RESPONSE OF PONDEROSA PINE TO CONTROLLED-RELEASE FERTILIZERS

A Dissertation
Presented in Partial Fulfillment of the Requirements for the
Degree of Doctor of Philosophy
with a
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ABSTRACT

Prior to sowing seeds, three controlled-release fertilizers (fast release (FR), moderate release (MR) and slow release (SR)) were incorporated into the growing media at rates of 0.8, 1.6 or 3.2 grams per seedling as supplements to nursery supplied soluble fertilizer. Effects on seedling caliper and height growth, biomass allocation, nutrient status and root growth potential of the "160/90" container ponderosa pine (*Pinus ponderosa Doug. ex Laws*) both in the greenhouse and after planting were evaluated. At lifting (December 1 of 1996), the caliper, height and total dry weight of fertilized seedlings ranged from 3.2 to 3.6 mm, 15.8 to 17.9 cm and 2.6 to 3.9 grams, respectively, compared to the 2.8 mm, 14.8 cm and 2.0 grams of unfertilized seedlings. The 3.2 grams of MR or SR fertilizer treatments produced foliar N, Mg, B, Fe and Cu deficiency patterns and decreased ponderosa pine seedling root growth potential. Two years after planting, fertilization significantly increased seedling caliper, height, total and component biomass, but did not change component dry weight ratios and shoot/root ratios. The 3.2 grams of MR or SR fertilizer treatments produced significantly higher mortality (55 and 36 % respectively) than the controls. The mortality was strongly correlated with root growth potential. The best dosage for caliper and height growth was 2.0 and 1.9 grams per seedling for FR fertilizer, 1.8 and 2.0 grams per seedling for MR fertilizer and 1.8 and 2.1 grams per seeding for SR fertilizer, respectively.

In another experiment, four controlled-release fertilizers (fast release (FR), moderate release (MR), slow release (SR) and slow-release with micro-nutrient extended (ME)) were applied at rates of 5, 15 and 30 grams per seedling respectively, into a hole 6 inches deep and 3 inches apart from the planting point of the "160/90" ponderosa pine seedlings on the up-hill side immediately after planting. No significant caliper and height growth was found after three growing seasons. Insufficient nutrient supply resulted in continuous decrease of foliar N and P concentrations and foliar B, Cu and Fe deficiency and subsequently non-significant growth response at the experimental site.

Introduction

Fertilizing planted seedlings at or near the time of planting to enhance seedling growth and survival is an increasingly common practice. Fertilization experiments have shown that application of soluble inorganic fertilizers in new plantations generally results in increased growth (Ballard 1978). However, some fertilization experiments in conifer plantations also showed that soluble fertilizers increase mortality rates and do not improve early growth (White 1960, Sutton 1982). Increased mortality is primarily a consequence of the osmotic effect of high salt concentrations in the rooting zone. Non-significant seedling response to soluble fertilizers seemed related to the inability of root systems of newly planted seedlings to use large quantities of applied nutrients, and nutrient uptake by competing vegetation as well as the movement of the applied nutrients through the upper soil profile (Brockley 1988).

Controlled release or organic fertilizers were used in some fertilization experiments (Arnott and Brett 1973) in order to overcome disadvantages of soluble inorganic fertilizers such as stimulating weed growth, leaching, volatilization and toxicity. Each controlled release fertilizer is characterized by different nutrient formulations and release characteristics. Nutrient release rates from controlled release fertilizers is determined predominately by the thickness and /or solubility characteristics of the coating materials and is temperature dependent. Tree growth response to controlled release fertilizers varies with nutrient formulations, release characteristics, application rates, and placement methods. For example, Carlson and Preisig (1981) reported that Osmocote produced greater shoot and root growth response for coastal Douglas-fir (*Psedutesuga menziesii (mirb.) Franco.*) seedlings compared to Agriform. In their trials, nitrogen application rate and /or placement methods appeared not to contribute to the superiority of Osmocote because a small difference in seedling height was found when the products were broadcast at similar nitrogen application rates. Three placement methods have been commonly used when seedlings are fertilized at the time of planting: 1) planting hole application; 2) adjacent application (i.e., placement in a hole or slit beside the seedling); and 3) broadcast application (i.e., surface application of fertilizer around the base of the seedling) (Brockley 1988). A study undertaken in British Columbia showed that broadcast application of controlled release fertilizer increased the growth of Douglas-fir seedlings significantly more than placement in a hole 15 cm from the tree. Another study on placement methods using sulphur-coated urea (36-0-0-17), Osmocote (17-7-12), and Agriform (21-10-5) also found that broadcast application generally resulted in larger growth response of interior spruce seedlings than adjacent placement, particularly with Agriform. In the same study, placement of fertilizer in the planting hole had a detrimental effect on survival (Brockley 1988). However, studies in Japan demonstrated that in-hole application of 360-day release Nutricote and isobutylidene diurea (IBDU) briquets to Japanese cypress (Chamaecyparis obtusa Endl.) was a reliable method of fertilizing newly planted seedlings and seedling height growth was increased without increasing mortality (Brockley 1988). One problem with broadcast application of fertilizer is the possibility of stimulating the growth of competing vegetation compared with either in-hole or adjacent placements. In New Zealand, all fertilizers applied at planting are placed in a slit approximately 15 cm from the seedling to stimulate tree growth and simultaneously avoid vegetation competition (Ballard 1978). The success of fertilization with controlled release fertilizers depends on factors such as nutrient formulations, release characteristics, application rates, placement methods and their interaction with stock type, climate and soil. Treatment effects have been measured in terms of tree growth, mortality, nutrient loss, weed competition, economical and environmental feasibility. Extensive field tests of seedling fertilization with controlled release fertilizer are needed before appropriate prescriptions can be developed (Brockley 1988).

