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Use of a Hammer-Mill to Produce Seed-Containing Mulch of Cone-Bearing Logging Residues Suitable for Ground Level Seeding

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The views, conclusions, and recommendations contained herein are those of the authors and should be construed neither as policy nor endorsement by Natural Resources Canada or the Ontario Ministry of Natural Resources.

† USE OF A HAMMER-MILL TO PRODUCE SEED-CONTAINING MULCH OF CONE-BEARING LOGGING RESIDUES SUITABLE FOR GROUND LEVEL SEEDING

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Running Header: Reforestation Procedure

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Abbreviations: PNFI, Petawawa National Forestry Institute; hp, horse power.

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ABSTRACT

A method for producing a seed-containing mulch of cone-bearing logging residues for ground-level seeding was developed. Running a 35 cm drum Farm King hammer mill at 812 rpm, i.e. 1/4 of the design speed (3250 rpm), resulted in a greater recovery of live seeds from black spruce and jack pine cones. At 812 rpm, release of live seeds from cones increased with batch size from 0.2 live-seed g-1 with 200 g batches to about 0.9 live-seed g^{-1} with 300 to 1 kg batches. At 812 rpm with 300 g batches, retention screens sizes of 1.0 -2.5 cm released live seeds from black spruce cones but little live seed was released from jack pine cones. In black spruce, 2.5 cm retention screens produced a mulch of cones and cone parts that contained 75% of the unprocessed cone's original live seed titre. In jack pine, screen sizes of 3.5 cm produced a cone mulch that contained more than 50% of the original live seed titre. Intact cones of jack pine and black spruce produced seeding ratios that were similar to those of heat extracted seed. Jack pine cone-bearing-foliage collected near Shinning Tree, Ontario and black spruce cone-bearing foliage collected near Iroquois Falls, Ontario were commuted to a mulch in the hammer mill that contained live seeds. A mulch jack pine and black spruce cone-bearing foliage chopped in the hammer mill produced seeding ratios that were similar to those of heat-extracted, air-purified seed standards.

INTRODUCTION

Black spruce cones may produce millions of seeds per hectare and some of these seeds remain in the cones for many years after opening (Viereck and Johnston, 1990). In jack pine the accumulated seed production of many years remain on the branches and may accumulate to millions of seeds per hectare (Rudolph and Laidy, 1990). After extensive timber harvesting, cones remain on the logging residues left near or on the cut over. These cones contain considerable amounts of live seed that are released over time but the quality of the remaining seed declines with the passing seasons (Fleming and Mossa, 1996). The redistribution of logging residues has been proposed as a possible aid in the regeneration of cut overs that may offer economy and maintenance of biodiversity (Jeglum, 1990). However, the seeds released from logging residues need to fall on a suitable substrate to establish seedlings (Fleming and Moss, 1995; Fleming and Moss, 1994) and so redistributing the logging residues on the cut over without other site preparations may not produce regeneration. The extensive site preparation of large surface areas in preparation for the random distributions of seeds from logging residues or from the air is costly and may have the disadvantage of increased soil erosion that perhaps may impact on future site productivity. Hence a method that would permit the specific targeting of these cone- bearing-residues to an appropriate number of small soil scars may satisfy the requirements to produce forest regeneration while maintaining biodivesity and limiting soil erosion (Jeglum, 1990). However, the labour cost of manually picking and planting cones would often be prohibitive. Thus the feasibility of a mechanical method of preparing and targeting the cones from logging residues to small ground scars is of interest. To this end, the mechanical feasibility of recycling cones from logging residues was investigated using a hammer mill.

A hammer mill is an attractive device to explore the feasibility of the mechanical preparation of harvesting wastes since the mill can be easily fitted with different retention screen sizes, hammers or gear ratios. The core of a hammer mill is a set of metal bars that hang freely towards the ground from metal pins in an ordered arrangement on a circular support hub attached to an axel. When the axel is rotated rapidly, centrifugal force pulls the heavy metal bars out straight from the hub so that they nearly fill the volume of the cylindrical grinding chamber formed by a metal screen. When materials are introduced into the path of the accelerated metal bars they are broken into smaller particles until they can pass out of the grinding chamber through the metal screen. Hence, the pore size of the metal screen size, the rotation speed and the length and shape off the hammers are major factors controlling the grinding characteristics of a hammer mill. Herein, modifications to an agricultural hammer mill are described for commuting logging residues to a mulch of relatively uniform particle distribution that still contains live seed and can produce 1 year seeding ratios similar to that of purified seeds is described.

