Growth of *Juniperus* and *Potentilla* using Liquid Exponential and Controlled-release Fertilizers

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Additional index words. container nursery, nitrogen, fertigation, runoff

Abstract. *Juniperus scopularum* Sarg. (Rocky Mountain juniper) and *Potentilla fruticosa* L. 'Gold Drop' (gold drop potentilla) plants grown in containers had similar or better morphology, higher nitrogen concentrations and contents, and higher N-use efficiency when grown with liquid fertilizer applied at an exponentially increasing rate as compared to the same amount of N applied via controlled-release fertilizers. More importantly, plants grown with a half-exponential rate were similar to those grown with controlled-release fertilizer but with a higher N-use efficiency, indicating that this type of fertilization may be a method for reducing the amounts of applied nutrients in nurseries and subsequent nutrient discharge.

Preserving water quality by controlling nitrogen and phosphorus runoff from nurseries remains a concern for the nursery industry. Industry's ability to effectively address this concern is important for its sustained viability within the current political framework (Grey, 1991; Johnson, 1992; Newbould, 1989). Much work has been done to reduce nutrients discharged in waste water from container nurseries. Investigators have looked at pulse or cyclic irrigation (Daughtry, 1990; Fare et al., 1994; Lamack and Niemiera, 1993), fixed vs. traveling overhead irrigation (Dumroese et al., 1992; Weatherspoon and Harrell, 1980), and slow or controlled-release fertilizers (Cox, 1993). Generally, higher concentrations of fertilizer result in increased nutrient runoff, particularly as the total amount of irrigation water increases (Tyler et al., 1996; Yelanich and Biernbaum, 1994). However, another technique based on steady state nutrition (Ingestad and Lund, 1986) avoids applying excess nutrients by matching nutrient inputs with maximum plant growth.

Using this technique, the amount of nutrient input increases exponentially to match plant growth (Timmer and Aidelbaum, 1996). Pine seedlings grown with an exponential fertilizer regime at the Univ. of Idaho received 50% to 75% less fertilizer than seedlings grown with fertilizer applied at a constant rate, but seedling sizes were similar (Dumroese et al., 1995). Nitrogen runoff from other conifer crops grown with constant fertilization ranged from 30% to 60% of the total nitrogen applied (Dumroese et al., 1995). Other researchers have also found that exponentially fertilized plants had a higher affinity for absorbing nutrients, more stress resistance, and were better able to compete with weeds (Timmer, 1997; Timmer and Aidelbaum, 1996; Timmer and Armstrong, 1987). Therefore, less applied fertilizer to plants with a higher affinity for absorbing nutrients should result in reduced nutrient runoff from nurseries.

My objective was to compare growth of two species growing in 2.8-L containers and fertilized with controlled-release fertilizers or fertigated with two rates of exponential fertilization.

Materials and Methods

My experiment used two species (*Juniperus scopularum* Sarg. and *Potentilla fruticosa* L. 'Gold Drop') grown under three fertilizer regimes [controlled-release fertilizer (CRF; control); full-rate exponential; half-rate exponential]. Both species are commonly grown in the western United States and represent deciduous and coniferous plants. The controlled-release fertilizer rate was the operational rate for these two species at Jayker Wholesale Nursery (Meridian, Idaho). The total amount of N supplied with the full-rate exponential treatment equaled that supplied by the controlled-release fertilizer. A half-exponential rate was included to determine if less applied N coupled with the reported enhanced N-use efficiency of exponentially fertilized plants could result in acceptable growth of these species.

To calculate exponential fertilizer regimes, biomass and N concentration of typical plants at the start of a growing season were needed. In spring, I harvested four replicates of five plants of *Juniperus* and *Potentilla* (20 plants total of each species). *Juniperus* liners were 1-year-old seedlings grown in 340-mL containers as part of a 2-year crop at the Univ.

of Idaho Forest Research Nursery, Moscow, Idaho. Hardwood *Potentilla* ramets were fall-collected and rooted during winter in an unheated polyhouse at Jayker Wholesale Nursery and were ≈6 months old when the experiment began. Roots of both species were carefully washed, separated from shoots, and both roots and shoots were dried 72 h at 60 °C to achieve constant weight. Nitrogen concentration was determined by Scotts Testing Laboratory (Allentown, Pa.).

