Western Canada have many differences in terms of tree species, harvesting practices, and forest policies. However, some of the Swedish silvicultural equipment and techniques can continue to be adapted to advantage in Western Canada's forestry operations.

INTRODUCTION

Western Canada and Sweden are rich in forest resources, with boreal climates and glaciated terrain common to both. These similarities make it logical to compare the forest management and silvicultural practices of the two areas. Sweden's long history of forest use and industrialization, as well as greater private land ownership and higher wood value, have resulted in a different social and industrial climate than in Canada. Government legislation in Sweden has helped to create a supportive environment for technological innovation and advancement. Considerable emphasis has been placed on marketing this technology overseas.

Mechanization of forestry work in Sweden began in the 1960s and was common by the 1970s. This move to high-production, low-labour methods of harvesting occurred partly in response to the characteristics of the forest resource (relatively small uniform stands), but more directly to changes in the labour force related to increased urbanization and higher job expectations (working environment and job satisfaction).

In Canada, the change from manual harvesting techniques to mechanization has occurred more slowly; in British Columbia difficult terrain and varied timber sizes make mechanical falling and processing unsuitable in many cases. In both countries, silvicultural treatments, with the exception of site preparation, have remained primarily manual and motor-manual.

As Canada has increased harvesting activities in its boreal forests, our industry has examined technology in other countries, particularly Sweden, to determine if Swedish harvesting and silvicultural techniques and equipment could be applied here. This testing, modification, and adaptation of Swedish equipment has occurred for 20 years or more, with both successes and failures.

In June 1989, two researchers from the Forest Engineering Research Institute of Canada (FERIC) visited Sweden on a two-week study tour. The purpose of the tour was to visit silvicultural operations in southern and central Sweden (Figure 1), and to observe the practices and methods employed, particularly by the larger forest companies. Manufacturers and distributors of equipment mentioned in the text are listed in Appendix II. This report documents the observations made and information gathered, and summarizes FERIC's actions pertaining to applicable technology observed. Site preparation, planting, stand cleaning, pruning, and commercial thinning are discussed, and comments on ergonomics and forest/machine interactions are made. Observations about applicability of technology are confined to British Columbia and Alberta because the researchers are most familiar with conditions in these two parts of Canada.

Figure 1. Locations visited during the tour.

SITE PREPARATION

Site preparation is a highly mechanized forestry activity in Sweden. At present, conventional disc or cone-type scarifiers account for 65% of the site preparation, with patch scarifiers and mounders accounting for 25%. Ploughing and spot scarification with excavators are undertaken on wetter sites. The current trend is towards site-specific scarification, which has led to development of multipurpose implements. Mounding treatments have become an option in this site-adaptive scarification. In the next few years, mounders and multipurpose machines are expected to increase in importance as the use of patch, conventional disc, and cone-type scarifiers decreases.

Disc Trenchers

Disc trenchers are rear-mounted continuous-row scarifiers. The discs are either powered or passive. Both the Donaren 180D and Donaren 280D, manufactured in Sweden, are used in Western Canada.

The Donaren 180D consists of two concave discs mounted on hydraulically powered arms; the circumference of each disc is fitted with ten fixed teeth. The rotating discs are positioned so that the disc teeth enter the soil. As the machine moves forward and the discs rotate, material is excavated and deposited to the side. The powered rotation of the discs helps the discs penetrate slash and organic material. Disc angle can be adjusted in some models to provide either a deep, narrow trench with a more pronounced berm, or a shallow, wide trench with more mineral-soil exposure. In favourable soil and slash conditions, the Donaren 180D can produce a continuous berm of overturned organic material and mineral soil.

The Donaren 280D disc trencher (Figure 2) is similar to the 180D, but the 280D has a more complex control system. It is a multipurpose implement that can prepare patches and continuous or intermittent furrows. The latter is accomplished by automatically raising and lowering the discs at predetermined intervals.

Mounders

Mounders, either towed by or mounted on a prime mover, provide raised mounds at intervals along the travel path. The prime mover may be a skidder, forwarder, crawler, or excavator. In Sweden, the Donaren 870H, the Bräcke two-row mounder with spades, the Bräcke three-row hydrostatically powered mounder, and the Öje Högen (mounder) were observed.

The Donaren 870H (Figure 3) is a rear-mounted implement consisting of two mattock-wheel assemblies, each mounted on an arm. Each mattock wheel consists of four pairs of digging tines. The position of the tine angle relative to the ground is controlled by a hydraulic motor. The hydraulic motor brakes the wheel as it digs into the ground, then releases, allowing the wheel to rotate and deposit the material in a mound. A final braking during the cycle firms up the mound over the underlying undisturbed ground. The wheel then rotates to the next fixed position to begin the cycle again. This sequence is repeated as each pair of tines engages the ground. The braking sequence is electronically controlled, with braking actuated by sensors that determine the wheel position. Mound shape and size are determined by the angle of the mattock teeth, braking distance, and applied downward pressure. The distance between mounds and downward pressure can be preset on the control panel. The downward pressure is controlled by a hydraulic cylinder on each arm.

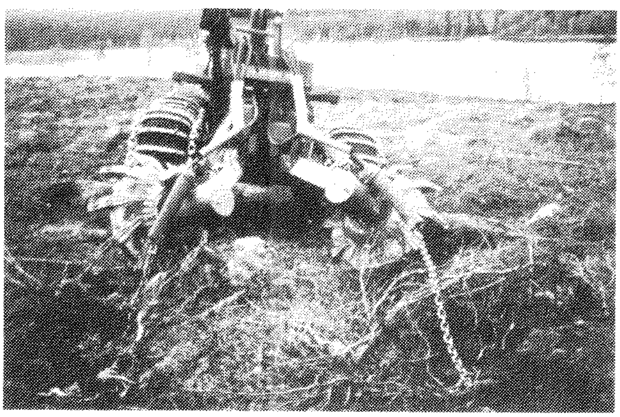


Figure 2. Donaren 280 disc trencher with seeder. Note that drags are used to cover the seed with soil.

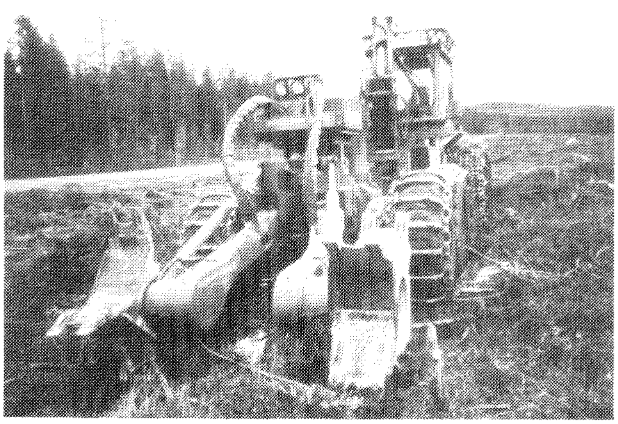


Figure 3. Donaren 870H mounted on a forwarder.

The design of the Bräcke mounder is based on the standard Bräcke spot scarifier. This towed implement produces either two or three rows of prepared spots. The scarifier is connected to the prime mover's frame with a cable or a coupling. Each mattock wheel is matched with a rubber tire for floatation and has four pairs of tines. (In Canada, three pairs of tines may be used.) As the prime mover pulls the scarifier, the mattock wheels turn at approximately half the speed of the rubber tires. This reduced rotation speed causes the tines to dig into the ground and scrape the organic material and mineral soil. As the mattock wheel continues to turn, the soil gathered by the tine is inverted, forming an accumulation, or mound, after the scalp. The sequence is repeated as the next tine engages the soil. If the tines become wedged into stumps or against rocks, the tire will spin to absorb the shocks and reduce the risk of damaging the implement.

The Bräcke mounder is able to increase the amount of mineral soil within the mound. A spade is located behind each mattock wheel. The spade is activated by a cam wheel on the mattock-wheel shaft and penetrates the soil at the back of the scarified patch. The spade deposits material on top of the inverted surface material and produces a small inverted humus mound. The placement of the soil may be adjusted to change the mound characteristics; for example, a mineral-on-mineral mound may be made by activating the shovel earlier and depositing the soil on the scarified patch. This machine has been used operationally in Canada.

