SPRAY STAKE IRRIGATION OF CONTAINER-GROWN PLANTS

by

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(ABSTRACT)

Studies were conducted to evaluate the effect of pre-irrigation media moisture deficit, irrigation application rate, and intermittent irrigation on irrigation efficiency \([\frac{\text{amount applied} - \text{amount leached}}{\text{amount applied}} \times 100]\) of spray stake-irrigated, container-grown plants. In the first experiment, pine bark-filled containers were irrigated to replace moisture deficits of 600, 1200, or 1800 ml. Deficits were returned in single, continuous applications at application rates of 148, 220, and 270 ml/min. Application rate did not affect irrigation efficiency. Efficiency decreased with increased medium moisture deficit. In the second experiment, containers, at 600 ml media moisture deficits, were irrigated with 400 or 600 ml (65% and 100% water replacement, respectively). Irrigation volumes were returned in a single, continuous application or in 100 ml applications with 30 min intervals between irrigations (intermittent). Irrigation efficiency was greater with intermittent irrigation, 95% and 84% for 400 and 600 ml replacement, respectively, than with continuous irrigation, 84% and 67% for 400 and 600 ml replacement, respectively. When applied intermittently, most water loss from
containers occurred after 400 ml were applied. In the third experiment, containers were irrigated with 600 ml (100% water replacement) in 50, 100, or 150 ml applications with 20, 40, or 60 min intervals between applications. A control was included in which 600 ml was applied in a single, continuous application. Irrigation efficiency increased with decreasing application volume and increasing length of interval between applications. The greatest efficiency (86%) was produced with an irrigation regimen of 50 ml applications with at least 40 min between applications. The control treatment (continuous) produced an irrigation efficiency of 62%. When applied intermittently, most water loss from containers occurred after a total of 300 ml were applied.
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Introduction

Container-grown crops are commonly irrigated with overhead sprinkler systems. Nurseries may apply approximately 24 million liters/ha per growing season with overhead irrigation (Rathier and Frink, 1989) and as much as 80% of applied water may fall between or leach from containers (Hawkins, 1976). This relatively low irrigation efficiency, amount of water retained by media divided by amount applied, is due to the use of highly porous soilless media necessary to avoid aeration problems.

Spacing of containers and plant canopy are also important factors causing low irrigation efficiencies with overhead irrigation (Beeson and Knox, 1991). Plants grown in 11 liter and larger containers are prevalent in today's nursery production. These containers require a significant amount of space between plants to allow for canopy development. Containers cover only 35% of the bed surface when set at a spacing of 1.5 times container diameter. Even if set edge to edge, containers cover only 78.5% of bed surface and as much as 63% of applied water falls between containers resulting in a high volume of runoff (Beeson and Knox, 1991).

The nation has become concerned with inefficient irrigation, as well as, other wasteful and environmentally harmful agricultural practices. This growing
environmental awareness has been triggered by pollution and depletion of aquifers (Koval and Moen, 1991). Many regions of the United States have experienced significant droughts within the past ten years, such as California which has endured a five-year-long drought (Higginbotham and Block, 1991).

Federal, state and local governments are responding to the public outcry by passing stringent laws for the regulation of water use. In March of 1991, six southern California counties announced that water deliveries to agricultural customers would be cut by 90% (Higginbotham and Block, 1991). Besides water restrictions, agricultural water prices in California are escalating (Zimmer, 1990) and heavy fines are given to those who exceed usage guidelines. Many states in the United States are studying California’s strict water regulations and will likely adopt similar regulations when water shortages occur (Higginbotham and Block, 1991). Federal regulations having far-reaching consequences for the nursery industry will be reviewed by U.S. Congress in 1992. Responding to public opinion, Congress will no doubt make pro-environmental revisions to the regulations (Koval and Moen, 1991).

One of the consequences of these revamped environmental acts will be tougher guidelines for how nurseries irrigate (Koval and Moen, 1991). The nursery industry should not wait until a water crisis exists to formulate a conservation policy. The industry would have a better public image if growers began using water more efficiently before they are forced to conform to sudden
and stringent regulations. Drip/trickle irrigation shows great promise as an efficient replacement for the relatively inefficient practice of overhead irrigation.

