Effects of Foliar Urea Fertilization on Nitrogen Concentrations of Containerized 2+0 Jack Pine Seedlings Produced in Forest Nurseries

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Abstract

A 7-day study of urea foliar fertilization was performed during the growing season (July) of containerized 2+0 jack pine (*Pinus banksiana* Lamb.) to evaluate if an application of either urea (U) or urea with surfactant (US) can rapidly increase foliar nitrogen (N) concentration relative to no fertilization control (NF) treatments. Adding a surfactant to the urea solution significantly improved N concentration in needles, stems, and entire seedlings. At day 0 (2 hours after fertilization), foliar N concentration of US-fertilized seedlings was already significantly greater than that of seedlings in the U and NF treatments by 10 and 11 percent, respectively. After 7 days, foliar N concentration of US seedlings (2.03 percent) continued to be significantly greater than that of seedlings in the U and NF treatments (1.80 and 1.67 percent, respectively). These results show that foliar urea application, especially with addition of a surfactant, along the growing season is an effective tool to rapidly increase the foliar N concentration of jack pine seedlings.

Introduction

In 2015, 94 percent of the 133 million seedlings produced in Québec's (Canada) 19 forest nurseries were containerized seedlings and among them, 24.3 million (18 percent) were jack pine (*Pinus banksiana* Lamb.) seedlings (Arseneault 2015). In Québec nurseries, containerized conifer seedlings must not only meet morphological quality criteria (e.g., height, diameter, height/diameter), they must also have a minimum foliar nitrogen (N) concentration before delivery for outplanting: 1.6 percent for seedlings grown in cavities with volumes smaller than 200 cm^3 (12 in^3) and 1.8 percent for those produced in cavity volumes equal to or larger than 200 cm^3 (Veilleux et al. 2014). These seedlings are fertilized weekly during the season to satisfy their N, phosphorous (P), and potassium (K) requirements for growth by using the nutritional approach utilized in Québec nurseries (Langlois and Gagnon 1993). In complement to weekly NPK fertilizations in forest nurseries, foliar N fertilization of conifer seedlings grown in containers could be used during the growing season for rapidly increasing their foliar N concentration to the minimum N target. Foliar N applications can also be used to provide a quick "green-up" of seedlings before shipping to planting sites (Landis et al. 1989, Dumroese 2003).

Numerous foliar N fertilization studies have been conducted in agriculture and horticulture over the last 50 years (Handreck and Black 1984, Swietlik and Faust 1984, Alexander and Schroeder 1987, Gooding and Davies 1992, Wojcik 2004). In forest tree nurseries, however, only a few studies have been carried out with conifer seedlings grown in containers (Coker et al. 1987, Montville and Wenny 1990, Coker 1991, Montville et al. 1996, Gagnon 2011, Gagnon and DeBlois 2014). This lack of research may be explained by the small absorptive surface of conifer needles in comparison with hardwood leaves and by the waxy cuticular surface of needles, which slows nutrient absorption (Landis et al. 1989, 2010; Marschner 1995, Mengel and Kirkby 2001, Lamhamedi et al. 2003).

In order to ensure nutrient diffusion across the cuticle, a surfactant is often used with foliar fertilization because the hydropobic nature of the cuticle impedes the diffusion of hydrophylic ions (Mengel and Kirkby 2001). By reducing the surface tension of water droplets, the surfactant permits a thin layer to adhere to the needle surface, thus improving nutrient absorption (Wittwer and Teubner 1959, Wittwer et al. 1963, Landis et al. 1989, Mengel and Kirkby 2001, Wojcik 2004).

In studies of foliar N fertilization conducted in agriculture and horticulture since the 1960s (Wittwer et al. 1963, Handreck and Black 1984, Swietlik and Faust 1984, Alexander and Schroeder 1987, Gooding and Davies 1992, Mengel and Kirkby 2001, Wojcik 2004), urea [$CO(NH_2)_2$]) was much more utilized than ammonium (NH_4^+) or nitrate (NO_3^-) due to its high solubility in water and oil, low-phytotoxicity potential, and nonpolarity relative to the other two N sources. Indeed, being a neutral molecule, urea is absorbed more quickly by needles than either NH_4^+ or NO_3^- because it rapidly diffuses through the waxy cuticule. Coker et al. (1987) showed that after a foliar application of these three N sources on containerized Monterey pine (*Pinus radiata* D. Don.), urea was absorbed 3 and 10 times more rapidly than NH_4^+ and NO_3^-, respectively. Urea was used with success to rapidly increase (7 days) foliar N concentration of containerized 2+0 black spruce (*Picea mariana* [Mill.] B.S.P.) after fall budset (Gagnon and DeBlois 2014).

