JACK PINE (*Pinus banksiana*) SEEDLING EMERGENCE IS AFFECTED BY ORGANIC HORIZON REMOVAL, ASHES, SOIL, WATER AND SHADE

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Abstract. The effects of organic horizon removal, ashes, soil water, and shade on jack pine *(Pinus banksiana* Lamb) seedling emergence were investigated. For this purpose soil monoliths were taken to the laboratory and received prescribed burning, leading to 100%, 75%, 50%, 25%, and 0% organic horizon removal. One half of each monolith contained ashes generated from burning whereas the other half was kept ash-free. Each half of every monolith was sown with jack pine seeds and the monoliths were then watered under four watering schedules (100%, 75%, 50%, and 25% of the regional average daily June rainfall) or shaded under four shading levels (100%, 75%, 50%, and 25% photosynthetically active radiation). Seedling emergence was most successful under high watering schedules, increased depth of burn, high shading, and without ashes. Ash had an inhibitory effect on seedling emergence.

Keywords. *Pinus banksiana*, FIRE, SEEDS, REGENERATION, SOIL WATER POTENTIAL, LIGHT.

1. Introduction

Jack pine (*Pinus banksiana* Lamb.) is the most widely distributed pine species in Canada (Rudolph and Laidly, 1990) and has significant economic importance to the forest industry (Foster and Morrison, 1976; Anonymous, 1980; Rudolph and Laidly, 1990). The silvicultural implications of the role of fire in jack pine ecosystems are well known (Eyre and LeBarron, 1944; Cayford *et al.*, 1967; McRae, 1979) and have been investigated in terms of fire behaviour (Weber *et al.*, 1987), seedbed preparation (Fowells, 1965; Chrosciewicz, 1974, 1990), and regeneration (LeBarron, 1944; Thomas and Wein, 1985; Weber *et al.*, 1987; Chrosciewicz, 1988).

Little of the literature describing the effects of fire on jack pine regeneration provides quantitative detail concerning the relationships among organic horizon consumption, depth of burn, and post-fire regeneration. Chrosciewicz (1974) demonstrated that jack pine seedling abundance and height correlate negatively to the post-fire organic horizon depth. Thomas and Wein (1985) have proposed a model relating the effect of shade and fire severity (depth of burn) on post-fire conifer seedling establishment. In their model, jack pine seedling establishment is most successful under high fire severity and low shade levels. Other studies concerning the effect of fire on jack pine regeneration involve far less quantitative detail. Existing data (LeBarron, 1944; Fraser and Farrar, 1953; Chrosciewicz, 1974; Thomas and Wein, 1985) need to be complemented by studies that address the relationships among factors such as jack pine seedling emergence, ash content, organic horizon removal, shade, and soil water. The objectives of our study were to investigate the effects of organic horizon thickness, ash, shading, and soil water, on jack pine seedling emergence under greenhouse conditions. Previous attempts to investigate these factors in the field failed because of difficulties caused by variable weather conditions, depth of burn, and seed predation (unpublished data).

Water, Air and Soil Pollution **82**: 147–154, 1995.

2. Materials and Methods

Soil monoliths were collected from the forest floor of the Frontier Lake experimental site (46°00'N, 77°33'W) at the Petawawa National Forestry Institute (PNFI) within the Middle Ottawa Section (L.4c) of the Great Lakes–St. Lawrence forest region (Rowe, 1972). Site characteristics and overstory composition are described in Herr *et al.* (1994).

Portions of the forest floor, measuring 18 cm × 30 cm, were outlined with 30 cm serrated knives to produce soil monoliths. A wooden board measuring 18 cm × 30 cm and 2 cm deep was placed on the litter surface while the monolith was outlined to avoid disturbing the surface litter. Each monolith was measured to a minimum depth of 25 cm, including the organic horizon, the Ae horizon, and a variable portion of the B horizon. We use the term *organic horizon* to describe the L (litter), F (fermentation), and H (humification) horizons (Spurr, 1980). Monoliths were allowed to air dry at room temperature for several weeks to ensure uniform soil moisture levels. A total of 215 monoliths were collected for this investigation: 200 were used to evaluate the effect of shading and soil water (100 monoliths each) on seedling emergence. The remaining 15 were used as unseeded controls to determine the presence and level of the jack pine soil seed bank.