Progressive nursery operators are using drip/trickle systems to irrigate 17 liter and larger containers. Drip/trickle irrigation systems dispense water directly into the container, and thus save water that would evaporate or fall between containers with overhead irrigation (Gregory, 1991). With drip irrigation, water is dripped from an emitter onto a small area of the medium surface which results in very little lateral water movement especially in today's porous, soilless potting mixes (Furuta, 1973). With trickle irrigation, water is sprayed across the medium surface (Furuta, 1973), which results in more lateral distribution of water and thus a more thorough wetting of the medium when compared with drip (Hoadley and Ingram, 1982).

Spray stakes, one type of trickle emitters popular with nursery operators, apply water in a fan pattern over the medium surface. Relative to overhead irrigation, spray stakes can reduce water use and runoff by 75% and 90%, respectively (Weatherspoon, 1977), and also reduce nitrate-N runoff significantly (Rathier and Frink, 1989). Besides the savings in water and fertilizer, other advantages to trickle irrigation are reduced electric bills by pumping less water at lower pressures, reduced weed growth between containers which may in turn reduce pest populations, and irrigation does not interfere with spraying, pruning, or harvesting (Shemin, 1991; Stefanczyk, 1984). Disadvantages of drip/trickle
irrigation are the initial cost of installation and clogging of emitters. Manufacturers, to reduce clogging, design emitters with large orifices, but this causes relatively high application rates which can reduce irrigation efficiency. Despite these disadvantages, drip/trickle irrigation combined with slow release fertilizer and a runoff storage and recycling reservoir will satisfy heightened environmental concerns and maintain plant quality (Summers, 1988).

Very little research has been conducted with drip or trickle irrigation for container-grown plants, especially in respect to irrigation regimens. Even with trickle systems, nursery operators are applying excessive amounts of water (personal observation) which leads to an excessively large leachate volume. Irrigation scheduling, using spray stake emitters, needs to be studied to determine the most efficient regimen.
Literature Cited


Chapter One: Literature Review

Drip/Trickle vs. Overhead Irrigation

Drip/trickle irrigation systems have been estimated to irrigate over one-half million acres of crops worldwide (Hall, 1985). Due to the scarcity of fresh water sources for irrigation, Israel has been using various forms of drip irrigation on agronomic crops for the past 30 years and now also use it for greenhouse and nursery production (Shemin, 1991). With strict federal, state and local water-use regulations already enacted or looming on the horizon, U.S. growers will be forced to adopt water conserving practices, such as drip/trickle irrigation, to remain in business. In fact, many U.S. nurseries are switching to drip/trickle irrigation and only using overhead irrigation when absolutely necessary (Higginbotham and Block, 1991). This is especially prevalent in states such as California and Florida where fresh water has become an expensive and dwindling resource.

Drip/trickle irrigation for container-grown plants, when compared to overhead irrigation, produced saleable plants while reducing water usage by 78% (Bonaminio and Bir, 1983) and 55% to 60% (Weatherspoon, 1977). Irrigation efficiency of containerized woody plants under various drip/trickle systems ranged from 44% to 72% (Weatherspoon and Harrell, 1980) and 44% to 62%
(Weatherspoon, 1977) in medium consisting of equal volumes of ground pine bark, Canadian peat, and coarse sand. Efficiency for overhead has been found to be less than 30% (Hawkins, 1976; Weatherspoon, 1977; Weatherspoon and Harrell, 1980). Compared to overhead sprinkler, trickle irrigation reduced nitrate-N leachate and runoff loss by 84% from 2 species of container-grown woody plants in medium fertilized with nutrient solutions (Rathier and Frink, 1989). There was no significant difference in plant quality between the two irrigation methods (Rathier and Frink, 1989).

Spray stakes (Roberts Spot Spitters, Roberts Irrigation Products, Inc., San Marcos, Calif.), a popular type of trickle irrigation emitter, are easy to check for clogging, emitter placement, and rodent damage (Harrell and Weatherspoon, 1980). Spray-type emitters that apply water over the medium surface generally have a more even wetting pattern (Hoadley and Ingram, 1982), and are less likely to allow excessive salt accumulation compared to a drip system which applies water to one spot on the medium surface (Furuta et al., 1976). Spray stake emitters were chosen for this research since they are commonly used in the industry and are a suitable alternative to overhead irrigation.
Intermittent Irrigation

