The Effects of Near-zero Leachate Irrigation on Growth and Water Use Efficiency and Nutrient Uptake of Container Grown Baldcypress (*Taxodium distichum* (L.) Rich.) Plants[1]

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Abstract

Fertilization and irrigation practices affect water- and nutrient use-efficiencies in container-produced nursery crops. This study was conducted to determine if gravimetric monitoring of a plant-substrate-container unit could manage real-time irrigation volume to achieve a near zero leachate fraction and to study baldcypress (*Taxodium distichum* (L.) Rich.) growth, nutrient accumulation and water-use efficiency under a factorial combination of two irrigation leachate fractions and two controlled release fertilizer (CFR) rates. Baldcypress plants were grown at either 45 or 90 g of 15N–3.1P-12.5K (15-7-15 Multicote, six-month controlled release fertilizer top dressed on each container), and two irrigation rates, near-zero or 0.2 leachate fraction. Height growth, whole plant dry mass and shoot:root dry mass ratios, and water-use efficiency were not affected by a fertilizer and irrigation interaction. The higher fertilizer rate increased the whole plant N and K concentrations. Relative to a 20% leachate fraction irrigation regime, a near-zero leachate fraction decreased leachate volume and root, shoot and whole plant dry mass, while leachate electrical conductivity (EC), plant tissue mineral nutrient concentrations and water use efficiency increased. Although baldcypress whole plant dry mass was reduced under the near-zero leachate irrigation regime (presumably due to high soluble salt levels) there was no difference in height and stem diameter at the higher fertilizer rate between the two irrigation regimes. The near-zero leachate irrigation regime applied approximately one-half the irrigation volume of the 0.2 LF irrigation regime.

Index words: leachate, container capacity, effective container capacity, water use efficiency, nutrient use efficiency evapo-transpiration rate, and substrate moisture content.

Significance to the Nursery Industry

Nursery managers are under pressure to reduce costs while maintaining production schedules and plant quality. Irrigation and fertilizer are two significant production costs. This study was conducted to determine if similar sized baldcypress plants could be produced with half the fertilizer if the container plants were grown under near-zero leachate conditions. At the high rate of fertilizer, 0.98 Kg $N{\cdot}m^{-3}$ (2 lb $N{\cdot}yard^{-3}$ from 15-7-15 Multicote six-month controlled release fertilizer) similar sized plants (height and stem diameter) could be grown with nearly half as much water as plants under a 0.2 leachate fraction irrigation regime. The near-zero irrigation regime and the 0.98 Kg $N{\cdot}m^{-3}$ treatment combination also increased the concentrations of N, P and K in the plant tissue. However, growing baldcypress plants under a near-zero leachate fraction at 0.49 Kg $N{\cdot}m^{-3}$ resulted in smaller sized plants. Thus, growing baldcypress plants under a near-zero leachate fraction saved water, but when combined with a lower fertilizer rate resulted in smaller sized plants.

Introduction

For container-grown plants the rooting volume is limited, compared to that available to field grown plants. This limited rooting volume can be quickly depleted of moisture and nutrients by a rapidly growing plant. The typical soil-less substrate used in container production is porous with low mineral nutrient retention potential. There is the potential for nutrient loss due to excessive leaching. Thus, nursery growers manage the substrate's moisture and nutrient supply on a daily basis.

Fertilizer effectiveness relies on adequate substrate moisture; as substrate moisture is reduced so is the effectiveness of the applied fertilizer (8). Because most fertilizers used in container nursery production are inorganic salts, low substrate moisture can result in soluble salt damage to plant roots. However, as irrigation volume is increased the leaching of nutrients from the container substrate is increased (2, 15). Controlled release fertilizers (CRF) have been used to reduce leaching of available N; leached N from containers fertilized with CRF has been reported to be between 12 and 29% (12). Improving irrigation and nutrient use efficiencies (NUE) in container nurseries requires an understanding of the interaction of between irrigation and fertilizer practices. To maximize NUE, fertilizer release rate should match plant uptake potential. Until plant nutrient uptake patterns are better understood, the best way to improve NUE is through refining irrigation rate and delivery techniques (9).

Irrigation scheduling refers to how much irrigation to apply and when to apply the irrigation (13, 14). An effective strategy to schedule irrigation is to measure how much water the plants are using during a given period of time and then replace that amount; this strategy would be defined as precision irrigation. Several studies have examined various methods and recommendations for estimating irrigation amounts and are summarized in Sammons and Struve (7).

Best management practices (BMPs) recommend the use of a 0.2 leachate fraction (LF) as a guide for determining irrigation volumes (18). Leachate fraction is calculated by

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dividing the volume of irrigation leached during an irrigation event by the total volume of irrigation (16).

Leaching fractions are used to managing soluble salt accumulation in the substrate to maintain electrical conductivity (EC) levels below those that damage plant roots. Tyler et al. (12) showed that a low LF reduced irrigation volume, leachate volume and leached N by 44, 63 and 66%, respectively, compared to a high LF, but resulted in a 10% reduction in plant growth. However, if plants are produced outdoors in a region with plentiful rainfall during the growing season, careful management the LF may not be needed (13). A high LF can deplete CRF materials within 100 days of application (5, 16, 17). Also, CRF nutrient release rates can exceed that of plant uptake (11). This suggests fertilizer rates could be reduced without reducing plant growth. By matching fertilizer rate to plant uptake potential, plant injury caused by soluble salts could be reduced, even under near-zero leachate fractions.