The Bräcke three-row mounder (Figure 4) is a prototype. The mechanical mode of action has been replaced by self-governing hydraulic motors, and the unit is mounted directly on the prime mover instead of being towed. The mode of action is identical to that of the Donaren 870H. However, the Bräcke mounder is fitted with three pairs of tines, while the Donaren has four. Because the implement is mounted on the prime mover, it is steady in slash and rough terrain, penetrates the soil more easily, and should produce better mounds than the Bräcke shovel mounder.

The Öje Högen is mounted on an excavator (Figure 5).

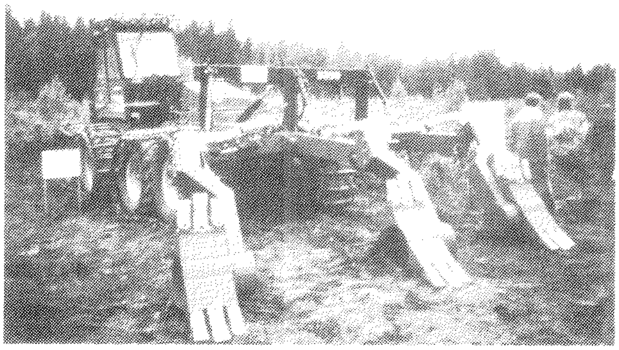


Figure 4. Bräcke three-row mounder.

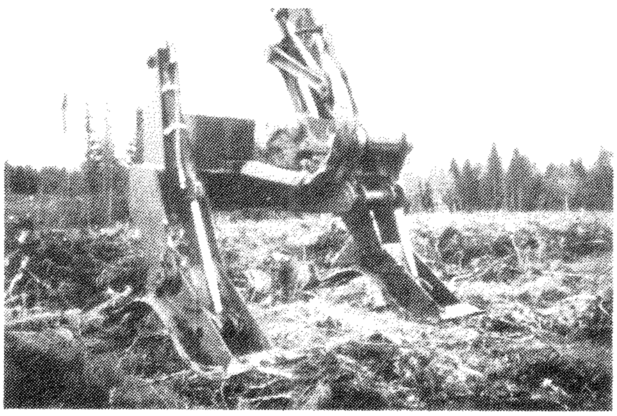


Figure 5. Öje Högen attachment in mound position.

It produces large firm mounds where towed mounders are not effective, i.e. on wet sites or in heavy slash. A two-scoop assembly is mounted at the end of the excavator boom with quick-disconnect couplings. The hydraulic cylinder locks the scoop in the vertical position as it penetrates the soil to a depth of 50 to 75 cm; the operator activates the cylinder, causing the scoop to rotate while simultaneously pulling the boom towards the machine. Two inverted humus mounds can be produced with each attempt. Where heavy slash or brush is present, the operator can push the material aside with the implement before forming mounds. The operator has a greater opportunity to influence the quality of mounds with this implement than with towed or rear-mounted mounders. The quick-disconnect feature makes the prime mover flexible and easily available for use with other attachments.

Drainage Implements

To improve forest productivity, construction of drainage channels in swampy forests and on wet sites is increasing in Sweden. As a rule of thumb, 5 ha of forest land are reclaimed for every kilometre of drainage ditch. In 1985, 54 000 ha of forest land were drained. Ditches are wide and deep so that they will remain intact and clear of cave-ins (Figure 6). Standard excavator buckets or specialized ditching buckets may be used. Ditching buckets are wide and have a pointed digging side to ease penetration and create a sloping sidewall.

Summary—Site Preparation

Swedish site-preparation implements have been used in Western Canada for the past 15 years. The recently

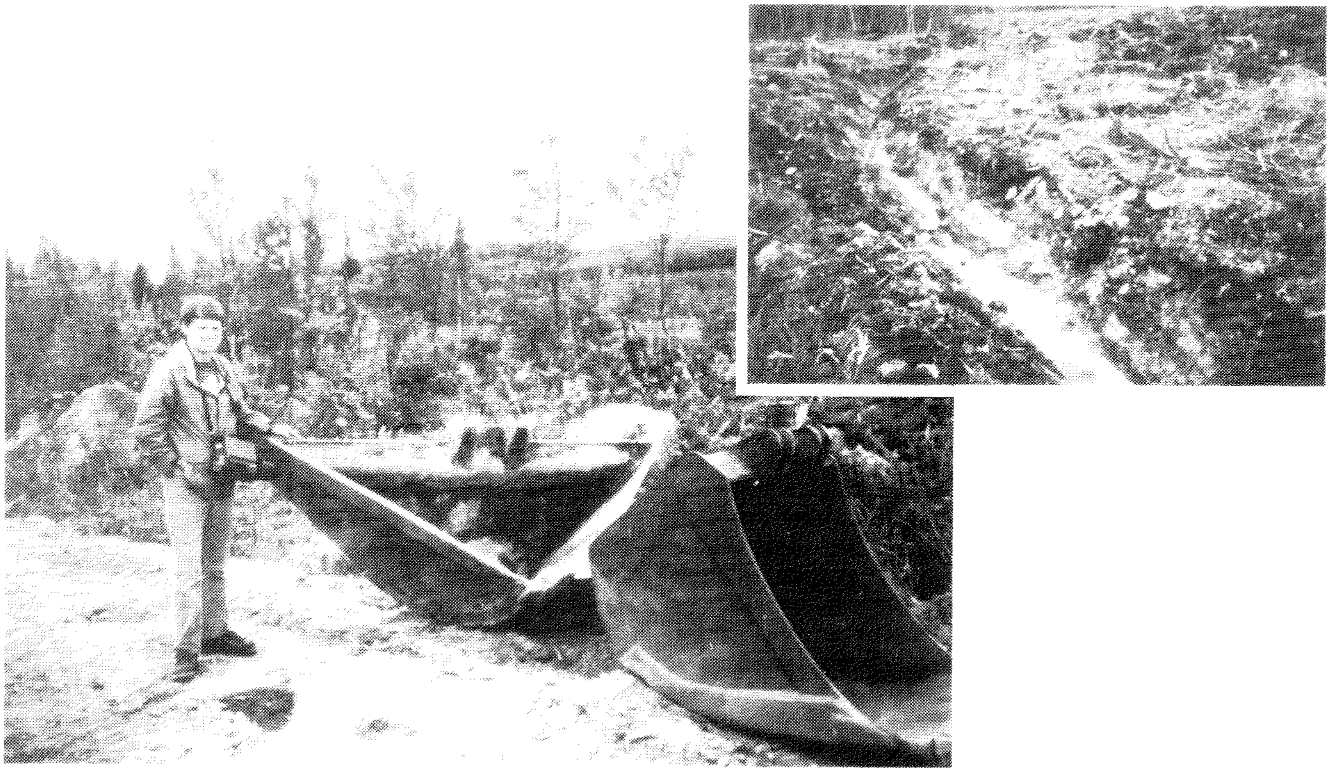


Figure 6. Two ditching buckets. Inset shows a wide, deep ditch.

developed mounding implements viewed in Sweden, i.e. the Donaren 870H, the Bräcke three-row hydrostatically powered mounder, and the Öje Högen, have potential in Western Canada. The concept of site-adaptive treatments is being applied in Canada as well, and equipment with this capability is increasingly common in both countries.

PLANTING

Planting is the main method of regeneration in Sweden. Of the area clearcut, 85% is planted, 14% is regenerated naturally, and 1% is seeded. Seeding is used only on thin rocky soils that cannot be manually planted.[1]

Mechanical Planting

Current and anticipated labour shortages in the forest industry in Sweden have fuelled interest in mechanical planting. For many years a consortium of forest companies has been working to develop an effective planting machine, i.e. the Silva Nova tree planter (Figures 7, 8, and 9).

The functional components of the Silva Nova tree planter are a pair of scarifiers and planting heads. A powered cone scarifier is placed immediately in front of the planting head. This head (Figure 9) penetrates the scarified soil, and produces a planting hole by opening its jaws. A seedling is fed from the seedling compartment through a tube to the planting head by compressed air. Once the seedling reaches the planting head, it drops into the hole created in the scarified soil and is tamped in place before the head is retracted. The machine will abort the attempt if the ground is too hard or too soft. Ground hardness is determined by a pressure sensor in the planting arms. The complete planting cycle is controlled by an on-board computer. The Silva Nova is still in the prototype stage of development; an operational machine will not be available for several years. The primary development tasks remaining include finalizing the automated seedling delivery system, changing the scarification units from cones to discs, and repositioning the scarification units in front of the rear wheels of the prime mover so that the wheels will compact the scarified berm. Productivity is estimated at 1000 to 2000 seedlings/h.