Spray stakes are designed with large orifices to reduce clogging and consequently apply water at relatively high rates. Additionally, the daily irrigation allotment occurs in a single application and the application rate exceeds the medium's capacity to adsorb the applied water. Spray stakes deliver water at 80 cm/h and greater while overhead sprinklers deliver water at rates as low as 0.7 cm/h. As application rate increases, lateral movement of water is reduced and channeling occurs, thereby reducing the interaction between medium and water (Hoadley and Ingram, 1982). A more efficient alternative to this is intermittent irrigation (II). Intermittent irrigation is the application of the daily water allotment in a series of cycles, each cycle composed of an irrigation application and a resting interval (Karmeli and Peri, 1974; Mostaghimi and Mitchell, 1983). When compared to a single, continuous application, II was found to significantly reduce vertical movement of water below the root zone in mineral soils which reduced water and nutrient losses (Jackson and Kay, 1987; Levin and van Rooyen, 1977; Levin et al., 1979; Mostaghimi and Mitchell, 1983). Intermittent irrigation with various drip emitters was more efficient than a single application in a bark medium (Weatherspoon, 1977; Weatherspoon and Harrell, 1980). Irrigation efficiency for II was 64% to 80% compared to 44% to 62% for a single, continuous application (Weatherspoon, 1977). Intermittent irrigation allows
irrigation water to be delivered at a low application rate (Jackson and Kay, 1987; Levin and van Rooyen, 1977; Zur, 1976) while allowing for use of large orifices that reduce clogging.

Increased efficiency using II is described in terms of the time-averaged application rate. An equation (Zur, 1976) for determining the time-averaged application rate, \( R_{av} \), is:

\[
R_{av} = \frac{R_i \cdot t_p}{T}
\]

- \( R_i \): nominal application rate of water emitter
- \( t_p \): operating phase duration
- \( T \): interval between operating phases

These three factors: \( R_i \), \( t_p \), \( T \), can be manipulated to influence the time-averaged application rate. While the irrigation system is operating, water is being applied at a relatively high rate, but when the resting or 'off' interval (between operating phases) is taken into account the actual application rate is relatively low (Karmeli and Peri, 1974).

In mineral soil, water applied intermittently moves down in "flux waves". The amplitude of these waves are "damped" or diminished at increased depth in the soil (Zur, 1976). At the depth where waves dissipate, water distribution and advance will correspond to the time-averaged application rate. The volumetric soil water front behaves as if the water was applied continuously at a lower rate.
than what the emitter had produced while operating (Jackson and Kay, 1987; Zur, 1976).

There are several reports investigating point source drip irrigation of mineral soils with intermittent application regimens. With II, emitter application rates could be doubled and produce similar moisture distribution patterns as applying water in a single, continuous application at the low rate (Levin et al., 1979; Mostaghimi and Mitchell, 1983). Intervals between applications ranged from 10 to 60 min (Jackson and Kay, 1987; Levin and van Rooyen, 1977; Levin et al., 1979; Mostaghimi and Mitchell, 1983). In mineral soil, Levin et al. (1979), using point source drip irrigation, found that 1 liter/h applied continuously and 2 liter/h applied intermittently with a 30 min resting interval resulted in the greatest efficiency and similar moisture distribution patterns.

Intermittent irrigation methods are being practiced commercially with both sprinkler and trickle systems. At El Modeno Gardens, Irvine, Calif., containers are irrigated with five to six applications at 1 h intervals (Ball, 1989). This irrigation regimen significantly reduced water and fertilizer use and subsequent runoff compared to applying water in a single, continuous application. At Ball Seed Co. (West Chicago, Ill.) water is applied to container-grown plants three times a day, at intervals of 4 h (Stefanczyk, 1984). Weatherspoon and Harrell (1980) increased irrigation efficiency by splitting daily irrigation into applications at 1000 HR and 1400 HR. Intermittent operation of sprinkler irrigation at a large
container-growing nursery in Virginia has dramatically increased irrigation efficiency (personal observation). Despite these examples, little irrigation research has been done with soilless growing media used in container production. Factors such as the volume of water delivered at each application and the length of the interval between applications need to be investigated.

