Effect of Root-Plug Incorporated Controlled-Release Fertilizer on Two-Year Growth and Survival of Planted Ponderosa Pine Seedlings

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ABSTRACT: *Three controlled-release fertilizers (fast release [FR], moderate release [MR], and slow release [SR]) were incorporated in the root plug at rates of 0.8, 1.6, or 3.2 g/seedling at the time of sowing as supplements to nursery supplied soluble fertilizer. Effects on seedling growth, survival, and foliar nutrient status of the "160/90" container ponderosa pine (*Pinus ponderosa*) were evaluated after outplanting. At the end of the second growing season, fertilized seedlings had significantly greater diameter and height than unfertilized seedlings. The 3.2 g of MR or SR fertilizer treatments produced significantly higher mortality (55 and 36%, respectively) than the controls. The fast release fertilizer included at a rate of 0.8 g in each seedling's container was the preferred treatment since it produced good survival and seedling growth response. A 2-yr growth response of about 25% was similar to that observed in a nearby study using adjacent placement of controlled-release fertilizer after planting ponderosa pine seedlings. West. J. Appl. For. 17(4):216–219.*

Key Words: Fertilizer, *Pinus ponderosa*, seedling growth.

Initial fertilizer toxicity and later deficiency in seedlings and most factors contributing to loss of efficiency in seedling fertilization are directly related to rapid dissolution and hydrolysis of the applied fertilizers. Controlled-release fertilizers may be considered as potential solutions to the problem, because they provide a continuous supply of nutrients over an extended period of time. Brockley (1988) discussed the potential for incorporating controlled-release fertilizers in the root plug of containerized seedlings for stimulating greenhouse and field growth performance and simplifying fertilizer operations. However, the reported results were not consistent. The release characteristics, relative nutrient proportions, and application rates of controlled-release fertilizers (Patel and Sharma 1977), and their interaction with stock type (Brockley 1988) have been identified as priorities for future research.

Our study's objective was to evaluate the effect of three controlled-release fertilizers and several application rates on ponderosa pine seedling survival and growth. We established a fertilization experiment with three controlled-release fertilizers characterized by various release rates and nutrient proportions incorporated in the root plugs of container-grown ponderosa pine seedlings. Seedlings were then planted on the University of Idaho Experimental Forest in April 1997. Specifically, the study addressed the following questions: (1) What are the differences in growth and survival between fertilized and unfertilized ponderosa pine seedlings? and (2) How are survival and growth affected by fertilizer types and dosage? Based on the answers to the questions above, we make recommendations on fertilizer products and dosages.

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Materials and Methods

Plant Materials, Controlled-Release Fertilizers, and Growing Environment

The Scotts Company provided the three types of controlled-release fertilizers (Table 1) tested in this study. Each type of three controlled-release fertilizers, corresponding to 0.8, 1.6, and 3.2 g/seedling application rates, was first fully mixed into the 50/50% peat-vermiculite growing media. The container cells were then hand filled with the mixture of growing media and fertilizers on February 24, 1996. No controlled-release products were incorporated in the growing media for the control treatments. The experiment included ten fertilizer treatments (three products × three rates and one control). Seedlings were grown at the University of Idaho Forest Research Nursery. The containers used for growing ponderosa pine seedlings were 160/90 (160 cavities/container, 90 cm^3/cavity). Ponderosa pine seeds, collected from natural stands in northern Idaho within the same seed transfer

Table 1. Percent by weight of nutrients provided by three controlled-release fertilizers used in the ponderosa pine experiment.

	Product		
Nutrient	Fast release (9 months)	Moderate release (12–14 months)	Slow release (16–20 months)
N	16	18	18
P	9	6	5
K	12	12	12
Ca	1.5	1.5	1.5
Mg	1	1	1
B	0.02	0.02	0.02
Cu	0.05	0.05	0.05
Zn	0.05	0.05	0.05
Fe	0.4	0.4	0.4
Mn	0.1	0.1	0.1
Mo	0.001	0.001	0.001

zone as the planting site, were sown at three seeds/cell with a vacuum seeder and covered with about 0.6 cm of Target Forestry Sand® on March 1. Once sowing was complete, the containers were irrigated until the media was thoroughly moist. Phosphoric acid was injected into the irrigation water to adjust pH to around 6.0. On the growing bed, containers were arranged according to a completely randomized design with four replicates (containers). The seed germination process was completed by March 22, and cells were then thinned to one seedling when most seedlings shed their seed coats. During the growth phase (from March to June), day temperatures of 24–27°C and night temperatures around 18°C were maintained. Photoperiod was extended to 24 hr in the greenhouse. In addition to the fertilization treatments, the regular nursery-based liquid fertilizer solution was also applied during twice-weekly irrigations through an overhead traveling boom system. Top dressing rates and nutrient compositions for the regular nursery regime were adjusted based on seedling growth phases. Wenny and Dumroese (1987) describe the growing regime for ponderosa pine in detail.

Seedlings were lifted, wrapped with plastic in bundles of 20, and placed into polylined wax boxes with treatment labels on December 1, and stored at 0.5°C, with relative humidity near 100% before planting in April of the next year.

