SECTION 12
WATER MANAGEMENT

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An Aquatic Plant Production and Nutrient Mitigation System

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Nature of Work: Aquatic plants are a new and exciting specialty market for commercial nursery production. Aquatic plants have at least three primary markets including: (1) aquascaping to create residential pool gardens and aesthetically pleasing habitats around ponds in commercial business parks and residential housing developments; (2) wetland mitigation and restoration projects and (3) use of aquatic plants with high nutrient uptake capacity for treatment of excess runoffs such as recycling irrigation or effluent waters.

For many years wetlands were viewed as “nonproductive” areas that could be made “productive when drained or filled, turning them into areas useful for residential, industrial or agricultural activities. From an ecological point of view, wetlands are now regarded as vital ecosystems. During the past decade, the function and value of undisturbed wetlands have become more widely understood by the public and efforts to stop uncontrolled destruction has resulted in the Federal goal of “No Net Loss” of wetlands. Implementation of this goal is resulting in requirements that wetlands be replaced if they are destroyed. Constructing wetlands has given rise to a new horticultural nursery industry for the propagation and production of wetland species.

A research and demonstration program was implemented at the Tidewater Agricultural Research Station Aquaculture Pond Facility located near Plymouth, N.C. The project was a cooperative effort of faculty from four departments in the College of Agriculture and Life Sciences at North Carolina State University. An aquatic plant nursery facility was constructed to determine the feasibility of using water from catfish production ponds as a water and nutrient source for the production of aquatic plants and to evaluate the potential of such a system to reduce nutrients in recycled water before it was returned to fish ponds. It was further anticipated that the new methodologies could be adopted by commercial nurseries and other agricultural producers to eliminate discharge of nutrient laden wastewater from their facilities and eliminate the potential source of pollution. The report is a preliminary study initiated after construction of the nursery facility.

Three 1/4 acre research ponds used for catfish production were modified to allow drains to gravity flow into 18 constructed nursery cells. Water from a deep well was pumped into each fish pond to initially fill them. The aquatic plant nursery was constructed by excavating a shallow (2 ft. deep) by 180 ft. long pond. Nursery cells were created by using concrete highway dividers to serve as sides of the cells. A 20 ml rubber liner was spread over the entire length of the aquatic nursery and was looped over each set of dividers to create 18 cells with the dimensions of 10 feet by 30 feet. Approximately 4 inches of gravel was spread over the bottom of each cell to provide a level surface for placing trays of plants. Water entered at the front of each cell through a 6 inch PVC header pipe, equipped with a 1.5 inch ball valve outlets. The flow rate through the PVC header was approximately 100 gallons per minute. A 6 inch diameter PVC drain line with a 2 inch diameter stand pipe drain was located at the opposite end of each nursery cell. The stand pipe drains were adjusted to maintain approximately a 4.0 inch depth of water in each cell. Water drained from cells was collected in a constructed concrete sump and a 1/2 hp. electric submersible pump recirculated the water back to the three ponds.

Five wetland species included in the study were: *Pontederia cordata* (Pickerel Weed), *Saururus cerneus* (Lizards Tail), *Juncus effusus* (Soft Rush), *Scirpus cyperinus* (Woolgrass) and *Myrica cerifera,* (Wax myrtle). Divisions or liners were potted in 4.5 inch square pots. The container substrate consisted of unamended arcillite (a calcined montmorillonite and illite clay distributed by the tradename Turface by Amicor, Inc., Deerfield, Ill.). A layer of horticultural rockwool (American Rockwool, Spring Hope, N.C.) was placed in the bottom of the pots to prevent the arcillite from falling out of the pot through the drainage holes. Sixteen pots were placed in plastic trays and 30 trays of one species was placed in each wetland nursery cell. All five species and a nursery cell which contained no flats of plants was considered to be an experimental block. Plants were arranged in a randomized complete block design with three replications. A total of 1440 plants per species (8640 pots) were utilized in the study. Nitrogen was determined by Kjeldahl and P was determined by ICP procedures.

Results and Discussion: Nitrogen concentrations entering the aquatic nursery averaged 3.39 ppm (mg/l) during the 47 day period that nutrient levels were monitored (Table 1). Effluent leaving the aquatic nursery averaged 2.71 ppm. The resultant mitigation of N by the aquatic plant nursery was a decrease of 0.68 ppm.

Considering that the average flow rate into the aquatic nursery was 100 gallons (378.5 liter) of effluent per minute, 257.4 mg N were retained per minute in the aquatic nursery (0.68 mgA x 378.5 l/min = 257.4). Over a 24 hour period, 370.6 g (0.82 lbs) N were retained (per day, 1440 min/day x 257.4 mg/min). During the 47 day period, this amounted to 38.5 lbs of N mitigated by the aquatic plant nursery system. Phosphorus levels were reduced at a rate of 34.0 mg/ min., 49.1 g /day (0.12 lbs) and 5.6 lbs over the 47 day period.

Further reduction might have been realized if more plants had been grown in the nursery. Each nursery plant cell held 480 plants, but approximately five feet of each nursery cell was open surface water. Considerable floating macroscopic algae growth occurred in the open ends of the nursery cells and had to be removed to avoid clogging drains. When plants were removed from the nursery cells to prepare for a second study, heavy sedimentation had occurred in cells containing plants, while little sedimentation occurred in the cells containing no plants. Obviously, sedimentation and algae growth played a role in reduction of nutrients. However, when viewed as a system with all three factors, nutrient reduction was accomplished.