MATERIALS AND METHODS

PLANT MATERIALS

Whole cones for testing the hammer mill were obtained from a mixed collection from the provincial seed plant in Angus, Ontario. Air-purified, heat-extracted seed-standards (≥97% viable) were obtained from a mixed collection of boreal seeds obtained from the Petawawa National Forest Research Institute (PNFI) in Chalk River, Ontario. Cone-bearing-branches for field trials were collected from local slash piles at cut overs near Shinning Tree and Iroquois Falls Ontario.

HAMMER MILL

Cone-bearing branches were commuted to a mulch with a 35-cm-drum, Farm King hammer mill powered by a 3250 rpm, 5 hp, triple-phase, electric motor (John Buhler Inc., Morden, Manitoba, Canada). The hammer mill was welded to a frame separated from a motor that could attach by turn screws at an adjustable distance from the mill to permit the use of 1:1 (i.e. 3250 rpm) to 4:1 reduction gears (i.e. 812 rotations per minute). The cylindrical grinding chamber formed by the metal screen was 35 cm in diameter and 15 cm deep. The mill had 18 hammers arranged six rows of three hammers each. Each hammer was 12.5 cm long, 2.8 cm wide and were 0.625 cm wide (or 0.312 cm wide where indicated) and where square cut (or bevelled to 30° where indicated). The hammer mill was set up and tested using batches of hand picked cones, or cone-bearing logging residues, with the batch size, speed, screen sizes and batch mode indicated.

SEED TESTING

Seeds released from cones in mechanically produced mulches were screen-purified between

2.5 mm and 1 mm before live seeds were measured by incubating on peatmoss saturated with the solution of Benlate (a commercial antifungal compound) in open germination boxes. Seeds within untreated cones or cones and cone-parts from the hammer mill were heated 3x at 60°C for 24 h, vigorously agitated, and the extracted seeds combined. Live-seed counts of heat extracted cones were made on kimpac cotton pads that had been moistened with 100 ml of distilled water and suspended on a plastic grid above and additional 110 ml of distilled in a sealed germination box. The germination boxes were placed in a conviron G30 chamber with day/night cycles of 8/16 h under fluorescent light with an intensity of 12 $\mu E/m^2/s^{-1}$ at 20 °C and 85% relative humidity for at least 21 days (International Seed Testing Association, 1993).

FIELD TRIALS

In order to more fully limit test variation to the treatments imposed, seeds, intact cones, or cone mulch were distributed on replicate scars that were located close together on in an small area selected with limit physiographic variation. The rationale for this design is that variation of in humidity, soil moisture, temperature, and light would be reduced by establishing multiple test scars for each treatment within close proximity on Latin plots located to minimize variation in slope and vegetation. Each replicate treatment scar received at ≥ 150 black spruce seed or ≥ 125 jack pine seed, or 5 intact cones, or 1 l (jack pine) or 300 ml (black spruce) of mulched logging residues. Trials were established in June or October 1994 as indicated. At the Iroquois Falls experimental site seeds were distributed on 25x25 cm square scars that were 2.5 cm deep and made using a hoe or flat shovel on slow growing moss with a mottled white, orange, brown, green appearance over growing upon elevated, shallow bedrock in the Abitibi Model Forest about 22 km north of the Abitibi River bridge on the Northwest Industrial Road. Competing vegetation was removed by hand. In contrast, at the Shinning Tree Experimental Site, seeds were distributed on 25x25 cm application spots in power disc trencher rows in a moist sandy loam 1 km south of the junction of Highway 144 and the main entrance of the E.B. Eddy timber limits near Shinning Tree Ontario.

RESULTS

Running the hammer mill at 3250 rpm damaged all jack pine seeds released from the cones and the seeds within the remaining cone fragments (Table 1). Operating the mill at 812 rpm with retention screen sizes of 1.75-2.25 cm resulted in the production of a mulch that, after screening, seemed to contain large amounts of visible seeds but most seed were damaged and less than 10% of the original seed titre remained in the damaged cones as tested by germination on peat moss (Table 1). In black spruce a significant proportion of viable seed were released from cones when processed at 3250 or 812 rpm with a retention screen size of 1.25 centimetres (Table 2). The mill released more live seed when the hopper was filled prior to starting the motor as opposed to running the motor continuously during sample loading (Table 2). In black spruce batch sizes of 300 g or greater sustained less damage to the released spruce seed (Table 3).