The growth substrate for both species was custom-mixed at Jayker Wholesale Nursery and consisted of the following: composted fine-grind fir bark (≤1 cm; 65%); sawmill waste (sand–sawdust mixture; 20%); and local source cinders (≤0.6; 15%). Using a blending machine, I amended 0.76 m^3 of substrate with 4.3 kg 14N–6.1P–11.6K (14–14–14 Apex Blue Polyon Coated Fertilizer, 4-month release rate at 21 °C, J.R. Simplot Co., Boise, Idaho), 0.9 kg Apex Micronutrient Formulation (J.R. Simplot Co.), 0.9 kg dolomitic lime, 1.8 kg $MgSO_4$, and 0.9 kg elemental S (99.5%). The growth substrate for the exponential treatments was amended with all of the fertilizers except the Apex Blue Polyon Coated Fertilizer.

Once the growth substrate was prepared and appropriate fertilizers included, nine plants of each species were randomly assigned to each of three fertilizer treatments and planted into 2.8-L (#1) containers. On 1 May, I randomly placed potted plants within an open-sided growing area with a polycarbonate roof. All containers were watered to saturation, allowed to drain for 0.5 h, and weighed to obtain a saturated weight. At least three randomly chosen plants from each species × treatment combination were weighed daily, and plants were irrigated (control plants with controlled-release fertilizer) or fertigated (exponential fertilizer) when the average container weight within a species × treatment combination was 80% of saturated weight. The volume of water added brought the substrate back to saturation with minimal leaching. Leachate was collected for 0.5 h in plastic trays beneath each container and then reapplied to the plant. Every 6 weeks, I slowly watered the growth substrate in each container to saturation with plain water and determined a new saturated weight as described above.

The basic formula for exponential fertilization is:

$$N_T = N_S (e^{rt} - 1)$$

where r is the relative addition rate required to increase N_S (initial N content in plant) to a final N content ($N_T + N_S$); where N_T is the desired amount to be added over t, the number of fertilizer applications (Ingestad and Lund, 1986; Timmer and Aidelbaum, 1996). Using the biomass and nutrient concentration of plants at the beginning of a growing season, I calculated that N_S was 54 mg (3.56 g and 15.2 mg·g^{-1} N) and 17 mg (1.49 g and 11.4 mg·g^{-1}) for *Juniperus* and *Potentilla*, respectively. N_T was 2375 mg for full-exponential fertilization (equal to the amount of N added to each container via the controlled-release fertilizer) and 1187.5 mg for half-exponential fertilization. I assumed that t equaled 123, the number of days in a grow-
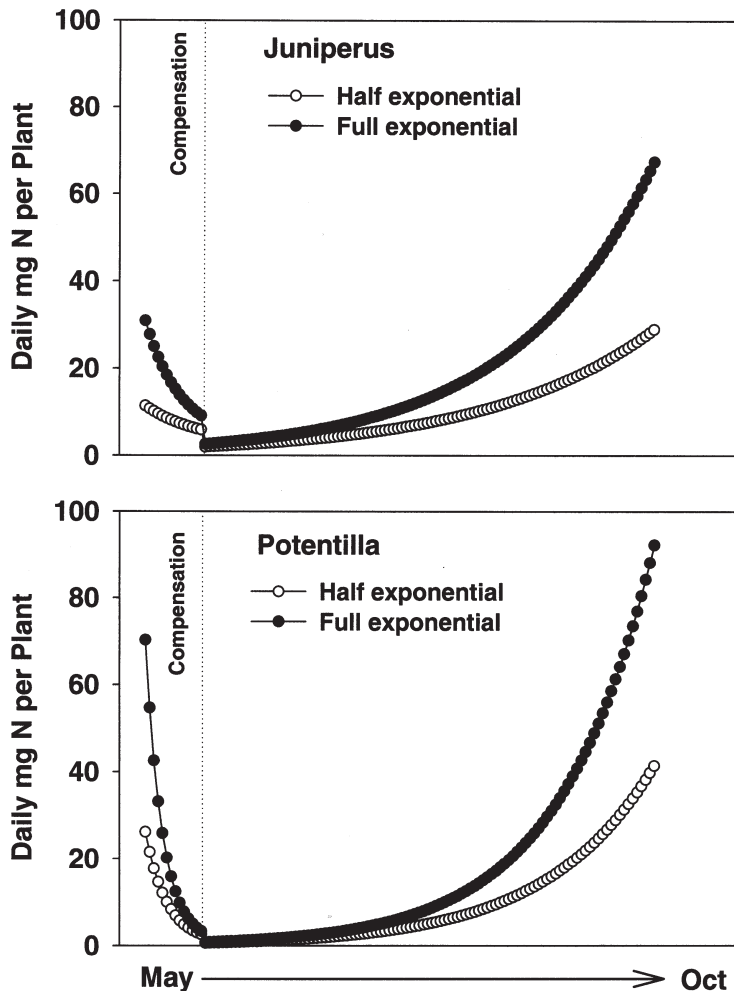
Fig. 1. Schedule of daily nitrogen applications for *Juniperus* and *Potentilla* calculated at either full- or half-exponential rates and modified with 14-d compensation periods.