**Pre-irrigation Moisture Content**

Pre-irrigation moisture content effects irrigation efficiency. When mineral soil is relatively dry, thorough rewetting can be difficult because water will channel rather than move uniformly through the soil profile (Hillel, 1980). When pine bark and other organic media dries, it can be very difficult to rewet due to the hydrophobic nature of dry particles. Even after subsequent irrigations which result in excessive leaching, water does not rewet bark evenly and tends to channel down through macropores or along the perimeter of the container (Powell, 1987).
Leaching Fraction

The most common method of avoiding excessive salt accumulation in container-grown plants is to irrigate with enough water to leach salts from the medium. This method wastes fertilizer and water and is harmful to the environment (Biernbaum et al., 1989). Fertilizer pollution and water use can be kept to a minimum by limiting the leaching fraction in potting medium to 10% or less, used in conjunction with drip/trickle irrigation (McAvoy, 1990). Leaching fraction is the volume of liquid leached divided by the amount applied multiplied by 100. Without adequate leaching, medium soluble salt levels may increase, but can be avoided by using lower amounts of fertilizer and leaching containers only when needed (Biernbaum, 1992; Harrell and Weatherspoon, 1982; Lieth and Burger, 1989). Biernbaum et al. (1989), growing poinsettias in containers, maintained similar medium nutrient levels when applying 200 mg N/liter with 12% leaching fraction as when applying 400 mg N/liter with 50% leaching. Compared to 400 mg N/liter with 50% leaching, applying 100 mg N/liter with 12% leaching produced a quality poinsettia crop (Biernbaum, 1992) and was estimated to reduce N runoff 40 fold (Biernbaum et al., 1989).
Literature Cited


Chapter Two: Spray Stake Irrigation of Container-Grown Plants

Introduction

When applying irrigation water to container-grown plants, irrigation efficiency (amount retained in medium divided by amount applied) is an important environmental and economic concern. Overhead irrigation, the most frequently used method of irrigation of container-grown crops, is relatively inefficient (Furuta et al., 1976; Hawkins, 1976; Rathier and Frink, 1989). Poor uniformity of overhead irrigation, spacing of containers, and water deflection by plant canopies, contribute to the inefficiency (Beeson and Knox, 1991). Low efficiencies, in conjunction with fertilizing through the irrigation systems, result in large volumes of runoff that contain high concentrations of nutrients (Hawkins, 1976; Rathier and Frink, 1989).

Drip and trickle irrigation can significantly increase irrigation efficiency compared to overhead irrigation (Bonaminio and Bir, 1983; Weatherspoon, 1977; Weatherspoon and Harrell, 1980), since emitters are in the container and deliver water directly to the medium (Furuta, 1973). With drip irrigation, water is dripped onto a small area of the medium surface which results in very little lateral water movement especially in today’s porous, soilless potting mixes (Furuta, 1973).
In trickle irrigation, water is sprayed across the medium surface (Furuta, 1973), which results in more lateral water distribution and thus a more thorough wetting of the medium when compared with drip (Hoadley and Ingram, 1982). Spray stakes, which are one type of trickle emitter popular with nursery operators, apply water in a fan pattern over the medium surface.

Trickle irrigation, while more efficient than overhead irrigation, can still produce excessive leaching especially with today’s porous, soilless potting mixes (personal observation). Emitters are designed with large orifices to reduce clogging and thereby deliver water at a rate which exceeds a medium’s capacity to absorb water efficiently. Emitters may deliver water to medium surface at application rates that are 100 times greater than overhead sprinkler application rates. A relatively low application rate increases irrigation efficiency by increasing lateral movement of water and decreasing channeling (Hoadley and Ingram, 1982). Pre-irrigation moisture content also affects irrigation efficiency. When pine bark dries excessively between irrigations, it can be very difficult to rewet due to the hydrophobic nature of the dry particles. Even subsequent irrigations which result in excessive leaching do not rewet bark evenly due to water channeling through the medium (Powell, 1987).

Trickle irrigation efficiency may be increased by intermittent irrigation (II), which is the application of the daily water allotment in a series of cycles, each cycle composed of an irrigation and a resting interval (Karmeli and Peri, 1974;
Mostaghimi and Mitchell, 1983). This method reduced vertical water movement below the root zone in mineral soils when compared to applying the total volume in one application (Jackson and Kay, 1987; Levin and van Rooyen, 1977; Levin et al., 1979; Mostaghimi and Mitchell, 1983). Intermittent irrigation of container-grown plants has been investigated to a limited extent and has increased irrigation efficiencies with overhead sprinklers (personal observation) and drip/trickle irrigation (Ball, 1989; Stefanczyk, 1984; Weatherspoon, 1977; Weatherspoon and Harrell, 1980).