Figure 7. Silva Nova tree planter, side view.

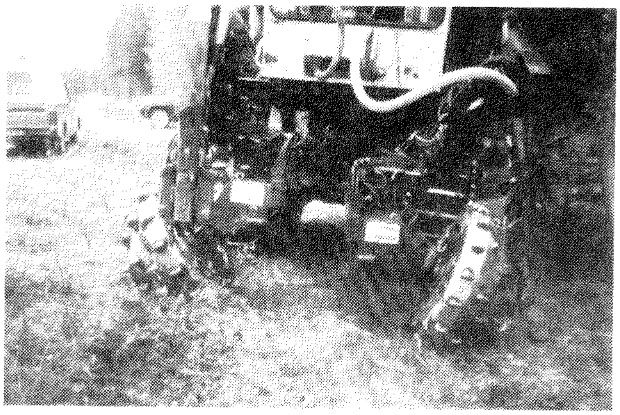


Figure 8. Silva Nova tree planter, rear view.

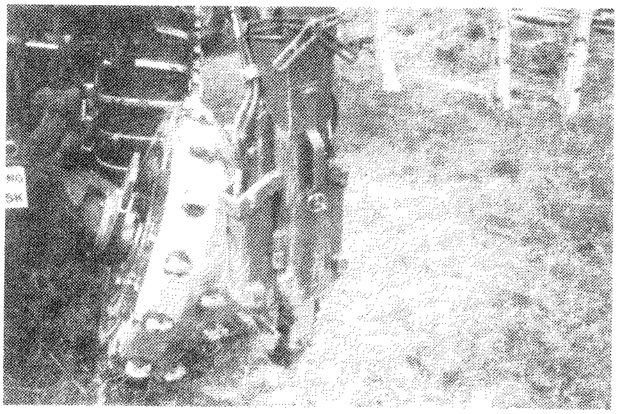


Figure 9. Silva Nova tree planter, detail of planting head.

Seedling-Propagation Systems and Planting

Although not directly within the scope of the tour, nor within FERIC's mandate, two nursery systems are discussed here because they affect seedling distribution.

The seedling propagation systems observed were the Hiko and the Planta 80. The production lines of both systems are almost totally automated while the greenhouse and artificial aging systems are controlled by computer. The Hiko seedlings are delivered to the field in the same containers in which they were seeded (Figure 10), while the Planta 80 system requires that seedlings be machine sorted and repackaged in cardboard boxes for field distribution (Figure 11). In the Hiko system, the containers and racks are returned for reuse, while the Planta 80 boxes are disposed of in the field. Planters are equally well-serviced by the two systems.

[1] Göran Adelsköld, Skogsarbeten; pers. comm.; May 1989.

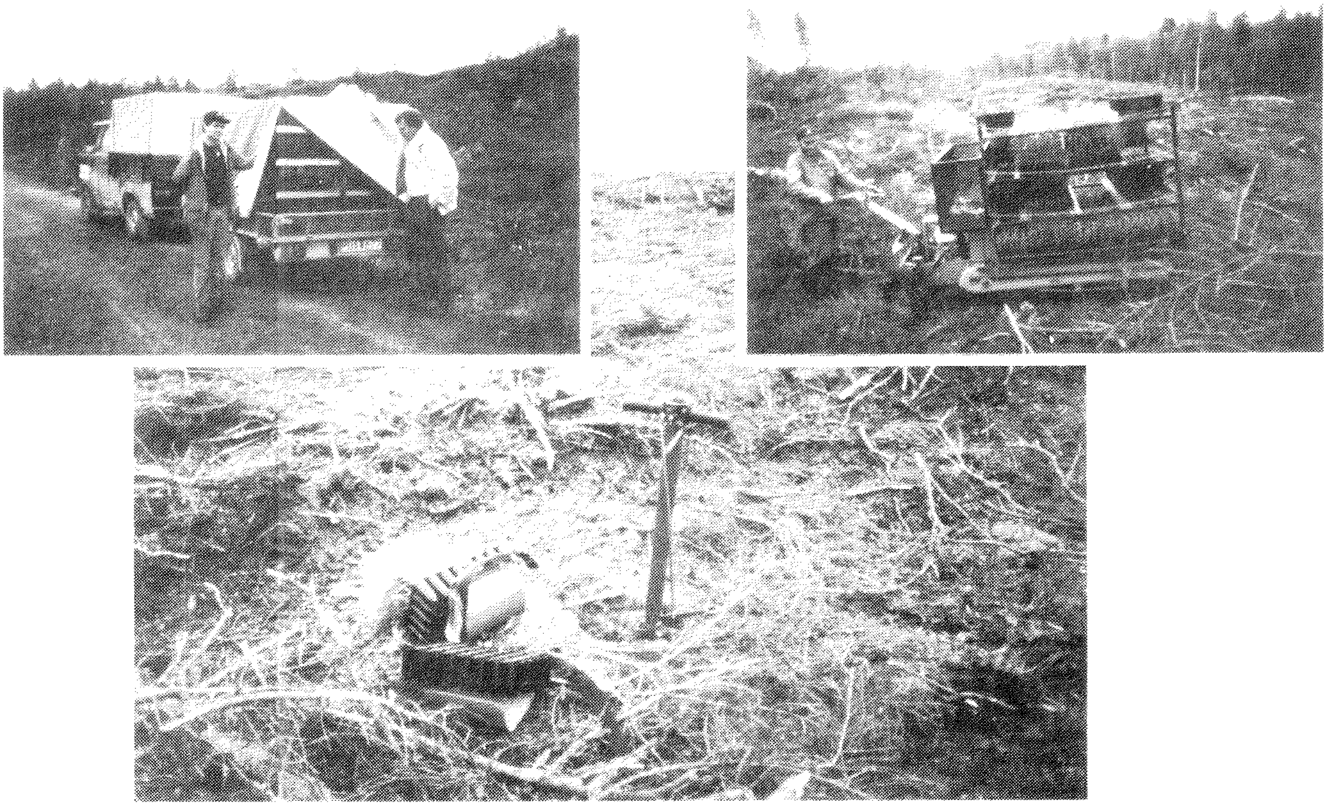


Figure 10. Seedling delivery and distribution method, Hiko system. Clockwise from top left: van and trailer, Combi-Trac, seedling carriers and Pottiputki.

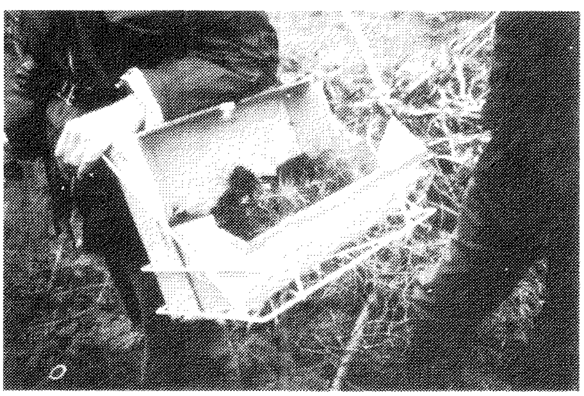


Figure 11. Seedling container and carrier, Planta 80 system.

