Nursery Cultural Practices to Achieve Targets: A Case Study in Western Larch Irrigation

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Abstract: Nursery cultural practices are used to help growers achieve pre-determined size and physiological targets for seedlings. In that regard, irrigation is used to accelerate or slow growth and as a trigger for changing growth phase. In a case study highlighting the effects of irrigation on seedling development, western larch (*Larix occidentalis* Nutt.) seedlings were grown under three irrigation regimes to study seedling irrigation frequency, growth, and instantaneous water use efficiency (WUE_I). Seedlings were irrigated when daily container weights were reduced to 65% of saturated weight (SW), 85% SW, or at 85% SW for 8 weeks and then 65% SW for the remainder of the growing season. Mean irrigation frequency was once per 7.9, 4.6, and 3.8 days for the 65%, 85% to 65% and 85% treatments. Root-collar diameter (RCD) and height of all seedlings measured mid-way through the experiment revealed that seedlings receiving higher irrigation frequency (85%) were more variable in height than those receiving less irrigation. Irrigation regime did not influence final height or dry mass root:shoot. Mean RCD of seedlings in 85% moisture content treatments was only 2.4% larger than seedlings grown at 65% SW, and WUE_I measured on five sample dates during moisture stress periods did not vary between irrigation treatments. Our results show that the environmental costs of increased nursery water use were not justified by a return of increased seedling size and that reduced irrigation decreased variability in seedling height.

Keywords: nursery water use, water use efficiency, seedling crop uniformity

Introduction

Myriad factors influence plant growth: temperature, as a function of season; the form, quantity, and timing of precipitation; light quantity and quality; and nutrient availability being just a few. In a nursery setting, many of these factors are managed to manipulate seedling growth to meet objectives related to crop production and achieve morphological and physiological targets. These nursery cultural practices vary in their impact across species, timing, and intensity.

In the case of irrigation, the challenge is to strike a balance between supplying sufficient quantities of water to maintain and/or manipulate seedling growth at desirable rates to achieve target plant characteristics without being superfluous and wasteful. Frequency of irrigation depends upon the growth phase of seedlings (Landis and others 1989). Irrigation during the establishment phase should maintain sufficient moisture without creating anaerobic conditions that may inhibit seed germination; during the rapid growth phase, irrigation should saturate growing media to maintain high productivity and flush media to prevent the buildup of salts (Landis and others 1998). Practical determination of irrigation needs may be based upon daily sampling of container capacity weights expressed as a percentage relative to saturated weight (Timmer and Armstrong 1989).

In addition to initiating bud set and limiting late-season height growth, the hardening phase in container nurseries is intended to acclimate seedlings to environmental stresses (Landis and others 1998). Water uptake after outplanting is important for seedling growth and survival (for example, Mullin 1963), and nursery irrigation regime affects seedling performance both during nursery production and after outplanting (Duryea 1984; Seiler and Johnson 1985). Mild moisture stress conditioning during July and August increases winter cold hardiness in Douglas-fir (*Pseudotsuga menziesii*) (Blake and others 1979). Moisture stress conditioning during hardening is thought to acclimate seedlings to drought and improve their capability of withstanding additional water limitation after transplanting (Rook 1973). Seiler and Johnson (1985) found that severely moisture-stressed loblolly pine (*Pinus taeda*) seedlings, despite having smaller initial root and shoot volume, demonstrated better field performance than moderate or non-stressed seedlings, and hypothesized that physiological, rather than morphological, changes associated with stress treatment were responsible. Increased root growth and limitation of stem growth are morphological goals of the hardening phase in western larch (*Larix occidentalis* Nutt.) that, as a deciduous conifer, may invest less long-term photosynthates to foliage than other western conifers. Bassman and others (1989) found that irrigation of *Larix* spp. seedlings at 75% of saturated weight resulted in maximum root and stem growth.

As a case study in manipulating irrigation to achieve targets, we present an examination of western larch seedlings grown under three irrigation regimes. The objectives of this study were to: 1) quantify the number of irrigation events required to maintain minimum target moisture content container weights within a plausible range for container-grown western larch seedlings; 2) characterize water use efficiency (WUE) of seedlings grown under these irrigation regimes when provided with ample water (saturation) and across a range of dry-down stress values (container moisture contents); and 3) characterize the effects of these irrigation regimes on seedling morphology.