Intermittent irrigation increases irrigation efficiency by decreasing application rate (volume applied divided by unit time). The II application rate can be described as a time-averaged application rate (Zur, 1976), which is composed of the nominal application rate of emitter, duration of application, and interval between applications (Zur, 1976). Water is delivered at a relatively high rate at each application, but when the interval between applications is taken into account, the time-averaged application rate is relatively low (Karmeli and Peri, 1974). Several reports investigating the influence of application volume on mineral soils (Levin and van Rooyen, 1977; Levin et al., 1979) showed that efficiency of emitters can be improved by decreasing the volume delivered at each application.

There has not been detailed research investigating II with trickle irrigation on soilless growing media. The purpose of this study was to investigate how
irrigation efficiency is affected by: 1) pre-irrigation medium moisture levels, 2) continuous vs. intermittent water application, and 3) intermittent application volume and frequency.

Materials and Methods

*Tagetes erecta* L. 'Apollo' seed was germinated and seedlings transplanted to 11 liter plastic containers filled with pine bark medium (*Pinus taeda* L.) amended with 3 kg dolomitic lime/m³. Bark had a bulk density of 0.174 g/cm³, 34% air space after thorough irrigation and 1 h drainage, and a particle size distribution of: 13.7% > 5.66 mm, 26.9% > 2.362 mm, 18.2% > 1.19 mm, 20.3% > 0.5 mm, 20.7% < 0.5 mm. Plants were irrigated by hand and fertilized three times weekly with approximately 1000 ml of a 150 mg N/liter solution (Peters 20N-5P-30K, Grace-Sierra, Milpitas, Calif.) until the start of the experiment (approximately 60 day old plants). At the start of all experiments, bark was thoroughly irrigated with watering wand. To ensure that containers were thoroughly saturated, moisture content of bark (following drainage) was determined. In all experiments, post irrigation moisture content was similar to container capacity moisture content, which was determined in a preliminary experiment. In all experiments, plants were grown in containers to extract water
from the medium to specific moisture deficits. Low and high flow Roberts Spot Spitters (part no. 030-001003 and 030-001002, respectively, Roberts Irrigation Products, Inc., San Marcos, Calif.), a type of spray stake recommended for 11 liter containers, were used for water application. Experiments were conducted in a completely randomized design with 10 replicates per treatment.

*Influence of application rate on irrigation efficiency at three moisture deficits.*

Bark was dried to three moisture deficits: 600, 1200, and 1800 ml per container which correspond to approximate gravimetric moisture contents of 200%, 160%, and 120%, respectively. Six hundred milliliters is approximately the amount of water a mature woody plant in a 11 liter container will lose in a day (unpublished data). When bark reached each of above respective moisture deficits, shoots were severed at the medium surface, and containers were sealed in plastic bags to prevent further moisture loss. When all containers reached targeted moisture deficits, they were spray stake-irrigated with 100% of the water needed to return moisture deficits. Spray stakes, one per container, were situated at perimeter, and pointed towards center of container. Containers were irrigated at 148 (low flow stake), 220, or 270 ml/min (high flow stake) in factorial combination with each moisture deficit of 600, 1200, or 1800 ml. Leachate from containers drained into
collecting trays for 1 h after irrigation and was measured. Leachate volumes were used to calculate irrigation efficiency using the following formula:

\[
\text{irrigation efficiency} = \frac{\text{vol. applied} - \text{vol. leached}}{\text{vol. applied}} \times 100
\]

Regression analysis was performed on arcsin transformed irrigation efficiencies.

**Intermittent vs. continuous irrigation.** Bark was allowed to dry to a moisture deficit of 600 ml (gravimetric moisture content of ≈200%) followed by shoot severance. Containers were irrigated (148 ml/min) with 600 or 400 ml which coincide with 100% and approximately 65% of the moisture deficit, respectively, in factorial combination with two irrigation methods: continuous (total volume applied in one application) or intermittent (100 ml applications at 30 min intervals between applications). Leachate volume was measured at the end of each time interval just prior to the start of the next application. Following the last application, containers drained for 1 h, and leachate was measured. Analysis of variance procedure was performed on arcsin transformed irrigation efficiencies. Contrast procedure was performed on arcsin transformed irrigation efficiencies obtained after each 100 ml II application.