The Planta 80 system was observed in detail, and is presented as an example of the extensive amount of planning which occurs before the seeding, seedling delivery, and planting processes are carried out. Stora Skog AB, which developed this system, has approximately 200 000 stands inventoried on their computer, each averaging 10 ha. Any area requiring a specific treatment can be accessed by computer and the operation can be planned in detail in the office. When the paper plan is completed, usually in the summer or fall prior to planting, the block is prepared. At the site, yellow and red stakes are laid out 65 m apart as illustrated in Figure 12. Helicopter drop zones are

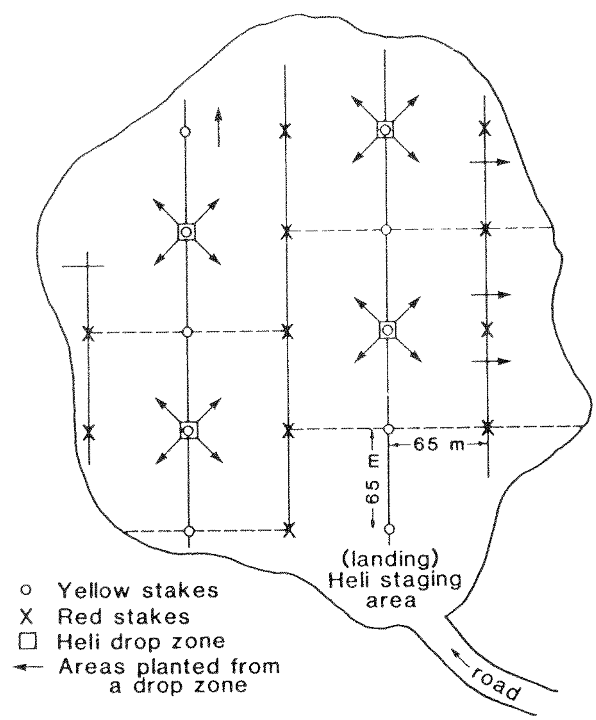


Figure 12. Example of block layout for seedling distribution by helicopter, Planta 80 system.

marked by large red plastic flags for easy identification by the pilot.

When planting is started, the seedlings are trucked to the staging area near the planting block; the staging area can service more than one block if required. Each pallet has 24 or 32 containers, with each container holding 65 seedlings. The pallets are slung under the helicopter for transport to the cutover (Figure 13). At the drop zone, the load is placed on the ground and the sling is released by the helicopter pilot. The seedlings can be moved from the staging site to the planting area (average distance of 400 m) for approximately C$0.005 to C$0.01 per seedling. The company distributes about 75% of its stock in this manner.

The majority of planting is done using tube-type tools (e.g. Pottiputkis, Figure 10). The planters work back and forth between the staked lines, with each planter carrying two containers of seedlings. At the 2-m by 2-m spacing used in Sweden, one container usually has enough seedlings for the "planting run" (Figure 11). An additional container can be carried if "long corners" are part of the run. Stora Skog reports productivity increases of 50 to 100% with the Planta 80 seedling-distribution system over conventional seedling-distribution systems. The length of unproductive walks to refill seedling containers has been significantly reduced and a greater portion of planter time is productive. Each planter averages 2 500 seedlings per day, or one hectare, based upon Swedish planting densities and ground conditions.

In contrast, a different seedling delivery and distribution method was observed with the Hiko system, as illustrated in Figure 10. A van and trailer combination carries 12 000 seedlings to roadside near the planting site. These service a five-person crew for 1.5 days. The racks are offloaded onto a small tracked vehicle (Combi-Trac) for field distribution (Figure 10).

Planting Tools

The tools most commonly used for planting containerized stock are the tube types, i.e. if soil conditions permit their use. "Carrot extractors" or dibbles (hole pipes) are also employed. The tubes are preferred because the planter can remain upright, thus reducing the back problems associated with the constant bending to place seedlings in the ground.

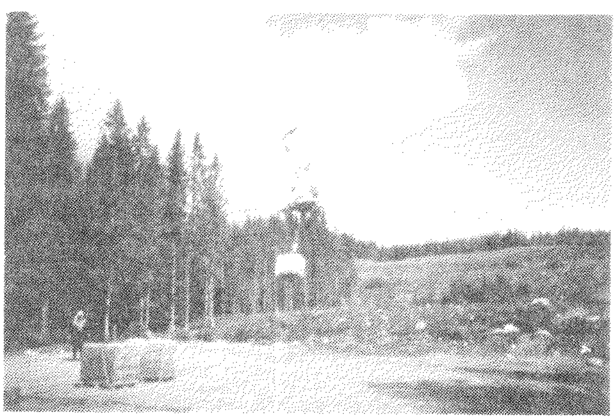


Figure 13. Seedling delivery by helicopter, Planta 80 system.

Summary—Planting

In Sweden, mechanical planting is not yet operational, although a prototype machine has been developed. Detailed planning, efficient seedling-distribution methods, and ergonomic tools have improved productivity and reduced costs.

MECHANIZED STAND CLEANING

Stand cleaning and spacing operations in Sweden currently treat 350 000 ha annually. In some areas, two or three cleanings are required to bring a coniferous plantation to the free-growing stage.

Two methods of cleaning and spacing in established conifer plantations prevail: using modified or purpose-built prime movers with cleaning heads, or using motor-manual clearing saws. Swedish studies indicate that the motor-manual method is more cost effective when the hardwood density is less than 15 000 to 20 000 stems/ha (Lindman et al 1986). At higher densities, mechanical cleaning is economically advantageous. Another economic rule of thumb states that areas less than 2 ha should be cleaned and spaced motor-manually. Terrain factors, of course, may dictate motor-manual treatments. Spring and fall are the optimal times to mechanically clean because there are no leaves on the deciduous vegetation to obstruct the machine operator's view. Mechanical treatments are not used when the temperature is below -15°C because the leaders and stems are susceptible to breakage when the undercarriage of the prime mover passes over them.

The original Swedish trials in mechanical stand cleaning used forwarders with reversed booms (Lindman et al 1986). (By reversing the boom, the operator was able to work in an arc ahead of the prime mover rather than behind as when loading.) A small flail-type cutting head was then mounted on the boom tip. The forwarders had limited clearance and poor weight distribution for this task, although operating costs were low. Ideally, ground clearance should be at least half the height of the conifer stand being cleaned (to allow the sapling to bend rather than break when passing under the prime mover), while ground pressure should not exceed 50 kPa.

The current trend in prime movers is towards using the purpose-built Häglinge Jumbo and medium-sized single-grip harvesters. The Häglinge Jumbo weighs 9 t and the front-end height can be adjusted hydraulically from 60 to 120 cm (Figure 14). This gives it adequate clearance for the task. Its disadvantage, though, is a 70-kPa ground pressure which is considered too high. A