Shoot and root dry mass were determined at the beginning and end of one seasons growth (Table 2). Shoot growth was greatest for pickerelweed with 579% increase in dry mass. Pickerelweed is one of the most frequently used species in constructed wetlands and grows well in sediment with leaves extending above and shading the surface of the water (1). Lizard's Tail had the second highest increase in dry mass, followed by soft rush and woolgrass. Wax myrtle liners grew least and were in poor condition by the end of the growing season due to variable water levels and occasional submerged conditions after heavy precipitation.

Significance to Industry: This study evaluated an environmentally compatible, large scale production system which can be used to grow marketable wetland species while reducing nutrients in a closed recycled water system. Water quality was monitored as it entered and left the aquatic plant nursery. The aquatic plant nursery reduced nitrogen concentration an average 0.8 lbs N per day and phosphorus 0.12 lbs per day. Aquatic plants grew rapidly in the system. Although further studies are required, this system appears to be easily adaptable for use in nurseries to reduce nutrients in irrigation runoff before it is retumed to irrigation ponds and construction of the aquatic nursery utilizes space that normally would not be used for crop production.

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Table 1. Nutrient reduction of effluent water entering and leaving the aquatic plant nursery.

Sampling Dates	Nitrogen Concentration			Phosphorus Concentration		
	Entering	Water Leaving	Difference	Entering	Water Leaving	Difference
			(mg/l)			
July 30	3.08	2.45	0.63	0.36	0.33	0.03
Aug. 4	2.59	1.75	0.84	0.48	0.32	0.16
Aug. 11	3.36	2.80	0.56	0.26	0.37	+0.11
Aug. 18	4.34	2.38	1.96	0.94	0.64	0.30
Aug. 25	4.34	3.92	0.42	0.64	0.41	0.23
Sept. 1	3.92	3.64	0.28	0.90	0.67	0.23
Sept. 8	2.80	2.52	0.28	0.35	0.40	+0.05
Sept. 15	2.66	2.24	0.42	0.78	0.85	+0.07
Mean Values	3.39	2.71	0.68	0.59	0.50	0.09

Table 2. Dry Matter Production and Shoot Growth of Wetland Plants Grown in a Flow Through Production System Using Effluent from Aquacultural Ponds.[z]

Shoot	Early Season		Late Season		New Shoot	Shoot Growth
	Shoots	Roots	Shoots	Roots	Growth	Change
			(g)			(%)
Lizard's Tail	1.59	3.42	3.86	10.54	3.34	210.0
Pickerelweed	0.80	2.78	5.43	12.28	4.63	579.0
Woolgrass	4.17	7.69	7.89	13.80	3.72	89.0
Soft Rush	4.46	5.44	10.07	17.12	5.61	126.0
Wax Myrtle[Y]	0.86	0.45	1.04	0.68	0.23	27.0

[z] Data are means of 15 plants, early season represents plant mass at the time of potting, late season is the dry weight of plants collected November 12, 1992. New growth and percent change are not shown for roots, as a

significant amount of the substrate could not be removed from the root system.

[Y] Plants were chlorotic and in poor condition; these plants did not respond well to completely flooded growing conditions.

Growth of Woody Landscape Plants in Water-Conserving Containers

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Nature of Work: Water management is the most crucial component of nursery production. Competition for water resources and regulations are limiting availability. Growers are seeking novel ways of using water efficiently.

One such innovation a new container in which the drainage holes are "raised" — located a few inches (depending on container size) above the base of the container. Thus, there are no drainage holes in the bottom or on the sides at the base of the container. This causes the media below the raised drainage holes to remain saturated after irrigation, providing a reservoir of water. Although this saturated media might be expected to induce root diseases and suppress growth, studies of containers with saucers have found increased growth and no problems with diseases (Tilt et al., 1991). It appears that the saturated media in the lower portion of the container remains saturated for at most a few hours before the root system or remaining media absorb the water.

This container design was patented by a grower in southwestern Florida and is being marketed as the EFC™ container (Oehlbeck 1992). This report summarizes my preliminary evaluations of 3- and 5-gallon versions of the EFC™ container in demonstrations conducted during the past 3 years.
Experiment 1 (1991). Silver maple, taiwan cherry, shore juniper, and 'Hetzi' holly were grown in EFC™ or conventional 3-gallon containers under conventional overhead irrigation of about 0.4 inches per day. The objective was to observe plant growth of a variety of species in EFC™ containers under typical nursery conditions with overhead irrigation. Height and width were measured 19 weeks after potting.

Experiment 2 (1992). Liners of redbud and 'Muskogee' crape myrtle were potted into EFC™ or conventional 5-gallon containers. Half of each group received 1.3 gallons per day applied with Roberts Spot-Spitters (Terra Cotta 160° Mini-Flow) while the other half received 2.6 gallons per day applied similarly. The objective was to determine whether the EFC™ containers could compensate for higher irrigation rates. Height, width, and caliper were determined 15 weeks after potting.

Experiment 3 (1993). Bare-root liners of dogwood and 'Simpson's Red' crape myrtle were potted into EFC™ or conventional 5-gallon containers and placed under micro-irrigation regimes of conventional or pulse irrigation. Pots of each container type were divided into 3 groups and given 0.5 gallons of water per day split into 1, 2 or 4 applications per day. The objective was to determine whether the EFC™ containers could increase growth beyond that possible through pulse irrigation. Height, width and caliper were measured 9 weeks after initiation of the irrigation treatments.

