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RECLAMATION OF COMPACTED FINE-TEXTURED SOILS ON THE ALEZA LAKE RESEARCH FOREST USING A WINGED SUBSOILER AND A HYDRAULIC EXCAVATOR

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Abstract

In July 1995, the Forest Engineering Research Institute of Canada (FERIC) participated in a joint British Columbia Ministry of Forests/Canadian Forest Service research project. The aim of this project was to investigate tilling options for reclaiming compacted surfaces of temporary roads and landings on fine-textured soils. FERIC observed two machines used to perform the tilling treatments: a crawler tractor equipped with a Tilth winged subsoiler, and a hydraulic excavator equipped with a hydraulic thumb and a five-tined site-preparation rake. This report reviews the productivities, costs, and performances of the two machines.

Introduction

Protection of the environment and conservation of forest site productivity are major themes of the Forest Practices Code of British Columbia (British Columbia Ministry of Forests; B.C. Environment 1993). Forest managers are responding to these issues by reviewing operating areas and developing plans to rehabilitate temporary roads, landings, and skid trails where needed. Therefore, the development of biologically and operationally effective rehabilitation techniques is a priority.

In 1995 the British Columbia Ministry of Forests (BCMOF), Prince George Forest Region, and the Canadian Forest Service (CFS), Prince George District Office, conducted a research trial on the Aleza Lake Research Forest east of Prince George to explore options for reclaiming fine-textured soils. Such soils are widely regarded as being highly susceptible to degradation, are inherently difficult to reclaim, and are widespread in the Prince George Forest Region. Several 5- to 10-year-old harvested areas on the research forest, representative of the road-building and timber harvesting practices in effect prior to the implementation of the Forest Practices Code, were selected as study sites. Three tilling treatments were performed using a crawler tractor and a hydraulic excavator.

FERIC was asked to participate in the trial to provide information on operational methods and costs for rehabilitating roads and landings. The BCMOF, Prince George Forest Region funded FERIC's work. This report describes the results of the operational study.

Keywords: Soil compaction, Forest roads, Landings, Reclamation, Tillage, Winged subsoilers, Rakes, Excavators, Tilth winged subsoiler, Caterpillar D7F crawler tractor, Caterpillar EL200B excavator, Finning site-preparation rake.

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Objectives

The goal of the trial was to establish a set of replicated treatments so that the long-term effectiveness of three soil reclamation treatments (described in the following section) for degraded fine-textured soils in central British Columbia could be studied. FERIC's objective was to assess the operational efficiency of the reclamation operations. Specifically, FERIC was to:

- Describe and document the reclamation operations.
- Determine the productivities and costs of the subsoiler and the excavator for tilling treatments.
- Identify key factors affecting these reclamation operations, and suggest opportunities for improving future reclamation treatments on similar sites and soil types.

Study Methods

Study Site and Treatments

The Aleza Lake Research Forest was chosen as the trial site because it was considered representative of the study's target sites and soil types; was close enough to Prince George for demonstration purposes; and had good climatic, soils and ecological records (Sanborn and Kranabetter 1994). During the summer and early fall of 1994, the BCMOF and CFS performed mapping and soil sampling to select appropriate study sites on the research forest.

The BCMOF and CFS decided upon the following soil reclamation treatments for testing:

- Deep tillage (approximately 50 cm) with a winged subsoiler, followed by legume seeding and fertilization.
- Topsoil recovery and shallow tillage (approximately 15–20 cm) with a standard site-preparation rake, followed by legume seeding and fertilization.
- Spreading and incorporation of chipped logging debris with a site-preparation rake, followed by legume seeding and fertilization.

The first treatment was applied to sites where the topsoil, removed during construction of the roads and landings, could not be easily recovered. The second treatment was applied wherever topsoil could be recovered in sufficient quantities to reconstruct a rooting zone of comparable depth to the natural (pre-harvest) condition. (Natural rooting depths on similar sites and soils in the Prince George area are typically very shallow, with almost all roots confined to the forest floor and upper 15–20 cm of mineral soil.) This was the preferred treatment because it was thought it would most closely approximate original pre-harvest conditions. The third treatment substituted chipped logging debris as a form of soil organic amendment where topsoil recovery was not feasible. Only the subsoiler and excavator treatments were monitored by FERIC.

Each of the three soil reclamation treatments was replicated on five separate landings, with each landing subsequently split into three subplots for planting treatments (white spruce, paper birch, and white spruce plus paper birch). The remaining roads and landings were assigned one of the soil reclamation treatments to provide additional sites for assessing machine performance, and were to be planted with a variety of conifer and deciduous tree seedlings for demonstration purposes. These additional areas included a wider range of structures (e.g., major road allowance, Sawmill Site) and coarser textures.

In May 1995, FERIC, BCMOF, and CFS researchers toured the study sites and assigned treatments to specific road sections and landings. The field inspection also defined other restoration work (e.g., restoring stream crossings) that was necessary to bring the sites to current Forest Practices Code standards. This was a condition of performing the trial on the Aleza Lake Research Forest.

Two equipment options were considered for the reclamation operations: a crawler tractor equipped with a frame-mounted Tilth winged subsoiler; and a hydraulic excavator equipped with a standard site-preparation rake. It was decided that enough work was available to use both machines. The crawler tractor with winged subsoiler was assigned the deep tilling treatments, and the hydraulic excavator was assigned the shallow tilling treatments and the task of recovering topsoil from roadside deposits. The excavator was also responsible for incidental reclamation work such as clearing logs and debris in advance of the crawler tractor, restoring stream crossings, and building traffic barriers to bar vehicle access to treated roads and landings.