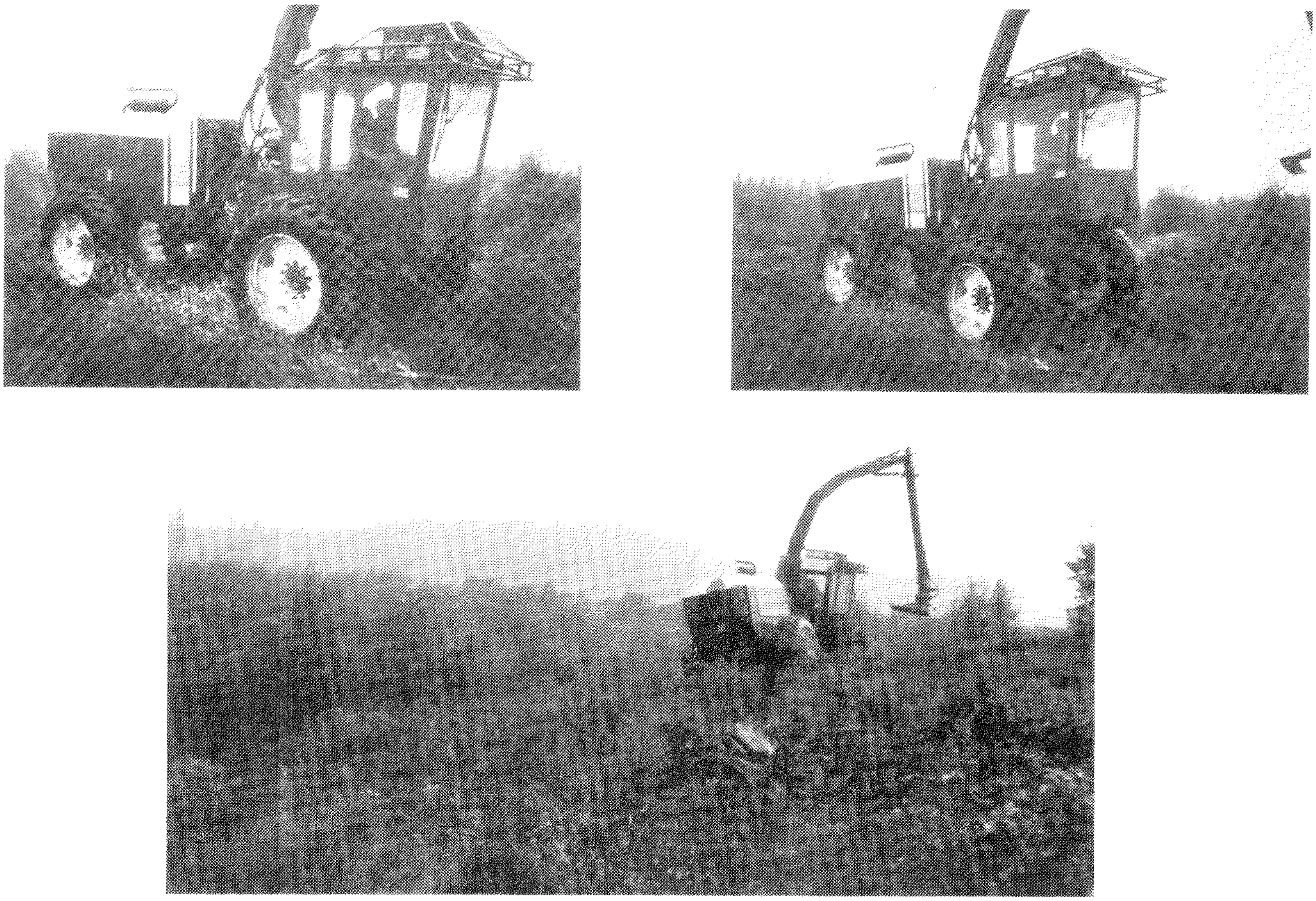


Figure 14. Häglinge Jumbo stand-cleaning machine. Clockwise from left: machine at 60 cm from ground height, machine at 120 cm from ground height, and machine in stand.

solution may be to increase the tire diameter (Wästerlund 1988a). Wider tires, however, are not an acceptable solution because these will increase the potential for stand damage. The FMG 0450 has been developed from the FMG 0470 single-grip harvester specifically for stand cleaning. It has been equipped with larger wheels and portal axles to give it a ground clearance of 960 mm at mid-joint.

To be effective for use in stand cleaning, the boom on the prime mover must be very light and easy to control in all directions. Proportional hydraulics allow precise positioning and smooth operation of the flail-type cutting head, as with the Valmet 901 prime mover (Figure 15).

Summary—Mechanized Stand Cleaning

At present, mechanized stand cleaning is rarely done in Western Canada. With some species, such as aspen, mechanized cleaning can create a coppice problem. Some mowing—cutting the hardwood stems slightly above the conifer understorey—has been done in Alberta to reduce aspen competition (Holmsen 1989). Although the aspen growth is slowed, retreatments are necessary.

PRUNING

Although pruning is not a common treatment in Sweden, interest in tools and methods is ongoing, as it is in Western Canada. A French-made manual pruning device called the Pellenc and Motte (Figure 16) was observed at the College of Forestry, Department of Operational Efficiency, in Garpenberg. The cutting action is similar to a garden pruning shear and the tool has a maximum cutting diameter of approximately 2.5 cm. The unit weighs 4.5 kg, costs approximately C$1000, and is powered by a rechargeable battery pack. In a test, it pruned 200 trees and averaged 27.5 branches per tree, to a height of 2.5 m, on a single charge. Average time per tree was one minute. Some modifications to the cutting mechanism are necessary because the branch stubs are too long. However, the unit has potential for pruning young trees.

COMMERCIAL THINNING

One-quarter of Sweden's 65 million m^3 annual cut is made up of commercially thinned wood (Skogsarbeten 1987). Of the total area thinned, 60% is "first thinnings," yielding an average of 50 m^3/ha. The large forest companies are highly mechanized, and 50% of

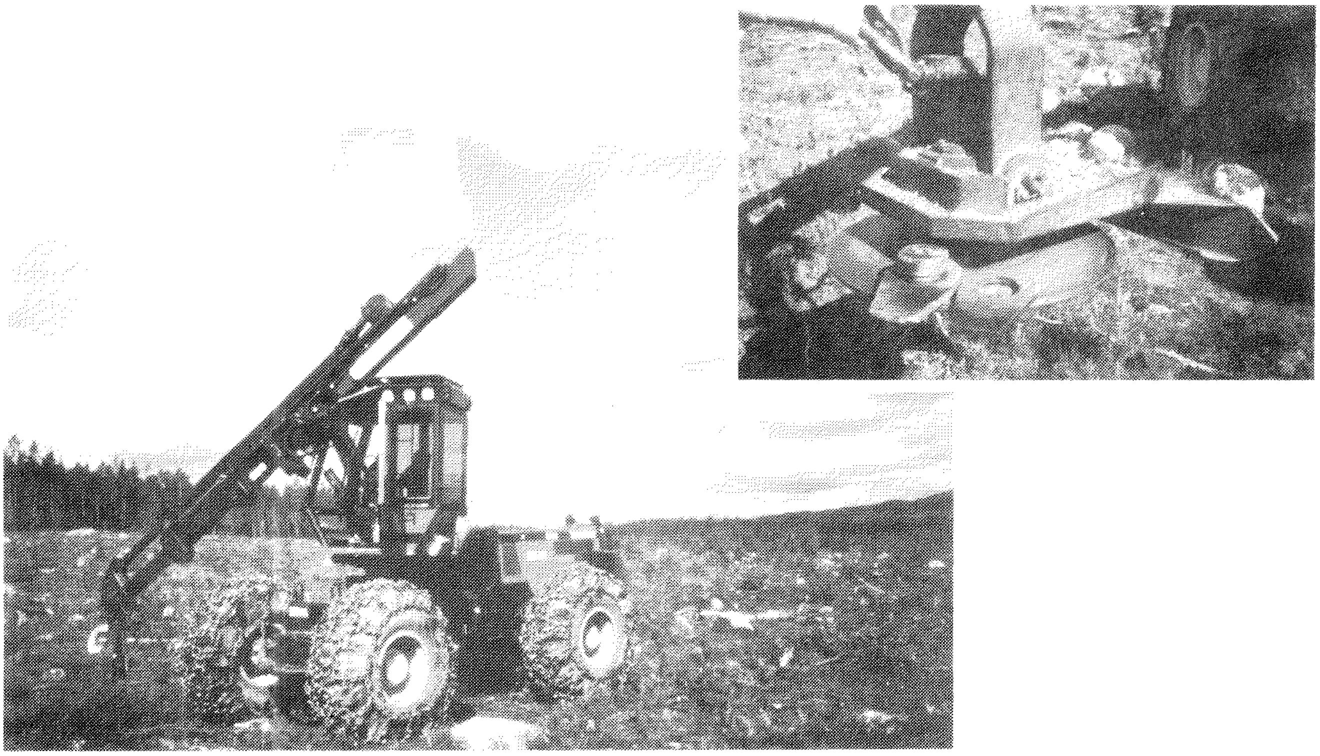


Figure 15. Valmet 901 prime mover configured with a stand-cleaning attachment. Insert shows cutting-head detail with a new blade placed beside the worn one.

Figure 16. Pellenc and Motte pruner.

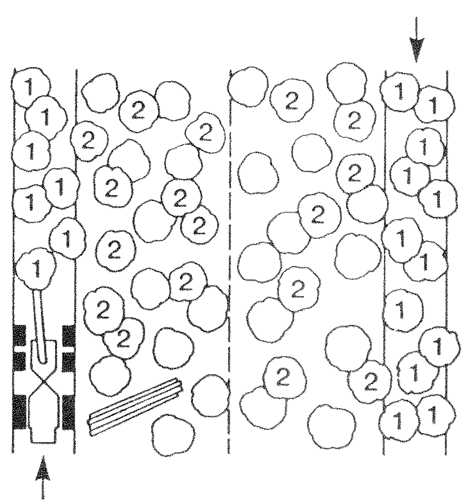
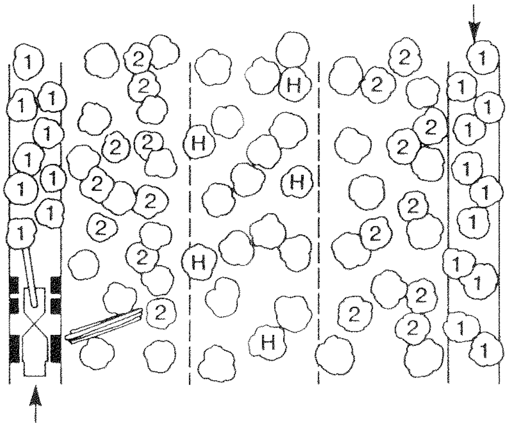


Figure 17. A single-grip harvester fells and processes trees (1) along the strip roads on the first pass. On the second pass, the harvester fells trees (2) to its maximum reach from the strip road.

their total volume is harvested mechanically by shortwood systems (Myhrman 1988).