The objectives of this study were to determine if gravimetric monitoring of a plant-substrate-container unit could be used to manage irrigation volume on a real-time basis and to study the effect of a near-zero leachate irrigation system on baldcypress growth, water use, and nutrient uptake. We hypothesized that under a near-zero leachate irrigation regime that irrigation and leachate volume would be decreased, leachate electrical conductivity values and water use efficiency would be increased, and at recommended fertilizer rates plant growth would be decreased.

Materials and Methods.

Preparation of plant material. In the summer of 2006, 400 baldcypress seedlings (from a local seed source) were transplanted into #1 Spinout®-treated (SePRO Carmel, IN) plastic containers (Classic 400, Nursery Supplies, Fairless Hills, PA) at the Howlett Hall greenhouses located on the Columbus campus of The Ohio State University. The substrate was Fafard 3B (Conrad Fafard, Inc. Agawam, MA). Plants were maintained weed free and watered twice daily with 100 ppm of 21N-2.9P-4.3K (21-7-7 Peters, Scotts Miracle-Gro Co., Marysville, OH) water-soluble fertilizer until September 1, then over-wintered in an unheated polyhouse until the spring of 2007.

One hundred and eighty-eight plants, selected for uniformity (height and caliper), were transplanted to #3 containers (12.4 liter, 27.9 cm top diameter, 24.1 cm tall, Classsic 1200 Nursery Supplies, Fairless Hills, PA) on May 1, 2007, and placed pot to pot on a gravel production pad within a retractable roof structure (RRS) (Cravo Equipment, Ltd., Brantford, Ontario, Canada) on the Columbus campus for a three week acclimation period. The roof of the RRS remained closed for the duration of the study to eliminate rainfall; side walls were opened when temperatures were above 23.8C (75F) and closed when the temperatures were below 23.8C (75F). The substrate was a 3:1 (by vol) pine bark and composted municipal sewage sludge (Com-til®, City of Columbus) mix. Plants were hand watered twice daily as needed until the study commenced on May 24, 2007.

Initial dry mass and total plant N, P and K determinations were made on May 24. Initial stem diameter, plant height measurements and destructive harvests were performed on three randomly selected plants. Stem diameter was taken 15 cm (6 in) above the substrate surface. Plant height was measured from the substrate surface to the shoot tip. All substrate was then washed from the roots. The plants were separated into roots and aerial parts (stems and leaves) and placed in a drying oven at 68C (155F) until a constant weight was obtained. Dry mass for each plant's parts was recorded. Dried root and aerial tissues of individual plant parts were ground to pass through a 2 mm (0.08 in) screen and 5 g (0.18 oz) sub-samples sent to the STAR Lab at the Ohio Agriculture and Research Development Center for macro-nutrition analysis (http://www.oardc.ohio-state.edu/starlab/). Total plant nitrogen (N), phosphorus (P), and potassium (K) contents were determined by multiplying the N, P, K concentrations of each sub-sample by their respective dry mass and summing the individual plant's root and aerial nutrient contents.

Total pore space, air-filled and water-filled pore space was determined gravimetrically for the substrate using #3 containers according to Sammons and Struve (7).

The remaining plants were randomly assigned to one of two experiments: Seasonal Growth and Nutrient Accumulation (Expt. 1) and Growth, Water Use Efficiency and Nutrient Accumulation (Expt. 2). Both experiments used similar factorial treatment combinations of two fertilizer rates and two irrigation regimes. The two fertilizer treatments were 45 or 90 g of 15N–3.1P-12.5K (15-7-15 Multicote, 4-month controlled release fertilizer). The 45 and 90 g treatments are equivalent to 0.49 or 98 Kg $N\cdot m^{-3}$ (1 or 2 lb $N\cdot yard^{-3}$), respectively. Forty-five grams of fertilizer were placed into individual ankle length panty hose packets. One or two packets (low or high fertilizer rates, respectively) were placed on the substrate surface near the center of the container under the irrigation stream. This method of fertilizer application was used to facilitate the determination of the N release from the CRF prills during the experiment. This fertilizer application method approximated a top-dress application method. The two irrigation treatments were daily irrigation events at 0730 and 1230 hr to maintain a weekly 0.2 or near-zero leachate fraction (LF) maintained by a plant integrated computer-controlled irrigation monitoring system (7). Regardless of the irrigation treatment, all irrigation was delivered by one Spot Spitter (Roberts Irrigation, CA, model SS-AG 160 LGN) per container which provided approximately 450 ml (0.12 gal) $water\cdot min^{-1}$. For the 0.2 LF, irrigation volume was adjusted weekly to account for plant growth.

The near-zero leachate fraction treatments (there were separate irrigation zones, one for each fertilizer rate) used one indicator plant per treatment to determine irrigation volumes based on the container-substrate-plant-substrate moisture weight, termed the effective container capacity (ECC). Also, there was one indicator plant per fertilizer rate in the 0.2 LF treatment. The ECC weight represents the combined weight of the container-substrate-plant unit plus the weight of the water held after the gravitational water has drained.

The ECC weight for each of the four indicator plants (one per treatment combination) was determined by monitoring gravimetric changes at one-second intervals while simultaneously irrigating all of the associated 'crop' plants. Gravimetric changes were obtained by placing each indicator plant on a balance connected to a computer. A macro written in Visual Basic for Applications (VBA) allowed the individual weights of the eight indicator plants to be collected and logged simultaneously into a spreadsheet. Pots were irrigated until the gravimetric changes held constant for twenty seconds, which we considered the effective saturation weight (ESW). Once ESW was reached, irrigation was discontinued and while the substrate drained, gravimetric changes were monitored every second for the next hour or until a constant weight was obtained. The combined mass of the plant, container and substrate after one hour (or until a constant weight was obtained) was used as ECC target weight for determining the initiation and termination of subsequent irrigation events.