The organic horizon thickness of each monolith was measured (mean thickness 5.0 ±1.44 cm std. dev.) and 100%, 75%, 50%, or 25% of the organic horizon was removed with a 30 cm serrated knife. Controls (0% removal treatment) consisted of monoliths in which the organic horizon remained undisturbed. Soil monoliths were placed in Rootrainer boxes (Spencer–Lemaire Industries Ltd., Edmonton, Alberta) lined with nursery shade cloth. The portions of organic horizon removed were combined with their respective treatments (i.e., all 25% organic horizon removal portions were combined) and burned *ex situ* using a propane torch in a fume hood until no further combustion was attainable. The total mass of ashes for each set of removal treatments (i.e., 25%, 50%, 75%, and 100%) was divided by the number of monoliths contributing to that particular treatment, and then half of that mass was spread as an uniform layer onto half of the area of each monolith. This created two treatments for each monolith: an organic horizon removal with ash present, and an organic horizon removal with ash absent. The two treatments were kept separate with plastic dividers to prevent the ashes from spilling over.

Each half (ash present and ash absent) of each of the 200 monoliths used in the shade and watering schedule experiments were seeded with 100 unstratified, viable jack pine seeds (PNFI seedlot number 75 30 200, seed year 1975, viability 99.9%, retested in 1991). The monoliths were then placed in a greenhouse at ambient air temperature at monolith surface (no shading) of 23.8 ±4.3 °C standard deviation, with maximum and minimum temperatures of 34.0 °C and 16.3 °C, respectively (Figure 1). Fifteen untreated monoliths (0% organic horizon removal) were placed under a 25% PAR level, and watered with 145 mL deionized water per day for 4 weeks to determine the presence and level of the jack pine soil seedbank.

Watering of the monoliths was conducted daily using the June precipitation records over a 30-year period from the Bransted weather station at PNFI (G. Péch, pers. comm.), which is located approximately 15 km east of the monolith collection site. June is the month of the growing season with the highest rainfall at PNFI (Weber *et al.*, 1987). Therefore, this value was used as the best case scenario for seed emergence. The average daily June precipitation of 2.7 mm per day was adjusted for the entire (18 cm × 30 cm) surface of the monolith, yielding a watering schedule of 145 mL