Results and Discussion: Under the overhead irrigation regime of Experiment 1, 'Hetzi' holly, shore juniper and taiwan cherry in EFC™ containers showed no significant improvement in growth (Tables 1 and 2). Silver maple in EFC™ containers had significantly less growth than maples in conventional containers. The irrigation rate was established for other plants on the same bed. This high irrigation rate may have masked effects of the water-conserving container.

In Experiment 2, irrigation rate had no effect on redbud growth (data not shown) probably because both rates saturated the soil. However, increased growth of redbuds occurred in EFC™ (Table 3). Results of crape myrtle are not presented because plants in conventional containers rooted into the ground thereby confounding results.

After 8 weeks, neither irrigation regime nor container type significantly affected growth of plants in Experiment 3 (data for increase in caliper shown in Table 4).

Significance to Industry: The EFC™ container appears to have species-specific effects on plant growth. Increases or decreases in growth are presumably due to the container's ability to retain a reservoir of saturated media. Although growth increases can be obtained through optimizing irrigation rates and applications, the EFC™ container is another tool that growers can use to improve nursery efficiency of water use.

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Table 1. Influence of container type on height growth of 4 woody landscape species.

	Increase in Height (in)			
Container Type	Maple	Cherrv	Holly	Juniper
EFC™	27b	7a	4a	2a
Conventional	33a	6a	4a	la

Table 2. Influence of container type on width growth of 4 woody landscape species.

	Increase in Width (in)			
Container Type	Maple	Cherry	Holly	Juniper
EFC™	l5b	4a	9a	17a
Conventional	l9a	3a	6a	16a

Table 3. Influence of container type on redbud growth from May through September 1992.

	Increase in Growth (in)		
Container Type	Height	Width	Caliper
EFC	22a	30a	0 . 49a
Conventional	8b	13a	0.28b

Table 4. Influence of container type and irrigation regime on increase in caliper of crape myrtle and dogwood.

	Increase in Caliper (in)			
	Irrigation	Crape Mvrtle		Do~wood
Regime	EFC	Conventional	EFC	Conventional
10 min. lx	0.16	0.12	0.17	0.17
5 min. 2x	0.23	0.15	0.15	0.20
2 1/2 min. 4x	0.20	0.21	0.19	0.21

Water Reservoirs as an Irrigation Management Tool for Large Containers

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Nature of Work: Irrigation scheduling for container-grown nursery plants is a subjective practice and must take into consideration the plants being grown, stage of growth of those plants, size of the containers, water source, weather conditions and other factors. Nursery producers generally examine the moisture in the top inch of medium. If the medium is dry, they irrigate for a period of time they "feel" to be adequate to thoroughly rewet the medium. This irrigation regime results in fluctuating levels of excessive and deficient moisture. Excessive moisture reduces root aeration (Kozlowski, 1985) and can contribute to stress and lead to root-rot diseases like those caused by Phytophthora (Hagen and Mullen, 1981). Lack of moisture can also result in disease problems and loss of plant growth. The nursery industry is actively searching for ways to reduce water use and run off from the nursery.

Subirrigation and capillary mats are methods utilized in the greenhouse industry to improve water management. It is possible to adapt these irrigation practices to the production of woody ornamentals in large containers. Water maintained at a certain depth beneath container medium surface can make water readily available to plants through water movement from the water table to roots by capillary action. Roots also move down to the zone of readily available water.

The purpose of this experiment was to examine the effect of growing pecan (Carya illinoensis 'Melrose') and pear (Pyrus callervana 'Bradford') trees in containers with a water-holding reservoir at the container base.

Thirty-six, three gallon 'Melrose' pecan trees and 36 field-grown 'Bradford' pear trees were subjected to three treatments in March, 1991. They included: 1) Control - Trees were grown in 20 gallon (76 liter) conventional polyethylene containers with six, 1 inch diameter drainage holes evenly spaced around the bottom edge of the container. 2) Raised holes (EFC) - trees were grown in the same size containers, but with the drainage holes located 2 inches (5 centimeters) from the container bottom (distance measured from bottom of container to bottom of the drainage holes). Drainage holes were the same in size as in the standard containers and with the same distribution around the container. This system was developed and patented by Robert Rigsby of Rigsby Nursery, Ft. Myers, FL. The containers are sold under the name Environmentally Friendly Containers™ (EFC). 3) Subirrigation - Subirrigation was accomplished by placing containers in water-holding frames (lined with plastic). Frame dimensions were three feet by three feet and 2 1/2 inches deep.

Irrigation for control and EFC treatments were provided by two low flow "spot spitter" emitters each delivering 0.12 gallons (0.45 liters) of water per minute (Roberts Irrigation Products, 700 Rancheros Drive, San Marcos, CA 92069-3007). Emitters are sprayed in a semi-circular spray pattern with enough water to cover the entire medium surface. Plants were irrigated for about 20 minutes supplying about 2.5 gallons (9.46 liters) of water for each container when the upper 1 inch of medium was observed to be dry. No surface irrigation was provided for the subirrigation containers, except for rainfall. The frames were filled with water to the full depth, and were refilled when the water level dropped to half-full.

Trees were transplanted into containers for the three treatments in May, 1991. They were planted into milled pine bark:sand (6:1 by volume) medium amended with 14 pounds, Osmocote 17N-3.0P-l0.0K, 12-14 mo. release (Grace/Sierra Horticultural Products, Milpitas, CA), 1.5 pounds Micromax micronutrients and 5.0 pounds dolomitic limestone per cubic yard. Supplemental Osmocote, 17N-3.0P-l0.0K, was topdressed at 1 pound per pot in April, 1992.