To maintain the ECC target weight a second macro, written in VBA, monitored each indicator plant throughout the study and logged their weights every 3 hours. At each 3 hour interval, if the weight of an indicator plant was less than its target weight, the solenoid controlling that indicator plant and the other 'crop' plants within the treatment group was opened and remained open until the target ECC target weight was recorded. When the target weight was reached, the solenoid was turned off. Plant water use over a given time interval was determined by summing the irrigation volumes (as weights) for that period. To account for possible changes in ECC target weights due to plant dry mass accumulation, root growth into air-filled pore space, and decomposition of the organic fraction of the substrate, new ECC target weights for each indicator plant were re-calculated monthly during the season.

Expt. 1: Seasonal growth and nutrient accumulation. The 84 plants in Experiment 1 were randomly assigned to one of four irrigation zones, each irrigation zone represented a single irrigation-fertilizer treatment combination. There were 21 single plant replications spaced at 0.3 m within and 0.6 m (1 ft × 2 ft) between row spacing. The plants were arranged on the gravel production pad under a retractable roof structure (RRS) in a completely randomized design. Natural light levels were reduced by 70% under the RRS (10).

At three week intervals, three randomly selected plants from each treatment were destructively harvested to obtain dry mass and mineral nutrient contents, as described earlier. These plants were used to develop incremental dry mass accumulation, and nutrient uptake curves and correlations between season-long dry mass weights and total plant N, P and K contents. Each curve was fitted with linear or quadratic equations at the $P \leq 0.05$ significance level using SigmaPlot for Windows® (Systat Software, Inc., San Jose, CA). The fertilizer packets from these plants were also harvested and sent to the STAR lab for N analysis. Nutrient release was estimated as the difference between the CRF's initial and harvested N, P and K contents.

Expt. 2: Growth, water use efficiency and nutrient accumulation. The treatments were the same factorial combination of fertilizer rates and irrigation regimes described in Expt 1. Each treatment had a separate irrigation zone controlled by the indicator plants described in Expt 1. The indicator plants in Expt. 1 were within 6.1 m (20 ft) of the plants in Expt. 2. This experiment had five, five plant replications per treatment combination arranged in a randomized complete block design. The plants were placed on one m (three ft) high benches constructed from dimensional lumber and covered with galvanized steel fencing (Fig. 1). A leachate collection system (LCS) was constructed to collect leachate from each plot. The LCS consisted of 24 acrylic troughs, one hung under each plot. The troughs were positioned with a gradual slope to funnel leachate to 24 five-gallon collection buckets, one per plot. The troughs were formed from sheets of acrylic by heating them with a blow torch followed by manually forming a lip that funneled the leachate into a bucket.

Monthly, stem diameters and plant heights were measured as described earlier. Leachate volume, pH and EC were measured weekly. Leachate pH, and EC of a subsample from each plot were measured using Cardy meters (Horiba Instruments, Inc, Irvine CA).

At the end of the growing season plants from the LCS were destructively harvested to obtain root and shoot dry mass and whole plant mineral nutrient contents as described earlier. For each treatment total whole plant nutrient N, P, and K contents and concentrations and water use efficiency (WUE) were calculated. Total whole plant nutrient accumulation was calculated as: $[N_e - N_b]$, where N_e is the end of season nutrient content and N_b is the initial nutrient content. Similarly, P and K whole plant nutrient accumulations were calculated. Water use efficiency was calculated as: $[(PDM_e - PDM_b) / I_t]$, where PDM_e is the end of season whole plant dry mass, PDM_b is the baseline whole plant dry mass, and I_t is the total irrigation volume applied to individual containers during the

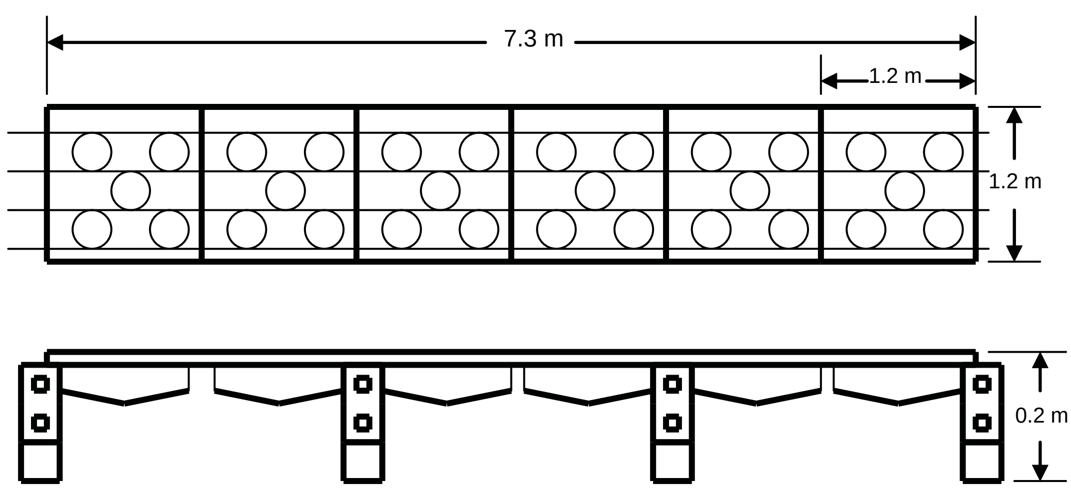

Fig. 1. Leachate Collection System (LCS). The LCS was constructed from dimensional lumber, galvanized steel fencing was used for the bench top to allow leachate to be collected. A 0.9 m square sheet of acrylic was hung under each plot to capture leachate. The acrylic was shaped to funnel leachate into a five gallon bucket. The benches were set on cinder blocks and irrigation lines ran across the bench tops.

