Cyclic Sprinkler Irrigation of Container Substrate Affects Water Distribution and Marigold Growth[1]

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Abstract

Two experiments were conducted to determine how cyclic sprinkler irrigation (daily water allotment applied in more than one application) influenced water distribution and leaching, and marigold growth in a pine bark (PB) or a PB:sand (S) substrate. Marigolds (*Tagetes erecta* L. 'Apollo'), were grown in PB-filled 3.8 liter (1 gal) containers. Substrate was allowed to dry via evapotranspiration (ET) to targeted pre-irrigation substrate water contents (PSWC) and respective ET volumes were applied as a single application (continuous) or by multiple applications (cyclic irrigation) via a simulated sprinkler irrigation system; leachates were collected. In the first experiment, the influences of irrigation method, continuous and cyclic irrigation, on water distribution in the top, middle and bottom substrate (9:1 pine bark to sand, by vol) sections were investigated. Two hundred seventy five (275) ml were applied continuously or cyclically (three 92 ml allotments with 1 hr interval between applications) to containers at 84% of container capacity (CC). In the second experiment, marigolds were grown in a growth chamber for three weeks and received 12 irrigations. In each irrigation, a complete nutrient solution was applied continuously or cyclically (three applications each of one-third of the total volume with 1 hr between applications). Substrate solution N concentration (via pour-through method), leachate N, and plant growth was measured. In the first experiment, gravimetric water contents of top and middle substrate sections were similar, whereas the water content of the bottom section was higher with cyclic than with continuous. In the second experiment, root dry weight was 43% higher, shoot fresh and dry weights were similar, and plant N concentration was 0.7% higher (absolute basis) with cyclic than with continuous irrigation. Irrigation method had no influence on substrate solution and leachate NO_3-N and NH_4-N concentrations. However, total N leached was 43% higher with continuous than with cyclic irrigation. These results demonstrate that cyclic irrigation increased root N concentration and root growth without a toxic accumulation of N in the substrate solution.

Index words: nitrogen, electrical conductivity, leachate, *Tagetes erecta* 'Apollo', pulse irrigation, water application efficiency, soilless substrate.

Significance to the Nursery Industry

With cyclic irrigation, a plant's daily water allotment is subdivided into more than one application. Compared to single application, cyclic irrigation resulted in a higher water content in the bottom third of the container, plants had higher shoot and root N concentrations, more root growth, and equal shoot growth. Growers that use cyclic irrigation can expect greater plant utilization of applied N as well as reduce water and nutrient loss from containers. Since the substrate solution N and EC of both irrigation treatments were similar after two weeks, toxic fertilizer accumulation in the substrate is not expected. Since less N is leached with cyclic, the possibility exists to reduce fertilizer application rates without negatively affecting growth.

Introduction

Karam and Niemiera (3) showed that applying a plant's daily water allotment in multiple applications (cyclically) to a pine bark substrate increased water application efficiency (WAE) by ≈ 5% compared to a single continuous irrigation. However, the influence of irrigation method on plant growth and substrate nutrient accumulation has not been determined. Ku and Hershey (5, 6) investigated the effect of leaching fraction (LF) (volume of leachate divided by volume of irrigation solution applied) on plant growth and substrate nutrient accumulation; they reported that the effect of LF was mainly dependent on the species salinity tolerance and the N concentration of the fertilizer solution. Limited information is available on the effects of cyclic irrigation on plant growth and the substrate nutrient solution content. Thus, the objectives of this sprinkler irrigation study were to determine how cyclic irrigation influenced 1) water distribution in a pine bark substrate and 2) plant growth, plant N content, substrate solution N content, and N leaching from the pine bark substrate.

Materials and Methods

With the exception of the following, the materials and methods were the same as previously described (3).

Substrate water distribution experiment. Prior to treatment, plants in 3.8 liter (1 gal) containers filled with a pine bark:sand (9:1, by vol) substrate and were fertilized with Osmocote 14N-6.2P-11.6K (14-14-14; 20 g/container; 0.7 oz/container) and glass house-grown for four weeks. The substrate was allowed to dry via ET to a water content of 84% at which point shoots were severed and irrigation was applied either continuously or cyclically. For continuous irrigation, two hundred and seventy five ml (≈ 0.3 qt) of water was applied (1.4 cm/h; 0.55 in/h). For cyclic irrigation and to determine the water distribution after applying one third, two thirds, and the total daily irrigation amount, there were three treatments: 92 ml, 184 ml, or 275 ml applied in one, two, or three 92 ml applications, respectively, with a 60 min interval between cyclic applications. Leachate volume was measured at the end of each interval just prior to the

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start of the next application to determine WAE of each irrigation event. After the last water application in the continuous and cyclic treatments, containers were covered, drained for 45 min, weighed, and leachate volume measured. Substrate in each container was transversely trisectioned into approximately equal sections (top, middle, and bottom) (5 cm; ≈ 2 in). After removing roots, substrate in each section was thoroughly mixed and a sub-sample of each section was weighed, oven-dried at 105°C (221°F) for 24 hr, and reweighed to determine gravimetric water content. A separate set of containers was used to determine gravimetric PSWC.

