Using Subirrigation to Grow Native
Plants for Restoration

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Abstract

Subirrigation (SI) watering systems are receiving increased attention in native plant nurseries as water conservation becomes an ever growing concern throughout the natural resources community. In 2013, we investigated the characteristics of four different types of fertilizer using a subirrigation regime for 18 weeks; our study species was red-flowering currant (*Ribes sanguineum*). Treatments included: organic fertilizer (OF), incorporated; controlled-release fertilizer, incorporated (MF) or top-dressed (TF); and water-soluble fertilizer (SF). Results revealed seedlings potted with OF used significantly less water than all other treatments. Media electrical conductivity (EC) levels were significantly higher in the OF treatment, and EC values in the top portion of the media were significantly higher than the middle or bottom portions for all fertilizer treatments. The remaining SI water at the end of 22 weeks held 17% of applied nitrogen from the water-soluble fertilizer and less than 1% of applied nitrogen from the other fertilizer treatments. There were no differences in plant morphological characteristics and similar quality plants were produced among all fertilizer treatments under a SI system. Seedlings were outplanted in May 2014 under two vegetative competition types; landscape fabric was used to create plots with low competition (LC), and existing vegetation was contained in other plots to create high competition (HC). We examined the effects of fertilizer type and competition on seedling morphological and physiological characteristics in the field. There were no residual effects from the fertilizer types used during nursery cultivation. Growth and net photosynthesis rates were significantly higher in LC plots compared to HC plots. Significant differences occurred between competition types in predawn and midday water potentials over the growing season. Volumetric soil water content was significantly higher in the LC plots in the upper soil profile (10 cm) June – September, while significant differences at the 40 cm soil depth occurred during August only. Vegetative competition for soil water limited seedling success. Seedlings grown in HC plots had significantly lower root-collar diameter and height measurements than plants grown in LC plots. We conclude that a variety of fertilizers can be used to grow red-flowering currant under SI; although, some fertilizers may require more management care than others. Furthermore, red-flowering currant seedlings establish more readily on sites without competing vegetation.

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Dedication

For Chris Street, always with us.

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Chapter One: Using Subirrigation to grow *Ribes sanguineum*

Abstract

Subirrigation watering systems are gaining recognition in native plant nurseries as water conservation measures and wastewater runoff issues gain attention. While recent studies have focused on determining appropriate fertilizer concentrations for these systems, very few have examined different fertilizer types. We grew red-flowering currant (*Ribes sanguinuem*) seedlings using subirrigation and four fertilizer treatments for 18 weeks to determine any difference in seedling quality. Treatments included: organic fertilizer (OF), incorporated; controlled-release fertilizer, incorporated (MF) or top-dressed (TF); and water-soluble fertilizer (SF). Results revealed seedlings potted with OF used significantly less water than all other treatments. Media electrical conductivity (EC) levels were significantly higher in the OF treatment, and EC values in the top portion of the media were significantly higher than the middle or bottom portions. The remaining subirrigation water at the end of 22 weeks held 17% of applied nitrogen from the SF, and less than 1% of applied nitrogen from the other fertilizer treatments. Fertilizer-use efficiency was similar among all treatments. There were no differences in plant morphological characteristics between the fertilizer treatments, and similar quality plants were produced between all fertilizer treatments. These results suggest than management of fertilizer regimes may be more involved while using OF to mitigate higher soil EC levels, and SF to restrict nutrient losses. The controlled-release fertilizer, whether incorporated or top-dressed, demonstrated minimal nutrient leaching, high nutrient uptake efficiency, and acceptable media EC levels. Top-dressing while using subirrigation allows greater flexibility of fertilizer applications because it allows additions as well as the ability to tailor regimes for growth stages.

Introduction

Throughout the restoration industry, seedling growers currently are making more environmentally conscious decisions. This includes a broad range of more sustainable practices including recycling plastic pots, using controlled-release and organic fertilizers, composting plant waste, and water conservation practices (Dennis et al. 2010). As water conservation measures and wastewater runoff issues gain more attention in native plant nurseries, the "ebb-n-flow" closed subirrigation (SI) watering system is beginning to gain recognition. This system waters plants via capillary action through the growing medium (Coggeshall and Van Sambeek 2002). Water is moved from a reservoir tank into an application tank where the plants are located. Post-irrigation, water is returned to the reservoir tank to be recycled through the system again at a later time. The main advantages of SI in nurseries include: decreased water use per application (Davis et al. 2011, Dumroese et al. 2006, Ahmed et al 2000); uniformity of crops due to uniform water application (Neal 1989); and recycling of unused water and reduced fertilizer use due to the recycling of nutrients (Landis and Wilkinson 2004).

As growers begin to recognize SI as a sustainable practice, choosing an appropriate fertilizer for individual systems will become an important decision. Recent studies have focused on determining appropriate fertilizer concentrations for use in SI systems, as well as comparing SI to overhead irrigation in plant quality, nutrient uptake, water use, and media EC. Very few studies, however, have looked at these attributes across different fertilizer types while using SI (Klock-Moore and Broschat 2001, Morvant et al. 2001).

Organic fertilizer (OF) use is attractive to such growers as market niches expand for organic nurseries and organic waste byproduct availability increases (Carpio et al. 2005). A U.S. survey of 120 nursery and greenhouse growers in 2009 revealed that 42% of those surveyed were currently using OF (Dennis et al 2010). While the use of OF has been studied in production nurseries (Guihong et al. 2010), the use of these fertilizers in combination with SI has not been widely analyzed. A study conducted by Krucker et al. (2010) found that organic substrate substitutes were successful in producing chrysanthemums (*Chrysanthemum morifolium* Ramat) that were equal to or better in root growth, shoot growth index, and number of flower buds than plants grown in a peat-perlite media while using SI. Because organic nutrients must go through a mineralization process in order for plants to use them, the timing and rate of nutrient release may vary from inorganic fertilizers (Guihong et al. 2010); therefore, growers must familiarize themselves with the necessary cultural adjustments as a result of using OF. Like traditional fertilizers, OF is available in liquid, water-soluble, and controlled-release forms.

It has been demonstrated that the quality of subirrigated plants can be similar or higher when compared to other watering methods. Morvant et al. (2001) determined that SI produced plants with greater dry mass than hand-watered or capillary mat irrigation. Pinto et al. (2008) found subirrigation produced plants with greater dry mass than plants grown using overhead irrigation, while Argo and Biernbaum (1995) found that top watering and SI produced similar shoot growth in plants. One study using SI found that plants grown using a controlled-release fertilizer (CRF) produced higher total dry masses than plants grown using a water-soluble fertilizer (SF) (Morvant et al. 2001). In addition to fertilizer having influence on the quality of plants, it can also impact the growth of plants due to different leaching factors and nutrient release rates. Furthermore, different fertilizer types may also affect carbon assimilation in plants as nutrient release rates vary among fertilizer types.

Greenhouse facilities often use SF or CRF to grow crops. While SF has been used with SI systems, it is recommended that these fertilizer concentrations be reduced to obtain quality plants (Klock-Moore and Broschat 2001, Dole et al. 1994). The use of SF with SI can result in a higher percentage of nutrients leaching in an open SI system, where the water is not recycled, because a portion of the fertilizer is being released immediately as runoff after moving through the media (Morvant et al. 2001). Due to the increased nutrients in SI water from liquid or SF, CRF may be a better choice to use with SI. In an open SI system used to grow geraniums (*Pelargonium xhortorum* 'Pinto Red'), Morvant et al. (2001) found that CRF increased nutrient efficiency while liquid fertilization led to higher concentrations of nutrient leaching and no increase in plant quality or growth. When incorporated into media, CRF nutrients are released by moisture in the media for uptake by plants, leading to less fertilizer pollution in leachate and improved fertilizer-use efficiency (Landis and Dumroese 2009).

The placement of CRF (incorporated in the media vs. top-dressed on the media) may influence the rate of nutrient release in the media. Fertilizer prills dry intermittently between irrigation events when top-dressed and therefore release nutrients slower than incorporated CRF (Oertli and Lunt 1962). Because SI involves the upward movement of water into media, CRF that is top-dressed may remain dry and therefore may make nutrient release difficult in this system. In an SI experiment growing New Guinea impatiens 'Illusion' (*Impatiens hawkeri* Bull.), Richards et al. (2004) demonstrated that incorporated CRF exhibited greater plant dry mass than those top-dressed with CRF, suggesting that nutrient release occurred more slowly in the top-dressed treatment. Klock-Moore and Broschat (1999) found no differences, however, in plant growth between top-dressed or incorporated CRF using SI. These results suggest that it is still unclear whether a top-dressed CRF used with a SI system can produce top quality plants.

Different types of irrigation systems may affect media chemical properties such as EC. In closed SI systems, media EC is typically higher than overhead irrigated media because fertilizer salts are recycled. This increase in media EC implies that not only could fertilizer amounts be reduced in these systems (Davis et al. 2011, Dumroese et al. 2011), but also the residual salts could act as a nutrient reserve to be used by the plant at a later time (Dumroese et al. 2006). Managing proper EC levels while using SI during nursery cultivation is important to sustain plant quality. Fertilizer type could influence media EC levels, depending on nutrient release rates and fertilizer placement.

Using SI to propagate horticultural species is well documented, but information on using SI in native plant propagation is limited. Because native plants can be outplanted in harsh environments, compared to horticultural species, it is important that high quality plants are produced during nursery culture to ensure successful establishment. Knowing how different fertilizer types influence nursery culture and seedling quality with a SI system will help growers determine which fertilizer is best to use for growing native plants. The objective of this experiment was to determine differences in morphological and physiological characteristics among different fertilizer types while growing red-flowering currant (*Ribes sanguineum* Pursh) using a closed SI system. We also examined the contribution of fertilizer to potential wastewater in a SI system. We hypothesized that red-flowering currant seedlings would successfully grow under a SI watering regime, and morphological and physiological differences would occur among the different fertilizer types.