and 123 (215.3 and 271.9 for exponential *Juniperus* and *Potentilla*, respectively, and 91.4 and 118.9 for half-exponential *Juniperus* and *Potentilla*, respectively). The daily amount of N compensated was calculated using:

$$N_C = N_S (e^{rt} - 1) - N_{t-1}$$

where t went from 14 to zero. Therefore, plants received N_T plus N_C for the first 14 d and zero additional fertilizer on days 121, 122, and 123. Intervals between fertigation events varied so I summed the daily N_T values and applied the cumulative amount when irrigation was necessary (Fig. 1). For the exponential treatments, I fertigated with 20N–3P–15.8K (20–7–19 Peters Conifer Grower, The Scotts Company, Marysville, Ohio).

After 151 d (plants were allowed to grow 28 d past the last exponential fertilization to make use of applied N), I harvested the plants and measured shoot and root biomass as described above. For the *Juniperus* seedlings, height growth was measured from the surface of the growth substrate to the tip of the terminal shoot and stem diameter was measured 1 cm above the growth substrate. Height and stem diameter were not measured on *Potentilla* due to multiple stems and the branching growth form. Before chemical analysis, shoot and root samples were redried at 60 °C for 24 h, ground to pass a 0.04-mm mesh, and analyzed for total N content with a LECO-600 CHN analyzer (LECO Corp., St. Joseph, Mich.). N-use efficiency was calculated by subtracting the initial N content (N_S) from final N content and dividing by total N applied.

For each species, an analysis of variance was used to compare seedling characteristics among treatments (PROC GLM; SAS Institute Inc., 1989). When $P \le 0.05$, means were separated using Tukey's HSD.

Results and Discussion

Juniperus plants given full-exponential fertilization grew taller, had higher N-use efficiency and shoot N concentrations, and contained more N in roots and shoots than seedlings grown with the same amount of N supplied by controlled-release fertilizer (Table 1). Seedlings grown with half-exponential fertilization, despite having received 50% less fertilizer, were similar to seedlings grown

ing season. Solving for r, the relative addition rate for exponential was 0.0309 and 0.0402 for *Juniperus* and *Potentilla*, respectively. The relative addition rate for half-exponential was 0.0255 and 0.0346 for *Juniperus* and *Potentilla*, respectively. The amount to apply on a specific day was calculated using:

$$N_T = N_S (e^{rt} - 1) - N_{t-1}$$

where N_T is the amount of N to apply daily, N_{t-1} is the cumulative amount of N applied, and t goes from 1 to 123 (Fig. 1).

Because root exploitation of the growth substrate is lacking immediately after planting, I compensated for the small amount of N applied during the first 2 weeks using:

$$N_C = N_S (e^{rt} - 1)$$

where N_C is the amount of N to compensate, N_S is the initial N content in the plant, r is the relative addition rate, and t equals the compensation period (I assumed 14 d). For both species, N_C equaled the cumulative amount N scheduled to be applied on days 121, 122,

Table 1. Mean (±standard deviation) of morphological characteristics and nitrogen status of *Juniperus scopularum* and *Potentilla fruticosa* 'Gold Drop' grown with substrate-incorporated controlled-release fertilizer or liquid fertilizer applied at exponential or half-exponential rates.

