Application of Foliar Fertilizer During Bud Initiation Treatments to Container-Grown Conifer Seedlings[1,2]

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Abstract. -- Foliar fertilizer applications to ponderosa pine and Douglas-fir seedlings during bud initiation treatments significantly impacted seedling quality. Timing of bud formation was undisturbed in ponderosa pine seedlings but delayed in Douglas-fir seedlings by foliar fertilization. Foliar fertilizer enhanced foliar nitrogen concentration, seedling caliper and height growth, bud length, and shoot-root ratio of both species. Root growth potential was unaffected by foliar fertilization, while differences in seedling cold hardiness were modest.

INTRODUCTION

Growers of conifer reforestation stock routinely moisture and nutrient stress seedlings to induce bud development after seedlings achieve desired height (Wenny and Dumroese 1987; Tinus and McDonald 1979; Owston 1974; van Eerden 1974). Since nutrients are applied through irrigation water, nursery managers are unable to separate moisture and nutrient stress. It is yet unproven that inducing nutrient stress to seedlings is required to initiate bud development (Tinus and McDonald 1979; Lavender and Cleary 1974).

Nutrient stress reduces seedling nutrient reserves. These reserves are vital for increasing seedling caliper and for root and bud development following cessation of height growth (Tinus and McDonald 1979). Moreover, seedling nutrient reserves are essential to sustain seedlings during winter storage and are used in spring for vigorous growth (Margolis and Waring 1986) which results in higher seedling field survival rates (Jopson and Paul 1984).

Growers usually apply increased rates of fertilizer after buds are set to renew nutrient reserves depleted during initiation stress, promote large bud development, and improve root collar diameter. Of course, if nutrient stress is unnecessary for bud initiation, and if seedlings could receive adequate nutrition during moisture stress, caliper growth and bud enlargement could continue uninterrupted. Foliar fertilization may provide seedling growers with an option for fertilizing seedlings while maintaining moisture stress since foliar fertilizer is only applied until runoff, thereby minimizing moisture additions to root systems. Foliar absorbed nutrients are used on woody ornamentals (Bramlage et al. 1985; Nielsen and Hoyt 1984), while coastal Douglas-fir trees *(Pseudotsuga menziesii* var. *menziesii)* (Miller 1979) and slash pine seedlings *(Pinus elliotii* Engelm.) (Eberhardt and Pritchett 1971) are also known to assimilate these nutrients. We examined foliar fertilizer application on ponderosa pine *(Pinus ponderosa* Dougl. ex Laws. var. *ponderosa)* and Douglas-fir *(Pseudotsuga menziesii* var. *glauca* Beissn.) Franco) seedlings as a means of reducing nutrient stress during bud initiation and to determine if a constant nitrogen supply was beneficial or detrimental to seedling quality.

Research described in this paper is part of a larger study which investigated impacts of different foliar fertilizer application rates, durations, and frequencies on seedling quality including foliar phosphorus and potassium concentrations.

METHODS

Ponderosa pine and Douglas-fir seeds were sown the first week of April 1988, week 0, into 24 trays each containing 200 Ray Leach ® pine cells ($66 cm^3$) Ponderosa pine seedlings during weeks 2 through 5 and Douglas-fir seedlings during weeks 3 through 6 received Peters' ® Conifer Starter (7-40-17), at 42 ppm N, and micronutrients twice weekly (see Wenny and Dumroese 1987 for micronutrient rates). Following this treatment seedlings received Peters' ®

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Conifer Grower (20-7-19), at 120 ppm N, micronutrients, and calcium nitrate (15.5-0-0-19), at 46 ppm N, once per week through week 9 for ponderosa pine and week 10 for Douglas-fir. At this point, seedlings had attained the target height of 12-15 cm and were subjected to two different treatments to induce bud formation.

The first bud initiation treatment employed both nutrient and moisture stress to induce bud formation. During weeks 10 through 14 ponderosa pine seedlings and during weeks 11 through 17 Douglas-fir seedlings were irrigated only after their growing media had dried to barely moist (approximately 75% of saturated tray weight) with irrigation water containing Peters' ® Conifer Finisher (4-25-35), at 24 ppm N, and micronutrients.

