Forest Ecology and Management 312 (2014) 203–215

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Amounts of logging residues affect planting microsites: A manipulative study across northern forest ecosystems

Amélie Trottier-Picard [a,b,*], Evelyne Thiffault [c], Annie DesRochers [a,b], David Paré [a,c], Nelson Thiffault [a,d], Christian Messier [a,e,f]

[a] *Centre d'étude de la forêt (CEF), QC, Canada*
[b] *Institut de Recherche sur les Forêts, Université du Québec en Abitibi-Témiscamingue, 341 Principale Nord, Amos, QC J9T 2L8, Canada*
[c] *Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Centre, 1055 du PEPS, C.P. 10380, Succ. Sainte-Foy, Quebec, QC G1V 4C7, Canada*
[d] *Direction de la recherche forestière, Ministère des Ressources naturelles du Québec, 2700 rue Einstein, Québec, QC G1P 3W8, Canada*
[e] *Department of Biological Sciences, Université du Québec à Montréal, C.P. 8888, Succ. Centre-ville, Montréal, QC H3C 3P8, Canada*
[f] *Institut des Sciences de la Forêt Tempérée (ISFORT), Université du Québec en Outaouais (UQO), Ripon, QC, Canada*

ARTICLE INFO

Article history:
Received 12 August 2013
Received in revised form 2 October 2013
Accepted 4 October 2013
Available online 8 November 2013

Keywords:
Logging residues
Microenvironment
Soil temperature
Competing vegetation
Nutrients
Seedling growth

ABSTRACT

We quantified the effects of different loads of forest logging residues on the microenvironment (soil temperature, soil volumetric water content, competing vegetation cover, and available nutrients) of planted hybrid poplars one year after planting, and assessed the corresponding seedling growth until the third growing season. In four experimental plantations across Quebec (Canada), we used a factorial design of four residue loads that were applied at the tree-level over three planted species: hybrid poplars (*Populus* spp.), black spruce (*Picea mariana* (Mill.) BSP), and either jack pine (*Pinus banksiana* Lamb.) or white spruce (*Picea glauca* (Moench) Voss), depending upon the site. Logging residues linearly decreased competing vegetation cover on two of four sites and reduced fluctuations in soil temperature on all sites. Logging residues also decreased summer soil temperatures at all sites through a negative quadratic effect. On one site, the frequency of freeze–thaw cycles increased under logging residues, while logging residues increased soil water content on another site, for certain measurement events. Logging residues did not affect available nutrients. Seedlings showed no consistent growth response to logging residues for three years after planting, except for a beneficial effect of logging residues on hybrid poplar growth on one site. Because logging residues affected seedling microclimate and competing vegetation, their maintenance and on-site spatial arrangement on site could be used to manipulate the growing conditions for planted trees.

1. Introduction

Over the past decade, interest has increased regarding the use of logging residues (tops and branches of harvested trees) as feedstocks for bioenergy production. Many studies have focused on comparisons of the ecological impacts of whole-tree (i.e., removal of stem, tops and branches) vs. stem-only harvesting (Freedman et al., 1986; Hall and Richardson, 2001; Powers et al., 2005; Lamers et al., 2013). Yet studies with more quantitative approaches (Harrington et al., 2013) are needed, because national guidelines are being established concerning the quantity of residues that can be sustainably harvested without adversely affecting soil productivity (Stupak et al., 2008), and because operational harvesting of the forest biomass leaves inconsistent and variable quantities of logging residues (Nurmi, 2007). Thus, the question arises: How much logging residue can be harvested while maintaining tree growth and soil fertility?

Modelling studies have shown that whole-tree harvesting consistently causes greater removal of nutrients from the forest than does stem-only harvesting (Weetman and Webber, 1972; Freedman et al., 1986), increases risks of nutrient depletion (Sachs and Sollins, 1986; Paré et al., 2002; Akselsson et al., 2007), and decreases stand productivity (Wei et al., 2000). However, Thiffault et al. (2011), in a review of 53 empirical field studies regarding the impacts of residue harvesting, found no consistent effect of logging residue removal on soil productivity. When effects on post-harvest growth of planted trees were detected, they were site-, species-, and time-dependent (Thiffault et al., 2011).