In 1996, a fertilization experiment using four controlled release fertilizers of various release characteristics and nutrient formulations (Table 1) was established in a new container grown ponderosa pine plantation on the University of Idaho Experimental Forest. The major objective of this study was to test the effects of various application rates of four fertilizer products applied using a dibble bar (adjacent placement) on ponderosa pine seedling survival, growth and foliar nutrient concentration. A secondary objective was to determine the release characteristics of the fertilizer products under the environmental conditions at the experimental site.

Table 1. Percent by weight of macromutrients and micronutrients provided by four controlled release fertilizers used in the ponderosa pine seedling experiment.

Nutrient	Controlled-release fertilizer			
	Fast release (FR)	Moderate release (MR)	Slow release (SR)	Slow-release with micronutrients extended (ME)
N	15	16	15	14
P (P_2O_5)	10	8	8	7
K (K_2O)	12	12	11	10
Ca	1.5	1.5	1.5	1.5
Mg	1	1	1	1
B	0.02	0.02	0.02	0.02
Cu	0.05	0.05	0.05	0.05
Zn	0.05	0.05	0.05	0.05
Fe	0.4	0.4	0.4	0.4
Mn	0.1	0.1	0.1	0.1
Mo	0.001	0.001	0.001	0.001

Materials and Methods

Trial description

West Hatter Creek Unit: 41N 04W S33

The experiment was located in Latah county in northern Idaho at 46° 51′ N and 116°50′ W. The elevation is 950 m, the Vassar Silt Loam soil is 1.5 m deep. The habitat type is *Abies grandis/Clitonia uniflora* (Daubenmire and Daubenmire 1968). A maritime climate moderates the extremes in temperature often associated with the Northern Rocky Mountains. In winter, the average temperature is 0 °C, and the average daily minimum temperature is –4 °C. In summer, the average temperature is 17 °C, and the average daily maximum temperature is 27 °C. Located just out of the rain shadow of the Cascade Mountains, the summers begin moist and gradually turn dry by mid-July and continue mostly without appreciable rain through mid-September. October has an increasing chance of rainfall. As autumn progresses into winter, the precipitation increases dramatically falling as either snow or rain. The total annual precipitation is 763 mm. Of this, 267 mm, or 35 percent, usually falls in April through September (Osborne and Appelgren 1996). The study site consisting of a mixed mature conifer stand dominated by grand fir (*Abies grandis*) was clearcut in 1995 and the slash burned in the spring of 1996

Experimental design and treatments

A randomized complete block design was used with six blocks per treatment on the 1.05-acre experimental site. Each block includes thirteen square plots of size 8 by 8 m, in which 6 by 6 (36) trees were planted at 1.3 by 1.3 m spacing. All ponderosa pine seedlings (160/90 stock type) planted for this study were raised the previous year (1996) at the University of Idaho Forest Research Nursery. Seedlings were stored at 0.5 °C, with relative humidity near 100 percent for 5 months (from December of the previous year to April) before outplanting. All seedlings were planted between May 22nd and 24th, 1996. Twelve fertilization treatments, that is, 5, 15 and 30 grams of four kinds of controlled release fertilizers (Table 1), and one control (no controlled release fertilizer applied) were randomly assigned to one of the thirteen square plots. Fertilizers were applied into a hole 6 inches deep and 3 inches away from the planting point on the up-hill side immediately after outplanting. To monitor fertilizer release rate, fifteen grams of the four fertilizer products were placed into 25 by 5 cm fiberglass bags. The bags were labeled and randomly placed into 6-inch deep slots in the middle of four sides of each plot. Six bags from each fertilizer product were collected every two months for two years and sent to Scotts Laboratories for analysis of nutrient release. In total, sixty bags for each fertilizer type were placed into the soil at the experimental site.