Conversely, the second treatment relied on moisture stress alone to induce bud formation. Seedlings were irrigated with water containing micronutrients only after their growing media became barely moist (as described above). Each species received four different rates of Peters' ® Foliar Feed 27-15-12 per 100 gallons of water: Control -- 0 pounds (0 gL^{-1}); Rate 1 -- 1 pound (1.2 gL^{-1}); Rate 2 -- 2 pounds (2.4 gL^{-1}); and Rate 3 -- 3 pounds (3.6 gL^{-1}) (Table 1). R-11, a spreader-activator, was added to foliar fertilizer solutions at a rate of 2 liquid ounces per 100 gallons of water (0.15 mlL^{-1}) to reduce water tension and enhance penetration of fertilizer into leaves. Both ponderosa pine and Douglas-fir seedlings received twice weekly applications for five consecutive weeks. Following bud formation all seedlings received alternating applications of Finisher (24 ppm N) with micronutrients and calcium nitrate (46 ppm N).

Table 1. Treatment rates of Peters' ® Foliar Feed (27-15-12)

RATE OF FOLIAR FEED (lbs./100 gal. H_2O)	gL^{-1}	NITROGEN CONCENTRATION ppm
0	0	0
1	1.2	324
2	2.4	648
3	3.6	972

Foliar fertilizer was applied with an Ortho sprayer nozzle attached to a garden hose connected to a 1:100 injector. Using an injector enabled precise foliar fertilizer concentrations to be applied to seedlings while the Ortho sprayer provided complete and accurate coverage. Foliar Feed was applied until it ran off from seedlings, thus only minimal moisture was added to roots. Each foliar fertilizer rate was applied early in the morning to three trays of 200 seedlings, replicated twice.

Measurements

Four morphological characteristics were evaluated: root collar diameter (caliper), height, shoot-root ratio, and bud length. Growth measurements of seedling caliper and height were collected from ten seedlings of each species/treatment combination monthly from start of bud initiation treatment through growing season conclusion. Seedling growth from treatment initiation until cessation of growth was the data of interest, thus data analyzed for each collection date was the difference between respective caliper and height measurements at that date and initial caliper and height measurements gathered during week 9 for ponderosa pine and week 10 for Douglas-fir. At growing season conclusion, bud length was measured and seedlings were oven dried 24 hours at 65°C to calculate shoot-root ratio (Thompson 1985). In addition, seedling physiological traits were investigated. On three occasions, prior to bud initiation treatment, after terminal bud formation, and prior to cold storage, W.R. Grace and Company performed foliar tissue analyses to determine foliar nutrient concentrations. Root growth potential tests were performed during the storage period by growing 16 seedlings per species/treatment combination for 30 days with 16 hour photoperiod at a constant temperature of 20°C (Ritchie 1985). New roots longer than 2.5 cm for ponderosa pine (Krugman and Stone 1966) and longer than 1.3 cm for Douglas-fir (Todd 1964) were tallied. Following cold storage, cold hardiness examinations were conducted by subjecting 15 seedlings of each species/treatment combination to three different freezing temperatures and then assessing freezing damage after seedlings had been in a growing environment for seven days. Damage assessment was performed as described by Glerum (1985).

Treatment means of tests containing two or more dependent variables were first compared using multivariate analysis with Wilks' Criterion as the test for multivariate significance, while tests containing a single dependent variable were initially analyzed with a general linear model. Fisher's Protected Least Significant Difference test was implemented to separate significant means.

RESULTS AND DISCUSSION

Regardless of foliar fertilizer rate, ponderosa pine seedlings formed terminal buds concurrently with control seedlings. However shortly after bud set less than 10 percent of the seedlings experienced lammas growth and then re-formed terminal buds. Foliar nitrogen concentration of seedlings increased with foliar fertilizer application rate during bud initiation (Table 2). All foliar fertilizer rates significantly increased caliper and height growth, bud length, and shoot-root ratio (Tables 3 and 4), with Rate 3 being most beneficial. This rate improved seedling caliper, critical for survival (Duryea 1984) and necessary for vigorous growth after outplanting (Ritchie 1985), by 45% over control seedlings; final caliper for seedlings receiving the 3 pound rate of foliar fertilizer was 3.02 mm compared to 2.58 mm for control seedlings. Although height growth was also significantly

Table 2. Foliar nitrogen concentrations of ponderosa pine seedlings. [1]

TREATMENT	PRIOR TO FOLIAR FERTILIZER TREATMENTS	AT BUD SET	AT GROWING SEASON CONCLUSION
	---------- percent ----------		
Control	1.4	1.1	1.2
Rate 1	1.4	1.6	1.6
Rate 2	1.4	2.1	1.5
Rate 3	1.5	2.4	2.0

[1] Statistical analysis were not performed on nitrogen concentrations

Table 3. Increases in caliper and height growth of ponderosa pine seedlings.