Black spruce cones milled with a speed of 812 rpm, a batch size 200 g and retention screens of 1.0-2.0 cm released a significant amount of live seed from black spruce cones (Figure 1a). However, screen sizes of 2.5 cm produced a mulch of cone parts that contained about 75% of the original seed titre (Figure 1a). Jack pine cones milled at 812 rpm with 300 g batches released little live seed but at a screen size of 3.5 cm about half of the original seed titre remained undamaged within cones or cone parts (Figure 1b). Hence it was possible to modify the hammer mill to grind batches of hand picked cones into a mulch containing a significant proportion of the original seed titre. The feasibility of producing a mulch of cone-bearing foliage was tested using foliage collected from Shinning Tree and Iroquois Falls Ontario. Jack pine foliage milled at 812 rpm with 2.5 cm retention screens had an air-dry bulk density of 0.27 kg/l and contained 77 live seeds per litre. Black spruce foliage milled at 812 rpm with 1.25 cm screen had an air-dry bulk density of 0.16 kg/l and contained 53 live seeds per litre.

The effect of a mulch containing intact cones or cone-parts was simulated using whole cones of jack pine and black spruce. Five intact cones or live seed ($\geq$125 seed, jack pine) and ($\geq$150 seed, black spruce) were sown in each replicate scars. In black spruce, cones produced sparse, but detectable, numbers of seedlings, and had average seeding ratios that were numerically greater than the absence of 1 yr seedlings produced by heat extracted seed (Table 4). Jack pine seeding ratios were similar between seeds in cones and those of naked seed (Table 4). A trial of jack pine cone-bearing foliage commuted in the hammer mill produced at the sub-optimal retention screen size of 2.5 cm produced 1 year seeding ratios similar to heat purified seeds (Table 4). Black spruce cone-bearing foliage milled at the sub-optimal screen size of 1.25 cm also produced very sparse, but detectable, seeding ratios (Table 4).

DISCUSSION

A hammer mill run a using low motor speeds, larger sample sizes (≥300g) and/or starting batches with a full hopper produced a 50% yield of the original live-seed titre in jack pine cones and produced a 75% yield for black spruce (Figure 1). However, the poor production of live seeds observed when the mill was run at high speeds, in a continuous mode, or with low sample volumes indicates that when the hammers attain a high velocity more of the seed are damaged (Tables I,II,III). Hence higher yields of seeds may be possible using even lower speed grinding methods that produce the appropriate particle size with less trauma to the cones.

Significant amounts of live seeds were released from black spruce cones that were milled at small screen sizes (1.25 cm) but little viable seed was released from jack pine. In both species the greatest total number of live seeds were obtained when cones where commuted to particle sizes large enough that many of the cones fell though the retention screen intact (i.e. ≥ 2.5 cm for black spruce and ≥3.5 cm for jack pine). Hence higher yields of live seed within the cone or cone fragments will likely result from grinding to even larger particle sizes to produce mostly intact cones (Figure 1).

The effect of milling cone-bearing logging residues to such large particle sizes was simulated by sowing intact cones compared to heat extracted seeds. Intact black spruce cones were found to produce some seedlings after all heat extracted seed had perished both on sandy soil and on peat. In jack pine, intact cones had seeding ratios that were similar to heat extracted seeds. Hence there does not seem to be any additional benefit from heat extracting jack pine and black seeds from cones prior to sowing (Table IV). Seeding ratio that were at least similar to those of heat extracted seeds were obtained when jack pine cone-bearing-foliage that had been milled with sub-optimal retention screens, i.e. < 2.5 cm in black spruce and < 3.5 cm in jack pine (Figure 1), indicating that it is mechanically feasible to prepare a cone mulch from logging residues that will produce reasonable seeding ratios (Table IV).