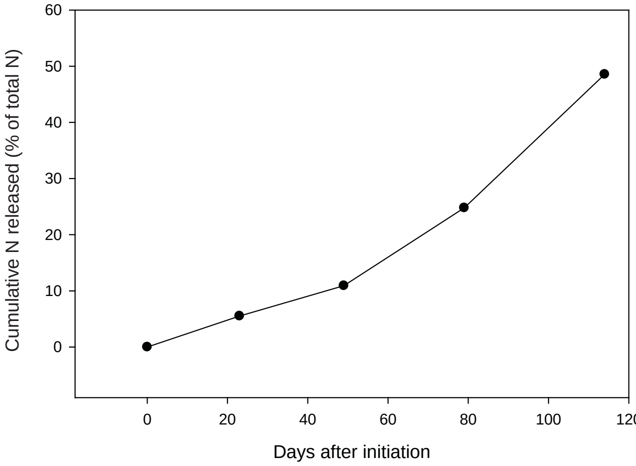

Fig. 2. Cumulative N release as a percentage of the total N applied from the controlled release fertilizer (CRF, 15-7-15 Multicote 6 month formulation) prills placed in mesh bags and laid on the substrate surface. The bags were periodically harvested and analyzed for total N during the growing season. Each value is mean of 12 replications; the equation predicting N release is: PNR = 0.748 + 0.07x + 0.003x²; P = 0.0001 level, R^2 = 0.99 where PNR is percent nitrogen release and x is days after initiation.

experiment. Water use efficiency is a measure of the volume of water lost through evapotranspiration for each one gram increase in plant dry mass.

Results and Discussion

The pinebark:Com-til® substrate in the 11.4 liter containers averaged total, air- filled and water-filled pore space of 50, 32, and 18%, respectively. Initial ECC target weight was 6.8 kg (15 lb) for all treatment groups. ECC values were calibrated at 45 and 81 DAI; at 45 DAI the ECC target was adjusted to 7.0 kg (15.5 lb) and remained at this value following the 81 DAI calibration. The total irrigation volume applied to individual plants in the 90 g and ECC, 45 g and ECC, 90 g and 0.2 LF, and the 45 g and 0.2 LF treatment groups during the 114 day experiment was 106, 94, 208 and 208 liters (28, 25, 55 and 55 gal), respectively.

Expt 1. Over the course of the study nitrogen (N) release from the CRF fertilizer was best described by a quadratic equation (Fig. 2). Du et al. (1) and Shaviv et al. (8) describe nutrient release from Multicote CRF as sigmoidal with lag, steady release, and decay phases. The CRF used in this study had a six month release profile, while the duration of the study (114 days) was less than four months. Therefore, the quadratic equation describing release of N (Fig. 2) would be representative of the lag and steady release phases described by Du et al. (1) and Shaviv et al. (8). At 114 DAI the CRF had released 48.5% of its N content (Fig. 2). The release rate of the CRF probably was less than if the experiment were conducted outdoors because of the more benign RRS environment (10).

Initial stem height averaged 30 cm (13 in) and stem diameter six mm (0.02 in). For all four treatment groups, incremental stem height and caliper were best described by linear and quadratic equations, respectively (Fig. 3). Height and caliper growth were reduced between 23 and 39 DAI for all four treatment groups (Fig. 3). This lag in growth likely