**Intermittent irrigation efficiency influenced by volume and frequency of application.** As in the previous experiment, water was withheld from plants until a
deficit of 600 ml was attained. Six hundred milliliters were applied (148 ml/min) in a 3 x 3 factorial combination of three application volumes (50, 100, or 150 ml) with three intervals between applications (20, 40, or 60 min); a control treatment was included in which 600 ml was applied in a single continuous application. Collected leachate was measured at the end of each interval. Regression analysis was performed on arcsin transformed irrigation efficiencies.

Results and Discussion

Influence of application rate on irrigation efficiency at three moisture deficits.

Application rate did not affect irrigation efficiency (data not shown). Apparently, application rates less than 148 ml/min are needed to increase efficiency. Irrigation efficiency decreased as medium moisture deficit increased from 600 to 1200 ml with no further decrease beyond 1200 ml (Fig 1.1). Bark at relatively low moisture contents exhibits a hydrophobic character and shrinkage from container walls, which allow considerable channeling of applied water. In a preliminary experiment, sectioning of container medium into top, middle, and bottom thirds revealed more channeling in a relatively dry medium (data not shown). This channeling was not evident in medium at a lower deficit. The greatest efficiency (65%) resulted when the moisture deficit was 600 ml. This efficiency is similar to
other work (Weatherspoon, 1977; Weatherspoon and Harrell, 1980) in which irrigation efficiencies of various drip/trickle systems ranged from 44% to 72% and is greater than efficiencies produced by overhead irrigation which ranged from 13% to 26% in medium consisting of equal volumes of ground pine bark, Canadian peat, and coarse sand.

The fact that only 65% of applied water is retained indicates the wasteful nature, leached water and nutrients, of continuous spray stake irrigation. Furthermore, the relatively low efficiency suggests the necessity for an application rate less than 148 ml/min or the deficit be applied in more than one application.

**Intermittent vs. continuous irrigation methods.** Irrigation efficiency was greater with II than with continuous with degree of efficiency dependent on the amount of deficit replacement (Fig. 2.1). Efficiency was relatively high for II (94%) and continuous application (84%), at 65% replacement. Efficiency for the continuous treatment at 100% return was 68%, a 16% decrease compared to the 65% treatment. This relatively low efficiency is similar to those reported by others (Weatherspoon, 1977; Weatherspoon and Harrell, 1980), however, a comparison between other research is difficult since amount of water applied relative to deficit is not often stated. Since most growers apply an amount of water in excess of deficit (personal observation), the advantage of spray stake irrigation over sprinkler irrigation is greatly reduced and in some cases may be eliminated.

For II, the lower efficiency at 100% replacement than at 65%, a 10%
difference, is explained by the efficiency of the last three 100 ml applications (Fig. 2.2). Efficiency decreased in a linear fashion for the fourth, fifth, and sixth 100 ml applications ($p = 0.0001, R^2 = 0.87$). Thus, after 300 ml are applied, a water-holding threshold is reached, beyond which bark can no longer absorb water as fast as it is applied.

**Intermittent irrigation efficiency influenced by volume and frequency of application.** There was no interaction between length of time between applications and volume of application. There was a decrease in efficiency when application volume was increased (Fig. 3.1). Efficiency increased as time between applications increased up to 40 min (Fig 3.2).

Efficiency was greatest (86%) with a regimen of 50 ml applications and at least 40 min between applications. Efficiency of the control treatment (total deficit returned in a single, continuous application) was 62% (data not shown). All irrigation regimens, except the 150 ml application with 20 min interval, were more efficient than the control treatment. The irrigation regimens that produced the highest efficiency (86%), 50 ml applications with 40 min intervals and 50 ml applications with 60 min intervals, also had the lowest time-averaged application rates, 1.3 and 0.8 ml/min, respectively (Fig. 3.3). The fact that three of the regimens, 50 ml applications with 20 min intervals, 100 ml applications with 40 min intervals, and 150 ml applications with 60 min intervals, had the same time-averaged application rate, 2.5 ml/min, and produced efficiencies that were not
significantly different at the 0.05 level indicates that the time-averaged application rate has merit in formulating irrigation regimens for soilless medium in containers. This is supported by the relatively high correlation ($r = -0.82$, $p = 0.01$) of the time-averaged application rate and efficiency relationship.