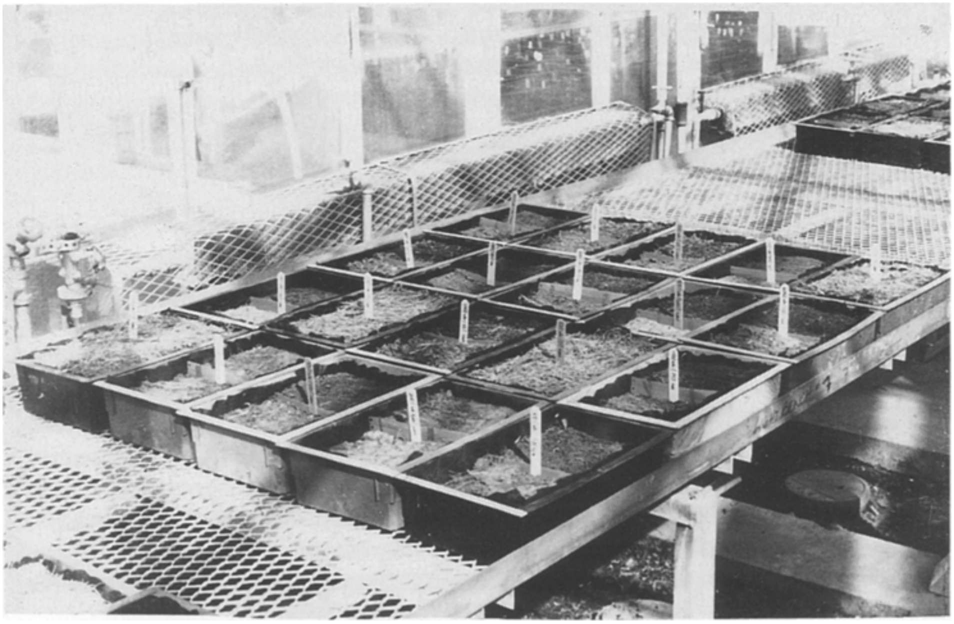

Fig. 1. Soils monoliths on a greenhouse bench.

deionized water per monolith per day. Moreover, one hundred monoliths were used (20 of the 0% removal treatment, and 20 of each of the 25%, 50%, 75%, and 100% removal treatments) to determine the effect of watering schedule on jack pine seedling emergence. Five monoliths from each removal treatment were randomly assigned to one of the four different watering schedules. The four watering schedules used in this portion of the study included 25%, 50%, 75% and 100% of the average daily June rainfall from the Bransted weather station. The monoliths were then placed on greenhouse benches (Figure 1) in a completely randomized design, and watered daily according to their prescribed watering schedule.

One hundred monoliths were used (20 of each of the 0%, 25%, 50%, 75%, and 100% removal treatments) to determine the effect of shading on jack pine seedling emergence by establishing four separate shading levels (25 monoliths per shade level) performed simultaneously, each in a randomised complete block design. Repetition of the shade factor was not possible due to greenhouse space limitations; therefore statistical comparisons could not be made among the four different shading levels. The shading experiments were conducted during July, 1993. The four shade levels were: 25%, 50%, 75%, and 100% of PAR in greenhouse conditions. Shading was accomplished by suspending wooden lattices 60 cm above the monoliths. Measurement of PAR at solar noon above and below the lattice was accomplished with a Li-Cor LI-190SB Quantum sensor (Li-Cor, Lincoln, NE, USA); the number of slats in the lattice was then adjusted to obtain the desired PAR level. Monoliths were watered daily using the June average daily rainfall as before. Seedlings were considered to have emerged when the seed coat was lifted above the substrate by the hypocotyl. Percent emergence was thus measured by counting the number of seed coats lifted off the surface of the monolith. Total percent jack pine seedling emergence was determined at the end of June, 1993, four weeks after the beginning of the experiment.

For statistical analysis of percent emergence, the data were arcsine-transformed, tested for homoscedasticity, and analyzed using the PROC GLM procedure of SAS (SAS Institute Inc., 1985). To test for significant differences among treatments, the Tukey's HSD multiple comparison test was used ($\alpha = 0.01$).

3. Results

No jack pine seedlings emerged from the 15 untreated monoliths. Therefore, no corrections to the final emergence data were necessary to account for the presence of a natural soil seedbank.

Jack pine seedling emergence was not observed under either the 25% or the 50% watering schedules (data not shown). The effects of watering schedule, organic horizon removal, ash, and the watering schedule × organic horizon removal interaction on jack pine seedling emergence were significant (Table I). The interaction effects of organic horizon removal × ash, watering schedule × ash, and watering schedule × organic horizon removal × ash were not significant. The effects of watering schedule, organic horizon removal, and watering schedule × organic horizon removal accounted for the majority of the total variance (Table I). Under the 75% watering schedule, the effects of organic horizon removal, ash, and organic horizon removal × ash on jack pine seedling emergence were not significant (Table I). Under the 100% watering schedule, the effects of organic horizon removal and ash on jack pine seedling emergence were significant, but the organic horizon removal × ash effect was not significant (Table I). The effect of removal accounted for most of the total variance (Table I).