Methods

Nursery Culture and Fertilization

We grew red-flowering currant, a shrub native to the pacific-northwest and west coast that is frequently planted on restoration sites (Houghton and Uhlig 2004; Hobbs and McGrath 1998; Vanbianchi et al. 1994) and ornamental landscapes (Brennan 1996). Styroblock container seedlings (340 ml [Beaver Plastics Ltd, Edmonton, Alberta, Canada]; n = 240) were acquired from the University of Idaho Pitkin Forest Nursery in Moscow, Idaho, and transplanted into 1-gallon pots with Sunshine Mix #4 Aggregate Plus soilless potting media (Sun Gro Horticulture Inc., Elizabeth City, NC). Each treatment and replicate was mixed separately. Four fertilizer treatments were set up for a target N of 1.92 g N seedling^{-1} for 18 weeks. Fertilizers used included: NutriRich Organic 8N-2P_2O_5-4K_2O (Stutzman Environmental Products, Inc., Canby, Oregon), Osmocote Pro Control Release 17N-5P_2O_5-11K_2O (3-4 month) (Everris NA Inc., Charleston, South Carolina), and Peter's Professional 24N-8 P_2O_5-16 K_2O water-soluble fertilizer (Everris NA Inc., Charleston, South Carolina) (Table 1). Gale et al. (2006) found on average that 60% plant available N was contained within the OF over a 70-day growing period; thus additional fertilizer was added to this treatment to ensure equal target N rates. The SF treatment was added to SI buckets once per week on the same day for 18 weeks (0.17 g N week^{-1} • 18 weeks = 1.92 g N seedling^{-1}). The transplanted seedlings were grown in Carnation, Washington under a Cravo Retractable Roof Greenhouse with ambient lighting for 22 weeks (Cravo Equipment Ltd., Brantford, Ontario).

Subirrigation System

For this experiment, a manually operated, "ebb-n-flow" SI system was constructed (Figure 1). Five benches were built to hold four cement mixing trays (Plasgad Advanced Logistic Solutions, Kibbutz Gadot, Israel) (0.61 x 0.91 x 0.20 m). Each tray was outfitted with four plastic risers so that each pot was capable of air-pruning roots; the risers were designed to not impede SI. A hole was drilled into the middle of each tray (1.9 cm diameter) for drainage. A rubber stopper was used during SI and removed after to allow the remaining water to drain into a bucket. Each individual tray had its own assigned bucket. Buckets were outfitted with a filter (tulle fabric) over the top to catch debris, as well as a bucket lid with a drilled hole to act as a splashguard as the water drained. In this system, water was poured from 5-gallon (gal) buckets into the trays to saturate plants. Trays were randomly rotated once every two weeks within and among SI benches to minimize microclimate differences.

To protect the SI water from debris, airborne pathogens, and algal growth, a second lid (with no hole) was placed on the bucket after watering. Buckets were covered with a white blackout cloth (Rockland Industries, Baltimore, Maryland) while not in use, to discourage algal growth throughout the experiment. Buckets were cleaned with a phosphate-free soap (Biokleen, Vancouver, Washington) once a month.

Subirrigation Methods

Irrigation scheduling was determined by gravimetric water content (GWC) (White and Marstalerz 1966) using a pot plus media as a system unit (randomly selected from each tray). Seedlings were irrigated when GWC reached a target dry down percent of field capacity. These pots were labeled and used as indicators for subsequent irrigations. Indicator plants were weighed each day until the pot plus media unit reached the target dry down of 75 percent (%) (weeks 1-11), 65% (weeks 12-15), and 50% (weeks 16-22).

Once the target dry down was reached, the tray was subirrigated for one hour. The first SI event for each tray involved filling each 5-gal bucket with 16 liters (L) of water and pouring it into the individual trays. After an hour, the rubber stoppers were removed from the trays and the water drained back into each 5-gal bucket for 15 minutes. The water in the buckets was retained and reused. Throughout the study period buckets were maintained at 16 L. When the SF fertilization ended at 18 weeks, SI at the target dry down of 50% continued for four more weeks for all treatments. Afterwards, three randomly chosen plants from each tray (n=60) were chosen for destruction. Destruction of the seedlings included separating the roots, stems, and leaves, placing the individual parts into paper bags, and drying the samples in an oven at 60 degrees Celsius (°C) for 72 hours (hr.). Individual root volumes were obtained following the methods of Harrington et al. (1994). Dried samples were sent to A&L Great Lakes Laboratories, Inc. (Fort Wayne, IN) for nutrient analysis.

Measurements

Irrigation data was recorded in detail so that water use could be calculated for all treatments. Water use efficiency (WUE) was determined at the end of 22 weeks by dividing total plant mass (g) by the total amount of water applied (L) throughout the experiment. After each SI event, the drainage buckets were weighed to determine how much water the plants used. The EC and pH of the SI reservoir tank effluent were measured after each SI using a Fieldscout EC probe (Spectrum Technologies, Plainfield, IL) and an IQ 150 pH Meter (Spectrum Technologies, Plainfield, IL), respectively. Water samples were taken during weeks 3, 9, 14-18, and 22 from all 20 buckets directly after watering events. Samples were sent immediately to JR Peters Laboratory (Allentown, PA) for nutrient analysis. Media EC and pH levels were monitored weekly with the Fieldscout EC probe and the IQ 150 pH meter. Measurements were taken from three plants in each tray at three different depths in the pots: 2 cm below the media surface, 8 cm below the media surface (the middle of the pot), and 2 cm above the bottom of the pot.

Height and root-collar diameter (RCD) measurements were performed weekly. Foliar samples (5 g, fresh weight) were taken for nutrient analysis (A&L Great Lakes Laboratories, Fort Wayne, IN) from one plant in each tray. Prior to shipping, sampled leaves were agitated in deionized water and phosphate-free soap for 10 seconds, towel dried, and placed in paper bags. Fertilizer-use efficiency (FUE) was calculated by dividing total seedling N (g) by total N applied (g). Nitrogen use efficiency (NUE) was determined by dividing total seedling mass (g) by total seedling N (g). Seedling nitrogen concentrations (%) were determined by dividing total seedling N (g) by total seedling mass (g).

During weeks 8, 11, and 14-16 gas exchange measurements were taken on the upper-most, fully expanded leaves of three randomly selected plants from each tray using the LI-6400XT (LI-COR, Lincoln, NE) equipped with a standard leaf chamber (model 6400-02B) with a LED light source. Depending upon weather, measurements were made 3 to 6 hours after sunrise. Three light response curves were averaged to determine photosynthetic active radiation (PAR) settings for the study. Settings on the LI-6400 for all sampling periods were as follows: PAR of 1100 μmol m^{-2} s^{-1}, reference CO_2 concentration of 400 μmol m^{-2} s^{-1}, flow rate at 400 μmol m^{-2} s^{-1}, leaf temperature at 22 °C, and relative humidity of 50 to 75%.

Pest Control

Aphids (*Aphis spp.*) were detected on the plants approximately six weeks after planting. In order to control the aphids, Safer® Brand Insect Killing Soap (Lititz, PA) or Neem oil (Bonide Products Inc., Oriskany, NY) were applied per label instructions to the plants on a weekly basis for six weeks.

Statistical Analysis

This was a randomized complete block design (RCBD) (four fertilizer treatments × five replicates). Statistical analyses were completed using R (Version 3.1.1, The R Foundation for Statistical Computing, 2013). An analysis of variance (ANOVA) was performed to identify differences in water use, SI water EC, pH, and nutrient concentration, foliar nutrition, and seedling morphology among fertilizer treatments. When ANOVA indicated significant differences ($p < 0.05$) among fertilizer treatments, multiple comparisons were calculated using Tukey's mean separation test ($\alpha = 0.05$). A repeated measures ANOVA was used to assess any differences among media EC and pH variables, and net carbon assimilation. When a repeated measures ANOVA indicated significant differences ($p < 0.05$) among fertilizer treatments, Tukey's test was performed ($\alpha = 0.05$).

Once it was determined that the OF had a significantly higher WUE, a post hoc analysis was performed to examine the available water content of the chosen peat-based media with, and without, organic fertilizer. A high-range pressure system and ceramic plates at -0.033 MPa (field capacity) and -1.5 MPa (wilting point) were used to determine the water holding capacity (WHC) of the two media (Klute 1986). Five samples of each media type were analyzed for field capacity and wilting point. Bulk density and the gravimetric water content of each sample were obtained, and soil water content (SWC) was calculated as:

$$\mathrm{SWC} = (D_b \times \theta_m) / D_w$$

where D_b = bulk density of media, θ_m = gravimetric water content, and D_w = density of water ($D_w = 1\ \mathrm{g\ cm^{-3}}$). Once SWC was determined at the field capacity and wilting point of each media sample, plant available water (P_w) was calculated as

$$P_w = \text{field capacity SWC} - \text{wilting point SWC}$$

ANOVA was completed to determine differences SWC.

Results

Water Use and Plant Available Water

Plants treated with OF took up an average of 100.03 L (± 5.66) of water, while plants in the MF, TF, and SF treatments took up an average of 149.09 L (± 3.77) of water over the 22-week span (Table 2). This contributed to a significantly higher WUE in the OF treatment ($p = 0.0090$), averaging $5.6\ \mathrm{g\ L^{-1}} \pm 0.43$ (Table 2). Overall, the OF treatment used 33% less water than other treatments.

The SWC at field capacity was higher in the peat-based media with OF than media without OF ($p = 0.0114$), while there was no difference in SWC at the wilting point between the two medias ($p = 0.3280$) (Table 3). There were no differences in the amount of plant available water between peat-based media and peat-based media incorporated with OM ($p = 0.152$) (Table 3).