Data Collection and Analysis

A FERIC researcher, stationed on-site for the duration of the trial, maintained a diary of the reclamation project and continuously timed each machine for several workdays. Machine time data were compiled for each road section and landing according to FERIC's standard work-study methods (Bérard et al. 1968). The data were then summarized to show each machine's time distribution and productivities. For the purposes of this trial, the following were defined as productive activities: tilling only; recovering topsoil only; recovering topsoil plus tilling; restoring stream crossings and drainage; clearing debris; and constructing traffic barriers.

Each road section and landing was surveyed after treatment using a hand compass and measuring tape. Road-section areas were determined by measuring the treated road's width at 25-m intervals if road width was relatively uniform, or at shorter intervals if non-uniform. The area of each segment was calculated and summed to establish the total treated area for each road section. Landing areas were determined by surveying the treated boundaries and digitizing the resulting polygons.

The BCMOF randomly sampled tilling depths on treated surfaces and provided this data to FERIC to supplement the descriptions of the treated sites.

Hourly machine ownership and operating costs were calculated using FERIC's standard costing procedures (Appendix I). Machine costs were based on prices for new prime movers and attachments, and labour costs were based on 1995 International Woodworkers of America (IWA) rates. The calculated costs do not include crew supervision and transportation, overhead, or profit, and are not the actual costs incurred by the contractors.

Site and Machine Descriptions

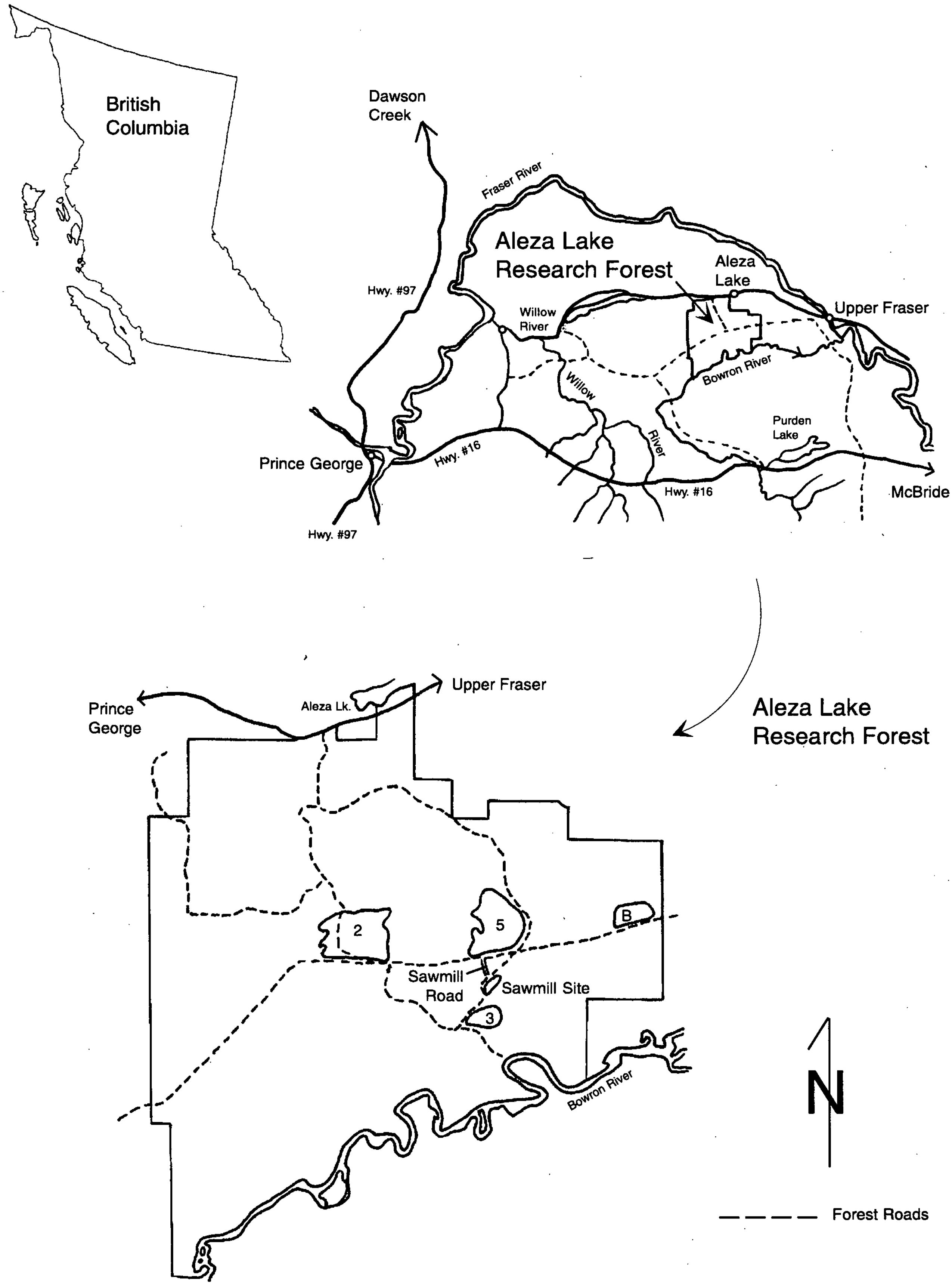
Study Site

The 7 957-ha Aleza Lake Research Forest is located 60 km ENE of Prince George (Jull 1992) (Figure 1). Six sites in the forest were selected for this study. These sites consisted of four winter-logged clearcut areas (Blocks 2, 3, 5 and B) harvested between 1986 and 1990, the site of a former bush mill (Sawmill Site), and a short road (Sawmill Road) connecting the bush mill site with the Bear Forest Road.

