Nursery Waste Water: The Problem and Possible Remedies

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Dumroese, R.K. Wenny, D.L.; Page-Durnroese, D.S. 1995. Nursery Waste Water: The Problem and Possible Remedies. In: Landis, T D.; Cregg, B., tech. coords. National Proceedings, Forest and Conservation Nursery Associations. Gen. Tech. Rep. PNW-GTR-365. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 89-97. Available at: http://www.fcnanet.org/proceedings/1995/dumroeses.pdf

Abstract - We found between 49 and 72% of the water applied to a production crop of container-grown conifer seedlings was discharged from the nursery. The amount discharged varied by species and by seedling growth stage. Our results showed between 32 and 60% of all nitrogen was also discharged, again influenced by species and growth stage. In another study, Douglas-fir and western white pine seedlings were grown using relative addition rate fertilization and 60% less nitrogen than our conventional crop. Based on our results and the literature, we feel a combination of improved greenhouse efficiency, irrigating crops based on container capacity, using intermittent irrigation, and applying fertilizers with a relative addition rate can improve irrigation and fertilization efficiency and reduce nursery runoff.

INTRODUCTION

Producers of container-grown seedlings use large volumes of water because nearly all fertilizers and pesticides are applied through irrigation systems. Our earlier work also showed large volumes of water are discharged from container nurseries during the first 15 weeks of growing reforestation stock (Dumroese and others 1992). Within the discharged water are appreciable amounts of nitrogen (N). One study found nitrate levels greater than 1700 lbs per acre (2000 kg/ hectare) in the top meter of soil below commercial greenhouses (Molitor 1990). The potential, negative environmental impact from runoff from nurseries producing container- grown stock is serious from a water quality standpoint. However, public perception of container nursery runoff is probably more important in dictating regulation (Johnson 1992). Nonetheless, increasing levels of nitrates in drinking or surface water will force political action to control nitrogen fertilizer (Newbould 1989) or its discharge from nurseries, as in Oregon (Grey 1991).

At the University of Idaho Forest Research Nursery, we decided to evaluate our water usage and the quality of water discharged to ascertain environmental impacts. Our objective was to determine the efficiency of irrigation applications and the quality of water being discharged. Results from the first 15 weeks of the growing cycle were previously reported (Dumroese and others 1992). In this paper we will only highlight the results of N and water used and discharged from three species over one growing season (The Problem) and some possible remedies, including some best management practices for water use and a pilot study examining the effects of relative addition rate fertilization as a means to reduce N discharge.

PART 1. THE PROBLEM

Methods At the time of this study (1991), the University of Idaho Forest Research Nursery grew about 850,000 conifer seedlings annually in Ray Leach' pine cells filled with a 1:1 peat: vermiculite growing medium (Grace/Sierra, Portland, OR). Seed was sown during the first week in April. Seedlings were grown on rolling benches and 86% of the greenhouse area was in production. Water was supplied by an on-site well. Crops were watered and fertilized with an overhead, traveling-boom irrigation system. Fertilizer was applied via a 1: 100 Smith injector.