The objectives of this study were to evaluate: (1) the effects of one foliar application of urea during the growing season on N concentration in needles of containerized 2+0 jack pine seedlings, and (2) the impact of adding a surfactant to the urea solution on the efficiency of urea foliar fertilization.

Materials and Methods

Seedlings

Large 2+0 jack pine seedlings (seedlot: PIG-V1-PAR-2-2) grown in 25-310 containers (25 cavities with a volume of 310 cm^3 [19 in^3] each, IPL 25-310, Saint-Damien, Québec, Canada) were used for this study. Seedlings were produced at Normandin nursery, a governmental forest nursery (ministère des Forêts, de la Faune et des Parcs, MFFP du Québec) located in the Saguenay-Lac St. Jean region of Québec (48°48’48” N, 72°45’00” W), Canada. Cultural practices of containerized 1+0 and 2+0 seedlings grown in Quebec forest nurseries are summarized in Gagnon and DeBlois (2014).

Seedlings were fertilized biweekly from May 8 to October 2 according to the seedlings’ weekly nutritional needs (Langlois and Gagnon 1993) determined by Plantec 2 software, a new version of PLANTEC (Girard et al. 2001). Fertilization totalled 170 mg (0.0057 oz) N (40 percent NH_4^+, 42 percent NO_3^-, and 18 percent urea), 17 mg (0.0006 oz) P, and 37 mg (0.0012 oz) K. The seedlings also received small amounts of calcium and magnesium as well as micronutrients present in commercial soluble fertilizers. No fertilizer was applied between June 22 and the foliar fertilization treatments of July 7. Irrigation was managed using IRREC irrigation software (Girard et al. 2011).

Foliar Fertilization Treatments

A completely randomized block design with three treatments of foliar urea fertilization and eight blocks was installed on July 6, 2015. A total of 432 containers (54 per block x 8 blocks) received 1 of the 3 treatments of foliar urea (46-0-0) fertilization on day 0 (July 7): (1) urea (U), (2) urea + surfactant (US), or (3) no fertilization (NF: control).

For each urea treatment, 4.1 kg (9.1 lb) of 46-0-0 was mixed in 55 L (14.6 gal) of water, producing a solution with a concentration of 74.3 g urea per L [0.6 lb per gal]. For the US treatment, the surfactant used was Sylgard 309 (Norac Concepts Inc. 2009, Guelph, Ontario, Canada). This nonionic, silicon surfactant was mixed with the urea solution at a rate of 2.5 ml per L (0.28 oz per gal). Because the addition of Sylgard 309 to urea solution leads to foam formation, Fighter-F® 12.5 antifoaming/defoaming agent (Loveland Products, Inc., Greeley, CO) was added at a rate of 15 ml (0.51 oz) to the 55-L (14.6-gal) mix of urea and surfactant.

The U and US treatments were applied at a rate of 937 L per ha (102 gal per ac) using a tractor-mounted boom sprayer (Model 695 XL, Case International Inc., Vars, Ontario, Canada) with a 1100-L (292-gal) reservoir and 2 rails of 12-nozzle irrigation (Model Teejet XR 11004, TeeJet Technologies, Spraying Systems Co., Wheaton, IL) (figure 1). This application rate resulted in application of 15 mg (0.0005 oz) N per seedling or 31 kg N per ha (28 lb per ac), corresponding to a dose of 33 mg (0.0011 oz) urea per seedling or 68 kg per ha [60 lb per ac].

At the time of fertilization (9 h), air temperature was 24 ºC (75 ºF) and relative humidity was 48 percent. No irrigation to rinse the foliage was applied either following foliar urea fertilization or during the 7-day study.