Cyclic and continuous treatments were replicated nine and five times, respectively and treatments were arranged in a completely randomized design, with one container per block. ANOVA was performed on WAE data of continuous treatment and the cyclic treatment that received a total volume of 275 ml. Contrast analysis was performed to accommodate for unequal replicate numbers. The initial weight of the container was used as a covariate and weighted means of WAE were reported. A repeated measure analysis was performed on gravimetric water content percentages of top, middle, and bottom sections for continuous and cyclic treatment that received a total volume of 275 ml. A straight-line regression analysis was performed on WAEs of the first, second, and third intermittent applications using the volume of water applied as an independent variable.

Plant growth experiment. Prior to treatment commencements, marigolds ('Apollo') in 100% PB-filled 3.8 liter (1 gal) containers were glass house-grown for three weeks during which plants received ≈ 400 ml (three times weekly) of a 200 mg N/liter solution (20N-4.4P-16.6K) and were hose-irrigated as needed. Three days before treatment commencement, container capacity (CC) was determined by soaking containers in a nutrient solution whose nutrient concentrations (mg/liter) were 150 N (as NH_4NO_3), 10 P (as H_3PO_4), 50 K (as K_2SO_4), 1 B (as H_3BO_3), 1 Mn (as $MnCl_2$), 1 Zn (as $ZnSO_4$), 1 Cu (as $CuSO_4$), 1 Mn (as H_2MnO_4), and 5 Fe (as ethyenedinitrilo-tetraacetic acid ferric sodium salt); containers were drained for 1 hr, and weighed (= 100% CC weight). A nutrient solution instead of water was used to determine CC to avoid the depletion of nutrients from the substrate. Plants were then grown in a growth chamber at day/night cycles of 23°/18°C, 75–85% RH, with a daily 15-hr photoperiod (500 to 2000 HR) provided by cool-white fluorescent lamps, and an average PAR at plant height of 250 µmol/m²/s. Bark was allowed to lose 300 to 450 ml water from CC (86% to 80% CC, respectively) via ET (determined gravimetrically by regularly weighing containers after post-irrigation drainage). Once the substrate reached a targeted ET volume in the targeted deficit range, that container was removed from the growth chamber and covered in a white plastic bag to prevent water loss until all containers lost a similar ET volume. At each irrigation, plants were uncovered and fertilized with the above nutrient solution via a simulated overhead irrigation system (3). During the three week study, plants received 12 irrigations. To avoid the influence of a varying LF over time, plants were irrigated with a volume that resulted in a LF of 0.2 to 0.3. In the first two irrigations, LF was about 0.5 after which LF was 0.2–0.3. In each irrigation, the previously described nutrient solution was applied at 1.4 cm/hr continuously (a single application of the total volume) or cyclically in which three applications (each of one-third of the total volume) were applied with a 1 hr interval between applications. After the ET volume was applied, containers were drained for 1 hr, weighed, and returned to the growth chamber. Leachates per replicate (container) were cumulatively collected and analyzed for EC and NO_3-N and NH_4-N (ion-selective electrodes). WAE was determined.

After the termination of the experiment, the substrate solution for all containers was extracted using the pour-through

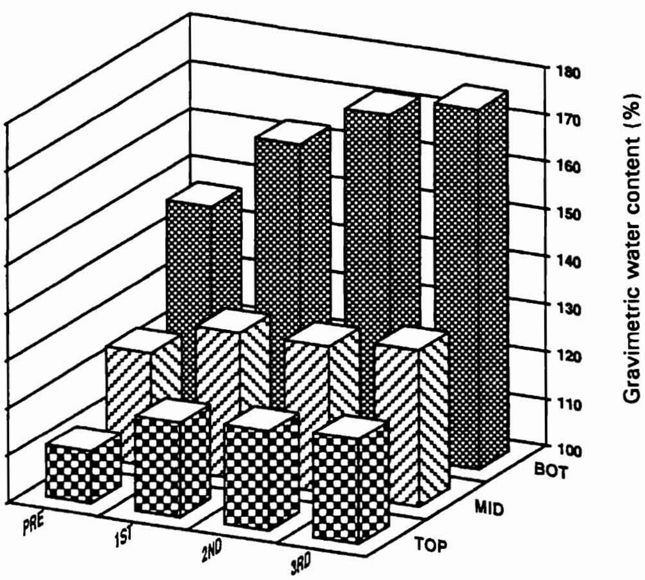

Fig. 1. **Gravimetric water content (%) of top, middle (MID), and bottom (BOT) sections of a pine bark:sand (9:1, by vol) substrate before irrigation (PRE) and after the first (1ST), second (2ND), and third (3RD) cyclic volumes were applied (substrate water distribution expt.).**