Three species were evaluated for N and water use efficiency: Douglas-fir (*Pseudotsuga menziesil*), ponderosa pine (*Pinus ponderosa*) and western white pine (*Pinus Pensacola*). Our initial growth phase started three weeks after germination. We fertilized seedlings twice each week with Peters' Conifer Starter' (N:P:K=7:40:17) at 42 ppm N and micronutrients. Each application supplied about 14 ml of water/fertilizer solution to each seedling (0.36 gal/ft^2) . After four weeks for the pines and six weeks for Douglas-fir, we switched to an accelerated growth phase. Again, seedlings were fertilized twice each week but with Peters' Conifer Grower® (N:P:K=20:7:19) and micronutrients (see Wenny and Dumroese 1987a,b, 1992) alternated with calcium nitrate (14 ml per seedling (0.36 gal/ft^2). Ponderosa pine received 50 ppm N for four weeks, Douglas-fir 120 ppm N for six weeks, and white pine 192 ppm N for nine weeks. To promote buds and hardening, seedlings received lower amounts of N, in alternating forms of Peters' Conifer Finisher® (N:P:K=4:25:35)(24 ppm N), calcium nitrate (46 ppm N), and micronutrients when the growing medium became barely moist (about 75% saturated block weight). Application rates ranged from 14-21 ml per seedling (0.36 - 0.55 gal/ft^2) . Four weeks after initiating buds, seedlings received finisher at 24 ppm N and micronutrients alternated with 92 ppm N calcium nitrate when the growing medium became barely moist (about 75% saturated block weight). Seedlings were also foliar fertilized (2.5 ml per seedling (0.06 gal/ft^2) with Peters' Foliar Fertilizer® (N:P:K=25:15:12) about once every two weeks at 972 ppm N (3 lbs/100 gal (3.6 g/L)) until lifting. Douglas-fir received only one foliar application.

To determine the quality and quantity of errant spray (the combination of water dripping through the trays, Teachers from containers and water being sprayed directly onto the floor) entering the drains, we placed a series of gutters beneath the tables. Two 10-foot sections of plastic gutter were connected with wing-nuts and the entire assembly held beneath the benches with bungie cords. Gutters were positioned under the tables to intercept all errant spray, including that sprayed directly onto the floor. The gutter assembly drained into a plastic bucket. Three assemblies were used per species for each sample collection. The buckets were emptied about 1.5 h after irrigation ceased. The gutters sampled all errant water. Surface area of the gutters was determined so the volume of water per square foot being discharged could be calculated.

The amount of water applied per irrigation event was determined by directly measuring output from each traveling boom. The output delivered by each nozzle during one minute was measured so an average volume per nozzle per minute could be determined. We also timed the boom as it made one pass over the greenhouse. By recording the time the system was irrigating the crop, we then calculated gallons of water applied per irrigation At lifting, three replications of ten seedlings from each of the three species were oven dried (60°C for 24 h) for dry weight measurements. Whole seedling nutrient concentration was determined by Grace/Sierra Testing Laboratories (Allentown, PA).

RESULTS

During irrigation, our traveling boom system sprayed 12.5% of the water directly onto the floor, the walls, or through openings in the tops of the containers, indicating 87.5% of the applied water reached the crop.

Water use varied by species and so did water discharged (Table 1). For the growing season, 49% of the water applied to ponderosa pine was discharged from the nursery. For Douglas-fir and white pine, 67% and 72%, respectively, was discharged. Discharged amounts also varied by seedling growth stage. For ponderosa pine, 73% of the water applied during the initial growth stage was discharged, but the value dropped to about 45% for the rest of the growing season. Water discharged from Douglas-fir during the initial growth phase was 7 1 % of applied, and interestingly, was 72% during hardening. White pine discharge was highest during initial growth (88%) but declined to 79% during the accelerated growth period and 69% during hardening.