By law, access roads within thinned stands cannot account for more than 20% of the area. Therefore, if 4-m wide access roads are used, they must be a minimum of 20 m apart. The companies that FERIC staff visited normally spaced roads between 20 and 30 m. Figures 17, 18, and 19 illustrate three methods of thinning using two types of equipment.

In Figure 17, the single-grip harvester clears the strip roads and processes the trees in the first pass. In the second pass, the harvester extends into the stand to its maximum reach. Leave strips 20-m wide can be thinned in these two passes. Figure 18 illustrates the method used with wider leave strips. After clearing the strip roads, the machine fells and processes to its maximum



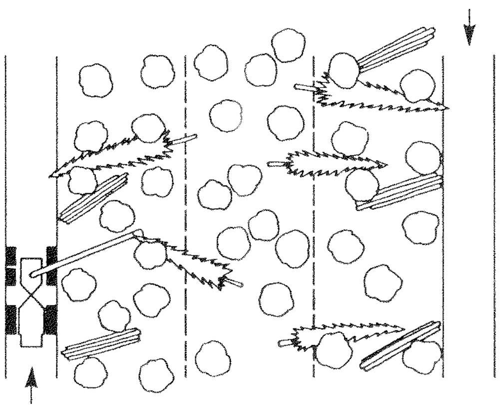


Figure 18. In addition to the first and second passes (1 and 2), the wider leave strip requires a hand faller for mid-zone trees (H).

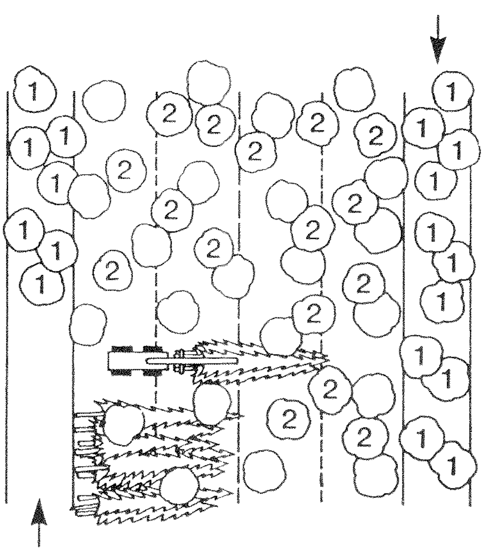


Figure 19. The "tree section" method is carried out with a narrow feller-skidder.

reach. The following forwarder extracts the wood while a hand faller (usually the alternate harvester operator) fells the mid-zone trees towards the skid trails for later processing by the harvester.

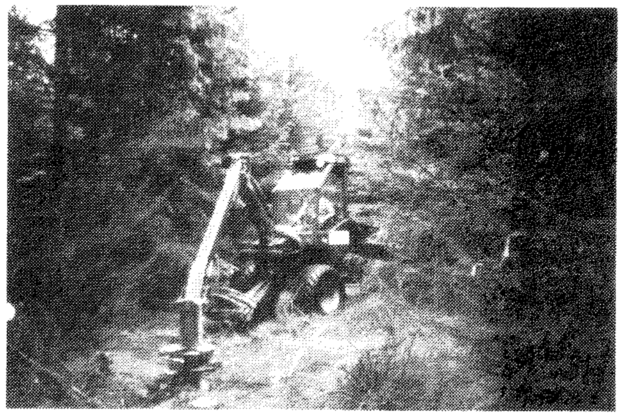


Figure 20. FMG 0410 feller-skidder working in a commercial thinning operation.

In Figure 19, a FMG 0410 feller-skidder (also shown in Figure 20) with a 5-m boom is shown working in a "tree section" thinning operation. The machine is only 1.8-m wide and its narrowness allows it to enter a stand easily to retrieve stems that are beyond the reach of the boom. It can then skid them to the access trail. In this operation, the "tree section" system (Skogsarbeten 1987) involved bunching the tree-length stems and placing them perpendicular to the access trails, manually bucking them into 5-m lengths, and forwarding the sections to roadside for transport to the mill. At the mill, the sections are run through a drum debarker to remove limbs and bark. The wood is then chipped and debris is used as hog fuel.

Sondell (1989) reports that average costs for thinning were C\$28-C\$38/m^3, with average stem volumes ranging from 0.05 to 0.10 m^3. Depending on tree size, the mechanized thinning now realizes a profit of C\$15-C\$20/m^3, while motor-manual methods break even.

The harvester usually runs for 12 h each day. Two operators have 9.5-h overlapping shifts starting at 06:00 and 09:00. Each runs the harvester for a 3-h period at the start and end of the shift, with a 3-h period in the middle of the day for manually felling, spacing checks, strip-road layout, and other associated tasks.

Numerous makes of single-grip harvesters and processing heads are available. The heads are powered hydraulically and perform four functions: holding, felling, delimbing, and bucking. The felling function is accomplished by jaws which wrap around the tree and hold it while it is cut by a chain-saw blade, pushed through the stem by a hydraulic cylinder and then retracted. Powered rubber or metal rollers (Figure 21), or tracks (Figure 22) mounted on the holding jaws, then press against the surface of the log and feed it through the processing head. Delimbing knives are placed around the log and remove the branches as the log passes through. The log feed may be stopped at any time and the log may be bucked by the chain saw. These single-grip harvesters can be used for thinnings and, depending on tree size, for some final harvests.

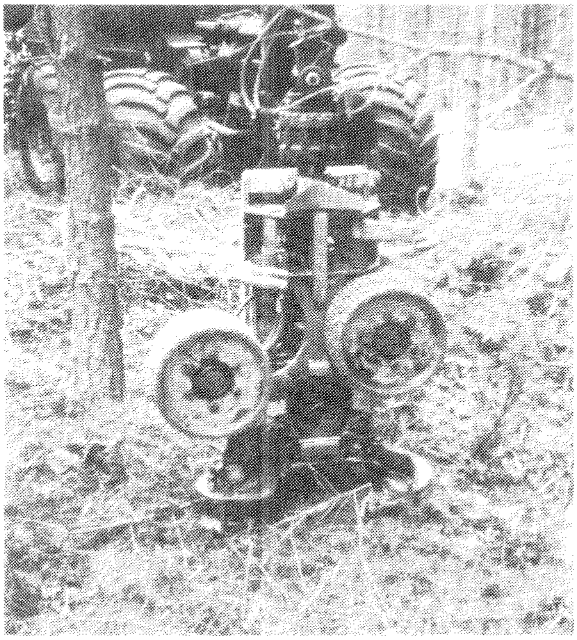


Figure 21. Single-grip harvesting head fitted with powered metal rollers.

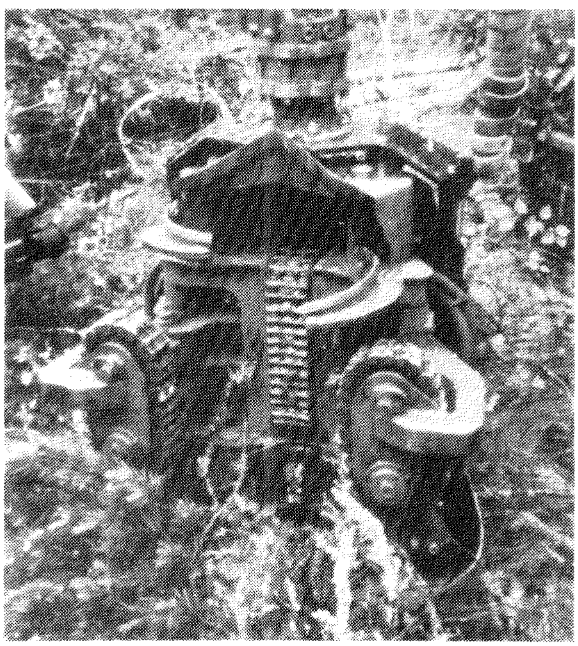


Figure 22. Single-grip harvesting head fitted with powered metal tracks (note measuring device below central track).