Figure 1. Foliar fertilization treatments with a urea solution were applied using tractor-mounted booms to 2+0 jack pine seedlings grown in 25-310 containers at Normandin nursery. (Photo by Jean Gagnon, 2015)

Seedling and Substrate Measurements

Immediately after application of the fertilization treatments (day 0: July 7) and at day 7 (July 14), a total of 72 seedlings per treatment and their root plugs (9 seedlings randomly selected in each of the 8 blocks) was harvested to assess seedling morphology (height, root-collar diameter, shoot, root, and total dry mass), total N concentration (Ntot) in tissues, and mineral N and urea concentrations in the substrate. Tissue and substrate analyses were performed by the laboratoire de chimie organique et inorganique (ISO/CEI 17025) de la Direction de la recherche forestière [DRF], MFFP du Québec. Additionally, foliar color and burning damage were assessed visually during the 7-day study.

Before the analysis of total N concentration (Ntot), seedling shoots of 3 treatments were washed for 15 seconds using a sink-mounted vegetable sprayer to remove urea residues from the needle surface. After washing, shoot and root tissues of all treatments were oven-dried for 48 hr at 65 °C (149 °F). Seedling tissues were placed in the oven 2 hours (day 0) or 7 days (day 7) after foliar urea fertilization. Seedling needle, stem, and root samples (n = 8 composite samples of 3 seedlings per block per treatment) were analyzed for Ntot using a LECO Nitrogen Determinator (model TruMac N, LECO Corporation, St. Joseph, MI). Substrate N was extracted by vacuum filtration (Whatman filters # 4) after saturating in water for 90 minutes. Urea was determined by liquid chromatography (HPLC Agilent-1200 chromatograph with diode array detector) using a Sugar-Pak I column from Waters. Mineral N (ammonium, nitrate + nitrite) was determined by colorimetry with a continuous flow spectrophotometer (model QuickChem 8000, Lachat Instruments, Milwaukee, WI).

Statistical Analyses

First, a linear mixed-effects model with repeated measurements was carried out to determine the effects, over time, of three foliar urea fertilization treatments using a variance-covariance matrix to account for the correlation between measurements done on the same experimental units. This matrix was chosen to minimize the likelihood value of the model while using as few parameters as possible. Thus, for N concentrations in needles, stems, shoots, and seedlings, the selected variance-covariance matrix was compound symmetry, whereas it was heterogeneous compound symmetry for N concentrations in roots.

Fertilization treatments, sampling days, and their interaction were introduced in the model as fixed-effect factors, whereas the replicates of fertilization treatments were considered as a random-effect factors. Because the interaction between the fertilization treatments and sampling days was significant for all variables, comparisons between the fertilization treatments were performed for each date.

All the statistical analyses were performed using the MIXED procedure of SAS (version 9.4, SAS Institute, Cary, NC, United States). When required, a simulation-based approach taking account of multiplicity was used to assess differences (Westfall et al. 1999). Normality of the residuals was confirmed using the Shapiro-Wilk's statistic and homogeneity of variance was validated using standard graphical methods. Differences were deemed significant when $\alpha < 0.05$.

Results

Seedling morphology (± standard error: SE) averaged among all treatments at day 7 was: height, 21.2 ± 0.8 cm (8.5 in); diameter, 3.1 ± 0.1 mm (0.1 in), shoot dry mass, 2.02 ± 0.09 g (0.07 oz); root dry mass, 0.71 ± 0.04 g (0.02 oz); and total dry mass, 2.73 ± 0.13 g (0.09 oz). The average substrate N concentration after 7 days was 0.8 ppm mineral N and 0.1 ppm urea-N.

For foliar N concentration, the interaction between fertilization treatments and days was significant (p = 0.0391). At day 0 (2 hours after fertilization) and day 7, foliar N concentration of US-fertilized jack pine seedlings was significantly greater than that of seedlings in the U and NF treatments (figure 2a). Foliar N concentration of US seedlings was 10 and 11 percent higher than U and NF seedlings after only 2 hours (day 0), respectively. After 7 days, foliar N concentration in US-fertilized seedlings continued to be significantly greater than that of seedlings in the U and NF treatments (figure 2a). Foliar N concentrations of U and US seedlings at day 7 were 8 and 22 percent, respectively, higher than that of NF seedlings (figure 2a). During the 7-day study, no burning damage from U or US treatments was observed.