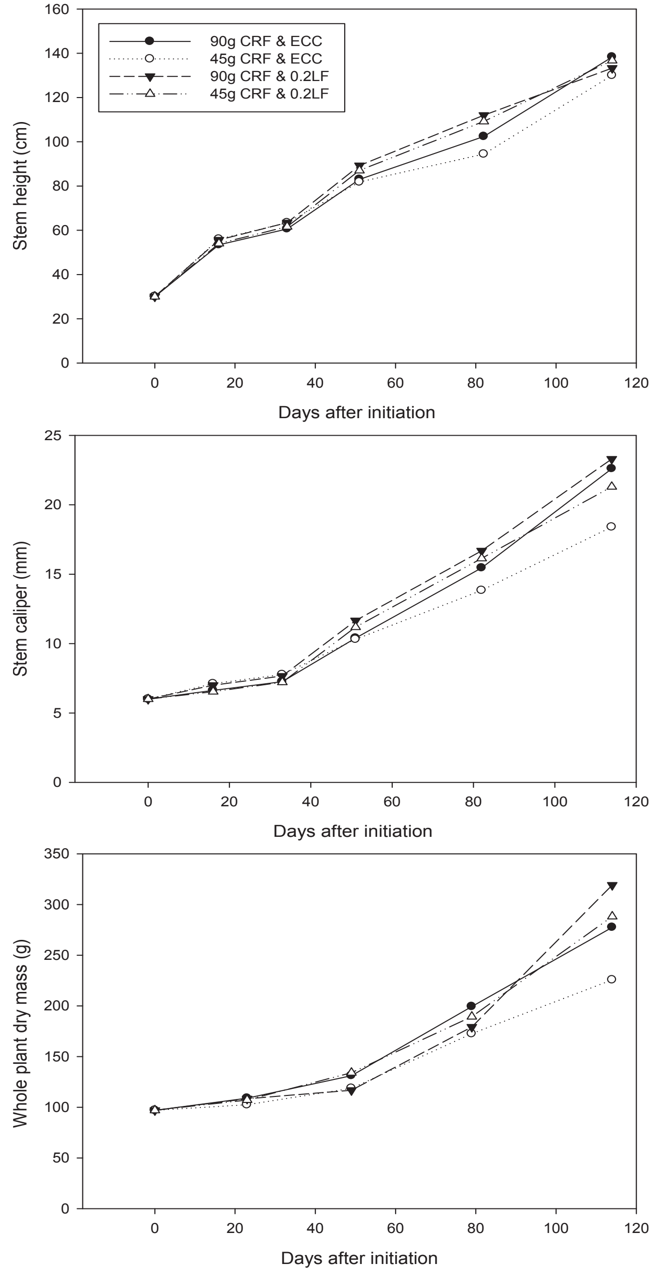

Fig. 3. Baldcypress seedling height (top), stem diameter (center) and whole plant dry mass (lower) when grown under a factorial combination of two controlled release fertilizer (CRF) rates (90 or 45 g 15-7-15 Multicote 6 month formulation) and two irrigation regimes (effective container capacity [ECC] or 0.2 leachate fraction [LF]) for 114 days. Each value is the mean of three plants per treatment combination; all equations were highly significant (P ≥ 0.001). The equations predicting height growth are: Ht_{90+ECC} (cm) = 33.4 + 0.90x (R^2 = 0.99); Ht_{45+ECC} = 36.5 + 0.80x (R^2 = 0.98); $Ht_{90+0.2 LF}$ = 36.7 + 0.89x (R^2 = 0.97) and $Ht_{45+0.2 LF}$ = 34.8 + 0.91x (R^2 = 0.99), those for stem diameter increase are: Cal_{90+ECC} = 5.83 + 0.03x + 0.001x² (R^2 = 0.98); Cal_{45+ECC} = 5.93 + 0.06x + 0.005x² (R^2 = 0.99); $Cal_{90+0.2 LF}$ = 5.72 + 0.06x + 0.0008x² (R^2 = 0.98); $Cal_{45+0.2 LF}$ = 5.46 + 0.07x + 0.0006x² (R^2 = 0.99), those for whole plant dry mass are: $WPDM_{90+ECC}$ = 95.64 + 0.30x + 0.012x² (R^2 = 0.97); $WPDM_{45+ECC}$ = 94.76 + 0.020x + 0.008x² (R^2 = 0.98); $WPDM_{90+0.2 LF}$ = 103.17 – 0.80x + 0.024x² (R^2 = 0.98); $WPDM_{45+0.2 LF}$ = 97.56 + 0.050x + 0.014x² (R^2 = 0.98); where the subscripts 90 + ECC, 45 + ECC, 90 + 0.2 LF, 45 + 0.2 LF represent treatment combinations of 90 g CRF and ECC, 45 g CRF and ECC, 90 g CRF and 0.2 LF and 45 g CRF and 0.2 LF, respectively.

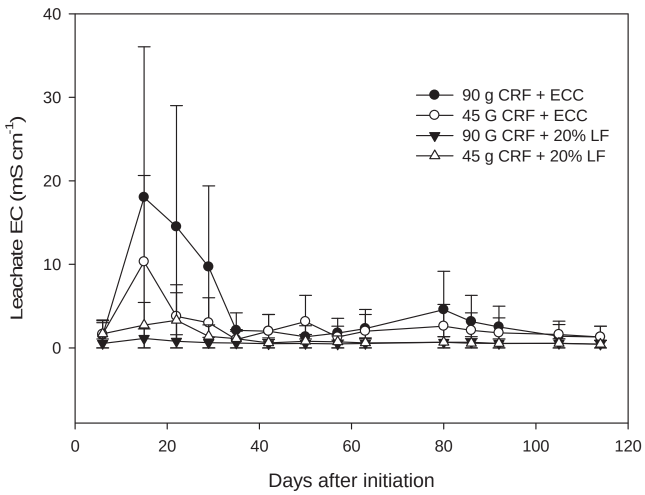

Fig. 4. Leachate electrical conductivity (EC) from container-grown baldcypress plants produced under a factorial combination of two controlled release fertilizer (CRF) rates (90 or 45 g 15-7-15 Multicote 6 month formulation) and two irrigation regimes (effective container capacity [ECC] or 0.2 leachate fraction [LF]) for 114 days. Each point is the mean of five, five plant replications.

resulted from the high soluble salts levels (Fig. 4) at this time. After the first calibration, EC values decreased while the rate of height and caliper growth increased likely resulting from the leachating (and the concomitant loss of salts) associated with the calibration procedure.

Whole plant dry mass accumulation was best described by quadratic equations for all four treatment groups (Fig. 3). Initial whole plant dry mass averaged 97 g (Fig. 3), with 53.6% of total plant dry mass contained in the shoots (Table 1). From 0 through 114 DAI, plants in the 90 g CRF and 0.2 LF treatment group accumulated the most dry mass (223 g per plant) while those in the 45 g CRF and ECC treatment accumulated the least dry mass (129 g per plant, Fig. 3). The percentage of whole plant dry mass contained in the shoots decreased for each treatment group in the experiment (Table 1).

Whole plant N uptake was best described by quadratic equations for all treatments except the 45 g CRF and ECC treatment, where N uptake was best described by a linear equation (Fig. 5). Season-long N uptake in baldcypress was highly correlated with dry mass accumulation in this study (Table 2). This was true for all treatment combinations. Similar results were found for red oak (*Quecus rubra* L) and 'Autumn Flame' red maple (*Acer rubrum*) (3). Initial whole plant N content averaged 2.8 g N (Fig. 5) with 78.9% of the total N contained in the shoots (Table 1). Plants in the 90 g CRF and ECC (4.11 g N) and 90 g 0.2 LF (4.76 g N) treatments accumulated 150% more N per plant than those in the 45 g CRF and ECC (2.67 g N) and 45 g CRF and 0.2 LF (3.04 g N) treatments (Fig. 5). The fraction of whole plant N content in the shoots decreased by nearly half between 0 to 23 DAI for all treatments (Table 1). The concurrent decrease in shoot dry mass and the percent of whole plant N in the shoot 23 DAI indicates a corresponding increase in root N.