Under the 75% watering schedule, jack pine emergence was variable and no differences were found at any organic horizon removal level with or without ash (Figure 1). Emergence was variable for the 75% watering schedule (Figure 2). Under the 100% watering schedule,

TABLE I

Effects of watering schedule (Water), organic horizon removal (Removal), and ash (Ash) on jack pine seedling emergence for the watering schedule experiment.

Level of ANOVA	Source of variation	% of variance accounted for	F	Significance[a]
Entire watering schedule experiment	Water	18.0	32.01	***
	Removal	12.4	5.54	**
	Ash	3.6	6.55	**
	Water × Removal	15.3	6.83	***
75% watering schedule level	Removal	10.1	1.21	NS
	Ash	3.2	1.53	NS
	Removal × Ash	2.7	0.33	NS
100% watering schedule level	Removal	38	7.83	***
	Ash	6.1	5.02	*
	Removal × Ash	6.3	1.29	NS

a NS - not significant; *** significant at $P < 0.001$; ** significant at $P < 0.01$; * significant at $P < 0.05$.

emergence was higher on the without ash treatments (Figure 2). Generally, germination increased with watering with ash (Pearson R: 0.437, $P < 0.001$) or without ash (Pearson R: 0.382, $P < 0.001$).

The effects of organic horizon removal, ash, and organic horizon removal × ash on jack pine seedling emergence under the 25% PAR level were significant (Table II). The effects of organic horizon removal and ash accounted for the majority of the total variance at the 25% PAR level (Table II). Jack pine seedling emergence was greatest under the 50%, 75%, and 100% organic horizon removal in the absence of ash under the 25% PAR level (Figure 2). The presence of ash reduced jack pine seedling emergence for all organic horizon removal levels compared to jack pine seedling emergence in the absence of ash (Figure 2). Seedling emergence increased as percent organic horizon removal increased (Figure 2).

The effects of organic horizon removal, ash, and organic horizon removal × ash on jack pine seedling emergence under the 50% PAR level were significant (Table II). The effects of organic horizon removal and ash accounted for the majority of the total variance (Table II). Jack pine seedling emergence was greater in the absence of ash under the 50% PAR level (Figure 2). Jack pine seedling emergence generally increased as increasing portions of the organic horizon were removed for the 50% PAR level (Figure 2).

The effects of organic horizon removal, ash, and organic horizon removal × ash on jack pine seedling emergence under the 75% PAR level were significant (Table II). The effect of ash accounted for the majority of the total variance (Table II). Seedling emergence was lower in the presence of ash than in the absence of ash under the 75% PAR level (Figure 2). Seedling emergence increased as percent organic horizon removal increased under the 75% PAR level (Figure 2).

The effect of ash on seedling emergence under the 100% PAR level was significant, while the effects of organic horizon removal and ash × organic horizon removal on seedling emergence were not significant (Table II). Ash accounted for the majority of the total variance under the 100% PAR level (Table II). No seedlings emerged in the presence of ash under the 100% PAR level at 25%, 50%, and 75% organic horizon removal. Seedling emergence increased as increasing portions of the organic horizon were removed; however, no significant differences in seedling emergence under the 100% PAR level were found for the various organic horizon removal treatments (Figure 2).

4. Discussion

The absence of jack pine seedlings in the soil seedbank of the unseeded control monoliths was expected. The majority of cones on older (> 10 cm diameter at breast height) jack pine trees are serotinous, and do not open unless exposed to the heat of a forest fire (Gauthier *et al.*, 1993). Because the forest stand at the Frontier Lake monolith collection site had not been exposed to fire for several decades, it is unlikely that any significant jack pine soil seedbank exists. This conclusion is strengthened by the observation that jack pine seedling recruitment is virtually non-existent at the Frontier Lake experimental site (data not shown).

In this investigation, seedling emergence improved with the removal of increasing portions of the organic horizon, particularly when shade treatments are considered. The relationship is less evident under full light or at reduced watering schedules.