	CALIPER GROWTH		HEIGHT GROWTH	
TREATMENT	AT BUD SET	AT GROWING SEASON CONCLUSION	AT BUD SET	AT GROWING SEASON CONCLUSION
	----- (mm) -----		----- (cm) -----	
Control	0.53 a[1]	0.94 a	3.3 a	5.0 a
Rate 1	0.62 b	1.10 b	4.0 b	5.3 a
Rate 2	0.63 b	1.22 c	4.2 bc	5.7 b
Rate 3	0.67 b	1.36 d	4.4 c	6.1 c

[1] Values in same column with different letters are significantly different at P , 0.05 using Fisher's Protected LSD test.

Table 4. Bud length and shoot-root ratio measurement data for ponderosa pine seedlings.

TREATMENT	BUD LENGTH (mm)	SHOOT DRY WEIGHT	ROOT DRY WEIGHT	SHOOT-ROOT RATIO
		----- (g) -----		
Control	9.3 a[1]	0.8 a	0.8 a	1.1 a
Rate 1	10.0 ab	1.0 b	0.9 a	1.2 b
Rate 2	11.2 c	1.3 c	0.9 a	1.4 c
Rate 3	10.4 bc	1.3 c	0.9 a	1.5 d

[1] Values in same column with different letters are significantly different at P , 0.05 using Fisher's Protected LSD test.

increased, the difference between final heights was only 1.3 cm, 15.8 cm for Rate 3 seedlings versus 14.5 cm for control seedlings, which is an inconsequential amount to growers. Seedlings which received Rate 3 developed buds 19.5% longer than controls, indicating an increased potential for improved early height growth in the field (Kozlowski et. al 1973; Hanover 1963). Shoot-root ratios are a good predictor of field survival (Rowan 1987; Thompson 1985), with low shoot-root ratios yielding higher survival. Although Rate 3 seedlings possessed the highest shoot-root ratio value, 1.5, this value is still considered low and will not represent biologically significant differences to field survival especially considering some of this increase was a result of improved caliper growth, a beneficial characteristic. Root growth potential was unaffected by foliar fertilizer, and cold hardiness was only slightly reduced (4°C) by the Rate 3 treatment when tested after four months of cold storage (Table *5).*

Table 5. Root growth potential and cold hardiness measurements of ponderosa pine seedlings.

TREATMENT	NEW ROOTS (number)	LD_{50} TEMPERATURE (degrees Celsius)
Control	26 a[1]	-20a
Rate 1	45a	-17bc
Rate 2	44a	-18b
Rate 3	43a	-16c

[1] Values in same column with different letters are significantly different at $P < 0.05$ using Fisher's Protected LSD test.

Conversely, terminal bud formation in Douglas-fir seedlings is more sensitive to foliar nitrogen concentrations. Seedlings receiving foliar fertilizer failed to form terminal buds on schedule, and consequently, foliar fertilizer applications were reduced and then suspended until bud formation. Suspension of foliar fertilization resulted in low nutrient reserves for all seedlings at bud set, however, seedlings receiving higher foliar fertilizer rates still contained greater foliar nitrogen concentrations (Tables 6 and 7). As foliar fertilizer rate increased, caliper and height growth, bud length, and shoot-root ratio significantly increased (Tables 7 and 8). Although foliar fertilizer improved some seedling quality attributes, especially caliper and bud length, treatments prevented timely bud set resulting in seedlings that exceeded target height; control seedlings final actual height was 15 cm while each foliar fertilizer rate produced seedlings between 19 and 21 cm tall. Shoot-root ratios were significantly increased because of the extra height growth gained by delayed bud formation, but shoot-root ratios for all foliar fertilized seedlings were low, below 1.5, consequently these differences in shoot-root ratio will have an insignificant impact on seedling quality. As with ponderosa pine, root growth potential was unaffected, and differences in cold hardiness were slight (Table 9).