Site Description

The experiment was located in Latah Co. in northern Idaho at 46°51′N and 116°50′W., elev. 950 m. The Vassar Silt Loam soil at the site is 1.5 m deep. The habitat type is *Abies grandis/Clitonia uniflora* (Daubenmire and Daubenmire 1968). 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, one-third usually falls in April through September (Osborne and Appelgren 1996). The study site was clearcut in 1995 and slash-burned in the spring of 1996.

Experimental Design and Treatments

A randomized complete block design was used on the 0.4 ha experimental site to study the effect of nursery-applied root-plug incorporated controlled-release fertilizers on growth and survival of ponderosa pine seedlings. The experiment consisted of 6 blocks. In each block, 36 ponderosa pine seedlings from each of the 10 greenhouse treatments were assigned randomly to a square plot of size 8 by 8m with trees planted at 1.3 by 1.3 m spacing. All seedlings were planted between April 20 and 22, 1997.

Field Sampling and Measurements

The potential variation in soil, seedling quality, and the amount of fertilizer incorporated in the root plug were considered in the design. Thus we used square plots as sampling units rather than individual seedlings to investigate seedling response to fertilization treatments. The response variables of interest were mean diameter at the root collar, height, and survival. Seedling height and diameter were measured at planting and at the end of each growing season (November). Survival was surveyed biweekly throughout the first growing season and at the end of the second growing season. It was calculated for each plot as the percentage of living seedlings of the total number of planted seedlings.

Data Analysis

A generalized linear mixed model (GLML) with repeated measures was employed for analyzing diameter and height response to the fertilization treatments as follows:

$$Y_{ijk} = \mu + blk_i + trea_{ij} + t_k + trea_{ij} \times t_k + \varepsilon_{ijk} \quad (1)$$
$$(i = 1, .., 6;\ j = 1,.. , 10;\ k = 1, .., 3)$$

where Y_{ijk} is the diameter or height mean for treatment j in block i and at time k, μ is the grand mean, blk_i is the random effect for block i, $trea_{ij}$ is the fixed effect for treatment j in block i, t_k is a fixed and repeated factor for time (year) k (1 represents the planting time and 2 and 3 represent fall measurements of 1997 and 1998, respectively), and ε_{ijk} is the random error effect for treatment j in block i and at time k. Because mortality predominately occurred during the first growing season, we only analyzed the first-year data to reveal survival patterns among treatments using GLML as follows:

$$S_{ij} = \mu + blk_i + trea_{ij} + \varepsilon_{ij} \quad (2)$$
$$(i = 1, .., 6;\ j = 1,.. , 10)$$

where S_{ij} is the survival for treatment j in block i, and the other terms are as defined in Equation (1). Regression analysis of 2nd-yr diameter and height, and 1st-yr survival as related to fertilizer dosage was performed using a parabolic model. The estimated fertilizer dosage associated with maximum diameter, height, and survival for each type of fertilizer was calculated using differentiation. All statistical computations were performed using PROC MIXED and PROC REG of SAS (SAS® Institute Inc. 1995).

Table 2. Pairwise comparisons of root-collar diameter and height means of ponderosa pine seedlings following various fertilization treatments (means labeled with the same letters are statistically nonsignificant at the adjusted Bonferroni $P = 0.05$).

Treatment	Root-collar diameter			Height		
	At planting	Yr 1	Yr 2	At planting	Yr 1	Yr 2
	(mm)			(cm)		
Control	3.3 a	6.2 a	16.6 a	15.1 a	22.6 a	43.2 a
FR-0.8g	4.1 b	8.2 bc	20.4 b	17.2 b	27.5 bd	54.1 be
FR-1.6g	4.1 b	8.6 b	20.4 b	16.8 b	27.8 b	55.4 b
FR-3.2g	3.8 b	8.1 bc	19.7 bc	15.1 a	23.9 a	50.2 cde
MR-0.8g	3.8 b	8.2 bc	19.9 bd	16.5 b	27.3 cd	52.1 bcde
MR-1.6g	3.9 b	8.4 b	20.7 b	15.9 a	26.0 bcd	54.4 b
MR-3.2g	4.2 b	7.9 bc	18.7 cd	15.9 a	23.4 a	51.5 bcde
SR-0.8g	4.4 c	7.7 c	19.3 bc	16.3 b	26.2 bcd	49.1 cde
SR-1.6g	4.1 b	8.5 b	20.2 b	16.2 b	28.0 b	55.1 b
SR-3.2g	4.2 b	8.3 bc	18.4 c	16.3 b	25.7 c	50.9 e

Results

Diameter and Height Growth

Overall treatment effect on both diameter and height growth was statistically significant ($P = 0.0001$). Significance was primarily derived from the overall fertilization effect contrasted with controls ($P = 0.0001$). All fertilization treatments differed from the controls ($P < 0.05$) (Table 2). Two years after outplanting, diameter and height response to 1.6 g of all three products and 0.8 g of FR were nearly identical.

The estimated dosage for achieving maximum diameter following two field growing seasons was 1.96, 1.84, and 1.84 g for FR, MR, and SR products, respectively. Similarly, 1.86, 2.02, and 2.06 g produced maximum height response for FR, MR, and SR products, respectively.