Subirrigation Effluent EC and pH

The SF treatment, which received weekly fertilizer applications, had significantly higher EC levels in the SI water than other treatments ($p < 0.0001$) (Table 2). The weekly application of the SF treatment produced significantly higher N concentrations in the SI water than other treatments ($p < 0.0001$) (Figure 2). The pH value of the SI water was significantly lower in the SF than MF and TF treatments ($p = 0.0190$) (Table 2).

The OF treatment had significantly higher media EC values than other treatments over half of the growing season ($p < 0.0001$). There were significant time × treatment interactions with OF having significantly higher EC values than the other treatments during weeks 1 and 10 ($p < 0.0001$ and $p = 0.0363$, respectively) (Figure 3). During week 21, SF had significantly higher EC values than the MF treatment ($p = 0.0122$) (Figure 3).

Overall, the EC level in the top layer of media was significantly higher than the middle or bottoms layers ($p < 0.0001$). There were significant time × layer interactions with the bottom layer of media having significantly higher EC levels than the top layer during week 1 ($p = 0.0207$) (Figure 4). During week 10, the top layer of media had significantly higher EC levels than the other layers ($p < 0.0001$), and EC levels were significantly higher in the top layer than the middle layer during week 21 ($p = 0.0157$) (Figure 4).

Media pH values were significantly higher in the OF treatment ($p = 0.0020$) than the TF or SF treatments. All treatment pH values ranged between 5.6 - 5.8, which are in the optimum range for growing plants (Dumroese et al 2009). There were no differences in pH among media layers between treatments ($p = 0.0600$). The average media pH was 5.7 ± 0.03.

Seedling Morphological and Physiological Parameters

No differences were detected among treatments for final root volume (100.34 g $\pm$ 2.92), root mass (21.77 g $\pm$ 0.86), stem mass (20.21 g $\pm$ 0.59), or leaf mass (8.24 g $\pm$ 0.29). Total seedling mass was similar among all fertilizer treatments and averaged 50.21 g $\pm$ 1.40. Plant height and stem caliper were similar among all treatments (Table 4), and all treatments displayed similar growth patterns (Appendix A, Figures 1 and 2).

Analyses of final individual root, stem, and leaf N concentrations, as well as total seedling N concentrations revealed no differences between treatments (Table 4). FUE was similar between all treatments (Table 4). The NUE of SF was significantly lower than MF ($p = 0.0008$) (Table 4). Seedlings with SF had significantly higher % N concentrations than the other fertilizer treatments ($p = 0.0009$) (Table 4). Net photosynthetic rates were similar among treatments each of the three times measurements were taken (average = 7.91 µmol m^{-2} s^{-1} ± 0.43) ($p = 0.1365$).

Discussion

Water Use and Plant Available Water

Seedlings grown in the OF used considerably less water than the other fertilizers treatments. With the use of OF increasing in greenhouse production, changes in media physical properties may need to be taken into consideration. The addition of organic matter has shown to increase the WHC of soil (Hollis 1977). Here, the OF treatment used ~50 L less water than the other treatments and had the highest WUE during the growing season. Because there were no differences in plant mass among treatments, the decreased water use may be attributed to the physical properties of media incorporated with OF, specifically SWC.

Post hoc analysis revealed no differences in SWC of P_W between the peat-based media with or without OF. The SWC at field capacity was higher in the media incorporated with OF; although, the saturation weights of the indicator pots were similar among all fertilizer treatments. Because a complete media water retention curve was not developed for either media type, it is difficult to determine a full understanding of plant water availability differences among the treatments. Also, physical properties of the fertilizer itself could affect media physical properties as well as media-water relations. With OF gaining attention in greenhouse use, further research needs to be conducted in order to understand how OF affects water-use and media physical properties.

Subirrigation Water Analyses

The subirrigation water with SF had the highest EC (Table 3) and contained 17% of N applied after 22-weeks, while the SI water of the other treatments contained less than 1% of N applied after 22-weeks (Figure 4). This is due to nutrients being immediately available as a SF after a SI event, and implies that SF concentrations could be lessened because nutrients are recycled in a closed SI system. Morvant et al. (2001) found similar results when comparing a constant liquid fertilizer (CLF) to a CRF growing geranium (*Pelargonium xhortorum* 'Pinto Red") seedlings using an open SI system. Not only were EC values higher in the collected CLF leachate, the percentage of N lost through leaching was 34% in a CLF treatment, while a CRF treatment leached 1.7% of N applied (Morvant et al. 2001).

Soil EC

Analysis of media EC revealed that there was a main treatment effect with OF having significantly higher EC values than the other treatments. This suggests that nutrient availability or release was high in this treatment. Similar results were found when measuring the EC of substrates amended with organic fertilizers while growing hand-watered marigolds (*Tagetes patula* L. 'Janie Deep Orange') (Guihong et al. 2010). However, there was a significant time × treatment effect, with SF having significantly higher EC values than MF in week 21; OF and TF treatments were similar to SF values. This indicates that weekly fertilizers additions to the SI water led to higher salt accumulation in the media of the SF treatment towards the end of the growing season.

Salt accumulation is common in the top portions of growing media when using SI. The cause is likely due to water evaporation at the media substrate surface (Argo and Biernbaum 1995) or because of the lack of roots in the upper portion of the media (Todd and Reed 1998; Kent and Reed 1996). In this study, all fertilizer treatments exhibited higher salt accumulation in the top layer of media compared to the middle or bottom layers. This is similar to other SI studies and can be contributed to the upward movement of the SI water through the media (Pinto et al. 2008; Todd and Reed 1998; Kent and Reed 1996; Argo and Biernbaum 1995). The EC in the top layer of media in all treatments was 47% higher than the middle or bottom layers, which is similar a study conducted by Pinto et al. (2008) where the top layer of media was 48% higher than the middle or bottom layers of the media while growing a coneflower (*Echinacea pallida* (Nutt.) Nutt.). Although nothing was done to deter high media EC levels here, an application of clear water can help eliminate excess salts (Fisher and Argo 2005).

Nutrient Efficiency

Although there were no differences in seedling mass among the fertilizer treatments, the MF treatment had significantly higher NUE than the SF treatment. This suggests that weekly additions of SF to the SI water effluent decreased the NUE in this treatment. Other SI studies have found that higher concentrations of N can lead to decreased growth while using a SF (Klock-Moore and Broschat 2001; Kent and Reed 1996). However, the % N contained within seedlings was significantly higher in the SF treatment than the other fertilizer types demonstrating that the weekly applications of SF increased % N concentrations in these seedlings. The increased % N stored in seedlings grown with SF may have the potential for continued fertilization once outplanted. Because, the SF treatment N increase did not lead to an increase in seedling mass, it is likely these plants were in luxury consumption. Dumroese et al. (2011) found similar results while growing koa trees (Acacia *koa* A. Gray) using SI. This may have occurred here due to the weekly application and accumulation of SF in the SI water resulting in a lower NUE. As the SF accumulated in the SI water, the fertilizer rate increased for each watering event, which resulted in continual plant N uptake with no additional allocation of plant biomass, thus leading to luxury consumption.

Conclusions

Subirrigation produced plants of similar quality regardless of fertilizer type or application method. The remaining SI water containing SF had more nutrients than the slow-release fertilizers implying that these fertilizer concentrations be lowered to reduce fertilizer waste. Management of fertilization regimes could become more involved to acquire the correct fertilizer concentration while subirrigating with a SF. The OF treatment produced plants comparable to the other fertilizer treatments demonstrating that environmentally safe slow-release fertilizers can be used effectively in SI systems with minimum nutrient loss. Because organic fertilizers have variable release rates and the potential for increased EC levels, a higher degree of nursery culture adaptation may be required. Although there were no differences between the CRF applications in seedling quality, TF offers additional benefits such as: increased precision in applying fertilizer amounts (Cox 1993), and more management control (McNabb and Heser 1997). With these benefits, growers would have the ability to select appropriate fertilizing regimes for individual species while using SI.

Chapter Two: Field Performance of *Ribes Sanguineum* Under Competition

Abstract

Seedling quality is an important component to restoration success. Nursery cultivation techniques can influence morphological and physiological characteristics that increase the ability to perform under harsh conditions. Red-flowering currant (*Ribes sanguineum*) seedlings were grown using a closed subirrigation system and four fertilizer treatments during nursery cultivation in 2013. Seedlings were outplanted in May 2014 under two vegetative competition types. Ten plots were selected; landscape fabric was used to create 5 plots with no competition (LC), and existing vegetation was contained in 5 plots to create high competition (HC). The objective of this study was to examine the effects of fertilizer type and competition on seedling morphological and physiological characteristics during the 2014 field. Results revealed no differences between fertilizer types for any of the measured variables. Growth and net photosynthesis rates were significantly higher in LC plots compared to HC plots. Significant differences occurred between competition types in predawn and midday water potentials over the growing season. Volumetric soil water content was significantly higher in the LC plots in the upper soil profile (10 cm) June – September, while significant differences at the 40 cm soil depth occurred during August only. Subirrigation used with a variety of fertilizer types produced high quality seedlings that performed well in the field. Vegetative competition for soil water access limited seedling success. We suggest removing vegetation before planting red-flowering currant seedlings if budgets allow such a cost. Red-flowering currant may survive among vegetative competition because of phenological differences among competing species.

Introduction

Restoration success is largely dependent upon seedling quality so that establishment can occur quickly and plants can grow competitively after outplanting. High quality plants increase field survival by demonstrating morphological and physiological characteristics that increase the ability to persist under harsh conditions such as low water availability and vegetative competition (Villar-Salvador et al. 2004). Nursery cultivation regimes affect these seedling characteristics, thereby determining how well adapted plants are to the environmental conditions in which they are outplanted (Burdett 1990).