Methods

Western larch seeds were sown in 1:1 (volume) peat: vermiculite growing medium in Superblock™ (Beaver Plastics, Limited, Acheson, Alberta, Canada) 160/90 mL (5.5 in^3) containers on 30 May 2007 at the University of Idaho Pitkin Forest Nursery (Moscow, ID). Medium was treated with Osmocote Classic Lo-Start 18N:6P_2O_5:12K_2O slow release fertilizer (Scotts-Sierra Horticultural Products Company, Marysville, OH), and seedlings were grown for 4 weeks under normal irrigation. After 4 weeks, three irrigation treatments were applied. Seedlings were irrigated when container weight reached 65% of saturated weight, 85% of saturated weight, or at 85% for 8 weeks and then 65% for the remainder of the growing season. Blocks were weighed daily during the morning and saturated on days when weights were less than 65% or 85% thresholds. Reference saturated weights were determined monthly.

Two sets of intensive measurements and five additional sets of extensive measurements were conducted. Intensive measurements following saturation were taken for three seedlings selected using two uniformly distributed pseudo-random numbers (one for container column and one for row) from each container on 23 to 24 August and 10 September. Intensive measurements included seedling height and root-collar diameter (RCD), root and shoot dry mass after oven-drying for 48 hours at 60 °C (140 °F), net photosynthetic assimilation (*A*), and transpiration (E). *A* and E were measured using a LI-COR® LI-6400 Portable Photosynthesis System (LI-COR® Biosciences, Lincoln, NE). Additional extensive sampling of *A* and E was conducted on 1, 5, and 9 September, as well as 19 and 23 September in order to sample across the range of media moisture content (container weight %). Instantaneous water use efficiency (WUE_I, μmol CO_2 / mmol H_2O) was calculated as $WUE_I = A / E$ (Lambers and others 1998). Final root and stem measurements were conducted on 16 December 2007. Twelve seedlings per container were sampled for height, RCD, and root and stem dry mass with needles off. Container weight data through 30 September were used for comparisons of irrigation timing and frequency.

Using the open-source statistical computing environment, R (R Development Core Team 2008), separate linear mixed effects models were fit to each response variable of interest (WUE, height, RCD, root-to-shoot dry mass) at each intensive measurement date and for the final measurements. While the initial study was established as a randomized complete block design with three treatment levels and three replicates, one of the replicates was removed mid-way through the experiment due to a high concentration of phosphoric acid inadvertently applied during irrigation. Separate linear mixed effects models of each response variable of interest were fit for post-saturation conditions for each intensive sampling date and final measurements.

Results

From 8 July to 30 September, the frequency of irrigation events differed between irrigation treatment (Figure 1; *P*=0.0088). Maintaining 20% higher minimum container weight required 52.1% more frequent irrigation. Containers irrigated at 85% of saturated weight required irrigation once in every 3.8 (SE 0.4) day period, while those irrigated at 65% required irrigation once every 7.9 (SE 1.5) days. This higher frequency irrigation required 135% more total irrigations. Those irrigated 85/65 required watering every 4.6 days

WUE_I of seedlings after saturation of growing media did not vary between irrigation treatment levels after 8 weeks, after the first dry-down period, nor after the second dry-down period. WUE_I, however, increased over time in all treatments during the hardening phase (Figure 2). Seedling WUE_I on the five sample dates during dry-down periods did not vary between irrigation treatments levels. A simple linear, least-squares fit of WUE_I regressed upon container weight for all moisture stress sample dates, across all treatments, showed that container weight explained less than 3% of the variation in WUE in this study (R^2 =0.028).