Summary—Commercial Thinning

Although not very much commercial thinning is done at present in Western Canada, Swedish equipment may have potential in the harvesting of small-diameter lodgepole pine stands. Included among the equipment that is presently used in Canada to harvest these stands is a feller-buncher, grapple skidder, and roadside processor, with an estimated total purchase price (new) of C$1 million. In comparison, a Swedish shortwood system consisting of a single-grip harvester and forwarder costs C$600 000. These figures suggest that the use of shortwood systems in the Interior of British Columbia and Alberta should be investigated to determine their overall cost effectiveness.

MACHINE ERGONOMICS AND CONTROLS

Since the 1970s, Swedish equipment designers and manufacturers have emphasized the importance of ergonomics. Improving the operator's work space and machine controls have increased machine and operator productivity. Also, increased accessibility to the machine's components has improved ease of maintenance and has reduced costs.

Machine cabs have been designed to optimize working conditions for the operator's comfort and safety, as well as to improve productivity. Cabs are constructed of a strong frame and shatter-proof glass (lexan) to protect the operator during a rollover and from sharp objects. They are equipped with heating and air conditioning, and noise levels are kept below 85 db. The cab also isolates the operator from high and low frequency vibration. Control panels are placed within the cab in convenient positions, and the overall feeling in the cab is one of relative spaciousness. The operator has a completely unobstructed view through the lexan windows. With good working lights and an unobstructed view, there is no need for the operator to position himself at an uncomfortable angle. The suspension seats are adjustable in inclination and height, and can be rotated and locked at the operator's most comfortable position. On some machines, retractable steps make it easier to enter and leave the cab.

The development of microelectronics has led to the improvement and miniaturization of machine controls and displays. Emphasis has been placed on the efficient arrangement of controls and displays (Figure 23). The number of pedals and levers has been reduced to one or two joy sticks, usually mounted near the armrest of the operator's seat. These joy sticks can accomplish most of the machine functions. Where possible, the joystick movements imitate the machine function.

Joy sticks control the flow of pilot oil or electrical signal to the control valves. The magnitude of the hydraulic or electrical signal determines the proportional valve opening and, consequently, the flow through the valve. Some machine functions are more complex than others, and in the past have required the simultaneous operation of several control levers. Today, computerization allows one simple joy-stick motion to govern each machine function.

Ease of maintenance is also important in these machines. Access to components is good; little time is required for service and replacement of parts (Figure 24). This reduction of downtime can have a large impact on overall cost.

The Valmet 901 is a good example of highly developed machine ergonomics (Figure 23). The boom is fixed to the cab, which rotates on the horizontal plane and tilts on the vertical. The clear lexan window allows good visibility both vertically and horizontally. The operator may also rotate or tilt the cab so that he does not need to twist his neck and body, thereby improving visibility further and reducing the risk of fatigue and injury. The tilting cab allows better weight distribution of the machine on steep side slopes. All the machine functions may be controlled by two joy sticks located near the seat armrests. The seat itself is a suspension seat with good back support, which again helps reduce fatigue.

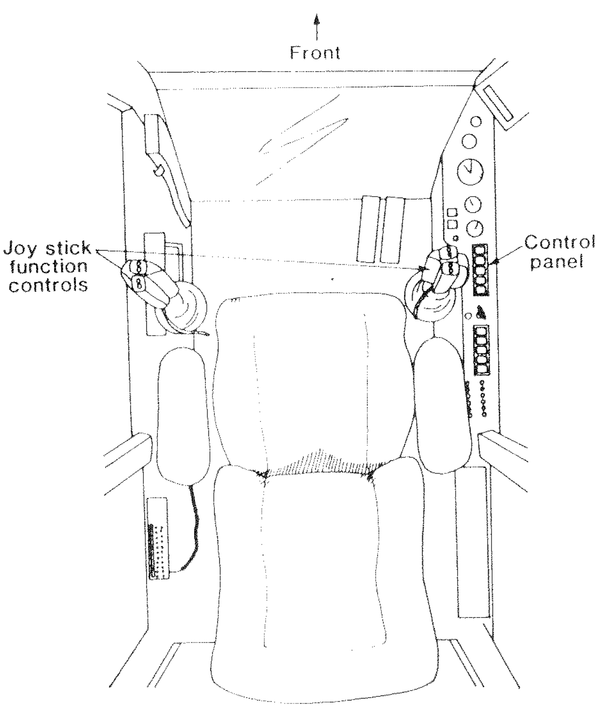


Figure 23. Cab layout of the Valmet 901 prime mover.

Summary—Machine Ergonomics and Controls

Incorporating ergonomic principles into North American equipment design benefits operators by reducing fatigue and injury. In particular, Swedish-style suspension seats with joy-stick controls offer great potential to the North American forest industry, and have been incorporated into some North American equipment.

FOREST/MACHINE INTERACTIONS

Large forestry machinery may damage the forest stand and floor. This damage can take the form of wounds to residual trees, root collars, and large roots; rut formation; soil compaction; and damaged fine roots (Figure 25). In most cases, a reduction in the productivity of the forest or the stand will occur. Wästerlund (1988b) reported that "14 to 25% of undamaged seedlings in Norway spruce stands showed a 25% annual height growth reduction the first two years after cleaning due to soil compaction and to possible root damage." Damage to soil and roots is caused by the weight of the equipment and the slippage of the wheels. Damage to stems and large roots may occur if the machine rubs against them.

In general, existing forestry machines are less harmful to the forest environment than earlier equipment because ground pressures have been reduced by increasing the number of tires and tire size. However, reducing wheel slippage is more complex. Slippage is inherent in rigid mechanical transmissions because of unequal wheel radii and constant wheel-rotation velocity. Hydrostatic transmissions offer a solution to reduce the problem because each wheel can be controlled separately by an individual hydraulic wheel motor.

Work is now being done at the Swedish University of Agricultural Sciences to solve the problems of soil compaction and rutting caused by forestry machines. To prevent rutting, the university is developing an elec-

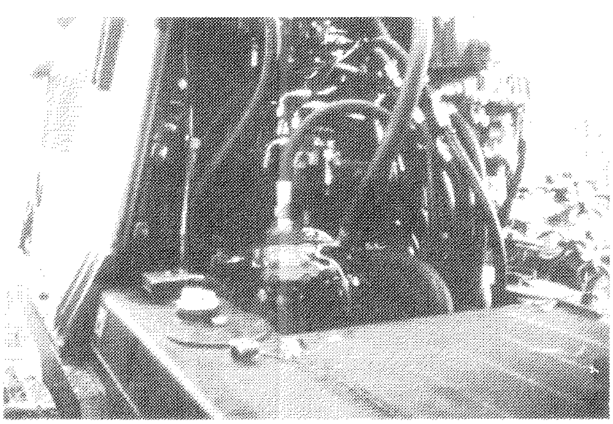


Figure 24. Valmet 901 prime mover has easy access to hydraulic components.

Figure 25. Soil compaction and root damage may be caused by rutting.

tronic system to control slip and torque, with possibilities of adapting the wheel forces to the strength properties of the forest floor. Each wheel will have an individual hydraulic motor. The pressure and flow to the wheel motor may be adjusted based on the load and speed requirements. Transmission restraint is reduced by individual wheel control, thus decreasing wheel slippage and, consequently, soil and root damage. In addition to this work, the university is investigating the strength characteristics of various soil types to determine what loads and shear forces may be applied without causing severe soil compaction. This information can then be used in conjunction with the hydrostatic transmission control to optimize operations.

Summary—Forest/Machine Interactions

Tire-slip control systems are very interesting developments in the design of forestry machines. In addition, the work on strength properties of forest soils will help to better identify suitable machine specifications for reducing environmental impact; Canadian and Swedish researchers have a common interest in this area of investigation.

FOLLOW-UP BY FERIC

Sweden and Western Canada have many differences in terms of tree species, harvesting practices, and forest policies. However, some of the Swedish silvicultural equipment and techniques can be adapted to advantage in Canada's forestry operations. The following points summarize the findings of the authors, and identify follow-up action that FERIC will undertake.

Site Preparation

The forest industry in Western Canada is becoming more precise in achieving site-adaptive planting microsites as it learns more about ecosystems and seedling requirements. Using implements that can provide a variety of microsites may be the cost-effective approach. In Sweden, this site-adaptive capability has been one of the design objectives.