Whole plant P uptake was best described by linear equations for all treatments, (Fig. 5). Initial whole plant P content averaged 0.26 g and the fraction of whole plant P content contained in the shoots was 71.1% (Table 1). As with the N content of the shoots, the fraction of whole plant P contained in the shoots was reduced between 0 and 23 DAI (Table 1). As with N uptake, season-long P uptake was highly correlated with dry mass accumulation (Table 2). This was true for all treatment combinations.

Whole plant K uptake was best described by linear equations for all treatment combinations (Fig. 5). Initial whole plant K content averaged 0.82 g and the fraction of whole plant K content contained in the shoots was 87.8% (Table 1). The fraction of whole plant P and K content contained in the shoots decreased from 0 to 23 DAI similar to relative fraction N (Table 1). As with N and P uptake, season-long K uptake was highly correlated with dry mass accumulation (Table 2). This was true for all treatment combinations.

Expt 2. Leachate EC spiked between 15 and 29 at DAI for all four treatment groups (Fig. 4). During this period EC was at or above values (0.8 dS·m^{-1}) for CRF-fertilized woody plant container production (16). Leachate pH values increased from an initial average pH of 6.8 to 7.0 114 DAI.

There were no significant fertilizer by irrigation interactions for root and whole plant dry mass, or root-to-shoot ratios (Table 3). There was a significant fertilizer by irriga-

Table 1. The seasonal percentage of total plant dry mass contained in the stem and leaves and the percentage of total plant N-P-K content contained in the stem and leaves between of baldcypress plants grown for 114 days under a factorial combination of two fertility and irrigation levels.

Fertilizer rate (g)[z]	Irrigation regime[y]	Dry mass (% of total plant) 0	23	49	79	114
90	ECC	53.6[x]	50.0	44.6	40.2	39.9
45	ECC	53.6	48.6	46.0	42.3	40.4
90	0.2 LF[w]	53.6	47.3	47.3	41.6	41.4
45	0.2 LF	53.6	47.7	43.0	42.2	45.1
Shoot N content (% of total plant)						
90	ECC	78.9	43.2	37.8	35.1	34.0
45	ECC	78.9	45.8	42.9	35.5	35.3
90	0.2 LF	78.9	42.3	38.4	35.7	34.1
45	0.2 LF	78.9	44.2	30.4	34.3	34.1
Shoot P content (% of total plant)						
90	ECC	71.1	49.1	53.3	49.4	35.8
45	ECC	71.1	47.8	52.3	43.8	42.3
90	0.2 LF	71.1	54.0	51.0	47.1	45.2
45	0.2 LF	71.1	46.3	45.9	56.2	49.2
Shoot K content (% of total plant)						
90	ECC	87.8	57.8	49.7	46.0	42.1
45	ECC	87.8	53.0	53.0	51.0	41.2
90	0.2 LF	87.8	60.0	48.5	50.2	41.3
45	0.2 LF	87.8	55.6	47.9	55.7	46.5

[z]Plants were top dressed with 90 or 45 g of 15N–3.1P-12.5K (15-7-15) Multicote six month controlled release fertilizer.

[y]Plants were irrigated to maintain a near-zero leachate fraction by using a plant integrated computer-controlled irrigation and monitoring system. The target weight, termed the effective container capacity (ECC), was the maximum weight of the plant-container-substrate unit that resulted in near-zero leaching after an irrigation event.

[x]Plants were irrigated daily at 0730 and 1230 hours to maintain a weekly 0.20 leachate fraction.

[w]Each value is the mean of three plants per treatment combination.