The choice of irrigation system used during nursery culture can affect plant field performance. The “ebb-n-flow” closed subirrigation (SI) watering system is new to native plant propagation and it is gaining recognition as water conservation measures and wastewater runoff issues gain more attention amongst nurseries. Equally, if not more, important to the environmental issues that SI faces are the advantages the system potentially offers for outplanting success. Thus far, SI systems have been shown to increase foliar nutrient concentrations in some native plants (Bumgarner et al. 2008, Pinto et al. 2008), which may improve field establishment (Davis et al. 2011). Bumgarner et al. 2008 found field performance improved with subirrigated versus overhead-irrigated northern red oak (*Quercus rubra* L.) seedlings. In the same study, SI stimulated first-year field root-collar diameter growth by 16% compared to plants grown with overhead irrigation (Bumgarner et al. 2008). Another study found subirrigated koa (*Acacia koa* A. Gray) seedlings performed equally well as overhead irrigated seedlings one year after outplanting (Davis et al. 2011). These findings indicate that SI could further improve seedling quality and field performance.

Fertilizing seedlings produces changes in biomass and enhances survival and growth in the field (Landis 1985), and thus promotes high quality seedlings. While growing Douglas-fir (*Pseudotsuga menziesii* Mirb.) seedlings, van den Driessche (1980) found that seedling size was correlated with foliar nitrogen concentrations, which was directly related to nursery fertilization. Controlled-release fertilizers have the potential for continued fertilization after outplanting. Haase et al. (2006) found significant benefits to using controlled-release fertilizers (CRF) compared to water-soluble fertilizers after outplanting Douglas fir seedlings, including greater foliar nutrient concentration, height, and root-collar diameter. The use of organic fertilizers (OF) is becoming more popular as demand for organic nursery products expand and organic waste byproduct availability increases (Carpio et al. 2005), but the field performance of plants grown with these fertilizers under SI needs analyzed has yet to be analyzed.

Nursery cultivation is a critical component of obtaining quality seedlings. After outplanting, access to soil moisture is important for establishment and growth. For this to happen, seedlings must establish root systems at depths where water is available or have little competition for existing water (Pinto et al. 2012). In order for planted seedlings to establish and access soil moisture, their roots must grow out of the planting hole into the surrounding environment (Burdett 1990).

The Pacific-Northwest experiences wet winters and warm, dry summers (Waring and Franklin 1979), thus exposing growing plants to dry soils from low amounts of precipitation. Reduced stomatal conductance and growth can result from seedlings growing in dry soils (Panek and Goldstein 2001). Dry soil conditions may also be caused by water uptake of competing vegetation (Pinto et al. 2012). Grasses are often able to outcompete seedlings or low shrubs for available resources because of their fibrous root systems (Caldwell et al. 1986; Köchy and Wilson 2000). Furthermore, grass competition has demonstrated the ability to lower seedling water potential (Elliot and White 1987). Numerous studies have shown that planted seedlings are able to establish more readily without competing vegetation because access to water is less challenging (Pinto et al. 2012; Devine et al. 2007; Roberts et al. 2005; Eliason and Allen 1998).

Because woody shrub species are often used in restoration projects, the cultivation and field performance of specific species need to be examined more closely to increase restoration success in regional areas. We chose red-flowering currant (*Ribes sanguineum*), a shrub native to the pacific-northwest and west coast that is frequently planted on restoration sites (Houghton and Uhlig 2004; Hobbs and McGrath 1998; Vanbianchi et al. 1994). The objective of our study was to assess the effects of four fertilizer SI cultural regimes on outplanting field performance. Because site characteristics are also important for plant establishment and success, we examined how vegetative competition would affect growth and survivability of red-flowering currant. We hypothesized that plants establishing without vegetative competition would have better growth and survival rates than plants grown with competition due to their increased accessibility to soil moisture.

Methods

Field Preparation

Red-flowering currant seedlings were obtained from the University of Idaho Pitkin Forest Nursery in Moscow, ID, and grown using four different fertilizer treatments under a SI watering system in Carnation, WA during 2013 (Dunlap 2015). The study site was located on a floodplain in the Snoqualmie Valley near Carnation, Washington. Annual average rainfall is 1581 millimeters (mm). Soil consisted of deep, moderately well drained Nooksack silt loam formed in alluvium on floodplains and low river terraces (NRCS 2014). Grazing occurred at the site over 50 years ago, and the predominant vegetation present was common velvetgrass (*Holcus lanatus*) and bentgrass (*Agrostis spp.*), which are often used for grazing (Gucker 2008; Esser 1994). In April 2014, ten 5 × 5 m plots were arranged in a grid, with 3 m of mowed spacing around the perimeter of each plot. From the ten plots, five were randomly selected to be one of two vegetation treatments, low competition (LC) and high competition (HC). The LC treatment plots were covered with landscape fabric (Dewitt Company, Sikeston, Missouri) to eliminate vegetation, while the vegetation in the remaining five plots was left to grow throughout the field season (HC).

Seedling Installation

In May 2014, once the vegetation under the landscape fabric in the LC plots had died, the HC plots and borders were mowed to begin planting the red-flowering currant seedlings. During May16-20, 16 seedlings were spaced 1m apart and planted into each plot (160 seedlings total). This was a split-plot design with two vegetative competition treatments (whole plots) × four nursery fertilizer treatments (split-plots) × five replications. The growing season lasted for 20 weeks. Because the use of landscape fabric has shown to increase soil temperatures (Clarkson 1960), grass cuttings were placed over the landscape fabric in the LC plots to limit temperature differences between HC and LC soils. Throughout the field season, the LC plots were weeded to keep any competition to a minimum, and the 3 m perimeters around the plots were mowed. To quantify aboveground biomass, a 0.5 m^2 area was randomly chosen in each HC plot and vegetation was clipped at ground level during June and August in the same sample areas. Clippings from each plot were bulked and dried for 96 hours (h) at 60 degrees Celsius (°C), and weighed.

Weather and Soil Measurements

A weather station (model 2900ET, Spectrum Technologies, Inc., Plainfield, Illinois) and data loggers were used to collect weather and soil moisture data. The weather station collected air temperature (°C), relative humidity (%), and rainfall (mm) measurements hourly and stored them on a data logger. Vapor pressure deficit (VPD) was calculated from ambient temperature (°C) and relative humidity (%):

$$\mathrm{VPD} = \left(a\ \mathrm{e}^{\left(\frac{bT}{T+c}\right)}\right)(1 - h_r)$$

where a, b, and c are constants (a = 0.611 kPa, b = 17.502, and c = 240.97 °C), and h_r is relative humidity (%/100; Campbell and Norman 1998). Volumetric soil moisture (θ, $m^3\ m^{-3}$) and soil temperature (°C) measurements were collected hourly in each plot at 10 cm and 40 cm below the soil surface using ECH$_2$O-TE soil moisture probes and Em50 data loggers (Decagon Devices, Inc., Pullman, Washington). During week 5, three HC and LC plots were randomly chosen to collect soil samples to determine any differences between competition types in nutrient concentrations due to decomposition of biomass underneath the landscape fabric. Soil samples were collected again in the same plots during week 16. All samples were sent to A&L Great Lakes Laboratories, Inc. (Fort Wayne, Indiana) for extractable inorganic nitrogen analysis. Soil cores were taken from the same plots and dried for 48 h at 100 °C to obtain soil bulk density (NRCS 1999).

Gas Exchange and Leaf Water Potential

Field gas exchange measurements were taken 6 October 2014, between 0830 and 1200 h to investigate fertilizer and vegetative competition effects. Measurements were conducted using the LI-6400XT portable photosynthesis system (LI-COR, Lincoln, Nebraska) equipped with a standard leaf chamber (model 6400-02B) with a LED light source. Two seedlings from each fertilizer treatment were randomly chosen from each replication for gas exchange measurements (n = 80 seedlings). Settings on the LI-6400 for all sampling periods were as follows: PAR of 1100 μmol $m^{-2}\ s^{-1}$, reference CO$_2$ concentration of 400 μmol $m^{-2}\ s^{-1}$, flow rate at 400 μmol $m^{-2}\ s^{-1}$, leaf temperature at 22 °C, and relative humidity of 50 to 75%.

Two weeks after seedlings were planted, leaf water potential measurements began and continued at four to five week intervals (2 June; 3 July; 6, 7 August; 28, 29 August 2014) to assess competition effects on plant moisture stress. Leaf water potential measurements were taken in the field using a pressure chamber (PMS Instrument Company, Corvallis, Oregon).

Measurements were conducted between 2430 and 0400 h (Ψ_{pd}), and again in the afternoon between 1300 and 1600 h (Ψ_{md}) on the same day. Two seedlings from each fertilizer treatment were randomly chosen from each replication for water potential measurements ($n = 80$ seedlings).

Seedling Growth

Height (cm) and root-collar diameter (RCD) (mm) measurements were taken on each plant during weeks 1 and 20. During week 20, the aboveground biomass of two plants from each fertilizer treatment was collected in each LC and HC plot and dried for 72 h at 60 °C to assess any differences in growth between fertilizer treatments and LC and HC plots ($n = 80$ seedlings).

Statistical Analysis

This was a two-factor, split-plot design, with competition treated as the whole plot factor, and the fertilizer treatments treated as the split-plot factor (two competition types four × fertilizer treatments × five replications). Statistical analyses were completed using R (Version 3.1.1, The R Foundation for Statistical Computing, 2013). ANOVA was used to detect competition and fertilizer treatments differences, as well as competition type × fertilizer treatment interactions for seedling height, RCD, and photosynthesis. When ANOVA indicated significant differences ($p < 0.05$) among fertilizer treatments, Tukey's significant difference test was used to identify significant mean differences at $\alpha = 0.05$. Differences in θ, soil nutrient concentrations, and Ψ_{pd}, and Ψ_{md} between competition types were examined using repeated measures ANOVA.