After 8 weeks of treatment at alternative irrigation regimes, there were no differences in seedling height, RCD, or root:shoot dry mass between treatments. RCD and height of all seedlings measured in a full-tally inventory mid-way through the experiment (21 to 24 September) revealed that

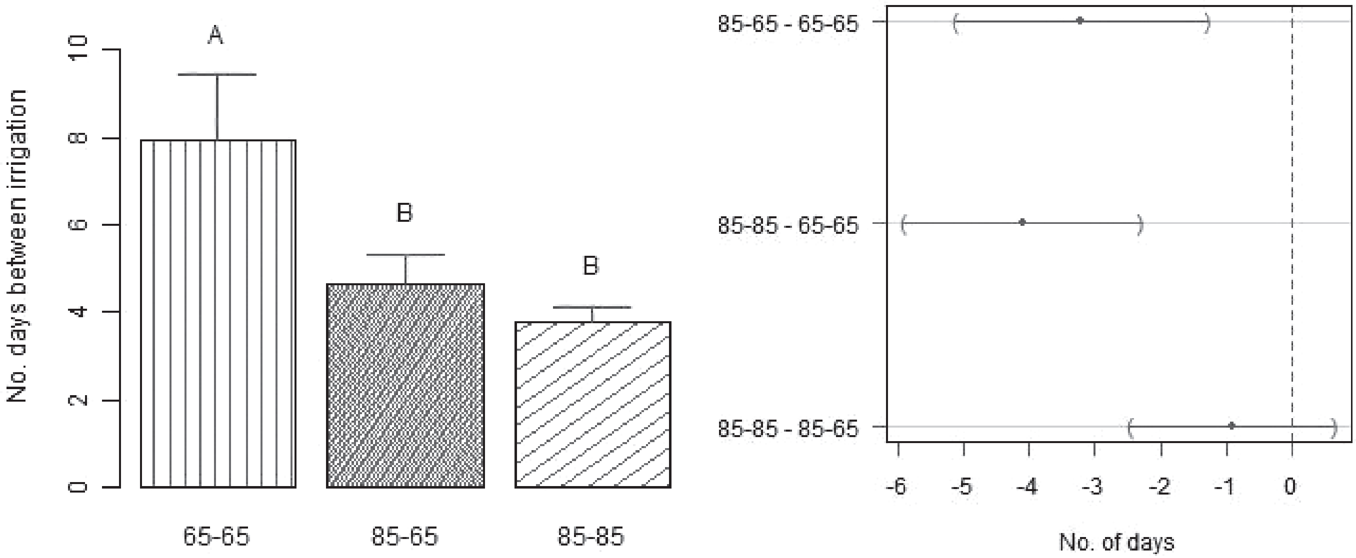

Figure 1. Mean number of days between irrigation plus one standard error for each of three irrigation regimes (left). Difference in mean number of days between irrigation events (Tukey type) and 95% confidence interval for *Larix occidentalis* seedlings grown under three irrigation regimes (right).