Table 1 describes the biophysical characteristics of the study area. Soils are primarily Gleyed Orthic Grey

Table 1. Description of Study Area

Location	Bear Road Compartment, Aleza Lake Research Forest (54° 07' N. Lat., 122° 04' W. Long.)
Elevation	650–700 m
Biogeoclimatic classification	Wet Cool Sub-boreal Spruce (SBSwk1)
Forest cover	
Primary species	white or hybrid spruce, subalpine fir
Secondary species	paper birch, Douglas-fir
Landforms	undulating plateau, low relief
Slope	
Average	0–5%
Range	0–25%
Soil	Gleyed Orthic Grey Luvisols (Pineview series) (glaciolacustrine clays and silts)
Soil textures (ranges)	
% clays	20–55
% silts	30–45
% sands	5–40
Rooting depth	20 cm or less
Site hazards	
Windthrow	High
Soil compaction	Very high


British Columbia
Dawson Creek
Fraser River
Aleza Lake Research Forest
Aleza Lake
Upper Fraser
Hwy. #97
Willow River
Bowron River
Willow
River
Purden Lake
Prince George
Hwy. #16
Hwy. #16
McBride
Hwy. #97
Upper Fraser
Prince George
Aleza Lk.
Aleza Lake Research Forest
2
5
B
Sawmill Road
Sawmill Site
3
Bowron River
N
Forest Roads

Luvisols developed from clayey to silty glaciolacustrine deposits. Rooting depths on these moist, fine-textured soils are typically 20 cm or less and windthrow hazard is high.

Machine Descriptions

Table 2 describes the operating specifications of the machines used for these trials. Forestech Renewal (D.C.) Inc. of Dawson Creek, B.C. performed the deep tilling treatments using a Tilth winged subsoiler mounted on the frame of a Caterpillar D7F crawler tractor (Figure 2). The subsoiler, manufactured by Tilth Inc. of Monroe, Oregon, is a site-preparation implement that can be either towed behind the prime mover on a rubber-tired dolly or, as in this study, mounted directly onto the rear frame of the prime mover. It consists of three tines, 87 cm in length, spaced 102 cm apart, each equipped with a winged shoe. The winged shoes are available in different widths and wing angles for different soil types and applications. Depending upon the shoe design used, the subsoiler can self-draft to a predetermined depth when the prime mover is in forward motion. Each tine is hydraulically controlled and can lift independently over buried obstacles and then return to the preset depth. De Long et al. (1990) and Rasmussen (1991) provide detailed descriptions of the Tilth winged subsoiler and its working principles.

Aleza West Contracting Limited of Prince George, B.C. performed the topsoil recovery and shallow tilling treatments, as well as other incidental rehabilitation tasks. These were done using a Caterpillar EL200B hydraulic excavator equipped with a site-preparation rake and hydraulic thumb. The site-preparation rake used by this contractor was a five-tined model manufactured by Finning Equipment Ltd. (Figure 3). The rake frame was 152 cm wide, with tines spaced 38 cm apart, and 109 cm in length including teeth. New teeth would have increased the rake's length to 117 cm.

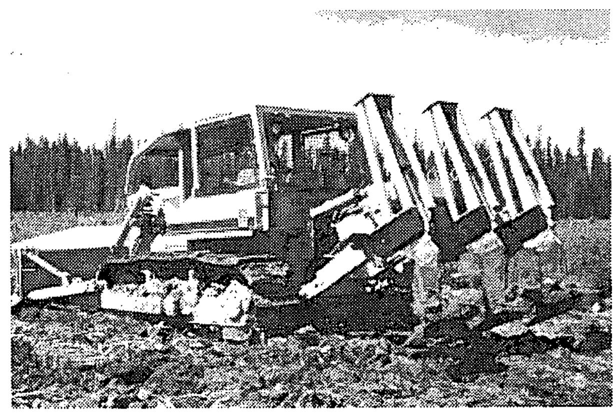


Figure 2. The Tilth winged subsoiler.

Table 2. Machine Specifications

	Caterpillar D7F crawler tractor	Caterpillar EL200B hydraulic excavator
Year of manufacture	1970	1992
Operating weight (kg)	19 500 [a]	20 100 [a]
Engine model	Cat D333	Cat 3116
Flywheel power (kW)	135	88
Rated engine (rpm)	2 000	1 800
Track dimensions		
Contact length (cm)	270	373
Width (cm)	61	71
Static ground pressure (kg/cm^2)	0.59	0.38
Attachments	Tilth subsoiler with three tines and winged plows, attached to rear frame of prime mover	Finning site-preparation rake with five tines plus hydraulic thumb

[a] Approximate.

Figure 3. Finning site-preparation rake.

Figure 4. Shallow tilling completed by the excavator and site-preparation rake.

This type of rake is one of several designed as attachments for hydraulic excavators for site-preparation work; von der Gönna (1992) describes several other rake designs that are also used in British Columbia.

Working Techniques

Most but not all spur roads required some preparatory work by the excavator prior to deep tilling by the subsoiler. The excavator usually travelled towards the far end of the spur road, doing only the work needed to make the road passable. As it worked its way back, the excavator completed reclamation tasks, including shallow tillage (Figure 4), clearing logs and debris off roads and landings slated for deep tillage, and repairing culvert sites and stream crossings. Where sufficient topsoil was available in sidecast deposits, the excavator also recovered this material and spread it across the adjacent road or landing in a layer approximately 10 cm deep.