Plant height and trunk caliper were measured at transplanting, and on August 23, 1991, and November 18, 1992. Of the twelve trees in each treatment, four were randomly selected for destructive sampling on November 18, 1992. Fresh shoot weight was measured as trees were removed from the containers and severed from the root balls. The remaining eight trees were retained for field planting in a subsequent experiment. Visible roots were counted in 5 randomly selected 1 in2 areas at the bottom of the root balls. For pecan roots, large roots >l0mm diameter were counted, while all visible roots were counted for pears. After counting, roots from sampled trees were washed, severed from original root balls, and divided into 2 categories by root diameter, secondary (2mm-lcm), and fibrous (<2mm) (Fare et al., 1985). There were no primary roots (>lcm) extending from the original pre-transplanted root balls. Roots in each category were weighed.

Results and Discussion: There were no differences for caliper or height of pear trees measured in August, 1991. Pecan trees grown in EFC and sub-irrigated containers were similar in growth but were both about 3% and 6% larger than the control treatment in caliper and height, respectively. Final growth measurements of pear trees were significantly greater when trees were grown in EFC containers except for height (Table 1). There were no height differences for pear trees among the treatments. There were no differences between the subirrigation and control treatments for pear. For pecan trees, EFC containers had greater caliper, height and fresh weight than the control treatments. Subirrigation treatments were similar to EFC treatments for all measurements but greater in height and caliper than the conventional containers. There were no differences between the two container treatments for top shoot weight.

When plants were removed from containers and root systems were examined, roots were obviously absent or sparse in the poorly-aerated layer where water stood at the bottom of subirrigated containers (Table 2). The absence of roots in the lower layer of medium in the treatments with subirrigation contrasted sharply with the proliferation of roots at the bottom of conventional containers in the treatments with free drainage. The influence of EFC containers on root growth were species specific with no differences in root count between the control and EFC containers for pear and a total absence of roots in the bottom of EFC containers for pecan. When root weights were compared for fibrous and secondary roots, no treatment differences were found for either species. Apparently, root growth in upper portions of EFC and subirrigated containers compensated for the sparsity of root growth in the lower portion of the containers.

Use of containers with water reservoirs appears to be a promising way, with the species tested, to increase growth of plants grown in a pine bark medium. We suggest that the improved growth is related to continuous access by roots above the increased saturated zone to the water contained in the reservoirs. Roots in traditionally irrigated containers are subjected to extremes in drying and wetting. It is possible that with increased frequency of irrigation of the traditional containers, equal growth could have been realized. However, subirrigation or water reservoirs can offer a larger margin for error in the water management program.

Significance to the Industry: Equal or better growth can be realized in our tree production systems through subirrigation or water reservoirs. If these changes are economically feasible to implement, an opportunity exists for improving our profits while acting as responsible role models in preserving our natural resources.

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Table 1. Effect of water reservoir treatments on pecan and pear growth.[Z]

Treatment	Caliper (inches)	Height (feet)	Top fresh shoot wt. (pounds)
		Pear	
EFC	1.7 a	8.2 a	9.5 a
Subirrigation	1.5 b	7.9 a	6.2 b
Control	1.5 b	7.9 a	5.5 b
		Pecan	
EFC	1.5 a	8.2 a	4.2 a
Subirrigation	1.6 a	8.2 a	3.5 ab
Control	1.3 b	6.9 b	2.4 b

[Z]Growth measurements were made on November 18, 1992 following two seasons of growth in the treatment containers.
[Y] Within a species and column, means followed by the same letter do not differ according to Duncan's Multiple Range Test, 5% level.

Table 2. Effect of water reservoir treatments on pecan and pear root growth.[Z]

	Root count at container base[Y]	
	Pear	Pecan
EFC	19 bx	0 a
Subirrigation	0 a	0 a
Control	23 b	2.3 b

[Z]Growth measurements were made on November 18, 1992 following two seasons of growth in the treatment containers.
[Y]Root counts represents roots in 1 in2 area that were visible on the lower medium surface when containers were removed on November 18, 1992. For pear, which produced many small roots, the count was for all visible roots of any size. For pecan, which had mostly large caliper roots at this location, the count was for roots with a caliper of >l0mm. x Within a species and column, means followed by the same letter do not differ according to Duncan's Multiple Range Test, 5% level.

Overhead Sprinkler Irrigation of Container-Grown Plants - Intermittent Irrigation and PreIrrigation Substrate Moisture Content Affects Water Application Efficiency

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Nature of Work: Overhead sprinkler irrigation is the predominant system to irrigate plants grown in small containers (≤ 12 liter, 3 gallon). Due to the relatively porous nature of soilless substrates, a significant fraction of the applied water leaches from containers. Intermittent irrigation, application of a plant's daily water allotment in more than one application with prescribed intervals between applications, is an irrigation strategy to reduce the amount of water and fertilizer lost from containers following irrigation. Intermittent irrigation was first proposed by Karmeli and Peri (2) working with mineral soil and was termed "pulse irrigation." Since the commercial irrigation industry uses the term pulse irrigation for a specific water delivery mechanism, this paper will use the term intermittent irrigation. Intermittent irrigation has been shown to increase water application efficiency of spray stake-irrigated plants compared to applying the daily water allotment in a single continuous application (3) but no work has occurred with sprinkler irrigation. Thus, the objective of this overhead sprinkler irrigation project was to determine how water application efficiency was influenced by the duration of the interval between intermittent applications and by pre-irrigation substrate moisture content.