The interaction between fertilization treatments and days was also significant for N concentrations in stems (p = 0.0391), roots (p = 0.0321), and whole seedlings (p = 0.0218) (figure 2). At day 0, stem (figure 2b) and

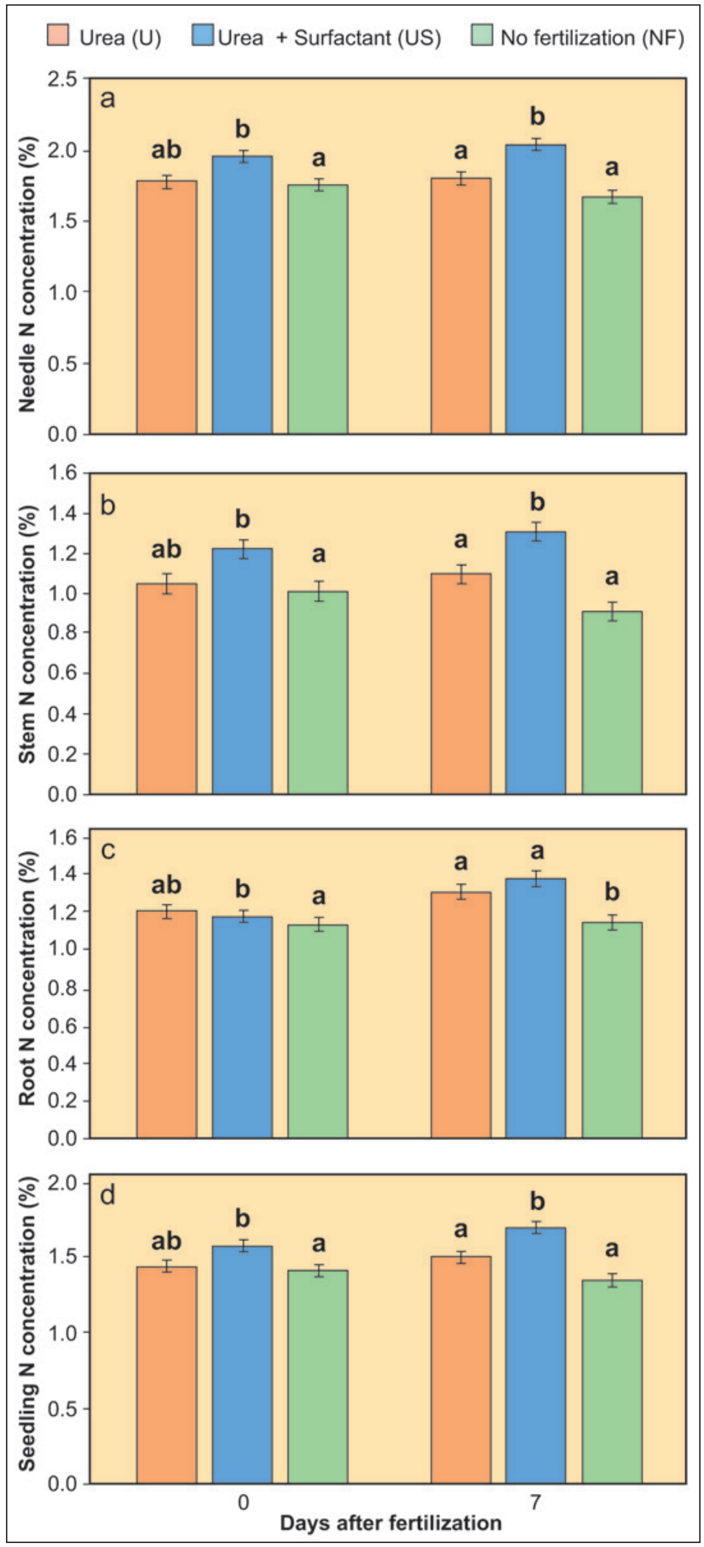

Figure 2. (a) Needle, (b) stem, (c) root, and (d) whole-seedling nitrogen concentration (percent) of 2+0 containerized jack pine seedlings 0 and 7 days after urea foliar fertilization. For each day, bars with different letters differ significantly at $\alpha \leq 0.05$ (n = 8 composites samples ± SE).

seedling (figure 2d) N concentrations of US seedlings were significantly higher compared with those in the NF treatment. After 7 days, stem and seedling N concentrations of US-treated seedlings were significantly greater than that of both U and NF treatments. At day 7, compared to NF seedlings, stem N concentration of U and US seedlings was 21 and 44 percent higher, respectively, and seedling N concentration was 12 and 26 percent higher, respectively (figures 2b and 2d). At day 0, root N concentration did not differ significantly among the 3 fertilization treatments (figure 2c). After 7 days, root N concentration of U seedlings was not significantly different than that of US seedlings, but these 2 treatments (U, US) were significantly greater than NF treatment.