The winged subsoiler then performed the deep tilling treatment, if required. One pass treated only half of the road width, so the subsoiler tilled as it travelled towards the furthest site to be treated, and completed the remaining width as it worked back toward the main road. When tilling landings, the subsoiler usually tilled along straight lines (Figure 5). Rather than turn around at the end of each tilling line, the crawler tractor usually offset onto the next line, backed up to the starting point, then tilled in the same direction for each line.

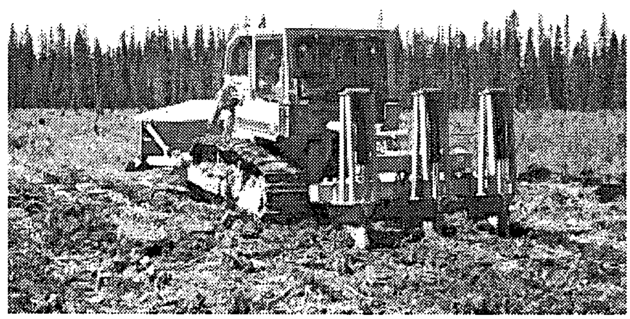


Figure 5. Crawler tractor and winged subsoiler working in straight lines.

Results and Discussion

Overview

The hydraulic excavator arrived before the subsoiler, and performed its reclamation tasks on Blocks 5, 2, 3 and B, and the Sawmill Road (in this sequence). It performed all of the shallow tillage and one section of deep tillage, recovered topsoil where feasible, restored four stream crossings and built four traffic barriers. The winged subsoiler completed deep tillage on Blocks 5 and 2, the Sawmill Site and the Sawmill Road, and constructed one traffic barrier.

Table 3 summarizes the reclamation work performed on these sites. In total, 3 133 lineal metres of temporary road and 16 landings within the four cutblocks, 428 lineal metres of the Sawmill Road, and the area of the Sawmill Site were tilled during the trial. In terms of area treated, 2.80 ha of roads, 3.99 ha of landings, and 0.48 ha of Sawmill Site, totalling 7.27 ha, were tilled by the two machines.

Table 3. Summary of Times, Treatments Applied and Areas Tilled

Block	Machines used	Treatment time (h)	Roads treated (no.)	Total road area (ha)	Landings treated (no.)	Total landing area (ha)	Total area treated (ha)	Other treatments applied (no areas attached)
2	Subsoiler	9.5	3	0.43	3	0.78	1.21	1 traffic barrier
	Excavator	15.6	2	0.16	2	0.41	0.57	topsoil recovery 1 traffic barrier
3	Subsoiler	-	0	-	0	-	-	-
	Excavator	10.6	2	0.15	2	0.59	0.74	topsoil recovery 4 stream crossings 1 traffic barrier
5	Subsoiler	14.0	7	0.79	6	1.58	2.37	-
	Excavator	10.7	0	-	0	-	-	topsoil recovery 4 stream crossings 1 traffic barrier
B	Subsoiler	-	0	-	0	-	-	-
	Excavator	13.3	3	0.22	3	0.63	0.85	topsoil recovery
Sawmill Road	Subsoiler	1.8	1	0.51	0	-	0.51	-
	Excavator	9.0	1	0.54	0	-	0.54	1 traffic barrier
Sawmill Site	Subsoiler	1.8	0	-	0	0.48 [a]	0.48	-
	Excavator	-	0	-	0	-	-	-
Travel time between sites	Subsoiler	1.3						
	Excavator	4.0						
Subtotals	Subsoiler	28.3	11	1.73	9	2.84	4.57	1 traffic barrier
	Excavator	63.2	8	1.07	7	1.63	2.70	topsoil recovery 4 traffic barriers 4 stream crossings
Totals for tilled areas		91.5	19	2.80	16	4.47	7.27	topsoil recovery 5 traffic barriers 4 stream crossings

[a] In this study, the Sawmill Site is not considered to be a landing, although its area is included in this column.

The weather preceding and during the study period was generally favourable although heavier, more frequent rain occurred in the second half. The hydraulic excavator and winged subsoiler were able to complete their primary tasks before the soils became too wet to work (although small portions of some landings were not tilled due to high soil moisture levels). The final treatment of applying and incorporating chipped logging debris could not be performed because the temporary roads that accessed the debris sources were too wet for truck traffic. As a result, treatment on three sections of road totalling 860 lineal metres and five landings on Blocks 2, 3 and B was not completed during the period of this study.

The excavator worked 63.2 hours and the winged subsoiler worked 28.3 hours to complete the reclamation work and study treatments on the six sites (Table 3).

FERIC observed and timed more than 80% of each machine's working time. Total machine hours include all organizational, operational and mechanical delay time as well as within-block and between-block travel time, but exclude all lowbed moves.

The hydraulic excavator's reclamation tasks varied from site to site (Table 3). On Blocks 2 and 5, it prepared the site for deep tillage by the subsoiler and recovered topsoil and restored stream crossings on these sites as required. It also performed shallow tillage on Blocks 3 and B, as well as two road sections and two landings on Block 2. In order to compare deep tilling treatments by the subsoiler and the excavator, the Sawmill Road was subdivided into two sections, one for each machine.

The winged subsoiler performed all of the deep tilling treatments except for the side-by-side comparison between the subsoiler and the excavator on the Sawmill Road. It also built a traffic barrier on a spur road in Block 2 because the excavator had moved to another site before the subsoiler finished tilling the spur road. The winged subsoiler's work was concentrated on the two largest cutblocks (Blocks 2 and 5), which had the largest road and landing networks requiring reclamation.