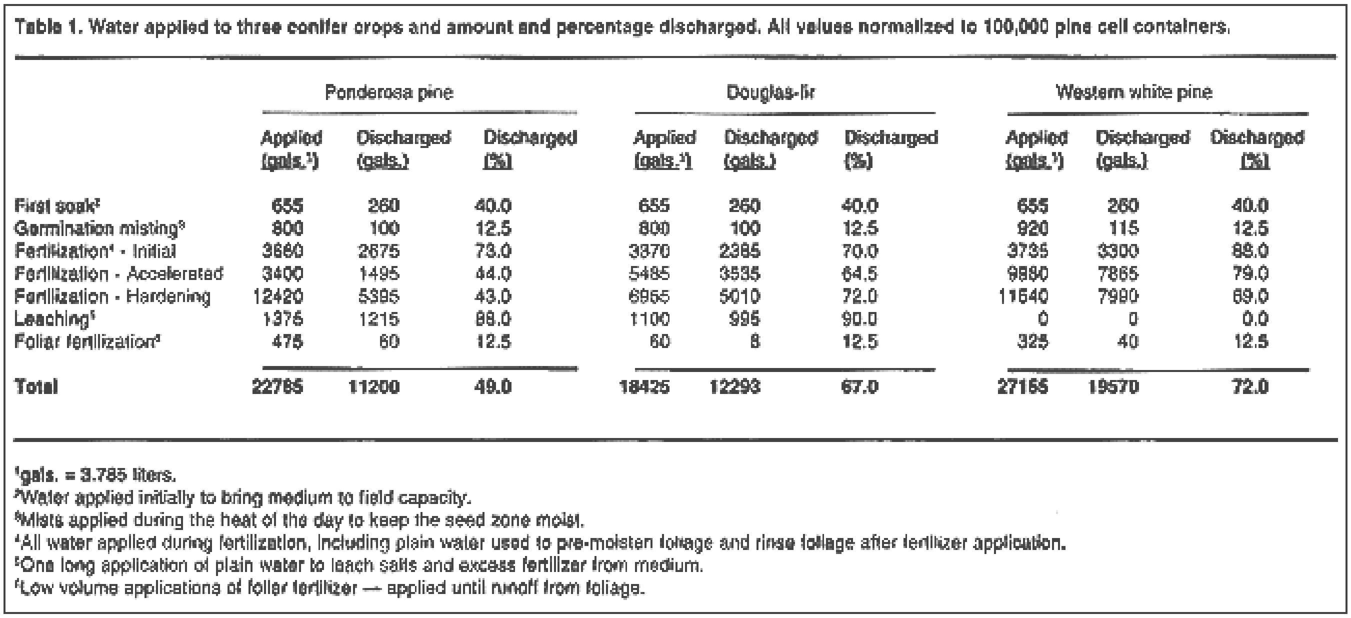

Table 1. Water applied to three conifer crops and amount and percentage discharged. All values normalized to 100,000 pine cell containers.

	Ponderosa pine			Douglas-fir			Western white pine		
	Applied (gals.[1])	Discharged (gals.)	Discharged (%)	Applied (gals.[1])	Discharged (gals.)	Discharged (%)	Applied (gals.[1])	Discharged (gals.)	Discharged (%)
First soak[2]	655	260	40.0	655	260	40.0	655	260	40.0
Germination misting[3]	800	100	12.5	800	100	12.5	920	115	12.5
Fertilization[4] - Initial	3660	2675	73.0	3370	2385	70.0	3735	3300	88.0
Fertilization - Accelerated	3400	1495	44.0	5485	3535	64.5	9880	7865	79.0
Fertilization - Hardening	12420	5395	43.0	6955	5010	72.0	11640	7990	69.0
Leaching[5]	1376	1215	88.0	1100	995	90.0	0	0	0.0
Foliar fertilization[6]	475	60	12.5	60	8	12.5	325	40	12.5
Total	**22785**	**11200**	**49.0**	**18425**	**12293**	**67.0**	**27155**	**19570**	**72.0**

[1] gals. = 3.785 liters.
[2] Water applied initially to bring medium to field capacity.
[3] Mists applied during the heat of the day to keep the seed zone moist.
[4] All water applied during fertilization, including plain water used to pre-moisten foliage and rinse foliage after fertilizer application.
[5] One long application of plain water to leach salts and excess fertilizer from medium.
[6] Low volume applications of foliar fertilizer — applied until runoff from foliage.