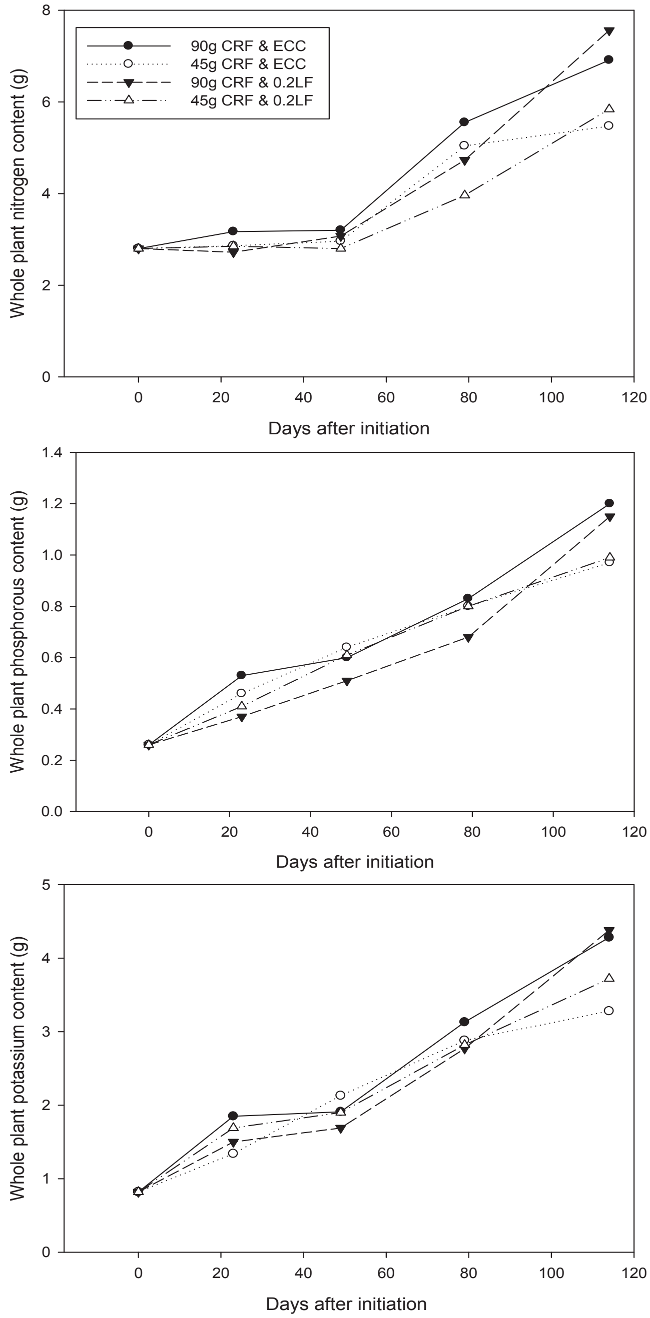

Fig. 5. Baldcypress seedling whole plant N (top), P (center) and K (lower) contents when grown under a factorial combination of two controlled release fertilizer (CRF) rates (90 or 45 g 15-7-15 Multicote 6 month formulation) and two irrigation regimes (effective container capacity [ECC] or 0.2 leachate fraction [LF]) for 114 days. Each value is the mean of 3 plants per treatment combination; all equations were significant at $P \geq 0.001$ level. The equations predicting N accumulation are: N_{90+ECC} (g) = 2.75 + 0.007x + 0.003x² (R^2 = 0.97); N_{45+ECC} = 2.40 + 0.027x (R^2 = 0.98); $N_{90+0.2\,LF}$ = 2.81 – 0.019x + 0.0005x² (R^2 = 0.99); and $N_{45+0.2\,LF}$ = 2.86 – 0.016x + 0.0004x² (R^2 = 0.98), those for P accumulation are: P_{90+ECC} = 0.275 + 0.008x (R^2 = 0.99); P_{45+ECC} = 0.301 + 0.006x (R^2 = 0.98); $P_{90+0.2\,LF}$ = 0.197 + 0.008x (R^2 = 0.98); $P_{45+0.2\,LF}$ = 0.270 + 0.007x (R^2 = 0.98); those for K accumulation are: K_{90+ECC} = 0.859 + 0.029x (R^2 = 0.98); K_{45+ECC} = 0.897 + 0.023x (R^2 = 0.97); $K_{90+0.2\,LF}$ = 0.640 + 0.030x (R^2 = 0.99); $K_{45+0.2\,LF}$ = 0.895 + 0.024x (R^2 = 0.96); where the subscripts 90 + ECC, 45 + ECC, 90 + 0.2 LF, 45 + 0.2 LF represent treatment combinations of 90 g CRF and ECC, 45 g CRF and ECC, 90 g CRF and 0.2 LF and 45 g CRF and 0.2 LF, respectively.

Table 2. Root, shoot and whole plant dry mass and root-to-shoot ratio of baldcypress plants grown for 114 days under a factorial combination of two fertility and irrigation levels.

		Dry mass (g)			
Fertilizer rate (g)[z]	Irrigation regime[y]	Roots	Shoots	Whole plant	Root-to-shoot ratio
90	ECC	193.6b[x]	165.3a	358.8b	1.2a
45	ECC	180.6b	133.6b	314.2b	1.3a
90	0.2 LF	220.0a	172.0a	391.9a	1.3a
45	0.2 LF	217.5a	172.9a	390.3a	1.3a

[z]Plants were fertilized with 90 or 45 g of controlled release fertilizer (CRF) of 15-7-15 Multicote 6 month formulation.

[y]Plants were irrigated using a effective container capacity (ECC) or a 0.2 leachate fraction (LF) to determine irrigation volumes.

[x]Means within a column followed by different letters are significantly different from each other at the $\alpha = 0.05$ level of significant using the Student-Newman-Kuels test of significance. Each value is the mean of 25 plants.

tion interaction for shoot dry mass (P = 0.01, Table 3). For plants under the 90 g CRF and ECC irrigation treatment, shoot dry mass was similar to those plants under either of the 0.2 LF treatments (Table 3) but more than that of plants receiving the 45 g CRF and ECC. Total plant dry mass for these plants was 29% lower. Root and whole plant dry mass were affected only by the irrigation regime (P = 0.001 and 0.01, respectively, Table 3); plants under the ECC treatment averaged 17% lower root dry mass and 16% lower total plant dry mass. It was hypothesized that if leaching were reduced, similar sized plants could be grown with half the fertilizer. Under these experimental conditions, the interaction between irrigation volume and CRF rate is more complex that originally thought. The 90 g CRF and ECC treatment had similar leachate EC readings as the 45 g CRF and ECC treatment, but whole plant dry mass was reduced 20% (133.6 vs 165.3 g, respectively). However, the irrigation volume applied to the 45 g CRF and ECC plants may have been underestimated by the indicator plant's smaller size; at season's end the whole plant dry mass of the 45 g CRF and ECC indicator plant was 20% less than the average whole plant dry mass of its constituent plants. The smaller sized plants under the 45 g CRF and ECC treatment may have been caused by reduced substrate moisture. The end of season root-to-shoot ratio was not affected by any treatment combination (Table 3).