Results

Site Conditions

At the time of planting, air temperature was 21.2 °C and VPD was 0.21 kPa. Maximum air temperature was reached on 11 August (33.9 °C), and maximum VPD was reached on 4 August (3.6 kPa). During the 20-week study period (20 May to 6 Oct), overall air temperature averaged 16.9 °C and VPD averaged 0.59 kPa. Mean maximum daily air temperature for the season was 22.8 °C, with mean maximum VPD of 1.28 kPa (Figure 5).

Total precipitation between 20 May and 6 Oct was 87.5 mm, and rainfall occurred each month of the study (Figure 6). Soils in the LC plots had the highest temperature at both depths (10 cm = 20.1 °C, 40 cm = 20.6 °C), with seasonal maximums of 24.7 °C and 25.2 °C

(10 cm and 40 cm, respectively). Soil temperatures in the HC plots averaged 17.2 °C and 17.1 °C (10 cm and 40 cm, respectively). Seasonal maximum temperatures in the HC plots were 20.9 °C at the 10 cm depth, and 20.0 °C at the 40 cm depth.

Volumetric soil moisture was significantly different in the LC and HC plots, and at the two different soil depths over the growing season ($p = 0.0400$ and 0.0170, respectively) (Figure 6). For the entire growing season, the interaction of vegetation type × depth was not significant ($p = 0.9130$). In May, there were no differences in θ between competition treatments or depths (Figure 6). Significant differences in θ occurred between LC and HC plots in June and July, but not soil depths (Figure 6). Throughout August, significant differences in θ occurred between LC and HC plots at both soil depths (Figure 6). In October, θ was significantly different between soil depths, but not competition type (Figure 6).

Aboveground vegetation competition biomass was measured in each HC plot twice in the same sample area over the growing season; and averaged at 197.6 g / 0.5 m^2. Soil bulk density was obtained from LC and HC plots to calculate soil nitrate and ammonium concentrations. Average soil bulk density for all plots was 1.05 g cm^{-3} and did not differ between competition levels. During week 5, there were no differences in soil nitrate (NO_3^-) and soil ammonia (NH_4^+) concentrations ($p = 0.152$ and 0.345, respectively). No significant differences were detected between NO_3^- and NH_4^+concentrations during week 16 between LC and HC plots ($p = 0.225$ and 0.374, respectively). Over the growing season, there were significant differences in NO_3^- concentrations between LC and HC plots ($p = 0.0471$), while there were no differences in soil NH_4^+concentrations ($p = 0.3530$). The soil nitrate average was 27.67 g cm^{-3} ± 10.84 in LC plots, and 3.0 g cm^{-3} ± 1.06 in HC plots. Ammonium concentrations in the soil averaged 6.67 g cm^{-3} ± 1.65 in LC plots, and 4.83 g cm^{-3} ± 0.91 in HC plots.

Gas Exchange and Leaf Water Potential

In October, plants within the LC plots had significantly higher net photosynthesis rates than plants in HC plots ($p < 0.0001$). The average net photosynthesis rate was 14.91 $\mu mol\ m^{-2}\ s^{-1}$ (± 0.36) in LC plots, and 10.10 $\mu mol\ m^{-2}\ s^{-1}$ (± 0.78) in HC plots. No differences in net photosynthesis rates were detected between the different fertilizer treatments ($p = 0.9000$).

Over the growing season there were significant differences in Ψ_{pd} between LC and HC plots ($p = 0.0482$) (Figure 7). No differences in Ψ_{pd} were detected during June and July (p =

0.1140 and 0.06150, respectively), but HC plots had significantly lower values for the August and late August dates ($p > 0.0001$ for both dates) (Figure 7). Significant differences occurred over the growing season in Ψ_{md} measurements between LC and HC plots ($p = 0.0422$) (Figure 7). While there was no difference in Ψ_{md} between LC and HC plots during June ($p = 0.6040$), there were significant differences for Ψ_{md} in July, August, and October between the two competition types ($p < 0.0150$ for LC and HC plots) (Figure 7).

Seedling Survival and Growth

In both, LC and HC plots, there were no seedling mortalities except one, which was due to beaver activity. No differences in height or RCD were found among fertilizer treatments. Plants in the LC plots had significantly greater heights and RCD than those in the HC plots ($p > 0.0001$ for both) (Table 5). The interaction effects between fertilizer treatment × vegetation type for height ($p = 0.0970$) and RCD ($p = 0.3542$) were similar. Aboveground biomass was significantly higher in LC plots than HC plots ($p > 0.0001$) (Table 5). No differences were detected in aboveground biomass among fertilizer treatments ($p = 0.5880$), or any interaction effects between fertilizer treatment × vegetation type ($p = 0.6740$).

Discussion

Fertilizer Treatments

While subirrigation watering regimes have shown to improve seedling quality when compared to overhead irrigation systems (Bumgarner et al. 2008), little is known about the use of different fertilizer types with SI during nursery cultivation and their subsequent outplanting effects. This study attempted to tease out the differences among SI and fertilizer types, but unfortunately, no morphological or physiological differences were detected after outplanting. These results suggest that any variability in seedling quality was minimal when considered within the range of outplanting conditions, and that seedlings were of adequate health to survive. The use of CRF has shown to have additional benefits after outplanting including continued fertilization, greater foliar nutrient concentration, height, and RCD (Haase et al. 2006), but our study did not reveal these results. The CRF used during nursery propagation had a 3-4 month release rate, therefore nitrogen stores of the MF and TF treatments may have been depleted once the growing season ended in December 2013, five months after SI began. Because the amount of applied N was set equal among the fertilizer treatments and based on the 3-4 month release rate of the CRF used during nursery propagation, it is possible the OF nutrients had been completely released by the end of the 2013 growing season. The SF treatment had the highest % N concentration at the end of the 2013 nursery phase (Dunlap 2015), suggesting the stored N could aid in continued fertilization once in the field. However, due to the morphological and physiological similarities among fertilizer treatments, there is no evidence that continued fertilization occurred in the SF. All seedlings were overwintered in the nursery, and hand-watered once per month in January and March 2014, and twice per month during April and May 2014. These watering events may have initiated additional nutrient uptake, or flushed out any remaining nutrients in the media before planting began on May 16, 2014. The potting media was not analyzed for nutrient content to determine if residual fertilizers remained before the field season. For these reasons, it is likely that site conditions, soil moisture, and vegetative competition influenced seedling field performance more than the fertilizer treatments that were applied in the nursery during the 2013-growing season.

Physiology, Soil Moisture, and Growth

Access to water is essential for increased stomatal conductance, and therefore photosynthesis. In October, net photosynthesis rates were significantly higher in LC plots than in HC plots, indicating that seedlings were able to access water and grow due to lower water stress from the lack of vegetative competition. In contrast, water potentials were lower in HC plots due to competing vegetation and water stress. Common velvetgrass and bentgrass were the most abundant species throughout HC plots. Velvetgrass has shallow fibrous root systems, occurring in the top 10 cm of the soil (Gucker 2008), and bentgrass species form sod-like mats with stoloniferous or rhizomatous roots (Carey 1995; Esser 1994). Both of these grass species could hinder red-flowering currant roots from establishing and accessing water easily and therefore limit seedling gas exchange rates. In a similar study, while examining the competitive effects of herbaceous vegetation on two oak species (*Quercus macrocarpa* and *Q. ellipsoidalis*), Davis et al. (1999) found that photosynthesis rates were correlated with soil water content, and rates were significantly lower when vegetation was present.

Seedling moisture stress can be quantified by measuring water potential in the field. Ψ_{pd} provides a measure of plant water stress early in the morning, when stress is minimal and plant and soil water are closer to equilibrium (Ritchie and Hinkley 1975). Ψ_{pd} values in HC plots were similar to values in LC plots in June and July, and were significantly lower throughout August. Grass biomass increased in HC plots between June and August indicating that increasing competitive vegetation led to decreased θ and increased water stress as competition for water persisted. Eliason et al. (1997) showed that grass competition significantly lowered California sagebrush (*Artemisia californica* Less.) water potential by outcompeting for available water. Other studies have found similar results while growing tree species with competing vegetation (Pinto et al. 2012; Elliot and White 1987). In contrast, Ψ_{pd} water increased over the season in LC plots. During August and September, θ at the 10 cm depth was at its lowest in LC plots (Figure 6). However, Ψ_{pd} was increasing during this same time period (Figure 7) indicating that seedlings were able to access soil moisture at the 40 cm depth and therefore increase Ψ_{pd}.

Ψ_{md} measures plant water stress during the afternoon, when stress may be higher due to an increase in VPD and plant transpiration rates (Larcher 2003). In June, Ψ_{md} measurements were comparable between the competition types. For the remainder of the season, Ψ_{md} was significantly lower in plots with HC. Competition among other species for available water contributed to these lower values. The LC plots exhibited higher Ψ_{md} values suggesting that higher θ contributed to less water stress during midday. Although water potential values were substantially different between LC and HC plots in October, Ψ_{md} was increasing in both competition types as VPD decreased, and cooler temperatures occurred. We would expect the same pattern in Ψ_{pd} values during October for the same reasons even though no measurements were taken to confirm this.