As might be expected with this much discharged water, and the bulk of it having passed through the growing medium, N was also observed departing the site. Ponderosa pine was the most nutrient thrifty - only 32% of the applied N was discharged and it did not vary much by seedling growth phase (Table 2). Douglas-fir, however, was poorer at assimilating N. Nearly 50% of the N applied during the initial growth phase was discharged and an incredible 70% was lost during the accelerated growth period. Even after budset, 60% of all applied N was discharged. We expected more N loss with white pine and we found that to be true. White pine is notoriously slow-growing and seemingly large amounts of N are required to reach target heights. However, during the initial growth period, 80% of the applied N left the nursery. This value dropped to 67% during accelerated growth and eventually dropped to a more respectable 50% during hardening.

Table 2. Nitrogen applied to three conifer crops and amount discharged.

	Ponderosa pine			Douglas-fir			Western white pine		
Growth phase	Applied (lbs.[1])	Discharged (lbs.)	Discharged (%)	Applied (lbs.[1])	Discharged (lbs.)	Discharged (%)	Applied (lbs. [1])	Discharged (lbs.)	Discharged (%)
Initial	4.0	1.10	27.5	1.20	0.58	48.3	2.13	1.71	80.4
Accelerated	4.4	1.5	34.1	5.71	3.92	68.7	30.73	20.72	67.4
Hardening	19.6	6.34	32.3	2.16	1.30	60.2	23.37	11.41	48.8
Total	**28.0**	**8.94**	**31.9**	**9.07**	**5.80**	**63.9**	**56.23**	**33.84**	**60.2**

[1] lbs.=0.4536 kg.

PART II. POSSIBLE REMEDIES

Best management practices (BMP's) for nursery managers are voluntary measures taken to reduce the potential for agricultural contamination of surface or ground water. BMP's include source controls and practices designed to reduce inputs into the nursery production system. BMP's also include practices designed to mitigate any potential harm from waste generated within the nursery production system. For container nurseries, this means a structural control, either containing and treating waste water before release, or containing and recycling water within the nursery. For the scope of this paper, we will focus on source controls [see Landis (1992) for several papers discussing other BMP's]. Regarding N in the nursery production system, we have two source controls: fertilizers, and the volume of water used to carry them.

Water Source Controls

There are several ways to reduce the amount of water discharged during seedling production. Obviously, maximizing the amount of greenhouse area in production allows more applied water to be intercepted by seedlings. Rolling benches can minimize aisle space while still allowing access to all seedlings. The type of irrigation system is also important.

As discussed earlier, 87.5% of the water applied with our traveling boom reached the crop. This efficiency is high compared with other fixed overhead systems (Weatherspoon and Harrell 1980). Traveling boom irrigation systems may have other advantages over fixed systems. Fare and others (1994) report better irrigation efficiency, less leachate volume, and fewer nitrates in leachate when the total volume of water applied to plants was divided into two or three spraying cycles rather than one cycle. Further, plants irrigated in two or more cycles grow similarly to plants irrigated in a single cycle, but with less water (Whitesides 1989; Daughtry 1990; Lamack and Niemiera 1993; Karam and others 1994). Traveling boom systems epitomize cyclic irrigation. In our nursery, the boom travels about 10 ft/min (3 in/ min) so plants receive less than a one second application every 10 minutes. Growers with fixed overhead systems could realize some benefits of cyclic irrigation by dividing the total amount of irrigation water to be applied into two or more parts, allowing a 20-60 minute resting phase between irrigations.