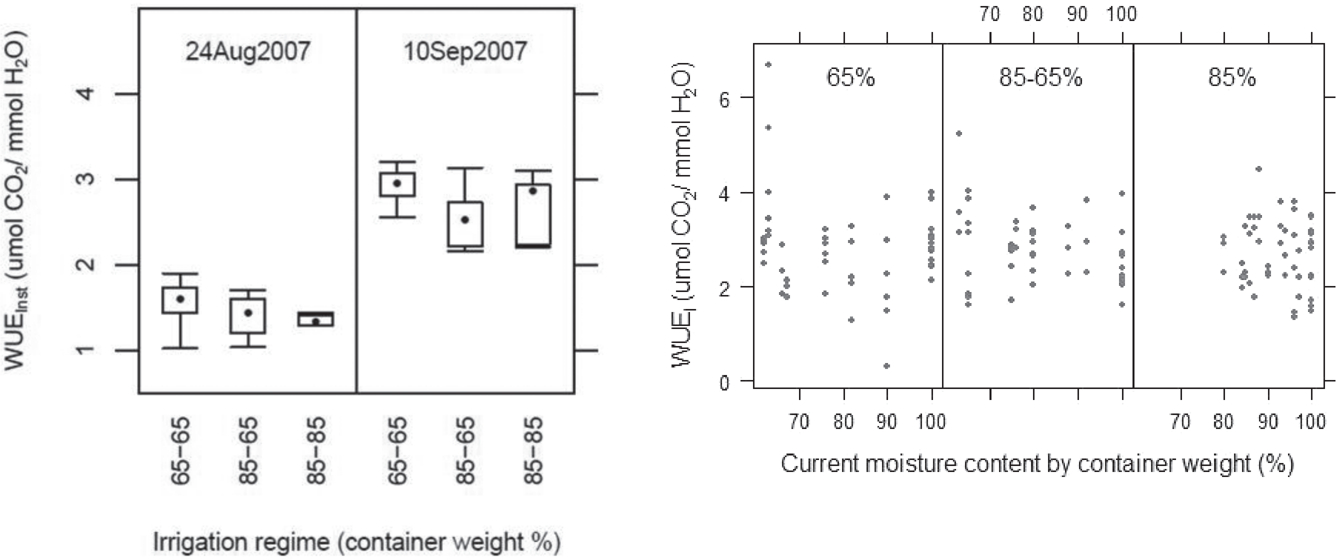

Figure 2. Water use efficiency (WUE$_I$) of *Larix occidentalis* seedlings following saturation for three irrigation regimes (left) and at varying levels of media moisture content throughout the growing period (right).

heights of seedlings receiving higher irrigation frequency (85%) were more variable than those at lower treatment levels (Figure 3). When final seedling size measurements were conducted in late December, differences were detected in mean RCD (*P*=0.016; Figure 4), but not seedling height or dry mass root:shoot (data not shown).

Discussion

Irrigation at 85% minimum moisture content, rather than 65%, required more than twice as much water use in the nursery. Morphological differences due to alternative moisture regimes were only observed in final mean RCD, which was 2.4% larger in the 85% irrigation regime than

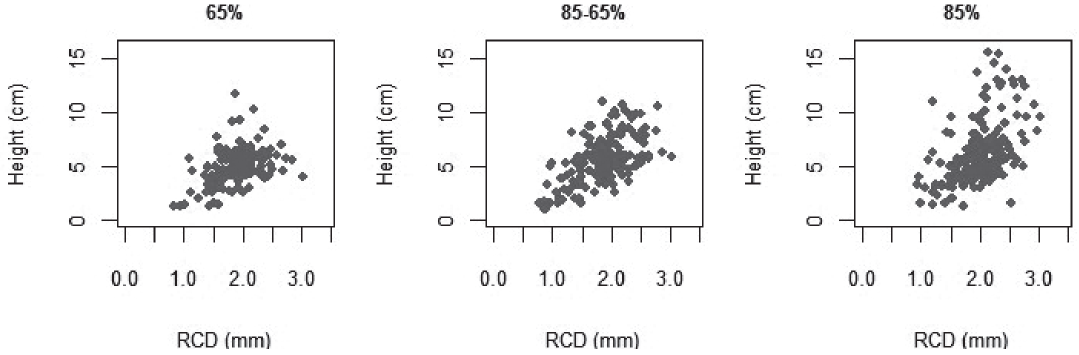

Figure 3. Root-collar diameter and height relationship of all seedlings for each of three irrigation regimes on 21 September 2008.