General methodology. A simulated overhead sprinkler irrigation system delivered water at 1.4 cm/h (0.55 inch/h) to containers. Pine bark (PB) was amended with sand (S), 9 PB: 1 S (v/v), and dolomitic lime at 0.19 lb/ft3 (3 kg/m3). Approximately 3.5 liters (3.7 qt) of substrate was added to each 3.8 (1 gallon) container. Marigold *(Tagetes erecta* L. 'Apollo') seedlings were transplanted into substrate-filled containers and greenhouse-grown. Plants were fertilized with Osmocote 14-14-14 (0.7 oz/container) and hose irrigated as needed until the commencement of the experiments. After irrigation treatments (to be discussed), leachate was collected and water application efficiency computed using the formula: [(vol applied - vol leached) ÷ vol applied] • 100. Treatments were replicated at least six times.

Time interval between intermittent applications (Expt. 1). Plants received seven irrigations during the two week period. Water was applied continuously (single application) or intermittently in which three applications (each one third of ET) were applied with 20, 40, or 60 min intervals between applications. Containers were weighed after irrigation and drainage (weight before evapotranspiration [ET]) and before irrigation (weight after ET). The volume of water applied in each irrigation was the difference between weight after ET and weight before ET. During the experiment, pre-irrigation moisture content ranged from 70% to 95% of container capacity (CC) and the volume of water applied (= ET) ranged from 66 to 663 ml (≈0.07 - 0.7 qt).

Time interval between intermittent applications (Expt. 2). Two hundred ml (≈0.21 qt) of water was applied continuously or intermittently in which three 67 ml (0.07 qt) applications were applied with 60, 90, or 120 min between applications.

Substrate moisture distribution after irrigation. Two hundred seventy five ml (≈0.3 qt) was applied continuously or intermittently in which 33%, 66%, or 100% or the 275 ml was applied in one, two, or three applications, respectively. Each intermittent application was one third (92 ml) of the total volume and interval duration between applications was 60 min. Leachate volume was measured at the end of each interval just prior to the start of the next application to determine efficiency of each application. After the last application in both continuous and intermittent treatments, containers were covered, drained for 45 min, weighed and leachate volume measured. Substrate in each container was transversely trisectioned into approximate equal sections (5 cm, ≈ 2 in). After removing roots, substrate in each section was mixed thoroughly and a sub-sample of each section was weighed then oven-dried to determine gravimetric moisture content.

Results and Discussion: *Time interval between intermittent applications (Expt. 1).* There was a positive linear relationship between efficiency and interval duration between intermittent applications for the seven irrigations (Table 1). Results are in general agreement with a trickle irrigation study (pine bark-filled 11-liter container) in which intermittent efficiency increased by ≈ 10% (absolute basis) when interval duration increased from 20 to 40 min (3). Increasing the interval duration between irrigations increased the time averaged application rate (TAAR); there was an inverse relationship between TAAR and efficiency (data not shown). Efficiency for the 60-min interval treatment (TAAR of 0.38 cm/h) was 6% greater than continuous irrigation in which water was applied at a nominal application rate of 1.4 cm/h. As interval duration between intermittent applications increased, the time for water to move through the substrate and enter micropores was increased. For both irrigation methods, as substrate moisture content and volume applied increased, leachate volume increased and relationships were expressed in regression models for continuous (Eq. [1]) and intermittent (60 min intervals) (Eq. [2]) irrigation:

$$VOL_L = (0.0662 \bullet M_{PI}2) + (0.0075 \bullet M_{PI} \bullet VOL_A) - 594 \quad R^2=0.89, P=0.0001 \; [1]$$
$$VOL_L = (0.0643 \bullet M_{PI}2) + (0.0063 \bullet M_{PI} \bullet VOL_A) - 567 \quad R^2=0.89, P=0.0001 \; [2]$$

whereby VOL_L = leachate volume (ml); M_{PI} = pre-irrigation substrate moisture content (% of CC); VOL_A = volume of water applied (ml); and are limited to a 9 PB: 1 S substrate, an M_{pl} range of 72 - 94%, and a VOL_A range of 125 - 610 ml. Regression equations were used to predict leachate volumes for combinations of pre-irrigation substrate moisture content and volume of water applied (Table 3). These data demonstrate the strong influence of these factors on the amount of water lost from the substrate.

Time interval between intermittent applications (Expt. 2). A positive linear relationship was exhibited between efficiency and interval duration between intermittent applications (Table 4). Efficiency increased by 7%, 10%, and 12% (absolute basis) with 60, 90, and 120 min intervals, respectively, compared to continuous irrigation. As in Expt. 1, efficency increased as TAAR decreased (Table 2). The relatively low efficiency values (Table 2) were most likely due to the combined effect of the relatively high pre-irrigation moisture content (89% of CC) and relatively high bulk density (0/ 38 g/cm3) of the sand-amended pine bark substrate. Ownley et al. (4) hypothesized that the proportion of large pores in a substrate decreases as bulk density increases. If so, a relatively high proportion of small pores was most likely water-filled resulting in less water absorbing capacity and a greater degree of macropore flow of applied water.