Although exposed mineral soil is generally considered the most suitable seedbed for regenerating many conifer species, total organic horizon reduction by fire or scarification may not yield maximum recruitment and/or growth. The forest floor acts as a nutrient

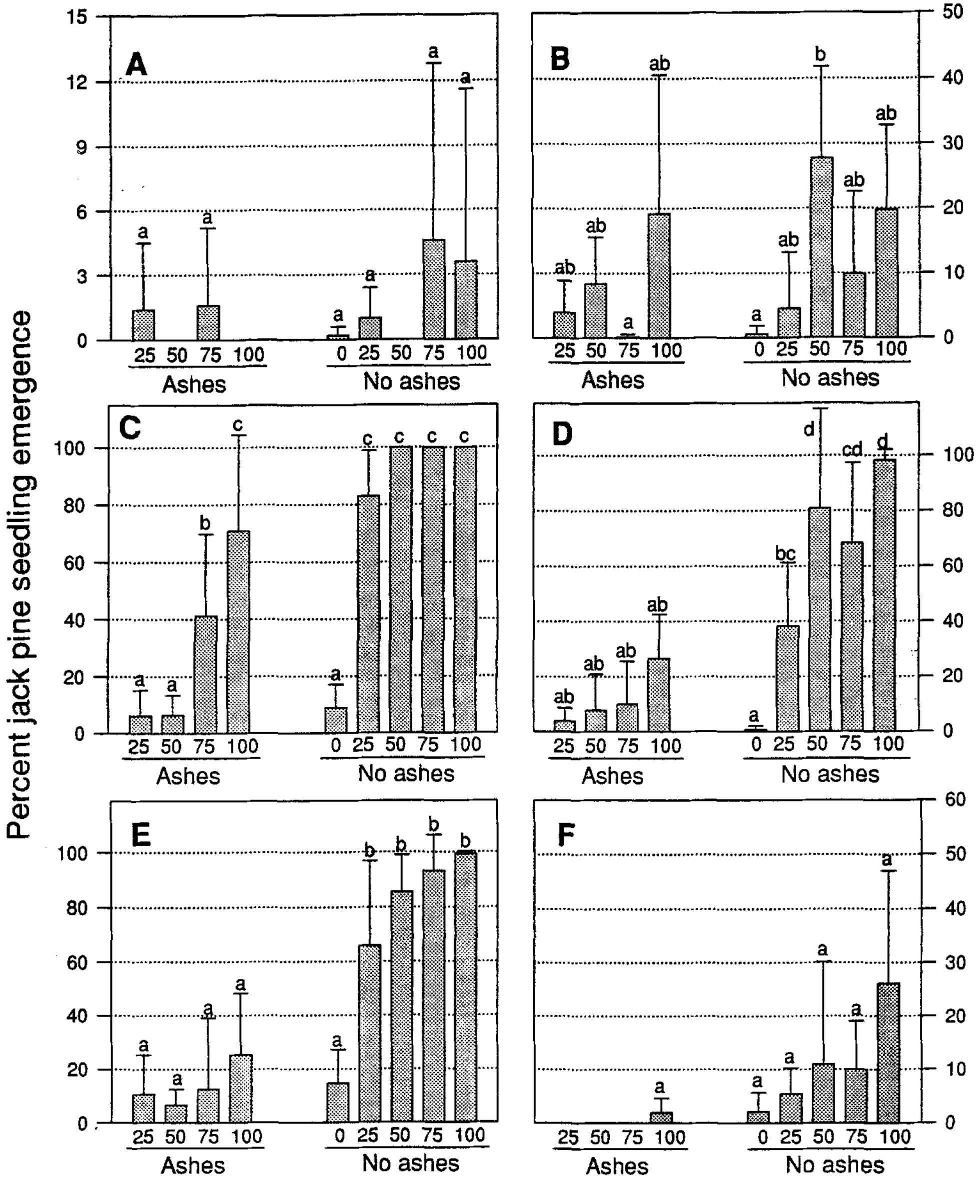

Fig. 2. Mean jack pine emergence ±1 SD (n = 5) affected by organic horizon removal and ash under the (a) 75% watering schedule, (b) 100% watering schedule, (c) 25% PAR treatment, (d) 50 PAR treatment, (e) 75% PAR treatment, and (f) 100% PAR treatment. Means followed by a different letter are significantly different (Tukey's HSD $\alpha = 0.01$).