The growth of planted trees after forest harvesting is affected by nutrient supply, light and water availability, and soil temperature (Margolis and Brand, 1990), all of which are affected by logging

---

* Corresponding author at: Institut de Recherche sur les Forêts, Université du Québec en Abitibi-Témiscamingue, 341 Principale Nord, Amos, QC J9T 2L8, Canada. Tel.: +1 819 732 8809x8327.

E-mail addresses: amelie.trottier-picard@uqat.ca (A. Trottier-Picard), evelyne.thiffault@rncan-nrcan.gc.ca (E. Thiffault), annie.desrochers@uqat.ca (A. DesRochers), david.pare@rncan-nrcan.gc.ca (D. Paré), nelson.thiffault@mrn.gouv.qc.ca (N. Thiffault), messier.christian@uqam.ca (C. Messier).

0378-1127/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.foreco.2013.10.004

residues at different times of stand establishment (Proe et al., 1999; Harrington et al., 2013). Residue effects on soil nutrients are limited during the first few years following harvest, as nitrogen is mostly retained in the litter and residues during this period and slowly released (Titus and Malcolm, 1999; Palviainen et al., 2004). In an evaluation of Norway spruce (*Picea abies* (L.) Karst) productivity 31 years after planting, Egnell (2011) found that removal of logging residues negatively affected tree growth. However, this response occurred only 8–12 years post-planting, most likely due to a nutrient effect, thereby emphasising the importance of a nutrient effect later rather than earlier during stand establishment. Logging residues can increase light and water availability very rapidly after harvest through a reduction of competing vegetation, by reducing available microsites, or limiting light penetration (Stevens and Hornung, 1990). Control of competing vegetation through the application of logging residues could diversify the tools that are available to foresters, considering that mechanical site preparation is partly aimed at controlling competing vegetation, that herbicides have been banned for use on Quebec forest lands (Thiffault and Roy, 2011), and that European countries are experiencing a similar trend (Willoughby et al., 2009). Logging residues also can immediately affect soil water through their influence on two processes: (1) a shelter effect, which limits evaporation from the soil but intercepts precipitation; and (2) a decrease in vegetation cover, which reduces total plant uptake of water (Roberts et al., 2005). Finally, logging residues quickly limit seasonal fluctuations in soil temperatures, and decrease mean temperatures over summer (Zabowski et al., 2000; Roberts et al., 2005; Harrington et al., 2013) while increasing them over winter (Proe et al., 2001). Proe and Dutch (1994) and Fleming et al. (1998) have suggested that during the first few years following the harvest of logging residues, vegetation cover and microclimate are the main drivers affecting seedling growth, while a nutritional effect drives physiological responses of trees much later in the rotation, when the canopy cover has ameliorated microclimatic extremes and nutrient requirements of trees have increased.

The objectives of this study were to quantify the effects of increasing loads of logging residues on planting microsites one year after planting and on the subsequent growth of seedlings over the first three growing seasons. We compared tree-level effects of four loads of logging residues on microclimate, competition from weedy vegetation, and soil nutrients, across a range of sites in the commercial forest land base of Quebec (Canada), which covers both boreal and temperate deciduous forest biomes. We hypothesised that logging residues would decrease soil temperature, increase soil moisture, hamper the emergence of competing vegetation, and increase planted tree growth, and that the effects would be proportional to residue load. Because of the short timespan of the study, we anticipated no effect of residues on soil nutrients.