Irrigation frequency has an impact on irrigation efficiency. Timmer and Armstrong (1989) and Langerud and Sandvik (1991) found seedlings grew best when irrigated after containers lost 8-10% of the liquid held at container capacity. Timmer and Armstrong (1989) found better seedling nutrient uptake and Langerud and Sandvik (1991) noted less total fertilizer was needed at this irrigation frequency. Langerud and Sandvik (1991) concluded frequent irrigations with small volumes would reduce both drought and drowning stress on seedlings, thereby yielding a more uniform crop. Developing a container weight scale (using container capacity), which is sensitive to water loss and relatively easy to apply operationally (Timmer and Armstrong 1989), is explained in Landis and others (1989). Besides irrigating sufficiently to saturate the root plug completely, applying enough water to keep salts from accumulating is also important. Landis and others (1989) recommend irrigating the necessary amount to saturate the rooting medium, and an additional leachate fraction of 10% more (based on container capacity) to complete this objective. For example, if seedlings were growing in a 70-ml capacity container and allowed to lose 10% of its liquid at container capacity, it would take 7 ml to saturate the medium and another 7 ml more to leach away salts (14 ml total). As the leachate fraction increases from 10%, the total amount of nitrate leached from the medium increases (Fare and others 1991; McAvoy and others 1992; Yelanich and Blembaurn 1993, 1994).

Once seedlings reach target size and bud initiation commences, less frequent irrigation will help induce buds and begin hardening. Seedlings preconditioned to water stress are known to exhibit a greater decrease in transpiration rates in response to dry soils than seedlings grown without prior moisture-stress (Unterscheutz and others 1974). Seedlings exposed to drought-stress can show increased drought resistance (Zwiazek and Blake 1989) which can translate into improved survival on dry sites (van den Driessche 199 1). Langerud and Sandvik (199 1) found Norway spruce (*Picea abies* seedlings irrigated when containers lost 10% of the water held at container capacity transpired significantly more (32%) than seedlings grown in medium allowed to lose 30% of container capacity. During irrigation in this experiment, we checked medium saturation by extracting sample seedlings and feeling the moisture content of the plug. Of course, finding a dry sample seedling dictates the need for continued irrigation until dry plugs are no longer found. This means, however, those seedlings whose medium saturated early in the irrigation yield larger leachate volumes, and although nitrates may be less concentrated, total nitrates discharged also increase (McAvoy and others 1992). This problem becomes more pronounced with larger seedlings and more moisture stress (70-80% container capacity) because of the hydrophobicity of dry peat moss.

FERTILIZER SOURCE CONTROLS

Using controlled-release fertilizers (slow-release fertilizers) intuitively seems like a viable way to decrease N runoff from greenhouses. However, Hershey and Paul (1982) and Cox (1993) found leachate nitrate could be as high or higher than with water-soluble fertilizers. Split applications and top-dressing applications of controlled-release fertilizers did reduce nitrate leachate better than single applications or medium-incorporated applications (Cox 1993). The rate of nitrate leaching from controlled-release fertilizers is also dependent on species (Brand and others 1993).

At the Research Nursery we have traditionally used water-soluble fertilizers. For this study, we fertilized twice each week, on schedule to avoid weekend watering, during the initial and accelerated growth phases. Most growers apply fertilizer during these growth phases; it is usually at a standard rate, or at least a rate consistent through that particular phase. Ingestad and Lund (1986) developed a method to control relative growth rates by controlling nutrient supplies. Essentially, they found that matching available nutrients with optimum seedling uptake over time is more important to seedling growth than the nutrient concentration in the growing medium. The optimum nutrient supply rate varies by species (Ingestad and Kahr 1985; Burgess 1990, 1991). In a study on red pine (*Pinus resinosa*), a species that grows very slowly like western white pine, researchers using relative addition rates successfully grew a crop with 75% less fertilizer than typically used to grow seedlings to a similar size (Timmer and Armstrong 1987). Obviously, growers could reduce their N discharges if they apply nutrient rates to seedlings at a rate that matches optimum seedling uptake.

This spring, we put in a trial testing relative addition rates on Douglas-fir and western white pine. The basis for relative addition rate fertilization is the equation described by Ingestad and Lund(1979):
$N_T=N\,(e^{rt}-1)$ where r is the relative addition rate required to increase N_s, the initial nitrogen level when fertilization begins, to a final level $N + N_s$, where N is the total amount to be added over t, the number of fertilization applications. For this study, we knew the N concentration and seedling biomass at bud initiation from previous work so we could calculate N content ($N_T + N$) per seedling. We assumed N_s for these species was similar to that used by Timmer and Armstrong (1987) for red pine. We also knew how many weeks we fertilized the crop conventionally (twice per week) which gave us our t value. The equation was then solved for r.