Machine Performance and Cost

Crawler Tractor with Tilth Winged Subsoiler. Table 4 shows the distribution of the subsoiler's time for the study period. Total productive time including within-block travel was 15.54 h, or only 55% of total machine time. (However, the study period was too short to provide a reliable estimate of long-term machine utilization.) Tilling time, at 14.67 h or 52% of total time, accounted for almost all of the subsoiler's productive time. Other productive work accounted for less than an hour of machine time.

Table 4. Time Distributions for Winged Subsoiler and Hydraulic Excavator

	Subsoiler			Excavator		
	Total detailed time (h)	Proportion total time (%)	Average per 8-h shift (h)	Total detailed time (h)	Proportion total time (%)	Average per 8-h shift (h)
PRODUCTIVE TIME						
Tilling only	14.67	52	4.16	9.53	15	1.21
Topsoil recovery + tilling	-	-	-	21.52	34	2.72
Topsoil recovery only	-	-	-	4.87	8	0.62
Clear debris	-	-	-	1.10	2	0.14
Restore stream crossing	0.30	1	0.08	1.35	2	0.17
Construct traffic barrier	0.22	1	0.06	0.77	1	0.10
Other				0.65	1	0.08
Travel within block	0.35	1	0.10	4.21	7	0.53
Total productive time	15.54	55	4.40	44.00	70	5.57
DELAY TIME						
Mechanical						
Service	2.63	9	0.74	4.10	6	0.52
Repairs	6.88	24	1.95	-	-	-
Nonmechanical						
Travel between blocks	1.28	5	0.36	3.96	6	0.50
Discussions	0.55	2	0.16	8.15	13	1.03
Breaks	0.57	2	0.16	2.97	5	0.38
Other	0.82	3	0.23	-	-	-
Total delay time	12.73	45	3.60	19.18	30	2.43
TOTAL TIME	28.27	100	8.00	63.18	100	8.00

The subsoiler experienced a high level of mechanical downtime during the trial due to repeated failures of the shear pins holding the Tilth subsoiler to the crawler tractor. Overall subsoiling productivity was reduced substantially as a result. The Tilth subsoiler's hydraulic system was designed to allow tines to individually release and lift when a buried object was struck, and this design feature generally worked well. After striking a buried object, however, the operator withdrew the tines while backing up the crawler tractor and then reinserted them when the tractor began moving forward again. Most of the pin failures occurred when this was not performed smoothly. The high frequency of shear pin failures could probably be reduced by taking more care during this procedure.

Table 5 compares the subsoiler's tilling rates and costs (in $/1000 m²) for roads, landings, and the Sawmill Road and Sawmill Site. Costs are based on an estimated ownership and operating cost of $139.72/h (Appendix I). The observed rates are based on tilling time only, and therefore represent maximum production rates and minimum costs. Tilling rates will be lower and costs will be higher when they are adjusted to account for normal operating circumstances.

Road sections which were obviously corduroyed were identified in advance and excluded from treatment (with one exception), but buried logs and stumps were still encountered in many of the roads. One road segment was recognized as difficult to treat, but it provided an opportunity to use the subsoiler in extremely adverse tilling conditions. The road was built across a low wet spot and was partly corduroyed, with numerous buried logs and stumps throughout its length. The subsoiler's tilling rate on this section was only about one-third that of the other road sections, and would have been much less if mechanical downtime had been included. On this road section the subsoiler broke two shear pins

Table 5. Productivities and Costs for Winged Subsoiler and Excavator

Study site	Sample size (no.)	Area treated (m²)	Treatment time (h)	Productivity (m²/h)	Average cost ($/1000 m²)	Range in cost ($/1000 m²)	Average tilling depth (cm)
Winged subsoiler							
Deep tilling							
Roads	7	8 771	2.43	3 609	39	26–59	51
Landings	8	21 214	7.35	2 886	49	67–84	56
Roads and landings		29 985	9.78	3 066	45	26–84	54
Sawmill Road		5 407	1.13	4 785	29		50
Sawmill Site		4 780	0.95	5 032	28		
Sawmill area		10 187	2.08	4 898	28		50
Hydraulic excavator							
Topsoil recovery plus shallow tilling							
Roads	3	2 691	4.02	669	152	129–170	15
Landings	6	12 972	15.33	846	120	77–164	15
Roads and landings		15 663	19.35	809	126		15
Hydraulic excavator							
Shallow tilling [a]							
Roads	3	1 961	1.50	1 307	78	56–102	10
Landings	1	3 340	2.22	1 504	67		
Roads and landings		5 301	3.72	1 425	71		10
Deep tilling [b]							
Sawmill Road		5 137	6.55	784	130		50

[a] Single pass.
[b] Double pass.

and damaged the hydraulic cylinder on one tine. Because this segment was only one small sample, it cannot be said that the observed decrease in productivity is typical for such roads. However, it does indicate that significant decreases in tilling productivity can be expected when deep-tilling roads and landings containing concentrations of debris beneath the surface. The result reinforced the decision not to treat other sections of debris-filled or corduroyed roads. Because this road segment is unique within the samples, it was removed from the productivity summaries.

The subsoiler's average tilling productivity was 20% less on landings than on roads, and the cost/1000 m^2 was higher ($49 vs. $39, respectively). When treating the roads the subsoiler made only two passes, one in each direction. Repositioning moves were few. On landings, turning the crawler tractor with the tines still in the soil was hard on the subsoiler. As a result, the operator preferred to lift the tines out of the soil, back up to the starting point, and reinsert the tines to start the next pass. Therefore, on landings, each tilling run was shorter and the subsoiler had to reposition more frequently.