2. Materials and methods

2.1. Study sites

Four sites were selected that represented a range of contrasting soil characteristics and bioclimatic conditions across Quebec (Table 1). In the Bouchette, Kamouraska and Weedon sites, mature stands were clear-cut by whole-tree harvesting before leaf fall in 2009, with logging residues (i.e., tree tops and branches of felled trees) being piled at the roadside and mechanical preparation being undertaken in autumn 2009. At Duparquet, the previous forest stand was clear-cut by stem-only harvesting in 2009; trees were felled, bucked and delimbed at the stump and residues were windrowed on the clear-cut site. Different site preparation techniques were used at each site prior to planting, and represented the operational techniques that were commonly used in these regions. Therefore, effects of mechanical preparation techniques are confounded with within-site effects, viz., harrowing at Bouchette, shearing using a V-blade at Kamouraska, mounding at Weedon, and no site preparation at Duparquet, where the forest floor was left intact on top of the mineral soil. Planting on all sites was carried out in spring 2010.

Soil pits were dug in two to six randomly selected locations per site to perform complete descriptions of their soil profiles. B-horizon samples were collected, air-dried, and sieved to pass a 2-mm mesh, after which soil texture was determined by hydrometer (Canadian Society of Soil Science, 2008; Table 1). Soil pH was determined on distilled water (Table 1) (Pansu and Gautheyrou, 2006). Soil organic carbon, total nitrogen, and sulphur were determined on an elemental analyser by dry combustion at 1350 °C, followed by thermo-conductometric detection of N, and infrared detection of C and S (CNS-2000, LECO Corporation, St. Joseph, MI, USA). Fe- and Al-organic complexes were extracted with Na-pyrophosphate and analysed by inductively coupled plasma optical emission spectrometry (ICP-OES) (Optima 7300 DV, PerkinElmer, Waltham, MA, USA) to confirm the soil subgroups (Table 1) (Soil Classification Working Group, 1998).

2.2. Experimental design

A factorial design of three planted species and four residue loads was replicated in each site. Hybrid poplars (*Populus* spp.) and black spruce (*Picea mariana* (Mill.) BSP) were planted on all sites. The third species that was planted was jack pine (*Pinus banksiana* Lamb.) at Duparquet and Bouchette, and white spruce (*Picea glauca* (Moench) Voss) at Weedon and Kamouraska. We chose these species to represent a gradient of ecophysiological requirements, where hybrid poplar grows quickly, is nutrient-demanding and shade-intolerant (Stettler et al., 1996), and black spruce tolerates shade and poor soil conditions; white spruce and jack pine are intermediate species with respect to their light and nutrient requirements (Nienstaedt and Zasada, 1990; Rudolph and Laidly, 1990; Viereck and Johnston, 1990). All conifer species were one-year-old containerised seedlings. Hybrid poplar clones were selected based on availability and recommendations that were provided by provincial guidelines: dormant bare root stock of *Populus maximowiczii* A. Henry × *Populus balsamifera* L. (clone 915319) at Duparquet and Bouchette; bare root stock of *Populus* × *canadensis* Moench [*deltoides* Marshall × *nigra* L.] × *P. maximowiczii* (clone 915508) at Weedon; and cuttings of *P. maximowiczii* × *P. balsamifera* (clone 915308) at Kamouraska. Plots were defined at the tree-scale, i.e., 9 m^2 around the planted trees, with a minimum buffer of 3 m between plots. Squared plots were used, except at Weedon, where the mounding site preparation technique forced us to use circular plots of the same area. Only one hybrid poplar was planted in each plot, while conifer plots had two trees, which allowed for destructive sampling in subsequent years.

Logging residue loads were defined based on previous stand characteristics. To estimate stand basal area prior to harvest, we used the production tables of Pothier and Savard (1998), given the species that were being harvested, the site index, and stand density. We computed an average mass of branches per hectare that was expected from these forest stands, using the aboveground biomass equations of Lambert et al. (2005). The corresponding load of residues for 9 m^2 was then estimated, with this mass being designated as a 'single load'. Based on these calculations, four residue loads were defined as: Control (no residues); Half load; Single load; and Double load. Consequently, the three residue treatment levels (on 9 m^2) were 20 kg, 40 kg and 80 kg,