Substrate moisture distribution after irrigation. Regardless of irrigation treatment and for both pre- and post-irrigation substrates, 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, 5). Prior to irrigation, gravimetric moisture contents of top, middle, and bottom sections were 111%, 124%, and 147%, respectively (Fig. 1). Application of the first intermittent volume (92 ml) resulted in a water content percentage increase (absolute basis and relative to moisture percentage of pre-irrigated substrate) 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 implies a significant channeling effect. The water content increase (relative to the previous moisture percentage) for the top, middle, and bottom sections following the second 92 ml application was 1%, 0, and 9%, respectively, and following the third 92 ml applications was 1%, 2%, and 4%, respectively. Similar to the water content distribution following the first application, water gain occurred predominantly in the bottom section which implicates macropore flow and not a sequential piston flow fashion as occurs in mineral soil (6). Following the frist application, water bypassed the already filled micropores of the upper sections percolating through macropores to the bottom third of the container. The likely reason that the bottom third collected 9% more water in intermittent treatment compared to the continuous treatment was that the intermittent time intervals between irrigations allowed water to be adsorbed to less accessible micropore sites and absorbed into intraparticle sites. Following all three intermittent applications, water contents of the top and middle sections were similar to those of the continuous treatment (Fig. 2). Apparently, the gravitational force acting on these sections did not allow for an increased water content relative to the bottom section.

Significance to Industry: This work demonstrated that water application efficiency can be improved by approximately 4% to 10 % via intermittent irrigation. However, efficiency, regardless of application method, is primarily a function of pre-irrigation moisture content and the volume of water applied; efficiency deceases as volume and substrate moisture content increases. For pine bark, relatively high efficiencies can be achieved if irrigation occurs when the pre-irrigation substrate moisture content is below 88% and the volume of water applied does not exceed 300 ml (≈0.32 qt). Work is needed to determine the extent to which a substrate can be allowed to dry without reducing plant growth or quality.

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Table 1. Influence of continuous (single application) versus intermittent (three applications with 20, 40, or 60 min intervals between applications) irrlgation on application efficiency and in a 9 pine bark: 1 sand substrate; data are means of seven irrigations (Time interval between intermittent applications, Expt. 1).

Irrigation treatment	Application efficiency (%)	Time averaged application rate (cm/h)
Continuous	85	1.40
20 min	87	0.73
40 min	89	0.50
60 min	91	0.38
Significance[Z]		
Linear	***	
Quadratic	NS	
Cubic	NS	

[Z] NS,*** Nonsignificant or significant at P = 0.001, respectively, n = 42.

Table 2. Influence of continuous (single application) versus intermittent (three applications with 60, 90, or 120 min intervals between applications) irrigation on leachate volume, application efficiency, and time averaged application rate in a 9 pine bark: 1 sand substrate. (Time interval between intermittent applications, Expt. 2).

Irrigation treatment	Application efficiency	Time averaged application rate
	(%)	(cm/h)
Continuous	56[Z]	1.4
60 min	63	0.29
120 min	68	0.21
Significance[Y]		
Linear	*	
Quadratic	NS	
Cubic	NS	

[Z] n = 6.

[Y] NS,* Nonsignificant or significant at P = 0.05, respectively.

Table 3. Predicted volume of water leached for intermittent and continuous irrigation as influenced by irrigation volume and substrate pre-irrigation moisture content (% of container capacity).

Vol applied (ml)	Vol leached (ml) Pre-irrigation moisture content (% CC) 73	80	87	94
	Intermittent			
125	0	0	0	75
250	0	0	57	149
375	0	34	125	223
	Continuous			
125	0	0	0	79
250	0	0	70	167
375	0	55	152	255

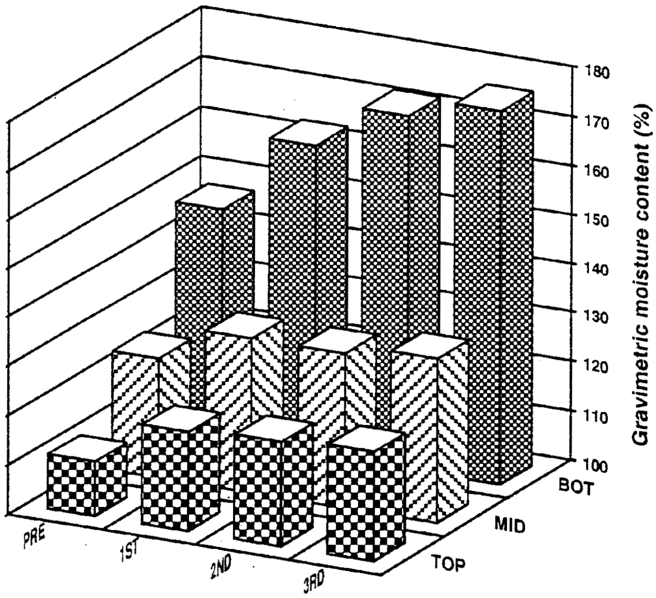

Fig. 1. Gravimetric moisture content (%) of top, middle (MID), and bottom (BOT) sections of a 9 pine bark:1 sand substrate before irrigation (PRE) and after the first (1ST), second (2ND), and third (3RD) intermittent volumes were applied (Substrate moisture distribution after irrigation, Expt. 1).