The average deep-tilling rate of 3 066 m^2 observed in this study is comparable to the 0.29 ha/h reported by De Long et al. (1990) for another subsoiler trial, also in the Prince George area. One of the trial sites for that study was also on fine-textured (silty clay loam) soils, and the observed tilling rate on that site was 0.31 ha/h. That study also used a Caterpillar D7F crawler tractor as the prime mover. The subsoiler unit was mounted to the frame, but it used a two-tined configuration (centre tine removed) rather than the three-tined system used in this trial. That study used the subsoiler for site preparation on the cutover area, while in this study the subsoiler was used to reclaim only compacted roads and landings.

The subsoiler's tilling rates for the Sawmill Road and Sawmill Site were substantially higher than for the other roads and landings at 4 785 and 5 032 m^2/h, with costs of $28–$29/1000 m^2. The coarser soils on these sites appeared to be easier to till than the clayey soils on the other test sites, and the large surface areas permitted steady tillage with relatively little time spent moving or repositioning the subsoiler.

Hydraulic Excavator with Site-Preparation Rake. Table 4 shows the distribution of the hydraulic excavator's time for the study period. The largest component of the excavator's productive time was for the combined activities of topsoil recovery and tilling, at 21.52 h or 34% of total time. Tilling alone, where topsoil was not available in sufficient quantities to warrant recovering, was the second largest component of productive time at 9.53 h. Topsoil recovery alone (recovering and spreading topsoil for the subsoiler) was the third largest at 4.87 h. In total, the activities of topsoil recovery and/or tilling accounted for 35.92 productive hours, or 57% of total time. The other reclamation tasks (clearing logs and debris, restoring stream crossings, and constructing traffic barriers) accounted for only 3.87 productive hours, or 6% of total time. Travel within block was a large component of productive time at 4.21 h or 7% of total time.

Delay time, including travel between study sites, totalled 19.18 h, or 30% of total machine time, yielding a machine utilization rate of 70% for the study period. (As with the subsoiler, the observation period was too short to provide a reliable estimate of an excavator's long-term utilization when performing reclamation work.) Mechanical delay time consisted of 4.10 h to service and refuel the excavator, most of which was done at the beginning or end of the workday or at mid-day breaks. No mechanical breakdowns occurred during the study period.

Table 5 presents the excavator's productivities and costs for topsoil recovery plus shallow tilling on roads and landings—the excavator's primary tasks in this trial. Costs were based on an estimated ownership and operating cost of $101.69/h (Appendix I). As with the subsoiler, the observed production rates are based on topsoil recovery plus tilling time, with no delay time included. Therefore, these data represent maximum production rates and minimum costs.

The hydraulic excavator's average productivity was about 26% higher on landings than on roads because, at least in part, topsoil recovery was faster on the landings. Recoverable deposits of topsoil were more easily recognized around landings, tended to be larger, and were more easily handled. Along roads, the excavator operator spent a greater proportion of total time searching for topsoil and testing likely deposits.

However, the excavator's average productivity on landings was strongly influenced by high production rates on two landings which had abundant recoverable topsoil. The other landings were more similar to the roads in terms of quantities and qualities of topsoil deposits. For topsoil recovery plus tilling on all roads and landings, the excavator's productivity averaged 809 m^2/h with a cost of $126/1000 m^2. If the two landings with the highest productivities are excluded from the calculation, the excavator's productivity averaged 719 m^2/h (about 7% higher than for roads), and the ranges of observed productivities are similar for roads and landings. This lower productivity is probably more representative of older logged sites where no concerted attempt was made to sort and stockpile topsoil during road and landing construction. The lowest productivity for the excavator was for topsoil recovery plus tilling on roads, at 669 m^2/h and at a cost of $152/1000 m^2.

Topsoil deposits on roads and landings were unsorted and contained large quantities of waste wood, slash and stumps. This significantly reduced the excavator's productivity as the operator spent time testing these piles. If topsoil is properly sorted and stockpiled when building roads and landings, in anticipation of future reclamation, costs should be reduced substantially.

When the excavator's productivities and costs for shallow tilling on roads and landings are compared (Table 5), the pattern is similar to that for topsoil recovery plus tilling: productivity is higher on landings than on roads by about 15%. However, this is based on only one landing sample, and its productivity is well within the range observed for roads.

As expected, the excavator's productivity for deep tilling on the Sawmill Road was substantially lower than for shallow tilling. The excavator had to make two passes to till to a 50-cm depth, rather than one pass for shallow tilling. On the first pass the operator tilled as deeply as possible while maintaining an even tilling action. The operator worked in a large arc and pulled the loosened surface layer toward the machine. On the second pass the operator tilled the exposed lower layer, again working toward the machine. Finally, the operator reversed the stroke to push the piled soil away from the excavator, and spread and levelled the tilled area with the rake. The additional tilling pass increased the treatment time and cost, and reduced tilling productivity proportionally. As a result, the excavator averaged 784 m^2/h when deep tilling, compared to an overall average of 1 425 m^2/h for shallow tilling on roads and landings (Table 5).

In this study, therefore, treatment time and cost per unit area for topsoil recovery plus shallow tilling are about 77% higher than for shallow tilling alone.

Comparison of Tilling Productivities and Costs. Although the tilling treatments performed by the two machines (deep tilling with the subsoiler and shallow tilling with the excavator) were not identical, the following comparison illustrates the differences in tilling rates and costs for the two machines.

Overall, the winged subsoiler averaged 3 609 and 2 886 m^2/h when deep tilling roads and landings, respectively, while the excavator averaged 1 307 and 1 504 m^2/h, respectively, when shallow tilling. Combined, the winged subsoiler's tilling rate was 3 066 m^2/h, or more than double the excavator's average tilling rate of 1 425 m^2. However, the excavator's tilling cost of $71/1000 m^2 was only about 58% higher than that of the winged subsoiler ($45/1000 m^2) because the excavator's hourly cost was less.