None of the foliar fertilizer treatments resulted in needle burn due to volatilization. Foliar fertilizer treatments were visually apparent as seedlings exhibited darker green foliage in comparison to control seedlings, but two weeks passed before these color differences became evident. Furthermore, foliar fertilized ponderosa pine seedlings possessed this darker green foliage throughout the remainder of the growing season. However, since foliar fertilizer treatments were suspended in order to induce bud formation Douglas-fir seedlings lost their dark green appearance.

Table 6. Foliar nitrogen concentration of Douglas-fir seedlings.[1]

TREATMENT	PRIOR TO FOLIAR FERTILIZER TREATMENTS	AT BUD SET	AT GROWING SEASON CONCLUSION
	- - - - - - - - - - -	percent	- - - - - - - - - - -
Control	1.6	1.0	1.0
Rate 1	1.5	1.0	1.1
Rate 2	1.8	1.3	1.1
Rate 3	1.7	1.4	1.1

[1] Statistical analysis was not performed on nitrogen concentrations.

Table 7. Increase in caliper and height growth of Douglas-fir seedlings

	CALIPER GROWTH		HEIGHT GROWTH	
	AT BUD SET	AT GROWING SEASON CONCLUSION	AT BUD SET	AT GROWING SEASON CONCLUSION
TREATMENT	- - - - - - - - - - (mm)	- - - - - - - - - - - -	- - - - - - - - - - (cm)	- - - - - - - - - - - - - - -
Control	0.52 a[1]	0.66 a	5.8 a	6.0 a
Rate 1	0.75 b	0.93 b	9.2 b	9.5 b
Rate 2	0.87 c	1.07 c	9.9 c	10.3 c
Rate 3	0.89 c	1.18 d	10.7 d	11.4 d

[1] Values in same column with different letters are significantly different at P , 0.05 using Fisher's Protected LSD test.

Table 8. Terminal bud length and shoot-root ratio measurements for Douglas-fir seedlings.

TREATMENT	BUD LENGTH (mm)	SHOOT DRY WEIGHT - - - - - - - - - - - - - (g)	ROOT DRY WEIGHT - - - - - - - - - - - - -	SHOOT-ROOT RATIO
Control	3.8 a[1]	0.5 a	0.5 a	0.9 a
Rate 1	4.7 b	0.7 b	0.6 a	1.1 b
Rate 2	4.9 bc	0.8 c	0.7 a	1.2 c
Rate 3	5.1 c	0.8 c	0.6 a	1.4 d

[1] Values in same column with different letters are significantly different at P , 0.05 using Fisher's Protected LSD test.

Table 9. Root growth potential and cold hardiness measurements for Douglas-fir seedlings.

TREATMENT	NEW ROOTS (number)	LD50 TEMPERATURE (degrees Celsius)
Control	31 a[1]	-17 a
Rate 1	42 a	-20 b
Rate 2	40 a	-17 a
Rate 3	65 a	-17 a

[1] Values in same column with different letters are significantly different at $P < 0.05$ using Fisher's Protected LSD test.

MANAGEMENT IMPLICATIONS

Nursery managers can improve ponderosa pine seedling quality by reducing nutrient stress during bud initiation via foliar fertilization. Using 3 pounds of foliar fertilizer per 100 gallons of water, applied with conventional irrigation systems, allows timely bud formation while maintaining high nutrient reserves which improve caliper and bud growth. Results from this project, coupled with further research that examined application frequencies on ponderosa pine, enable us to recommend applying 3 pounds of foliar fertilizer per 100 gallons of water once every other week during bud initiation instead of twice weekly to reduce lammas growth caused by high nutrient concentrations. Early morning applications prevent needle damage due to volatilization.

Douglas-fir seedlings were stimulated to grow, rather than develop buds, by foliar fertilization. Improvements in Douglas-fir caliper and bud length were achieved, but foliar fertilization prevented timely bud formation resulting in seedlings exceeding target height. Based on the results of this project and further tests on Douglas-fir seedlings using a 1 pound rate of foliar fertilizer, we recommend applying 2 pounds of Foliar Feed per 100 gallons of water to Douglas-fir seedlings every other week after terminal bud formation to increase seedling nutrient reserves and enlarge caliper development and terminal bud length. Finally, we have successfully applied the 3 pound rate of foliar fertilizer to western larch, grand fir, Engelmann spruce, Colorado blue spruce, western white pine, Scotch pine, and Austrian pine after buds are well developed to recharge depleted nitrogen reserves after bud initiation treatments.

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