Discussion

This 7-day study showed that foliar fertilization with a urea and surfactant mixture during the growing season of containerized 2+0 jack pine seedlings resulted in a significant increase in foliar, stem, and seedling N concentration under forest nursery conditions, compared with control seedlings and those fertilized without the surfactant. This rapid increase of foliar N concentration observed after only 2 hours (day 0) led also to a rapid increase of N concentration in stem and the whole seedling, indicating that the foliar N increase is a result of uptake, not by urea residues on the needle surfaces. To prevent this possibility, seedling shoots were washed before the analysis of N. Our previous 7-day study of foliar urea fertilization of black spruce seedlings showed that washing treatments significantly reduced foliar N concentration compared with those that were not washed (Gagnon and DeBlois 2014). We always recommend washing seedling shoots prior to nutrient analyses to remove fertilizer residues.

Rapid urea absorption and increased N concentration after foliar fertilization was also found in our previous experiment with containerized 2+0 black spruce seedlings (Gagnon and DeBlois 2014). Similarly, in studies with Monterey pine seedlings (Coker et al. 1987, Coker 1991) or apple (*Malus domestica* Borkh) trees (Dong et al. 2002), all or most foliar-applied ^{15}N urea was taken up within 6 hours or 2 days, respectively. A rapid increase of foliar N concentration after foliar urea fertilization has also been observed in agriculture and horticulture studies (Handreck and Black 1984, Swietlik and Faust 1984, Alexander and Schroeder 1987, Gooding and Davies 1992, Wojcik 2004).

According to Mengel and Kirkby (2001), the recommended concentration of urea solution for foliar fertilization to avoid leaf burning is 20 to 50 g per L (0.2 to 0.4 lb per gal). In the present study and a previous one with black spruce seedlings (Gagnon 2011), we did not observe any burning damage with urea solution concentrations of 74 g per L (0.6 lb per gal) and 80 g per L (0.7 lb per gal), respectively. Likewise, no foliar damage was observed on black spruce seedlings with a much higher concentration of urea solution of 146 g per L (1.2 lb per gal) (Gagnon and DeBlois 2014).

The efficiency of foliar urea fertilization is often improved by using surfactants (Swietlik and Faust 1984, Alexander and Schroeder 1987, Gooding and Davies 1992, Wojcik 2004). In our previous 7-day study with containerized 2+0 black spruce seedlings (Gagnon and DeBlois 2014), adding a surfactant (Agral 90) to the urea solution did not significantly increase foliar N concentration. In the present experiment, however, adding a surfactant (Sylgard 309) to the urea fertilizer significantly improved N concentration of containerized 2+0 jack pine seedlings.

In Québec forest nurseries, containerized conifer seedlings receive weekly NPK fertilizers during the season to satisfy their growth needs and to meet their minimum N targets. Growers try to produce seedlings that meet adequate foliar N concentrations throughout the growing season so that there is no need for a last-minute rapid increase. But, if the target is not reached due to varying circumstances (rapid growth, incorrect estimates of nutrient status/needs, rainfall causing N leaching, etc.), foliar urea fertilization in addition to the weekly NPK fertilizers would then be useful to increase foliar N concentration to the minimum target. The results of this 7-day study showed that foliar urea fertilization is a potential tool for rapidly increasing the foliar N concentration of containerized conifer seedlings to help Québec growers meet the physiological quality criteria of 1.8 percent N concentration for large conifer seedlings.

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Acknowledgments

The authors thank Michelle Simard of Normandin nursery for her technical assistance in this study and the staff of the nursery for their collaboration in seedling measurements. They acknowledge the staff of the laboratoire de chimie organique et inorganique (ISO/CEI 17025) de la Direction de la recherche forestière (DRF) of the Ministère des Forêts, de la Faune et des Parcs (MFFP) who performed analyses of tissue and substrate. They also thank Michel Campagna (DRF) for the revision of this article. They acknowledge Maripierre Jalbert (DRF) for the final edition of the figures. The authors thank Diane Haase (editor of Tree Planters' Notes) for her suggestions and editorial comments. Financial support for this research project was provided to Jean Gagnon by the MFFP (project: 142332084).

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