The subsoiler and the excavator both performed deep tilling on the Sawmill Road. On this site the subsoiler's tilling rate and cost were 4 785 m^2/h and $29/1000 m^2 respectively, while the excavator's tilling rate and cost were 784 m^2/h and $130/1000 m^2 respectively.

Rasmussen (1991) reported subsoiling productivities of 0.45 to 0.49 ha/h for tilling roads and landings in clayey soils of west-central Alberta with a three-tined, frame-mounted Tilth subsoiler on a Komatsu D85P bulldozer (a slightly larger prime mover than the Caterpillar D7F). However, he did not present information on tilling depth. If the subsoiler in the current study could achieve a tilling rate of 4 500 m^2/h for shallow tilling, treatment costs would be about $31/1000 m^2 (vs. $45/1000 m^2 for deep tilling), or about 40–45% of the excavator's cost. Although this option was not examined in the study, the shallow tilling treatments could have been performed by the subsoiler by adjusting the penetration depth of the tines. Shallow tilling would probably increase the subsoiler's productivity, but the extent is not known.

Analysis of Four Alternative Reclamation Projects

When selecting the appropriate machine for a reclamation project, the size of the project and the specific reclamation needs of the sites planned for treatment must be evaluated carefully. Compromises may have to be made to achieve an acceptable balance between the total cost and the overall completeness or effectiveness of the reclamation project. To illustrate some of these tradeoffs and their cost implications, total reclamation costs were estimated for four scenarios using the Aleza Lake reclamation trial as an example of a typical reclamation project. The options were:

A) Complete reclamation using the subsoiler and excavator, and the same distribution of tasks and workloads as in this study.

B) Complete reclamation using the subsoiler for deep tilling of all roads and landings, and the excavator for all other reclamation tasks.

C) Complete reclamation using only the excavator for shallow tilling of all roads and landings plus all other reclamation tasks.

D) Partial reclamation using only the subsoiler to deep-till all roads and landings and build traffic barriers (topsoil recovery and stream-crossing restoration excluded).

This analysis assumed the same machine costs, average tilling rates (from Table 5, for roads and landings combined), treatment areas and incidental tasks as were performed in this study. It also assumed two lowbed trips (at 2.5 h/trip and $110/h) and machine utilization levels of 80% for the subsoiling unit and 85% for the excavator.

Option A, the current study with modified machine utilization levels, requires 19.4 subsoiler hours and 51.8 excavator hours at a total cost of $9 100 to complete the project. All reclamation work is done but the workload is distributed unequally because the excavator is used to perform a significant proportion of the required tilling.

Option B also completes the reclamation project, but the workload is assigned on the basis of each machine's suitability and productivity. Therefore, all of the tilling is done by the higher-production subsoiler and the other reclamation activities are completed by the excavator. Assuming the redistribution of work does not result in excessive idle or travel time for either machine, this option requires 30.2 subsoiler hours and 25.3 excavator hours at a total cost of $7 900. The workload is more evenly distributed in this scenario, and the entire reclamation project could be completed in less than one week if both machines start at the same time. If operating windows for reclamation activities are short, rapid completion may be an advantage. However, it may not be practical to design a reclamation project that requires two machines if the project is small in size or if the project site is located in a remote area. Also, it may be difficult to schedule both machines for the same time period.

Option C uses only the excavator to do all of the reclamation work. It requires 80.6 excavator hours at a total cost of $8 750 (between the costs of Options A and B, which employ both machines). The advantages of this option are that it uses a readily available, versatile and lower-cost machine to perform all of the required work and therefore avoids machine scheduling problems. The cost of moving equipment into and out of the work area is a smaller proportion of total project cost. The disadvantages of this option are that the excavator is less productive than the subsoiler for tilling, and all of the tilling is shallow—not deep as achieved by the subsoiler. As a result, total project costs are higher than could be realized with two machines and the resulting treatment is different.

Option D is a partial treatment, and uses the subsoiler to perform all of the tilling operations and to construct the five traffic barriers. It requires 31.6 subsoiler hours at a total cost of $5 000. The main advantage of this option is that it uses just one machine to complete the largest reclamation task (i.e., tilling) at the least cost. Also, the high productivity of the subsoiler allows it to take advantage of brief working windows. However, this analysis assumes that stream-crossing restoration and topsoil recovery are optional tasks. In situations where such restoration work is necessary, the choice of which machine to use for these tasks must be made on a site-specific basis.

These examples demonstrate the importance of clearly defining the objectives, desired results, size, and scope of a reclamation project when trying to decide on the most appropriate and/or cost-effective machine alternative.

Other Observations. On the basis of this study, the subsoiler appears to be best suited to larger-scale reclamation projects where tilling of road and landing surfaces is the priority, and additional tasks are secondary or not required. The excavator appears to be better suited to smaller projects and projects requiring a significant amount of stream restoration, drainage control, and topsoil recovery.

The decision to use both machines on a reclamation project is particularly sensitive to project size and the nature of the reclamation work required. For example, during the planning stage the Aleza Lake reclamation trial was thought to have sufficient work to warrant the use of both the subsoiler and the excavator, but in retrospect the quantity of work may not have required both machines.

Operating windows for performing reclamation work on fine-textured soils in central British Columbia are not readily predictable, so reclamation plans that allow operators to respond quickly to favourable conditions are preferable. This favours smaller-scale operations using a single machine, and prioritizing treatment areas and activities to ensure that critical work is done first.