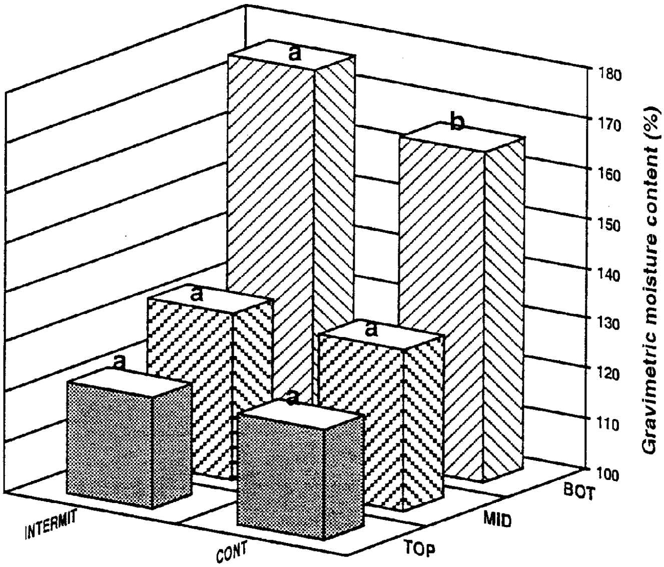

Fig. 2. Gravimetric moisture content (%) of top, middle (MID), and bottom (BOT) sections of a 9 pine bark : 1 sand substrate after receiving the same volume of water continuously (CONT) or in three intermittent (INTERMIT) applications. Letters above columns indicate section differences between continuous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

Oxyfluorfen Detection in Pond Water and Sediment from a Two-Year Nursery Study

N. D. Camper, Ted Whitwell, R. J. Keese, M. B. Riley and P. C. Wilson
South Carolina

Nature of Work: Herbicides are used extensively in container production nurseries for weed control. They are applied as broadcast sprays or granules followed by overhead irrigation. ROUT (Grace-Sierra) and OH-2 (Scotts) are commonly used formulations and contain one of the dinitroanilines, pendimethalin or oryzalin, plus the diphenylether oxyfluorfen. Since as much as 80 % of an application falls on the bed cover (3), granular or spray residues can be carried in runoff water into containment ponds. Leachates from potting medium can be an additional source of residues (1). These residues could result in plant damage when pond water is used for irrigation purposes, or cause potential environmental problems if contaminated water were to leave the nursery site.

Several factors influence herbicide movement in runoff water. These include the chemical and soil properties, container bed construction, timing of applications in relation to irrigation or rainfall, and adsorption to particulate materials. Oxyfluorfen is strongly adsorbed to soil and not readily released or leached (2). Keese et al (5) detected maximum residues of oryzalin, pendimethalin and oxyfluorfen in runoff within 15 minutes after beginning irrigation. Bedcover composition also influences residue movement, with a gravel composition allowing the least movement (6).

Materials and Methods: The site chosen for this study was a container production nursery (ca. 20 ha) in the Piedmont region of South Carolina where all beds were on slopped terrains. Runoff water was channeled through drainage ditches into a series of containment ponds which were interconnected. One pond served as an irrigation source. Granular applications of ROUT and OH-2 were applied to bed areas for weed control by the nursery operators. Water (from a depth of 15 to 30 cm) and sediment samples ffrom 20 to 30 cm in shallow areas or with an Eckman Dredge in deeper areas) were collected monthly from February 1991 until January 1993. Samples were collected in silanized glass jars, transported to the laboratory on ice and stored at 4 C until processed. Water and sediment samples were collected from multiple sites in each pond and the data is presented as an average of means across all ponds. Samples were collected monthly from Feburary 1991 to January 1993.

Water samples (200 ml) were adjusted to pH 2.0 to 2.3, filtered, extracted using C_{18} solid phase extraction columns and eluted with HPLC-grade acetone. Sediment samples (15 g) were dried, ground to a powder and extracted with methanol. Analysis was by HPLC (Varian with C_{18} column, UV detector, and a gradient of 60:40 acetonitrile:water to 100 % acetonitrile. Retention time for oxyfluorfen was 19.0 min. Detection limits were 1 ppb in water and 0.1 ppm in sediment.

Results and Discussion: Oxyfluorfen has a water solubility of 0.1 ppm (4) and is strongly adsorbed to soil and not readily released or leached (2). Large amounts (ca. 35 kg ai) of OH-2 were applied in May, July and October of 1991 (10, 11 and 12.5 kg ai, respectively - Figure 1A). Oxyfluorfen residues in pond water were highest in August and October, which roughly correlates with the time of highest applications (Figure 1 A). Prior to August, levels were at or below detection limits, and residues were low during the remainder of 1991. Applied material was less in 1992, with the highest applications made in May, June and July (Figure 1B). The highest 1992 oxyfluorfen levels detected in pond water were in April and June, which do not correlate with time of application. The highest residue level detected in 1991 sediment samples was in December (Figure 1 C). This followed a high application to the nursery beds in October. The greatest 1992 sediment residue levels were detected in April (Figure 1 D) which corresponds to the high residue levels detected in pond water in the same month (Figure 1B). In 1992 there were differences in residue levels detected between the different ponds, both in water and sediment samples (Figures 1 B and 1 D). Differences between ponds may be attributed to application and drainage patterns within the nursery operations.

Many factors can influence residue levels in water and sediment; however, a consideration of any single factor does not explain the results reported herein (e.g., water solubility). Perhaps the most significant observation from this study is that oxyfluorfen residues do not accumulate or build-up with repeated applications. Thus, the potential off-site contamination, if a “significant” rainfall would result in flooding and movement of pond water to surrounding areas, is low. Since residue levels do not accumulate, a dissipation mechanism must be operative, possibily chemical or biological degradative processes. Samples of irrigation water at the sprinkler head were not routinely collected; however, a random sampling showed levels above
detection limits only in April of 1992, the same time significant residue levels were detected in both pond water and sediment. Thus, potential for plant damage from residues in the irrigation water may be relatively low.