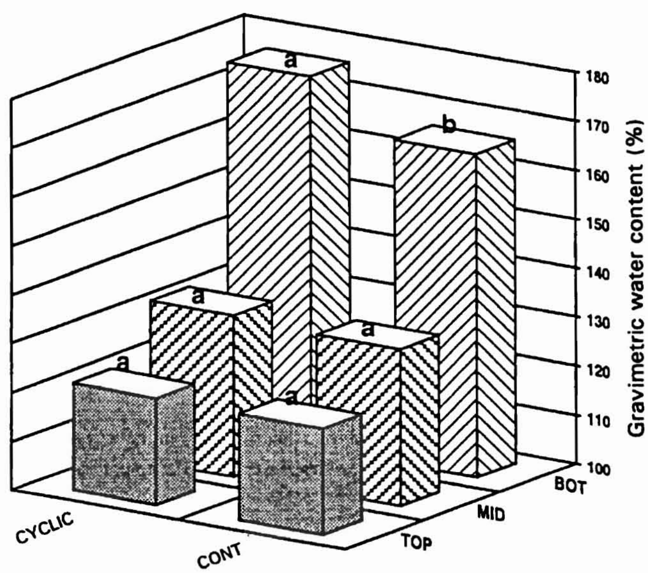

Fig. 2. **Gravimetric water content (%) of top, middle (MID), and bottom (BOT) sections of a pine bark:sand (9:1, by vol) substrate after receiving the same volume of water continuously (CONT) or in three cyclic applications. Letters above columns indicate section differences between continuous and cyclic irrigation at P = 0.01 (substrate water distribution expt.).**

extraction technique (11), where 1 hr after irrigation, 150 ml distilled water was applied to the substrate surface and leachates were collected and analyzed. Plant height, stem caliper, and leaf number were measured. Fresh and dry weights of shoots and roots were determined. Shoots (stem and leaves) and roots were analyzed for N (micro-kjeldahl technique), P (colorimetric procedure), and K (atomic absorption spectroscopy).

The experiment was conducted in a repeated measure design (over 12 irrigations) with irrigation treatments replicated six times, one container per replication, and containers arranged in a completely randomized design. Leachate parameters and plant growth were also tested by analysis of variance. The General Linear Model procedure of the Statistical Analysis System (SAS Institute) was used in all analyses of variance.

Results and Discussion

Substrate water distribution. Regardless of irrigation method, post-irrigation substrate gravimetric water content increased with increasing substrate depth (Figs. 1 and 2) which was expected due to the greater gravitational force acting on the top third than on the bottom third of the container (1, 8, 10). Relative to PSWC (Fig. 1), application of the first 92 ml resulted in a water content increase (absolute basis) of 9%, 7%, and 16% for the top, middle, and bottom sections, respectively. The relatively large water gain in the bottom third of the substrate implied that most of the applied water percolated through the upper sections or displaced water from upper sections. Following the second and third 92 ml applications, water content increased (relative to the previous post-irrigation water contents) for the top, middle, and bottom sections, respectively, by 1%, 0, and 9%, and 1%, 2%, and 4% respectively. Similar to the water content distribution following the first application, water gain predominantly occurred in the bottom section. The relatively low water gains of the top and middle sections after the second and third irrigations suggested that the most of the micropores in these sections were water-filled and water movement to lower sections was via macropore flow. These results were not in agreement with a cyclic irrigation mineral soil study in which matric potentials in the upper part of the soil profile were shown to approach saturation during each intermittent application and to decrease to potential values similar to those obtained between applications (9). Lack of agreement is most likely due to the fact that pine bark is much more porous than mineral soil. The comparatively large increase in gravimetric water gain in all substrate sections after the first irrigation relative to the second and third irrigations also implies that substrate water content has a significant impact on water movement. Increased water collection in the bottom third of the cyclic irrigation treatment compared to the continuous treatment (Fig. 2) was apparently due to the time intervals between cycles allowing more water to be adsorbed to intra- and extra-particle micropore sites. After the third irrigation, top and middle water contents of both irrigation methods were similar which indicated that gravitational forces in these layers did not allow for treatment affects (Fig. 2).