TABLE II

Effects of organic horizon removal (Removal), Ash, and Removal × Ash on jack pine seedling emergence for the shading.

Shade experiment	Source of variation	% of total variance accounted for	F	Significance[a]
	Removal	48.8	35.80	***
25% PAR	Ash	53.2	156.14	***
	Removal × Ash	6.4	6.30	**
	Removal	34.0	20.32	***
50% PAR	Ash	35.9	85.63	***
	Removal × Ash	13.3	7.97	***
	Removal	14.1	7.50	***
75% PAR	Ash	52.0	111.48	***
	Removal × Ash	14.7	7.80	***
	Removal	10.9	2.20	NS
100% PAR	Ash	33.9	27.31	***
	Removal × ash	5.5	1.11	NS

a NS - not significant; *** significant at $P < 0.001$; ** significant at $P < 0.01$; * significant at $P < 0.05$

storage site and it has been suggested that total removal of the organic horizon may be an inappropriate management strategy (Chrosciewicz, 1974). Weber *et al.* (1985) suggested that removal of the organic horizon can have negative impacts on future site productivity. Therefore, it is critical to understand how depth of burn affects jack pine emergence and subsequent natural regeneration.

Our results show that ash reduces the emergence of jack pine seedlings. Two explanations can be advanced for this. First, the increase in soil pH caused by ash may be responsible. Although considerable research has addressed the effect of fire on soil pH in many fire driven ecosystems, little is known about the effect of pH on jack pine seedling emergence (Wright and Bailey, 1982). Second, ashes dry faster, absorb less water, and absorb more heat than unburned organic material (Ahlgren and Ahlgren, 1960; Chandler *et al.,* 1983). These factors expose seeds on the ash treatment to lower water potentials with possible detrimental effects on seedling emergence.

An analysis of soil water potential in our experiment shows that a factor or factors other than soil water potential affect jack pine seedling emergence (data not shown). An hypothesis for reduced emergence on the control monoliths is that chemical leachate(s) from the L, F, and/or H horizons have an allelopathic-like effect on seedling emergence. Alternatively, it is possible that the litter layer acts as a barrier to seed movement to more favourable germination and seedling emergence conditions on the F horizon. Further investigations are needed to determine the effect of the litter layer on seedling emergence of jack pine.

Based on the hypothesis that climate change may lead to reduced summer precipitation in parts of eastern and central Canada (Flannigan and Van Wagner, 1991), the results presented here have implications for future jack pine distribution and abundance in relation to potential climate change. We have shown that a slight reduction in the watering schedule severely limits jack pine seedling emergence. The relationship between jack pine seedling emergence on soil monoliths under different watering schedules in greenhouse conditions and jack pine seedling emergence under field conditions needs to be investigated. However, it is important to note that our observations are derived from only one soil type in a greenhouse situation and that other soil types need to be studied. Nevertheless, the models presented in this investigation are the first to present a comprehensive picture of the relationships among ash, soil water, shading, and depth of burn on jack pine germination. Future work should focus on the long term effects of these factors on seedling survival and growth. Such information could be used by forest managers interested in optimising stand regeneration after disturbance.

Acknowledgments

This work was supported by research grants from Parks Canada and Canada's Green Plan climate change initiative. Thanks are addressed to L. Clark, G. Jones, J. Ahearn, and E. Audet for laboratory and field assistance. Constructive criticisms by staff members of the Fire Ecology and Behaviour project, and editorial review by A. Yapa at the Petawawa National Forestry Institute are appreciated.

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