Red-flowering currants have fibrous root systems that can reach a minimum soil depth of 40 cm (Hort et al. 2013), whereas grasses at the site had rooting depths of 10 cm (Gucker 2008). Once seedlings in HC plots were planted, seedling roots responded to competition for water by accessing water at the 40 cm depth. As water stress increased in HC plots through August and September, root mass may have continued to increase at the 40 cm depth in order to access water. This response would be consistent with a model of whole plant biomass partitioning (Schulze et al. 1983) that predicts that low absorption water rates will be compensated for by increased biomass partitioning to root growth (Kolb and Steiner 1990). Chaves et al. (2002) demonstrated that *Lupinus albus* increased fine root length under water stress, while Kolb and Steiner (1990) found that northern red oak (*Quercus rubra* L.) and yellow-poplar (*Liriodendron tulipifera* L.) responded to competition for soil resources by increasing root mass. In contrast, seedling roots in the LC plots were able to establish without competition, and seedlings were able to access water from the 40 cm soil depth as the upper soil layers dried. Despite decreased θ at 10 cm and 40 cm, plant water stress values indicated water was not limited in LC plots; therefore it is possible these plants were able to allocate more resources towards aboveground biomass. Higher soil temperatures may also influence root system growth, and elevated temperatures occurred in LC plots. Sayer et al. (2005) showed that higher soil temperatures produced greater root systems in pine seedlings. Because root excavation was not conducted it is difficult to speculate what biomass differences occurred between the two competition types.

Morphological characteristics (height, RCD, and shoot biomass) were significantly different between the two competition types. Seedling height in LC plots was 38% higher, and RCD was 24% higher, while aboveground biomass was 136% higher suggesting that vegetative competition was the mechanism stunting seedling growth in HC plots. Eliason and Allen (1997) found that depletion of soil water by competing vegetation led to reduced biomass in *Artemisia californica* plants, while Elliot and White (1987) found that competition for moisture led to reduced growth in *Pinus ponderosa* seedlings.

In addition to high water availability and lack of competition, other variables may have influenced growth within LC plots including elevated concentrations of NO_3^- and higher soil temperatures. Biomass was not removed before landscape fabric was installed. Over the season, vegetation contained under the fabric decomposed and nutrients may have been released. Decreases in soil water evaporation and temperature increases near the surface of landscape fabric have been shown to favor higher soil microbiological populations resulting in the accumulation of soil nitrates (Black and Greb 1962). With limited soil water evaporation and higher soil temperatures in LC plots, accumulation of NO_3^- may have occurred and contributed to seedling growth. Despite the grass cuttings placed over the black landscape fabric to mitigate high soil temperatures, soil temperatures in LC plots were 3 degrees higher than soils in HC plots. The use of plastic mulches has been shown to raise soil temperatures (Clarkson 1960), although decomposition of biomass under the fabric may have also contributed to the elevated temperatures in these plots. Higher soil temperatures are known to increase total plant biomass (Peng and Dang 2003; Domisch et al. 2001).

It is important to note that all seedlings survived, although seedling growth was decreased within HC plots. This suggests that despite competitive effects on seedlings in HC plots, plants were able to capture enough resources to maintain growth and survive. Additionally, because red-flowering currant flowers March through June (NRCS 2008), and grass species at this site flower later (velvetgrass, May – September (Gucker 2008); bentgrass, June – August (Esser 1994)), it is possible that currant plants could outcompete grass species for resources the following spring.

Conclusions

Restoration success depends on nursery cultivation practices to produce seedlings that can establish and survive harsh conditions. As subirrigation is gaining recognition in container nurseries, it is important to understand how plants propagated under this irrigation system will perform in the field. Our data demonstrates that fertilizer choice in an SI system has no residual, short-term impact on outplanting success of red-flowering currant. So long as quality seedlings are produced and used, as were in this study, outplanting establishment and growth is likely to be improved. This study further supports the management of soil moisture for establishment and growth. While there were no differences in survival, biomass accumulation and physiological functioning were much improved in plots were vegetation was controlled. When planting species such as *Ribes sanguineum* for restoration, effective control of competing vegetation will likely result in better field performance.

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Figures

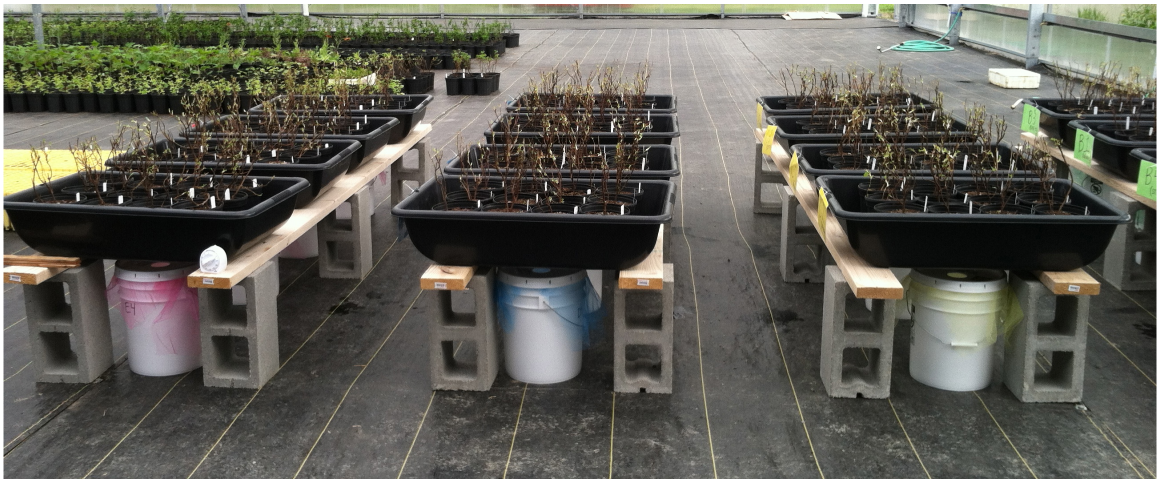

Figure 1. Subirrigation construction design used during the 2013 growing season.

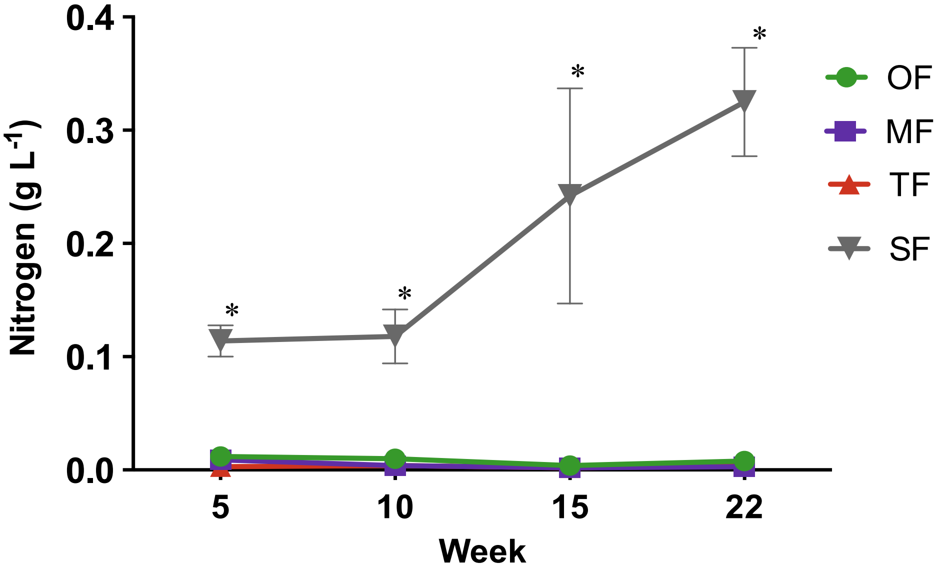

Figure 2. Nitrogen (N) concentration (g L^{-1}) in SI effluent over 22 weeks. Values at each point are mean N concentrations from the five SI buckets in each treatment. Error bars represent the standard error of the mean. * indicates significant differences between treatments at α=0.05. See Table 1 for treatment descriptions.

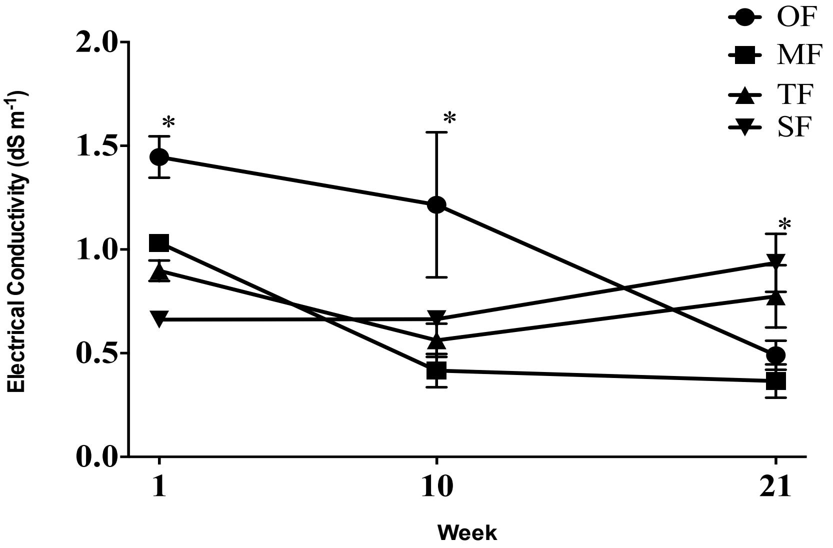

Figure 3. Mean media electrical conductivity of subirrigation effluent for four fertilizer treatments at weeks 1, 10, and 21. Error bars represent the standard error of the mean. * indicates significant differences between treatments at α=0.05. See Table 1 for treatment descriptions.