The subsoiler's productivity was significantly reduced by the presence of buried logs and stumps in the roadbeds. Even though road sections that were obviously corduroyed or suspected to contain large amounts of debris were left untreated, the subsoiler still encountered logs and stumps in many of the treated sections. As a result, shear pins attaching the subsoiler to the crawler tractor failed on several occasions. This problem may be overcome through continued operator experience. Alternatively, the dolly-mounted subsoiler configuration may be worth testing.

The excavator was well suited to the task of recovering topsoil from sidecast deposits, but its productivity was reduced because the deposits were poorly defined and poorly sorted. More careful sorting and piling of topsoil when building new roads and landings would improve the efficiency and lower the cost of topsoil reclamation. The site-preparation rake and hydraulic thumb proved to be a useful combination for locating and retrieving topsoil. The rake was effective for probing likely deposits to quickly assess their size and quality, and the hydraulic thumb simplified removal of stumps and logs from the topsoil.

Even though the objective of tilling was to create a loosened soil layer of about 20 cm (the typical rooting depth under natural conditions on these sites), the subsoiler was set to a depth of 50 cm and no attempt was made to evaluate its tilling performance at shallower depths. In contrast, the teeth on the excavator's site-preparation rake were quite worn and the excavator's average tilling depth was less than 20 cm. If the target depth of 20 cm is considered to be appropriate, future trials should evaluate the subsoiler at shallower tilling depths and the excavator with new teeth and/or different rake designs.

Conclusions

This report describes a study, performed by FERIC, of two machines engaged in the reclamation of old logging sites on fine-textured soils in central British Columbia. The study was part of a larger research trial to investigate the long-term effectiveness of three site-reclamation treatments on compacted roads and landings, and was funded by the BCMOF, Prince George Forest Region. This report compares the productivities and costs of a Tilth winged subsoiler mounted on a Caterpillar D7F crawler tractor, and a Caterpillar EL200B hydraulic excavator equipped with a five-tined site-preparation rake. The winged subsoiler performed deep tilling of roads and landings. The excavator performed shallow tilling of roads and landings, recovered topsoil from available roadside deposits, restored stream crossings, and built traffic barriers as required.

Tilling rates in compact, fine-textured soils for the winged subsoiler averaged 3 609 and 2 886 m^2/h, for roads and landings, respectively, at costs of \$39 and \$49/1000 m^2 respectively. The excavator's tilling rates in fine-textured soils were lower than for the subsoiler, averaging (for roads and landings combined) 1 425 m^2/h for shallow tilling and 809 m^2/h for topsoil recovery plus shallow tilling. Costs per 1000 m^2 for these two operations averaged \$71 and \$126, respectively.

Because the tasks most suited to each of these machines are different, the site characteristics and the objectives of the operation must be examined closely prior to choosing a machine. The operations are very sensitive to weather and soil moisture conditions. In addition, the productivity of the subsoiler configuration observed was significantly reduced by buried debris and stumps. When four options were examined, with transportation and machine utilization taken into consideration, the following results were found:

- Using the equipment as in the trial, with deep tilling done by the subsoiler and shallow tilling done by the excavator, the total operation would cost \$9 100.
- If all tilling is done by the subsoiler and all other activities by are done the excavator (i.e., each machine doing the job to which it is best suited), the total operation would cost \$7 900.
- If the excavator did all the reclamation work (with shallow tilling substituted for deep tilling), the total cost would be \$8 750.
- If only a partial treatment was done, with the subsoiler completing deep tilling and constructing all traffic barriers, the operation would cost \$5 000.

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Disclaimer

Appendix I

Machine Costs [a]

	Caterpillar D7F crawler tractor with mounted winged subsoiler	Caterpillar EL200B hydraulic excavator with 5-tined site-preparation rake
OWNERSHIP COSTS		
Prime mover	440 000	220 000
Attachment	45 000	8 000
Total purchase price (P) $	485 000	228 000
Expected life (Y) y	6	6
Expected life (H) h	9 600	9 600
Scheduled hours/year (h)	1 600	1 600
Depreciated value (% of P)	30	30
Interest (%)	9.0	9.0
Insurance (%)	3.0	3.0
Depreciated value ($)	145 500	68 400
Average investment ($)	315 250	148 200
Hourly ownership costs		
Depreciation ($/h)	35.36	16.63
Interest ($/h)	17.73	8.34
Insurance ($/h)	5.91	2.78
Total ownership costs ($/h)	59.01	27.74
OPERATING COSTS		
Fuel consumption (L/h)	25.0	25.0
Fuel cost ($/L)	0.40	0.40
Lube & oil (% of fuel)	15	15
Track & undercarriage replacement cost ($)	36 000	34 000
Track & undercarriage life (h)	4 800	4 800
Annual repair & maintenance expense ($)	46 000	35 000
Shift length (sl) h	10.7	10.7
Operator's wages ($/h)	21.68	22.03
Wage benefit loading (WBL) %	35	35
Hourly operating costs		
Fuel ($/h)	10.00	10.00
Lube & oil ($/h)	1.50	1.50
Track & undercarriage ($/h)	7.50	7.08
Repair & maintenance ($/h)	28.75	21.88
Wages (including benefits) ($/h)	29.27	29.74
Prorated overtime ($/h)	3.69	3.75
Total operating costs ($/h)	80.71	73.95
TOTAL OWNERSHIP AND OPERATING COSTS ($/h)	139.72	101.69

[a] These costs are based on FERIC's standard costing methodology for determining machine ownership and operating costs. They do not include supervision, profit, or overhead, and are not the actual costs for the contractor or company studied.