Field sampling and measurements

The response variables of interest were caliper (diameter at the root collar), height, survival and foliage nutrient concentrations. Seedling height and caliper were measured at planting and in late October of the 1996, 1997 and 1998 growing seasons. Relative caliper and height growth rates (RGR) were calculated for every plot by:

$$RGR= \ln Y2-\ln Y1 /(T2-T1) \qquad (1)$$

Where Y1 and Y2 are the seedling's average caliper or height for each plot at time T1 (year1) and T2 (year 2). Survival was surveyed bi-weekly throughout the first growing season (1996) and was calculated for each plot as the percentage of living seedlings compared to the total number of planted seedlings. At the end of each growing season, three fascicles of needles located nearest the top bud were removed from each interior seedling of a plot. Needles were oven-dried at 70°C for 2 days and ground for chemical analysis. We analyzed the following nutrients: N, P, K, Ca, Mg, B, Cu, Zn, Fe, Mn and Mo, all of which were included in the controlled-release fertilizers products. Foliar N was determined using a standard mico-Kjeldahl procedure. Phosphorus, K, Ca, Mg, Mn, Fe, Cu and Zn were determined by inductively coupled plasma (ICP) emission with digested plant tissue. Both procedures were completed by Scotts Laboratories in Allentown, PA (Shaw and Moore 1999). Soil moisture and temperature at 10, 20 and 40 cm depths at six points distributed uniformly across the trial were also monitored bi-weekly throughout the first growing season to evaluate their potential impacts on seedling growth and mortality. In November of 1998, nine plots were selected systematically as sampling points for soil chemical analysis. In each plot, four 30cm deep soil cores, one from each quadrant were taken and composited for soil pH, NO_3^--N, available P, Mn, Cu, Zn, Fe and exchangeable K, Ca and Mg analyses. Soil pH was measured 1:1 in H_2O. Nitrate was extracted with calcium oxide and was determined using automated colorimetry. Exchangeable K, Ca and Mg (1 N ammonium acetate, pH 3.0) were analyzed by ICP spetrometry. Available P was determined on a 2-g sub-sample of soil extracted with 12 mL of Bray's solution (Bray and Kurtz 1945). Available Mn, Zn, Cu and Fe were analyzed by atomic absorption.

Data analysis

For growth response analysis, the average caliper and height as well as the relative growth rates of the sixteen interior seedlings from each plot were used for detecting fertilization effects. Dunnett's multiple comparison test (Kirk 1995) was conducted to detect the differences in survival, caliper and height means and growth rates between the twelve fertilization treatments and the control. With respect to the twelve fertilization treatments (four fertilizer types by three application rates), both multivariate and univariate classification analysis of variance were conducted on caliper and height growth and foliar nutrient concentrations respectively to test the effects of fertilizer type and fertilizer application rate as well as their interaction on caliper and height growth and foliar nutrient concentrations of ponderosa pine seedlings. Regression of first-year caliper versus fertilization application rate was performed using a parabolic model of the form:

$$Y=a_0 + a_1 X + a_2 X^2 + \varepsilon \qquad (2)$$

Where Y is seedling first-year caliper, X is the fertilizer application rate, a_0, a_1 and a_2 are the regression parameters and ε is the random error which for the purpose of statistical inferences is assumed to be distributed normally with mean 0 and a common variance. The estimated application rate associated with maximum caliper and height was calculated via differentiation:

$$\text{Application rate} = -\hat{a}_1/2\,\hat{a}_2 \qquad (3)$$

The statistical computations were performed using the General Linear Model (GLM) procedure of SAS ($SAS_{®}$ Institute Inc. 1995).