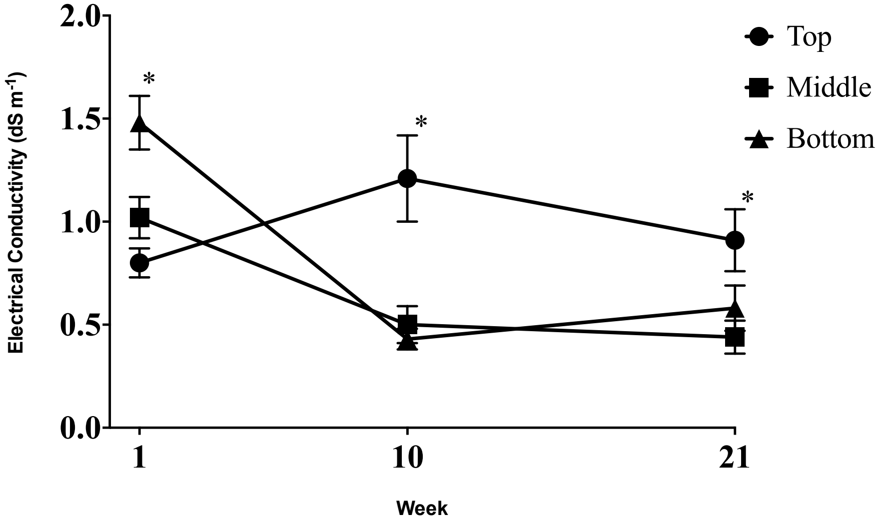

Figure 4. Mean electrical conductivity of container media layers at weeks 1, 10, and 21. Media layers included: top 2 cm of media, middle of media, and bottom 2cm of media. Error bars represent the standard error of the mean. * indicates significant differences between treatments at α=0.05.

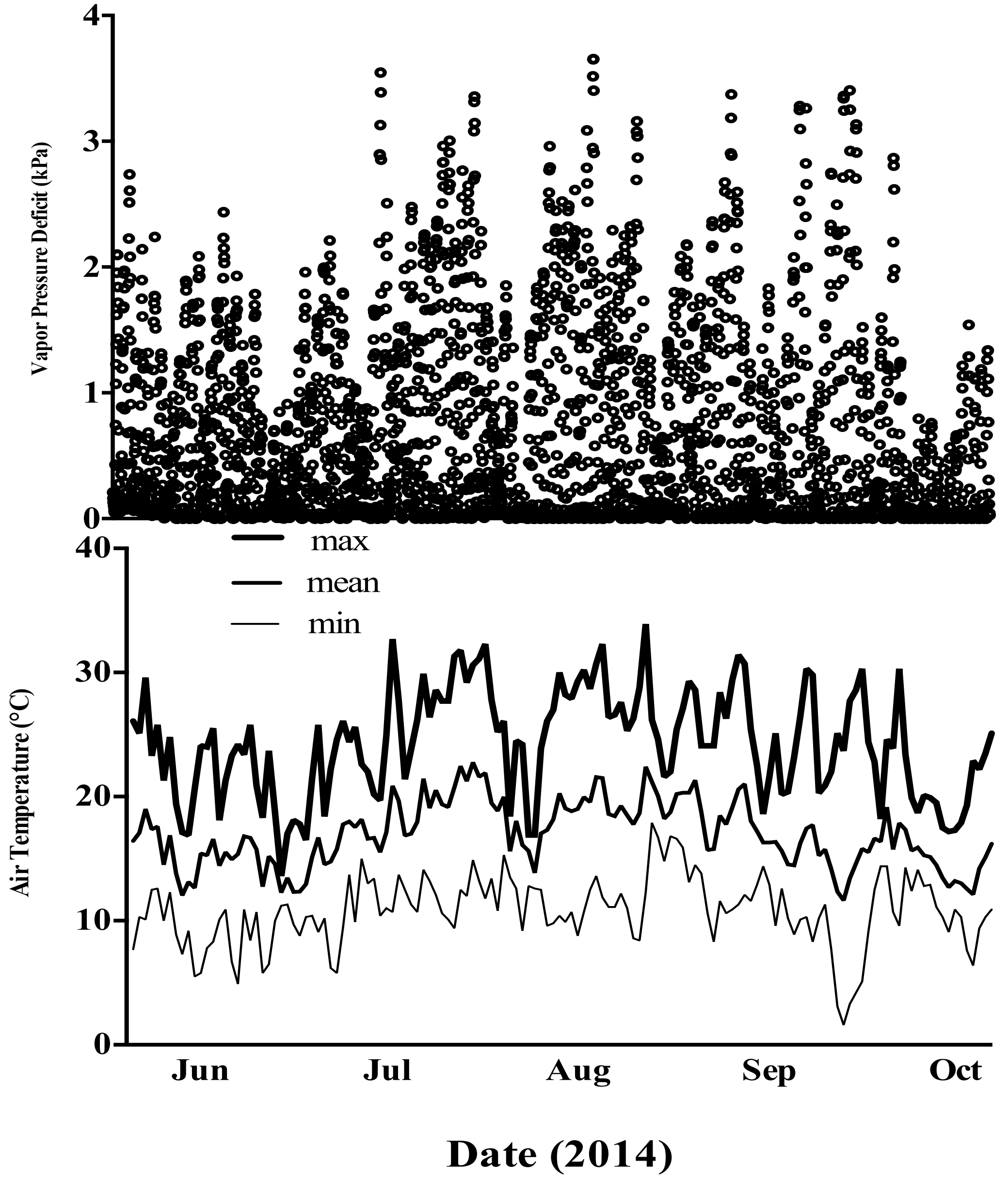

Figure 5. (A) Hourly vapor pressure deficit and (B) daily average air temperature conditions during the 2014 growing season at the outplanting site near Carnation, Washington, USA.

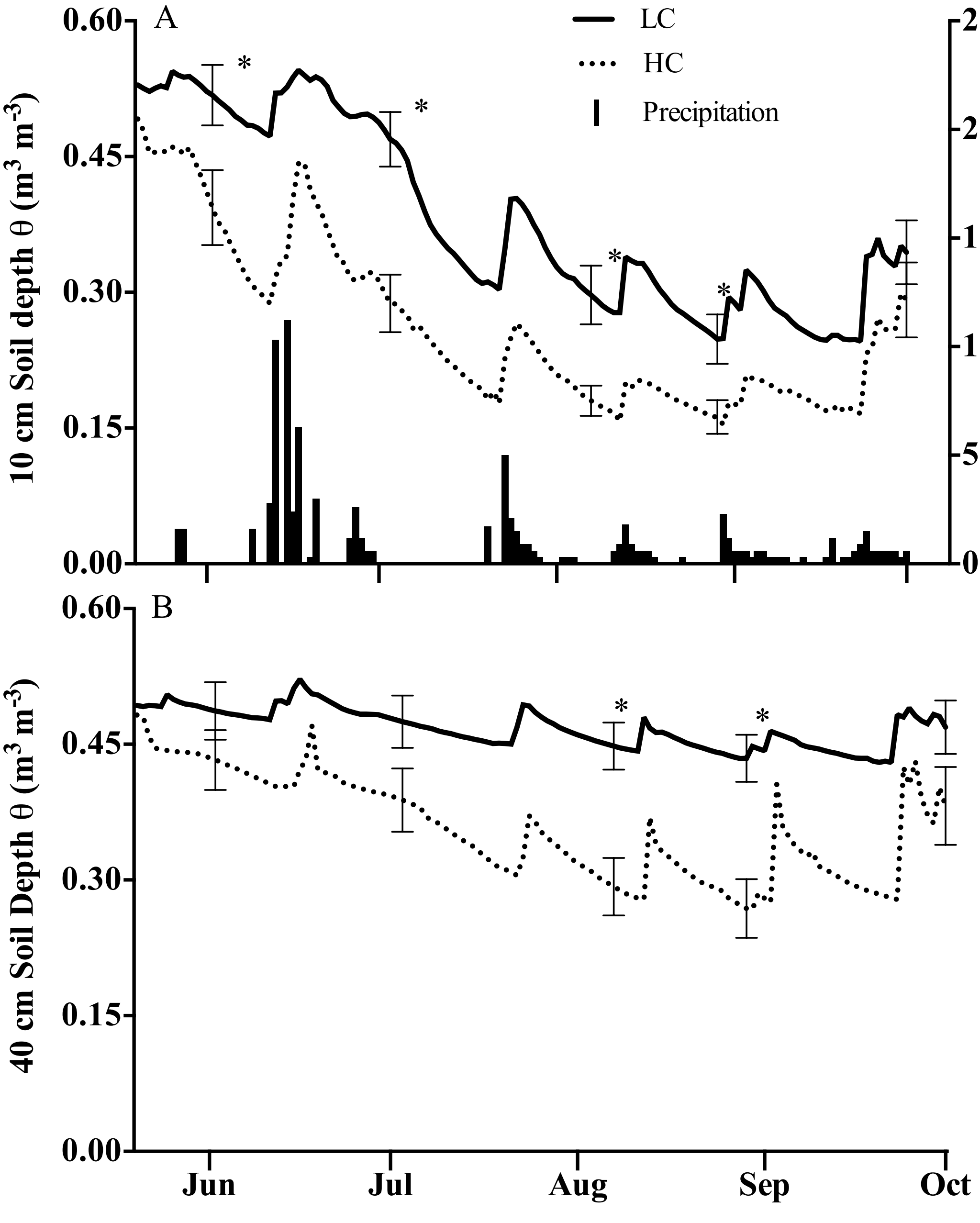

Figure 6. Vegetative competition treatment (solid and dotted lines) volumetric soil content (θ) at 10 cm (A) and 40 cm (B) soil depths, and daily precipitation totals (A, vertical bars) during the 2014 growing season. * indicates significant differences between treatments on dates where seedling physiological measurements were performed at α=0.05.