| | | | Biomass | | | Nitrogen | | | | | | |
| | | | | | | Concn | | Content | | | | Use |
	Ht (cm)	Stem diam (mm)	Root (g)	Shoot (g)	Total (g)	Root (mg·g⁻¹)	Shoot (mg·g⁻¹)	Root (mg)	Shoot (mg)	Total (mg)	Applied (mg)	efficiency (%)
						Juniperus						
Control (CRF)	32 ± 7 b[z]	7.5 ± 1.5	5.5 ± 1.5	14.8 ± 3.6 a	20.3 ± 4.6 ab	1.7 ± 0.2	1.6 ± 0.2 a	92 ± 24 b	244 ± 72 b	336 ± 91 b	2375	12 ± 4 c
Full-exponential	38 ± 4 a	8.2 ± 0.9	6.9 ± 0.9	15.7 ± 1.9 a	22.6 ± 2.5 a	1.8 ± 0.2	2.1 ± 0.2 b	124 ± 20 a	328 ± 36 a	452 ± 48 a	2375	17 ± 3 b
Half-exponential	30 ± 4 b	7.6 ± 1.0	6.3 ± 1.2	11.4 ± 1.7 b	17.7 ± 2.7 b	1.7 ± 0.3	2.2 ± 0.2 b	105 ± 31 ab	245 ± 31 b	350 ± 57 b	1188	25 ± 5 a
P value	0.01	0.5	0.08	0.004	0.02	0.4	0.0001	0.04	0.002	0.002		0.0001
						Potentilla						
Control (CRF)			16.2 ± 4.4	33.9 ± 12.0	50.1 ± 13.4	1.8 ± 0.2 b	1.8 ± 0.1 b	283 ± 81 a	595 ± 210 b	878 ± 235 a	2375	37 ± 10 b
Full-exponential			12.0 ± 2.9	36.9 ± 5.3	48.9 ± 7.8	2.2 ± 0.2 a	2.1 ± 0.1 a	263 ± 72 ab	782 ± 113 a	1045 ± 175 a	2375	44 ± 7 ab
Half-exponential			12.0 ± 5.7	26.8 ± 7.4	38.8 ± 12.8	1.5 ± 0.2 b	1.8 ± 0.3 b	186 ± 92 b	451 ± 86 b	634 ± 170 b	1188	53 ± 14 a
P value			0.09	0.06	0.1	0.0001	0.002	0.047	0.0003	0.0007		0.01

[z]Within each species and column, means with different letters are significantly different at *P* = 0.05 using Tukey's HSD.

with controlled-release fertilizer except that they had 30% less shoot biomass, but 38% higher shoot N concentration and twice the N-use efficiency (Table 1).

Potentilla plants grown with full-exponential fertilization were similar to those grown with controlled-release fertilizer except that they had higher root and shoot N concentrations and higher shoot N content (Table 1). Except for significantly less N content in roots and a 43% higher N-use efficiency, plants grown with half-exponential fertilization were similar to those grown with controlled-release fertilizer.

Both exponential fertilization and controlled-release fertilizers deliver discreet amounts of fertilizer over time. However, the availability of controlled-release fertilizers to plants is temperature dependent and not readily predictable outdoors, as was the case in this study. Several studies indicate that loss of controlled-release fertilizer through leaching can be substantial during the initial portion of the growing season when plant nutrient uptake is low (Conover and Poole, 1992; Cox, 1993; Huett, 1997), and although leaching from the growth substrate was averted by reapplication of leachate during this study, high amounts of N not used by the plants may have been used by microorganisms or lost to the atmosphere (Colangelo and Brand, 1997). Conversely, with exponential fertilization, the rate of applied nutrients increased exponentially, and during this study nearly 50% of the fertilizer was applied during the last 3 weeks of the fertilization period. Higher N concentrations and contents in shoots and roots of exponentially fertilized seedlings is probably a manifestation of this late-season, high dosage fertilization. The additional month of plant growth after the final fertigations was probably sufficient for the fertilizer to be translated into seedling growth. Similarly, most controlled-release fertilizer was also probably made available to the plant by the end of this growing season.

The ≈3:1 shoot to root ratio and ≈3:1 shoot to root N content ratio of plants grown with half-exponential rate indicates they were not receiving low levels of fertility (Catanzaro et al., 1998; Karam et al., 1994). Moreover, the incremental application of nutrients by half-exponential fertilization may have been closer to the nutrient demands of the plants since N-use efficiency was much higher in this treatment. Finally, the similar morphology and N status of plants grown with either controlled-release fertilizers or half-exponential fertilization indicates both species could be grown to similar size and quality specifications with less fertilizer—perhaps up to 50% less than that currently supplied by operational controlled-release fertilization. These results are similar to those reported by Imo and Timmer (1992) for desert mesquite [*Prosopis chilensis* (Molina) Stuntz], Burgess (1990) for black spruce [*Picea mariana* (P. Mill.) B.S.P.], Timmer and Miller (1991) for red pine (*Pinus resinosa* Soland.), and Dumroese et al. (1995) for Rocky Mountain Douglas-fir [*Pseudotsuga menziesii* (Mirbel) Franco var. *glauca* (Beissn.)] and western white pine (*Pinus monticola* Dougl. ex D. Don).

Fertilizing plants to match their growth requirements should improve efficiency of fertilizer use in nurseries, as demonstrated by Yeager et al. (1980). Exponential fertilization offers an opportunity to provide plants nutrition in such a manner using water-soluble fertilizers.

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