To determine how much N to apply at fertilization, the above equation was modified to account for N previously applied:

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

where $N_{(t-1)}$ is the cumulative amount of N added.

Noting we used two different formulations of fertilizers for this experiment is important. Conventionally-fertilized seedlings received conventionally-applied water-soluble fertilizers following our current regimes (Wenny and Dumroese 1987b, 1992) but seedlings grown with relative addition rates were fertilized with a liquid fertilizer applied with a watering can. A similar volume was applied to each treatment. A liquid fertilizer was used because extremely low ppm's of nutrients were required during the early fertilizations, and that, coupled with needing only small quantities of solution, made measuring and/or diluting water-soluble fertilizers impractical.

Two weeks after sowing, the conventionally grown Douglas-fir seedlings received 42 ppm N twice each week for four weeks and then 120 ppm N twice each week for six weeks. Seedlings receiving relative addition rate were also fertilized twice each week, but they started at 4 ppm N and by week 12 the final application was only 62 ppm N. At this point budset was initiated and all seedlings were fertilized the same. Heights and calipers (root collar diameters) of Douglas-fir when budset was initiated and one month later are shown in Table 3.

Table 3. Heights and calipers of Douglas-fir and western white pine seedlings grown with relative addition rate fertilization and conventional fertilization.

	Douglas-fir		**Western white pine**	
	Bud initiation	One month later	Bud initiation	One month later
Height				
Conventional	20.5 a	24.7 a	9.1 a	9.8 a
Relative Addition Rate	17.3 b	21.2 b 8.8 a	10.1 a	
Caliper				
Conventional	1.43 a	2.24 a	2.03 a	2.65 a
Relative Addition Rate	1.42 a	2.25 a	1.72 b	2.30 b

Means for heights and calipers within columns followed by different letters are significantly different at $p<0.05$ using Tukey's HSD.

There were no differences in caliper growth, but seedlings grown with relative addition rate were shorter. However, since caliper is a better indicator of stock viability than height (Chavasse 1977; Duryea 1984; Ritchie 1984; South and others 1993), the shorter height may be beneficial. Basically, we grew the same seedling by applying 7.4 mg N with relative addition rate and 25.7 mg N traditionally (60% less fertilizer). One month later, seedling sizes were still similar. It is important to note several other indices of seedling viability were not tested (seedling biomass, shoot-root ratio, N concentration and content).

Western white pine height growth for conventionally-grown seedlings was similar to those grown with relative addition rates but caliper in the relative addition rate seedlings was significantly reduced. The difference may be partially attributable to the reduced amounts of calcium delivered to seedlings fertilized with relative addition rates since calcium is important in cell wall formation and promotes sturdiness during hardening. Our western white pine grown conventionally receive appreciable calcium (184 ppm) once each week during the accelerated growth phase.

MANAGEMENT IMPLICATIONS

After examining water and nitrogen discharged from our nursery under operational conditions, it is apparent resources are not being used efficiently. Growers of reforestation and conservation seedlings can improve their water use efficiency by strict adherence to container capacities for deter mining irrigations, irrigating only enough to restore container capacity and leach excess salts (10% extra), and using some form of cyclic irrigation, either a traveling-boom system or breaking fixed overhead irrigation events into two or more cycles with a 20-60 minute rest between cycles. Besides improving irrigation efficiency, these steps should also reduce nitrate leaching from containers. it also appears that relative addition rate fertilization is a viable, if not better, alternative than applying fertilizers at a constant rate. Growing seedlings with significantly less fertilization coupled with less leaching of the fertilizer in our containers should have a significant impact on the quantity and quality of water our industry discharges.

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