Regardless of application volume, efficiency following the first 300 ml applied ($\approx 100\%$) was greater than after the second 300 ml were applied (Fig. 3.4). After 600 ml, significant leaching took place and differences between regimens were manifested. As in the previous experiment, after 300 ml are applied a threshold is reached beyond which the water absorption capacity of bark decreases. These data show that the first 300 ml could be delivered in two 150 ml applications with minimal leaching. Research is needed to determine if, following the first 300 ml, an interval of greater than 60 min increases efficiency. The possibility exists that for maximum efficiency such an irrigation should occur after water is lost via evapotranspiration. Even though we attempted to return the full moisture deficit, Kiehl et al. (1992) and Lieth and Burger (1989) found that container-grown chrysanthemums (Chrysanthemum x morifolium Ramat.) could be grown at a medium moisture tension of 1 to 2 kPa, while maintaining plant quality. Therefore, in this experimentation, returning less than 600 ml may be adequate to maintain plant quality with a relatively high irrigation efficiency. Research is also needed to determine how to apply liquid fertilizer in conjunction with II that maximizes growth and minimizes nutrient loss from containers.
Conclusions

Application rates of spray stakes used in this study exceeded capacity of pine bark to efficiently absorb water. Irrigation efficiency of a single continuous application, 65%, was improved to 86% by using IL. Intermittent irrigation increases irrigation efficiency by reducing the overall application rate which allows for more of the applied water to be absorbed by the medium. The amount applied and interval between applications affects irrigation efficiency. Efficiency can be increased by decreasing the volume delivered at each application and increasing the time interval between applications.

Importance to the Nursery Trade

Since ammonium and nitrate ions are readily leached from pine bark (Foster et al., 1983; Thomas and Perry, 1980), the relatively low efficiency of continuous spray stake irrigation would result in significant amounts of N leached from bark. Container nurseries can loss, as much as, 3226 m$^3$/ha of water and 169 kg/ha of nitrate-N through leaching and runoff when using continuous trickle irrigation (Rathier and Frink, 1989). Using IL with trickle irrigation, could reduce
water loss by 42%, which is equivalent to 1355 m³/ha of water and also reduce annual nitrate-N loss significantly. Intermittent irrigation is an easy and economical way of increasing irrigation efficiency without updating irrigation systems significantly or installing large scale runoff capturing or recycling facilities.

Most nursery operators apply high rates of nutrients and irrigate excessively to prevent soluble salt buildups. Because with II the amount of leaching is reduced, it is our belief that the rate of nutrients applied can be reduced while still maintaining optimal growth.
Figure 1.1  Irrigation efficiency as influenced by medium moisture deficit (pooled over application rate), vertical bars represent 95% confidence limits, \( y = 93.9 - 0.06x + 2.16 \cdot 10^5x^2 \), \( R^2 = 0.53 \).
Figure 2.1  Efficiency of continuous and intermittent irrigation at two deficit replacement values. SE indicates pooled SE of the means, n = 10.
Figure 2.2  Intermittent irrigation efficiency after 100 ml applications at 30 min intervals. SE indicates pooled SE of the means, n = 10.
Figure 3.1  Irrigation efficiency as influenced by intermittent application volumes (pooled over time intervals between applications), vertical bars represent 95% confidence limits, $y = 102 - 0.46x + 1.63 \cdot 10^{-3}x^2$, $R^2 = 0.38$. 

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Figure 3.2  Irrigation efficiency as influenced by time interval between applications (pooled over application volumes), vertical bars represent 95% confidence limits, $y = 46.5 + 1.44x - 0.016x^2$, $R^2 = 0.18$. 
Figure 3.3   Relationship between time-averaged application rate and irrigation efficiency. Data points represent treatment means, $n = 10$, $r = -0.82$, $p = 0.01$. 
Figure 3.4  Irrigation efficiency after 300 and 600 ml were applied with 50, 100, or 150 ml applications (pooled over time intervals between applications). SE indicates pooled SE of the means, n = 10.
Literature Cited


Vita

William F. Lamack was born to Joseph and Virginia Lamack on May 22, 1967, in Norristown, Pa. He grew up in nearby North Wales and then Harleysville, Pa., attending schools in the Souderton Area School District. In 1985, Bill graduated from Souderton Area High School and then enrolled in Delaware Valley College of Science and Agriculture, Doylestown, Pa. In May 1989, he received a B.S. in Ornamental Horticulture from DVC, graduating sum cum laude. During high school and college, Bill was employed at a local nursery and garden center. In August 1989, he began graduate studies in the M.S. program of the Department of Horticulture at Virginia Polytechnic Institute and State University, Blacksburg.

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