Economic and Ecological Considerations

The capacity to utilize cones from logging residues might be exploited to regenerate the native genotype without degrading the site capacity for future productivity (Nyland et a., 1979; Foster and Morrison, 1987; Jeglum, 1990). Consider that cut overs are often regenerated by mechanical scarification followed by aerial seeding of locally collected, heat-extracted seeds, by the use of seed trees or, in black spruce, by seed that is presumably transported some distance over snow by the winter winds. Regeneration using these random methods of distributing of seeds from the air requires expenditures to scarify extensive surface areas thus increasing the probability that seeds will land on a receptive substrate. The results here indicate that targeting cones or cone mulch to small scars from ground level may substitute for aerial distribution of heat extracted seeds. However in contrast to random aerial seeding, targeting cones to specific, small scars from ground level would require the scarification of much less total surface area. Direct seeding from ground level may produce a longer window of opportunity than artificially sown free but seeds left elevated in slash piles may have a significantly longer half-life than cones on the ground (Flemming and Mossa, 1996). Manual cone planting may reduce costs associated with the transportation, cataloguing, heat extraction, scarification and aerial distribution of direct seeding and the seedling costs of plantation. Hence manually planting cones may provide an economically feasible method of reforestation where costs from unionized labour are not applicable. The economic feasibility of designing mechanical methods to obtain and distribute cones or cone mulch on a large scale remain to be determined but the small scale experiments presented here indicate that mulch production is conceptually feasible. In jack pine where the cones are distributed over a large volume of foliage the cost of milling the cone-bearing foliage would certainly be prohibitive to the mechanisation of this process. In contrast, in black spruce where the cones are concentrated in a small volume at the tree top the cost mechanical milling of tree tops into a cone mulch would be markedly reduced.

IN SUMMARY

Laboratory experiments indicated that cone-bearing branches of jack pine or cone-tops of black spruce could be rapidly and mechanically commuted to mulch that contains significant amounts of viable seeds within intact cones or cone parts. Field experiments indicate that intact cones will produce seeding ratios that are at least comparable to those of heat extracted seeds in jack pine and black spruce. A mechanically produced mulch of jack pine or black spruce cone-bearing foliage produced seeding ratios similar to those of heat extracted seed. Together these laboratory and field experiments indicate that it is conceptually feasible to direct seed from ground level using cones or cone parts. Considerable further optimization of the reforestation procedure is possible.

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Table I. The effect retention screen diameter and mill speed on the production of live seed within cone parts and live seed released from the cones in jack pine. Greater than 300 g of cones containing 0.31 live seeds per gram were introduced into the hopper for each run. The hammer mill was fitted with 0.31 cm hammers that had a 30° bevel.

Mill Speed	Mulch Fraction	Retention Screen Size in cm		
		1.75	2.00	2.25
812 rpm	Free-Live-Seeds per gram	.008	.014	.012
	Live Seeds in Cones per gram	.003	.006	.027
3250	Free-Live-Seeds per gram	0	0	0
	Live Seeds in Cones per gram	0	0	0

Table II. The effect of mill speed and batch mode on free-live-seed release in black spruce. Three hundred grams of cones were processed continuously, or as a batch, in a Farm King Hammer mill fitted with 0.62 cm square hammers and 1.25 cm retention screen.

Mill Speed	Process	Total Germinants	Free-live-seed % Recovery	Live Seed $gram^{-1}$ cones
N/A	Heat Extraction	347	100	1.15
3500 rpm	Continuous-Feed Hammer Mill	84	24	0.28
3500 rpm	Batch-Feed Hammer Mill	223	64	0.74
875 rpm	Batch-Feed Hammer Mill	278	80	0.92

Table III. The effect of batch size on free-live-seed release in black spruce. Cones were processed at 875 rpm with a 0.5 inch retention screen. Other details as in Table II.

	Amount of Batch-Processed Cones			
	200 g	300 g	800 g	1000 g
Free-Live Seed $gram^{-1}$	0.2	0.9	1.0	0.8

Figure 1. The effect of screen size on the recovery of viable free seed (●) and viable seeds in within cones (▲) from: (**A**) 200 g batches of 1 year old black spruce cones containing 2.9 live seeds per gram, and (**B**) Greater than 300 g batches of ≥ 1 year old jack pine cones contained 1.49 live seeds per gram. Cones were comminuted in a Farm King hammer mill operated at 812 rotation per minute with 0.62 cm square hammers. Cones were introduced into the hopper prior to starting the motor.

Table IV. A comparison of seeding rations in intact cones and free seeds heat extracted from intact cones. Plots of black spruce seeds, cones, or cones mulch were sown at Iroquois falls and Shinning Tree in June or October 1994 and measured in October 1994 or October 1995. Each plot had N=6 scars per treatment with 150 or 300 heat extracted seed, or 5 intact cones, or 300 ml of cone mulch per scar. Jack Pine seeds, cones, or cone mulch, were sown at Shinning Tree in June 1994 and measured in October, 1995. The plot had N=12 scars per treatment with 250 heat extracted seed or 5 intact cones per scar.

Species	Seed Source	Seeding Ratio
Jack Pine	Heat Extracted Seeds	0.0061
	Intact Cones	0.0045
	Cone Mulch	0.0119
Black Spruce	Heat Extracted Seeds	0.0000
	Intact Cones	0.0112
	Cone Mulch	0.0066