Action. FERIC engineers and silviculturists will encourage manufacturers and developers to consider site-adaptive abilities in implements, where they are not already familiar with the concept.

Action. FERIC will undertake assessment of the Donaren 870H mounder, Bräcke three-row hydrostatically powered mounder, and the Öje Högen when they are available for operational testing. The intermittent abilities of the Donaren 280D disc trencher will be assessed by FERIC in Alberta in the summer of 1990.

Planting

Planning, seedling-distribution systems and ergonomically designed tools were the major features seen during the tour.

Action. Both the Eastern and Western Divisions of FERIC have been active in seedling-handling studies. Within these studies FERIC will investigate on-site seedling distribution using helicopters and all-terrain vehicles to determine their advantages and disadvantages.

Action. British Columbia's forest sites, planting stock, and planting-quality requirements do not allow Swedish tools to be immediately adopted. However, ergonomic principles are recognized as important in planting tools. FERIC's Eastern Division is working on improving the ergonomic characteristics of existing tools. These studies will continue.

Mechanized Stand Cleaning

Action. The prime movers used in mechanized stand cleaning in Sweden do not have equivalents in Western Canada. FERIC will maintain contact with the manufacturers and users of this equipment in Sweden, and potential users in Canada. When a need is expressed, FERIC will facilitate a testing program.

Commercial Thinning

Action. Shortwood systems in clear felling are planned for British Columbia and Alberta and FERIC will be taking an active role in monitoring these operations for productivity and cost of both harvesting and silvicultural treatments.

Commercial thinning in Western Canada continues to be a low-priority activity. The unavailability of equipment, other than conventional cut-and-skid types, has been a problem. The introduction of shortwood systems will provide a pool of equipment for trials in commercial thinning, and FERIC will encourage and monitor these studies.

Machine Ergonomics and Control

Action. Well-designed suspension seats, low vibration and noise levels, well-positioned joy-stick controls, and good visibility in all directions are among the ergonomic features of a machine cab that provide a safe and productive working environment for machine operators. These principles are recognized by FERIC and equipment designers, and they are becoming understood by operators and others in the forest industry. FERIC's mechanical engineers and ergonomist are working with the forest and equipment industries to incorporate ergonomically sound features in equipment and tools.

Action. The proportional hydraulics used in new Swedish equipment provide smooth and precise control of machine functions. As well, computer controls simplify complex machine operations and allow the operator to control the machine by simple levers. These features will be considered by FERIC engineers in their designs and discussed with manufacturers.

Forest/Machine Interactions

The forest industry is becoming more aware of the issues of forest/machine interaction and the need to reduce the impact of forestry operations on the site.

The relationship between equipment, the forest soil, and site productivity is not well documented in either Canada or Sweden. The results obtained in Swedish studies cannot be directly applied to the Western Canadian situation because soil characteristics and equipment are different. The general concerns in both countries, however, are similar.

Action. Tire-slip control systems are being studied in Sweden for forestry equipment, and they are being developed by the North American automotive industry for all-wheel-drive vehicles. FERIC's engineers will investigate these systems further to determine their utility in Canadian forestry equipment.

Action. In a contract project with Forestry Canada, FERIC is presently investigating soil mechanics, particularly soil strength, and trafficability of logging equipment. This project may lead to a more in-depth study that will culminate in equipment design and utilization recommendations.

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APPENDIX I

Hosts of the Swedish Field Tour

The authors thank Lynda Watson of the Canadian Department of External Affairs for her assistance in obtaining funding, and Jan Fryk of Forskningsstiftelsen Skogsarbeten for his help in organizing the tour. Our thanks also to the companies and personnel in Sweden for their hospitality and cooperation during this informative tour.

Organization	Place	Date	Personnel
Skogsarbeten	Stockholm	May 29 and June 9, 1989	Jan Fryk Göran Adelsköld Ingemar Nordansjö Nils Nilsson Ake Thorsén Per Ake Arvidsson Svante Scherman Magnus Larsson Dag Myhrman
MoDo Skogen	Örnsköldsvik	May 30, 1989	Lars G. Erksson Magnus Dahlberg Ragnar Fredholm
SCA Skog AB	Sundsvall	May 31, 1989	Mats Sandgren Jörgen Andersson
Korsnäs AB	Gävle	June 1, 1989	Gunnar Johansson Karl Gustaf Backlund
Stora Skog AB	Falun	June 2, 1989	Ulf Klensmeden Ove Stein
Domänverket	Växjö	June 6, 1989	Sven Magnusson Chryster Thoft
Holmen Skog	Norrköping	June 7, 1989	Claes Mellström Rolf Holmström Gun Blomqvist
Swedish University of Agricultural Sciences, Department of Operational Efficiency	Garpenberg	June 8, 1989	Alf Arvidsson Iwan Wästerlund Jan Swartström Eva Lidén

APPENDIX II

Equipment Manufacturers and Distributors

Machine or Product	Manufacturer/Distributor
Donaren 870H mounder 280 disc trencher	Skogsbruksmaskiner AB Box 5 S-78300 Säter Sweden Tel.: 0225 510 80 Telefax: 0225 504 61
	Forest Lease Inc. #100, 10821 - 182 Street Edmonton, Alberta Canada T5S 1J5 Tel.: (403) 484-0501 Telefax: (403) 486-7207
Bräcke Three-row mounder Two-row scarifier Three-row scarifier Two-row mounder with spades	Robur Maskin AB Box 150 S-840 60 Bräcke Sweden Tel.: 46 693 105 75 Telefax: 46 693 101 09
Öje Högen (mounder)	KBM Forestry Consultants 360 Mooney Street Thunder Bay, Ontario Canada P7B 5R4 Tel.: (807) 344-0811 Toll free: 1-800-465-3001 Telefax: (807) 345-3440
Häglinge Jumbo carrier	Häglinge Industri AB Häglinge S-28010 Sösdala Sweden Tel.: 46 0451 63200
FMG 0470 carrier/harvester 0410 carrier/harvester 0450 carrier/harvester	Rauma-Repola FMG AB P.O. Box 500 S-82200 Alfta Sweden Tel.: 46 271 19000 Telefax: 46 271 11040
	Timberjack Inc. P.O. Box 160 Woodstock, Ontario Canada N4S 7X1 Tel.: (519) 537-6271 Telefax: (519) 539-4750

Machine or Product	Manufacturer/Distributor
Valmet 901 Carrier/harvester	Valmet Logging P.O. Box 2124 S-90002 Umeå Sweden Tel.: 46 90 159000 Telefax: 46 90 191652
	Valmet Gafner, Inc. 103 North 12th Street P.O. Box 401 Gladstone, MI 49837-0401 U.S.A. Tel.: (906) 428-4800 Telefax: (906) 428-3922
Pellenc and Motte Pruner	Pellenc and Motte S.A. Quartier Notre-Dame 84120 Pertius France Tel.: 90.79.05.68 Telefax: 90.09.64.09
Hiko System for seedling production	Hilleshög Aktiebolag Forest Division Box 302 S-216 23 Landskrona Sweden Tel.: 46 0418 260 60
	BCC Silviculture Systems Inc. 789 Don Mills Road Suite 700 Toronto, Ontario Canada M3C 3L6 Tel.: (416) 421-7819 Telefax: (416) 421-4854
Silva Nova mechanical tree planter	Storebro International AB S-590 83 Storebro Sweden Tel.: 46 (0)492 301 60 Telefax: 46 (0)492 303 00
	Silvana Import Trading Inc. Suite 304 - 4269 St. Catherine Street West Montreal, Quebec Canada H3Z 1P7 Tel.: (514) 939-3523 Telefax: (514) 939-3863
Planta 80 System for seedling production	Stora Kopparberg Bergvik Skogsvårdsavd 79180 Falun Sweden Tel.: 46 23 80000

Machine or Product	Manufacturer/Distributor
Pottiputki Planting tube	Lännen Tentaat Oy Länne Plant Systems SF-27820 Iso-Vimma (Säkylä) Finland Tel.: 358 38 70300 Telefax: 358 938 73111 Hakmet Ltd. 1088 Great Street Prince George, B.C. Canada V2N 2K8 Tel.: (604) 561-2216 Telefax: (604) 561-0827