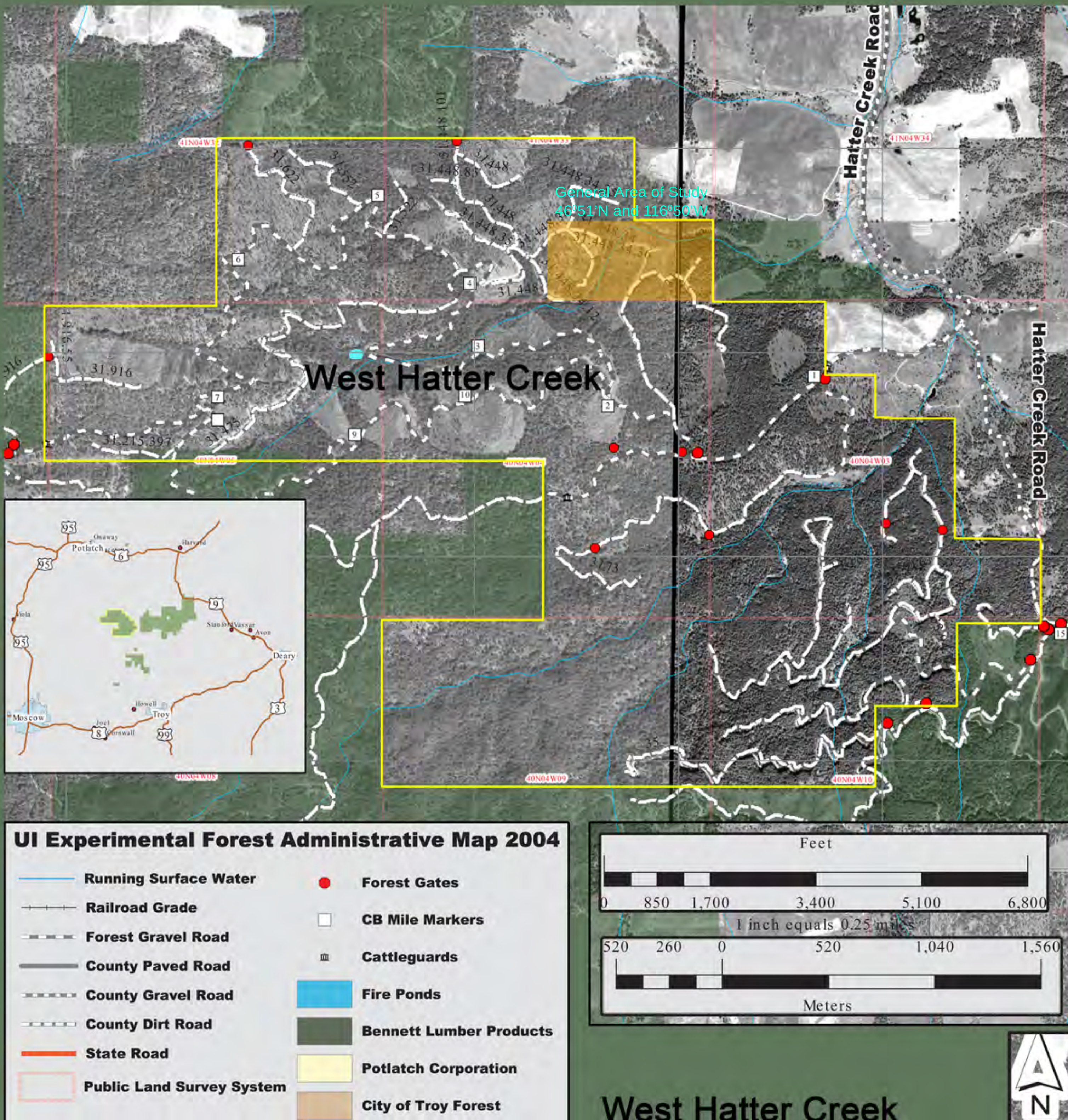
Results

Soil nutrient concentrations, moisture and temperature regimes

Measured soil chemical and physical properties, critical to tree growth are shown in Table 2 and Figure 1. Soil nitrate and Cu concentrations at the experimental site were very low. The experimental site experienced a very dry period from mid-July until late September. The soil moisture between 11-40 cm deep during this period was below 25%, which was disadvantageous for nutrient release and tree growth.

Table 2. Analysis of soil samples of 0-30 cm deep at the 1996 experimental site.

Attributes	Mean ±standard deviation	Coefficient of variation (%)
Cation exchangable capacity (CEC) (cmol/kg)	10.7 ± 1.1	10.1
PH	6.2 ± 0.4	7.0
NO_3^- -N(ppm)	3.0 ± 1.9	64.7
Available P(ppm)	54.9 ± 24.1	43.9
Exchangeable K (ppm)	150.1 ± 61.9	41.3
Exchangeable Ca (ppm)	1345.7 ± 251.0	18.7
Exchangeable Mg (ppm)	110.3 ± 19.8	18.0
Available Mn (ppm)	9.3 ± 3.9	42.0
Available Cu (ppm)	0.46 ± 0.13	28.3
Available Zn (ppm)	1.66 ± 0.37	22.3
Available Fe (ppm)	92.0 ± 40.8	44.3



Hatter Creek Road
General Area of Study
46º51'N and 116º50'W
West Hatter Creek
Hatter Creek Road
Onaway
Potlatch
Harvard
Viola
Stanford
Vassar
Avon
Deary
Moscow
Howell
Troy
Joel
Cornwall
UI Experimental Forest Administrative Map 2004
Running Surface Water
Railroad Grade
Forest Gravel Road
County Paved Road
County Gravel Road
County Dirt Road
State Road
Public Land Survey System
Forest Gates
CB Mile Markers
Cattleguards
Fire Ponds
Bennett Lumber Products
Potlatch Corporation
City of Troy Forest
Feet
0 850 1,700 3,400 5,100 6,800
1 inch equals 0.25 miles
520 260 0 520 1,040 1,560
Meters
N
West Hatter Creek

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