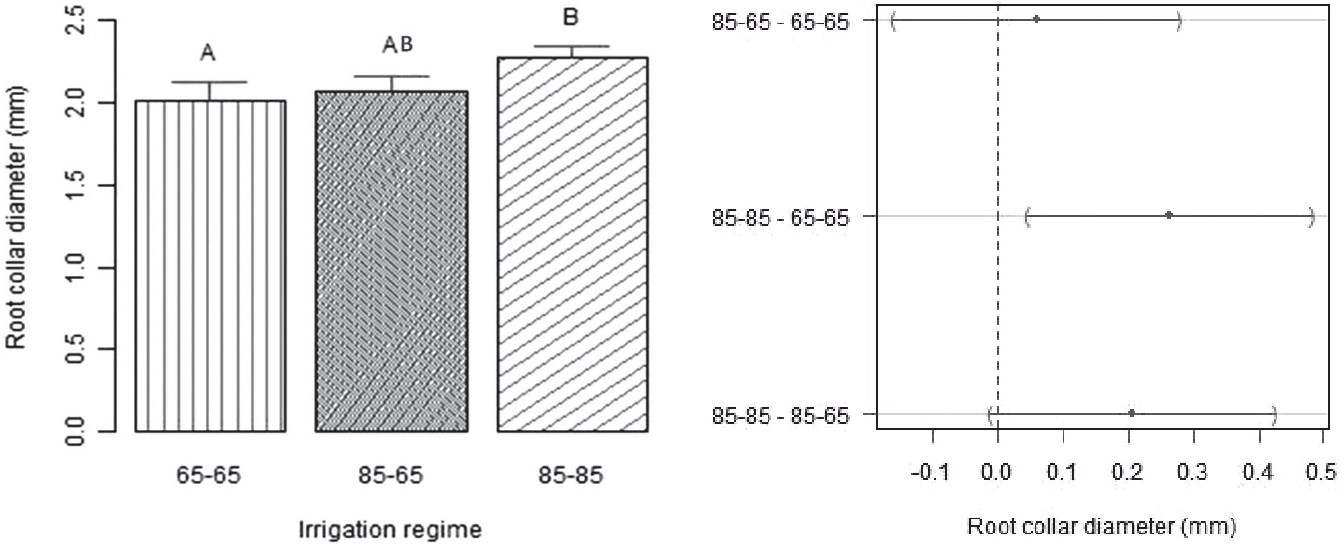

Figure 4. Western larch seedling root-collar diameter (RCD) following one season of nursery culture under three irrigation regimes (left); mean RCD plus one standard error (right). Difference in mean RCD is at the 95% confidence interval.

in the 65%. That final seedling height did not differ across irrigation regimes contrasts the findings of Royo and others (2001), who found differences in seedling height and RCD between moisture stress treatments in Aleppo pine (*Pinus halapensis* Mill.). That may be due to the growth habit of *Larix* versus *Pinus* spp. It should be noted, however, that well-watered seedlings exhibited the greatest variability, and thus lack of uniformity, of the three treatments at the end of the growing period (Figure 3). These impacts could lead to differences following outplanting, as lower relative height growth after field planting has been found in Douglas-fir seedlings given frequent irrigation treatments (van den Driessche 1992), in Douglas-fir and ponderosa pine (*Pinus ponderosa*) (Helgerson and others 1985), and in Allepo pine (Royo and others 2001).

While we hypothesized that greater WUE_I would be observed in seedlings treated with less frequent irrigation during hardening, differences in WUE_I were not detected between treatments after seedlings received saturation, nor did WUE_I vary between irrigation regimes at varying levels of moisture stress during the two dry-down periods. The extent to which plants lose water relative to the amount of CO_2 assimilated during photosynthesis at a given time is a measure of their WUE_I (Lambers and others 1998). This indicates that moisture stress was likely not limiting plant growth during the study period, a result that should be considered in designing irrigation regimes for western larch.

Our research provides evidence that seedling morphological and physiological gains from increased irrigation frequency in western larch did not justify the environmental or financial cost of added nursery water use. A post-hoc hypothesis of interest, based on our research and review of related earlier studies, is that the relationship of moisture stress during hardening and transplanting performance may depend more on fine details of root architecture than are exhibited either by root mass, the relationship of below- and above-ground mass, or WUE_I. It seems plausible, for example, that a mechanistic benefit of mean root diameter, or the distribution of root diameters, from adaptive root growth may facilitate equilibration with soil water potentials that are increasingly negative as moisture becomes tightly held in small pore spaces in drier soils.

Conclusion and Future Directions

In order to maintain a 20% higher minimum block weight percentage of saturated weight, it was necessary to increase total irrigation by 135%. However, there was not a corresponding increase in seedling growth. The environmental and economic savings of using a lower minimum block weight as the point of irrigation was justified. Further studies are needed to identify specific seasonal irrigation patterns to optimize seedling production while minimizing inputs. Further research should focus on characterization of the relationship between fine root architectural relationships as they relate to the soil pore size-water potential continuum, growing media, and conductance in western larch.

This case study highlights that cultural practices, such as irrigation, can have short-term and lasting effects on seedling size. For western larch, growers might find that a significant reduction in water yields decreases height growth and/or increases uniformity, both of which are desirable for such a species.

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