WAE with cyclic irrigation (57%) was greater ($P = 0.05$) than with continuous irrigation (53%) concurring with other work (3). WAE following the first, second, and third intermittent applications (92 ml per application) were 100%, 77%, and 57%, respectively, corresponding to leachate volumes of 0, 42, and 119 ml, respectively. This trend in WAE agrees with a spray stake irrigation study (7) in which replacement of 33%, 66%, and 100% of the deficit resulted in WAEs of 100%, 95%, and 83%, respectively. Our data implies that after the first 92 ml application (one-third of the 275 ml deficit), a water-holding threshold was reached beyond which the substrate water retention capacity decreased.

Table 1. Influence of continuous versus cyclic (three applications with 60 min intervals between applications) irrigation on 'Apollo' Marigold shoot (stem and leaves) and root fresh and dry weights and N concentrations (plant growth expt.).

Irrigation method	Shoot			Root		
	fresh wt	dry wt	N	fresh wt	dry wt	N
	(g)	(g)	(%)	(g)	(g)	(%)
Continuous	94[z]	6.0	5.9	51	7.0	2.3
Cyclic	97	7.0	6.4	62	10.0	2.5
Significance	0.43	0.48	0.0004	0.05	0.05	0.06

[z]n = 6.

Plant growth experiment. Irrigation method had no effect ($P = 0.05$) on shoot fresh and dry weights (Table 1), plant height, stem caliper, and leaf number (data not shown). However, marigold fresh and dry root weights were higher with cyclic than continuous irrigation (Table 1). Shoot (stem and leaves) and root N concentrations were higher with cyclic than continuous irrigation (Table 1) indicating that plants with cyclic irrigation were absorbing more N than those with continuous irrigation. Shoot and root tissue P and K concentrations were not affected ($P = 0.05$) by irrigation method (data not shown).

Compared to continuous irrigation, the cyclic treatment reduced the total amount of NO_3-N leached by 29% (Table 2). This was expected due to the larger volume of leachate

Table 2. Influence of continuous versus cyclic (three applications with 60 min intervals between applications) irrigation on concentrations and total amounts of NO_3-N and NH_4-N leached from a pine bark substrate after 12 irrigations (plant growth expt.).

Irrigation method	Leachate N concentration (mg/l)	Total leachate N (mg)
	NO_3-N[z]	
Continuous	38.9	4.4
Cyclic	35.9	3.1
Significance	0.47	0.03
	NH_4-N[y]	
Continuous	6.0	0.68
Cyclic	5.5	0.47
Significance	0.62	0.08

[z]n = 72.

[y]n = 60.

collected with continuous (overall WAE = 71%) compared to cyclic (overall WAE = 78%) irrigation. Leachate NO_3-N and NH_4-N concentrations (Table 2) and EC (data not shown) were unaffected (P = 0.05) by irrigation treatment. Since the interaction between substrate solution and applied solution is relatively limited in porous substrates (2, 4), displacement of substrate ions was most likely limited regardless of irrigation method. The magnitude of difference in N leached between cyclic and continuous irrigation is especially economically and environmentally noteworthy when considering the thousands of acres of container-grown plants grown by the industry and that these plants are generally irrigated on a daily basis.

Substrate solution EC and NO_3-N and NH_4-N concentrations (pour-through extraction) of both irrigation treatments were not different (P = 0.05; data not shown). This finding supported leachate data which showed that leachate N concentration (Table 2) and EC values did not differ between irrigation treatments. Less total N was leached with cyclic compared to continuous irrigation (Table 2), yet the substrate solution N concentration (leachate from pour-through) was not higher for cyclic than continuous irrigation. The reason for this apparent anomaly may be due to the finding that cyclically irrigated plants absorbed more N than the continuous treatment as evidenced by higher shoot and root N concentrations (Table 1) and total plant N (data not shown) for the cyclic compared to the continuous treatment.

In summary, compared to continuous irrigation sprinkler irrigation, cyclic irrigation reduced the total amount of N lost from containers, increased root weight, and increased shoot and root N concentrations. Additionally, after two weeks the substrate N concentration for cyclic irrigation was the same as for continuous irrigation. Since cyclic irrigation reduces N lost from containers, growers can then reduce fertilizer application rates. In support of this contention, Yelanich and Biernbaum (12) showed that fertilizer application can be reduced at relatively low LF without decreases in plant quality.

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