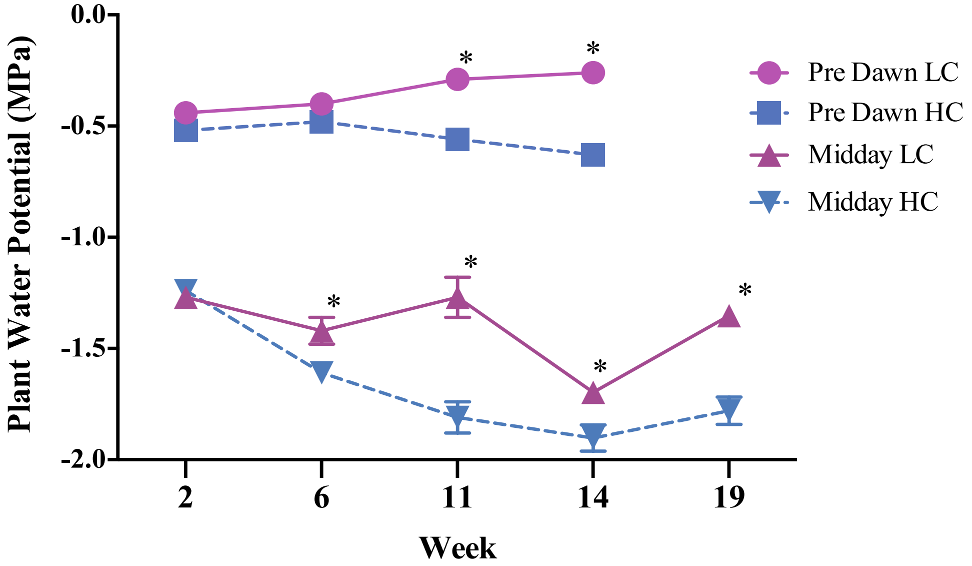

Figure 7. Predawn and midday water potential of red-flowering currant seedlings over the 2014 field season. Each point represents the mean (n=20) across all fertilizer treatments, within each vegetative treatment, no competition (LF, solid line) and high competition (HC, dotted line). Error bars represent the standard error of the mean. * indicates significant differences between treatments on dates where seedling physiological measurements were performed at α=0.05.

Tables

Table 1. Fertilizer treatments, application rates, target nitrogen (N) rates, and methods performed on *Ribes sanguineum* during the 22-week project, n=240.

Treatment	Fertilizer	Target N Rate	Applied Fertilizer Rate	Application Method
OF	NutriRich Organic 8-2-4	1.92 g N seedling^{-1}	40 g plant^{-}	Incorporated into media
MF	Osmocote Pro 17-5-11	1.92 g N seedling^{-1}	11.29 g plant^{-1}	Incorporated into media
TF	Osmocote Pro 17-5-11	1.92 g N seedling^{-1}	11.29 g plant^{-1}	Top-Dressed
SF	Peter's Professional 24-8-16	1.92 g N seedling^{-1}	5.33g tray^{-1}	Granular in SI Water, Weekly

*Contains only 60% plant available nitrogen (Gale et al. 2006). Additional fertilizer was added to this treatment to ensure equal target N rates among treatments.

Table 2. Water use efficiency (WUE) and subirrigation water characteristics. Data shown are statistical means with standard errors in parentheses. Different letters indicate significant differences at α=0.05.

Treatment*	WUE (g L^{-1})**	Amount of Water Used (L)	SI Water EC (dS m^{-1})	SI Water pH Values
OF	5.6 (0.43) b	100.0 (5.66) b	0.27 (0.03) a	6.8 (0.10) ab
MF	4.2 (0.20) a	145.3 (12.95) a	0.17 (0.00) a	6.8 (0.07) a
TF	4.1 (0.23) a	156.6 (6.70) a	0.14 (0.00) a	6.8 (0.05) a
SF	4.1 (0.37) a	145.3 (14.02) a	0.91 (0.08) b	6.5 (0.07) b

*See Table 1 for treatment descriptions.

**WUE = total seedling mass (g) / total amount of water applied (L) over growing season.

Table 3. Soil water content (SWC) at field capacity (0.33 MPa), wilting point (-1.5 MPa), and of plant available water (P_w). Data shown are statistical means with standard errors in parentheses. Different letters indicate significant differences at α=0.05.

Treatment	Field Capacity ($cm^3\ cm^{-3}$)	Wilting Point ($cm^3\ cm^{-3}$)	Plant Available Water ($cm^3\ cm^{-3}$)*
OF with Peat Media	0.36 (0.02) b	0.19 (0.01) a	0.17 (0.03) a
Peat Media	0.27 (0.01) a	0.17 (0.02) a	0.11 (0.03) a

*P_w = field capacity SWC – wilting point SWC

Table 4. Mean seedling height (cm), caliper (mm), seedling mass (g), and seedling nitrogen (g) for each fertilizer treatment. Mean fertilizer-use efficiency (FUE), nitrogen-use efficiency (NUE), and nitrogen (N) concentrations (%) across treatments. Data shown are statistical means with standard errors in parentheses. Different letters indicate significant differences at α=0.05. See Table 1 for treatment descriptions.

	Height (cm)	Caliper (mm)	Seedling Mass (g)	Total Seedling N (g)	FUE (g seedling N • g N applied^{-1})	NUE (g seedling • g seedling N^{-1})	N Concentration (%)
OF	55.6 (1.77) a	8.4 (0.37) a	46.9 (5.20) a	0.74 (0.06) a	38.3 (2.91) a	62.0 (2.29) ab	1.6 (0.07) a
MF	56.4 (1.16) a	9.1 (0.25) a	50.6 (6.08) a	0.71 (0.05) a	36.9 (2.71) a	70.5 (4.25) a	1.4 (0.10) a
TF	57.9 (1.25) a	9.4 (0.16) a	53.5 (3.96) a	0.85 (0.05) a	44.4 (2.74) a	62.5 (1.24) ab	1.6 (0.03) a
SF	53.4 (1.48) a	8.9 (0.37) a	49.7 (7.67) a	0.94 (0.13) a	48.7 (6.54) a	52.6 (1.27) b	1.9 (0.12) b

Table 5. Morphological characteristics of red-flowering currant seedlings at end of 2014 outplanting season. Data shown are statistical means with vegetative competition levels (LF = no competition, HC = high competition), with standard errors in parentheses. Measurements are height, root-collar diameter (RCD), and aboveground biomass (Shoot biomass). Different letters indicate significant differences at α=0.05.

Vegetation Treatment	Height (cm)	RCD (mm)	Shoot Biomass (g)
LC	97.84 (2.7) a	16.12 (0.55) a	185.81 (18.21) a
HC	70.47 (1.7) b	13.00 (0.33) b	50.23 (3.52) b

Appendix A

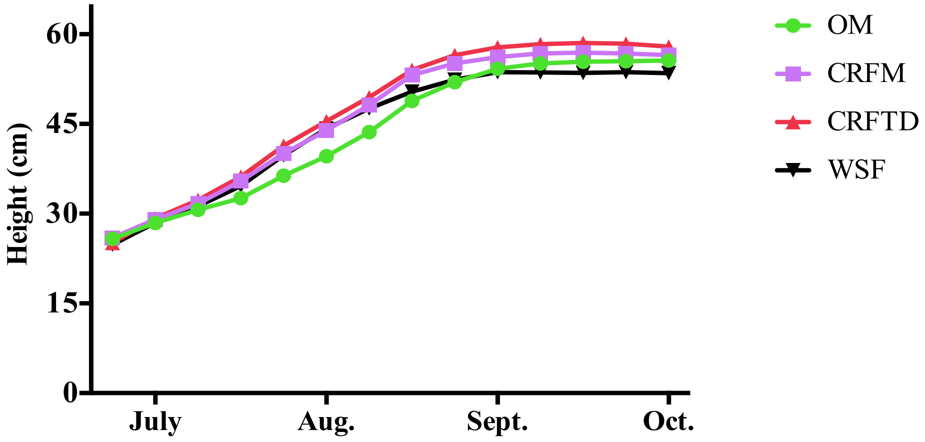

Figure 1. Mean seedling height (cm) over the 2013 growing season per treatment. OF = organic fertilizer, MF = incorporated controlled-release fertilizer, TF = top-dressed controlled-release fertilizer, and SF = water-soluble fertilizer.

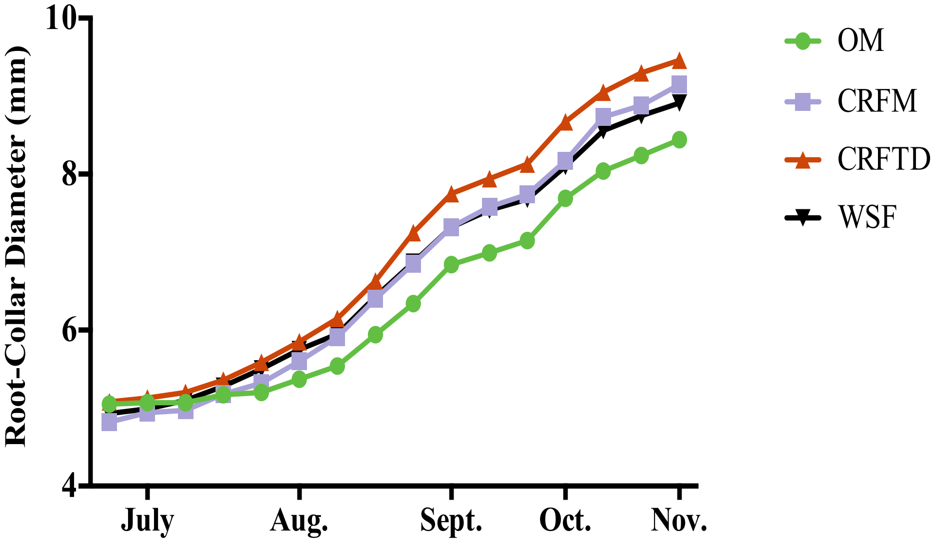

Figure 2. Mean seedling root-collar diameter (mm) over the 2013 growing season. OF = organic fertilizer, MF = incorporated controlled-release fertilizer, TF = top-dressed controlled-release fertilizer, and SF = water-soluble fertilizer.