Survival

Seedling mortality mainly occurred during the first growing season, particularly during the first 2 months (May and June) after planting. During this period, overall mortality dramatically increased, reaching 10.3% by the end of June. Subsequently, mortality increased slowly and reached 14% by the end of October. Very few seedlings (1.4%) died during the second growing season.

Seedling survival varied significantly among fertilization treatments (Table 3). Overall survival of fertilized seedlings was lower than the controls ($P = 0.0001$). Fertilizer type and dosage, as well as their interaction, had significant effects on seedling survival. FR fertilizer produced higher survival than SR fertilizer, and SR fertilizer produced higher survival than MR fertilizer. This was especially true with the 3.2 g dosage. Based on the estimated parabolic model, the dose for achieving maximum survival was 1.34 g/seedling for MR fertilizer. For FR or SR fertilizer, the dose was 0.8 g, the lowest application rate tested in this study.

Table 3. Pairwise comparisons of first-year survival means of ponderosa pine seedlings by fertilization treatments (means labeled with the same letters are statistically nonsignificant at the adjusted Bonferroni $P = 0.05$).

Treatment	Survival (%)
Control	92 a
FR-0.8g	96 a
FR-1.6g	97 a
FR-3.2g	83 a
MR-0.8g	91 a
MR-1.6g	93 a
MR-3.2g	45 c
SR-0.8g	97 a
SR-1.6g	97 a
SR-3.2g	63 b

Discussion

Significant diameter and height growth of fertilized seedlings in this study supports the idea that incorporating controlled-release fertilizers in the root plug of container-grown ponderosa pine seedlings could be an efficient way to stimulate growth while eliminating field fertilization of seedlings at planting. Ponderosa pine seedling growth responses were closely related to the characteristics of the three fertilizer products. The release periods for FR, MR, and SR products were preformulated as 9, 12 to 14, and 18 to 20 months, respectively. In the greenhouse, the 3.2 g/seedling rate of FR fertilizer was too high for the "160/90" seedlings due to the fast release characteristic of this product and the relatively small volume (90 cm^3) of these containers.

Continuous nutrient release and high salinity buildup and toxicity during 4 months of cold storage may have affected survival in our study similar to the results reported by Brockley (1988). The dramatic decline in survival associated with the 3.2 g rate, particularly for the MR product 1 yr after planting (Table 3), was probably caused by nutrient toxicity that occurred during cold storage. Necrotic needle tips were observed within 2 wk of planting for the highest rate of medium and slow release products. We did not find necrotic needle tips for other fertilization treatments.

Mortality of planted seedlings mainly occurred within the first 2 months after planting with the high dosage of MR and SR fertilizers. The high field mortality with 3.2 g of MR or SR treatments was totally due to dead root plugs which was strongly related to the release characteristics of the two products. Unlike FR fertilizer, both MR and SR fertilizer had a longer release cycle than the nine-month greenhouse production cycle. We observed that 9.2 and 4.4% by weight of nutrients were released from MR and SR fertilizers during cold storage. It is unclear if this magnitude of release completely explains our mortality results. Alternatively, the seedlings were "hardened-off" by reducing moisture near the end of the nursery growing regime. This may have produced

higher root zone salt concentrations and toxicity. Perhaps higher mortality for the 3.2 g of MR or SR treatments resulted from both the nutrient release during cold storage and the higher root zone salt concentrations. Whatever the reason, the 3.2 g of MR or SR treatments produced unacceptably high mortality rates.

The preferred treatment would probably be 0.8 g of the FR product since it produced good survival, about the same growth increase as other fertilizer treatments, and it presumably costs less than higher rates per seedling. The 0.8 g of FR product increased diameter about 23% and height about 25% after two field growing seasons. This response is similar to the relative growth increase observed from adjacent placement of controlled-release fertilizers just after planting in a nearby study under similar environmental conditions (Fan et al. 2001).

Conclusions

Fertilizer placed in the root plug of container grown ponderosa pine significantly increased both diameter and height after 2 growing seasons. Diameter and height of ponderosa pine seedlings without fertilizer incorporated in the root plug averaged 16.6 mm and 43.2 cm, while seedlings with fertilizer incorporated in the root plug ranged from 18.4 to 20.7 mm and from 49.1 to 55.4 cm, for diameter and height, respectively. No significant growth differences between fertilizer type and no interaction of fertilizer type by dosage were detected.

Ponderosa pine mortality mainly occurred within the first 2 months after planting. Incorporating 3.2 g of MR or SR fertilizer in the root plug produced significantly higher mortality (54 and 36%, respectively). Lower dosages did not significantly affect survival. The preferred treatment was 0.8 g of fast release fertilizer per seedling.

The best treatment produced growth response similar to adjacent placement of controlled-release fertilizer just after planting ponderosa pine seedlings in a nearby study area. Incorporating fertilizers in the growing media of container nurseries eliminates the cost of fertilizer field applications. These cost savings may compare favorably with the increased seedling production costs required to include controlled-release fertilizer in the growing media for container nurseries.

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