Table 3. Whole plant mineral nutrient content and concentration of baldcypress plants grown for 114 days under a factorial combination of two fertility and irrigation levels.

		Total plant (g)			Total plant concentration (%)		
Fertilizer rate (g)[z]	Irrigation regime[y]	N	P	K	N	P	K
90	ECC	7.41a[x]	1.39a	4.21a	2.08a	0.39a	1.17a
45	ECC	5.56c	1.03c	3.23c	1.76b	0.33b	1.03b
90	0.2 LF	6.72b	1.00c	4.05a	1.71b	0.26c	1.03b
45	0.2 LF	6.14bc	1.16b	3.86ab	1.60b	0.30bc	0.99c

[z]Plants were fertilized with 90g or 45g of controlled release fertilizer (CRF) of 15-7-15 Multicote 6 month formulation.

[y]Plants were irrigated using a effective container capacity (ECC)or a 0.2 leachate fraction (LF) to determine irrigation volumes.

[x]Means within a column followed by different letters are significantly different from each other at the $\alpha = 0.05$ level of significant using the Student-Newman-Kuels test of significance. Each value is the mean of 25 plants.

Table 4. **Correlations between seasonal whole plant dry mass and whole plant N, P and K contents for baldcypress plants grown for 114 days under a factorial combination of two fertility and two irrigation regimes.**

Fertilizer rate (g)[z]	Irrigation regime[y]	Total plant mineral nutrient content		
		N	P	K
90	ECC	0.97[x] ***[w]	0.97 ***	0.98 ***
45	ECC	0.84 *	0.93 **	0.91 **
90	0.2 LF	0.99 ***	0.98 **	0.99 ***
45	0.2 LF	0.91 **	0.88 *	0.96 ***

[z]Plants were fertilized with 90 or 45 g of controlled release fertilizer (CRF) of 15-7-15 Multicote 6 month formulation.

[y]Plants were irrigated using a effective container capacity (ECC) or a 0.2 leachate fraction (LF) to determine irrigation volumes.

[x]Each value is the mean of 15 plants.

[w]*, **, *** indicate significance at α = 0.05, 0.01 and 0.001 level of significance, respectively.

There were significant fertilizer by irrigation interactions for whole plant N, P, and K content and whole plant P and K concentration ($P = 0.05$, 0.001, 0.001, 0.001 and 0.001, respectively). Plants under the 90 g CRF and ECC treatment had the highest and plants under the 45 g CFR and ECC treatment had the lowest N, P, K contents (Table 4). The concentration of P and K was highest in plants under the 90 g CFR and ECC treatment, while plants under the 90 g CFR and 0.2 LF had the lowest P concentration. The concentration of N was affected by both the fertilizer rate and the irrigation regime ($P = 0.001$ and 0.01, respectively). Plants under the 90 g CRF and ECC treatment had the highest N concentration and plants under the 45 g CRF and 0.2 LF had the least (Table 4). Plants under the 90g CRF and ECC treatment had higher whole plant N, and P concentrations than baldcypress grown outdoors (7) or published N, P and K foliar concentrations (5). The tissue N-to-P ratio was 5.3-to-1 for all the treatments except the 90 g CRF and 0.2 LF, where it was 6.6-to-1. The K-to-P ratios were 3.0, 3.1, 4.0 and 3.3-to-1 for the 90 g CRF and EC, 45 g CRF and EC, 90 g CRF and 0.2 LF, and the 45 g CRF and 0.2 LF treatments, respectively. The N-P-K ratios in the plant tissues averaged 5.6-1.0-3.3 over all the treatment combinations. In contrast, the fertilizer N-P-K ratio was 7.2-1.0-1.4. One method to increase nutrient uptake efficiency (and reduce soluble salt build up) is to match fertilizer N-P-K ratios to plant tissue ratios. In this study the N and P fertilizer ratios were similar to the plant tissue ratios, but the plants accumulated K at nearly twice the ratio of the fertilizer's content. The implication for nursery growers is that the ratio of N-P-K accumulation was similar in plant tissue regardless of the irrigation and fertilizer treatment combination. Thus, reducing irrigation volume would not require a change in the N-P-K ratio of the fertilizer.

There was no significant fertilizer by irrigation interactions for water-use efficiency ($P > 0.05$). Irrigation did affect water use efficiency ($P = 0.001$); it was 175% higher under the ECC treatments than the 0.2 LF treatments (3.4 vs 1.9 g dry weight per liter water).

The EC values encountered during the first 39 DAI for the treatment groups receiving the ECC irrigation regime were extremely high and well above recommended substrate EC levels (17). Baldcypress did exhibit reduced growth in response to the EC levels, however there was no plant mortality. More salt sensitive taxa may be damaged by these EC levels under a near-zero leachate irrigation system. This irrigation system may require weekly leaching events during the first weeks of production to manage soluble salt level for salt-sensitive taxa. Under the conditions of this study there was no benefit to adding 90 g compared to 45 g CRF when using a 0.2 LF irrigation regime.

This study was performed an environment that excluded rainfall as water source. Warren and Bilderback (16) suggest that the use of LF may not be needed in production regions with plentiful and uniform rainfall during the growing season. Further research is needed to evaluate these two irrigation regimes and fertilizer rates with the inclusion of rainfall.

In conclusion, this study showed that a near-zero leachate irrigation system decreased irrigation volume by almost half and (by definition) decreased leachate volume and increased water use efficiency. At the 90 g CRF and near zero leachate treatment combination, N, P and K contents and concentrations were increased. Similar sized plants (height and caliper, but not dry mass) could be grown at the 90 g CRF rate under both irrigation regimes, but the ECC irrigation regime used about one half the irrigation volume.

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