Significance to Industry: This study showed that oxyfluorfen residues do not accumulate in containment pond water or sediment with continued applications. The potential movement of residues from the nursery site to surrounding areas and posing an environmental problem is remote.

Technical contribution No. 3437 of the South Carolina Agricultural Experiment Station, Clemson University. This research was supported in part by grants from the Horticultural Research Institute, Scotts Chemical Company, Grace-Sierra Chemical Company and the South Carolina Agricultural Experiment Station Horticultural Enhancement Program.

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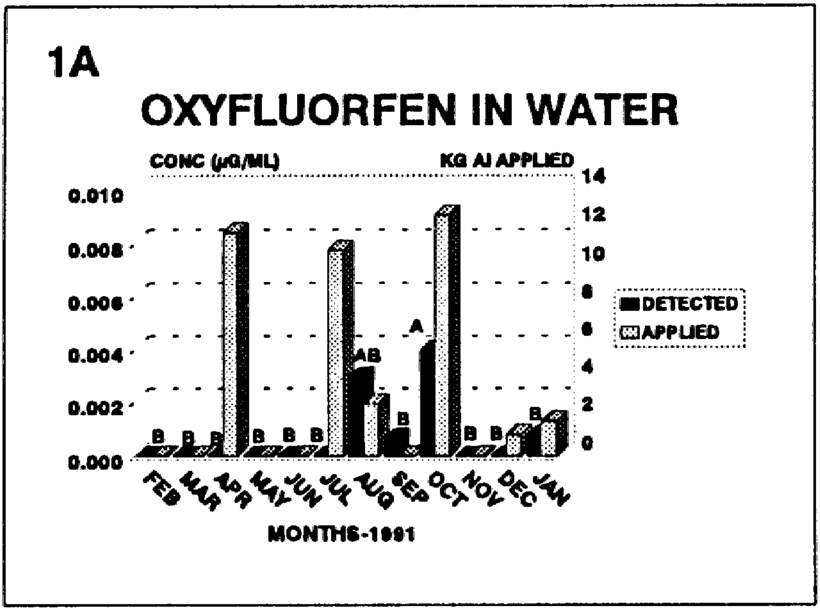
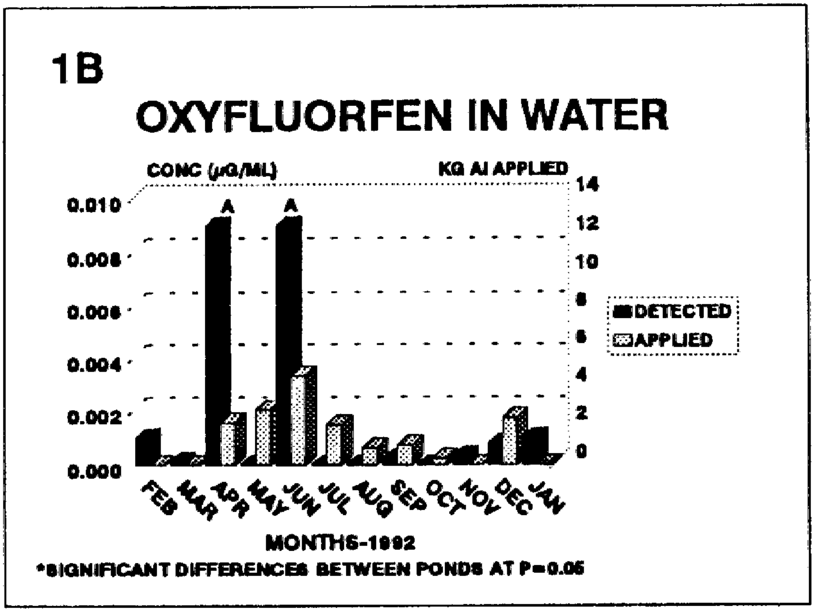
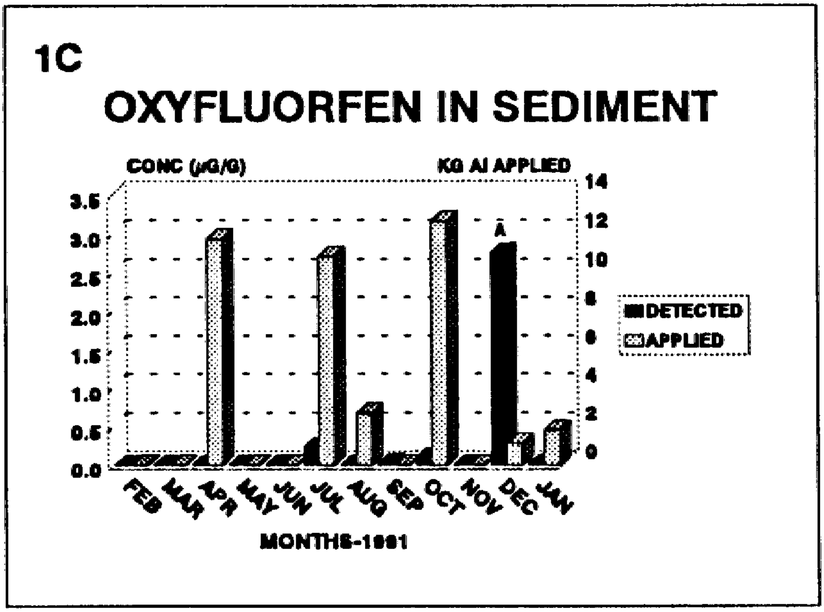
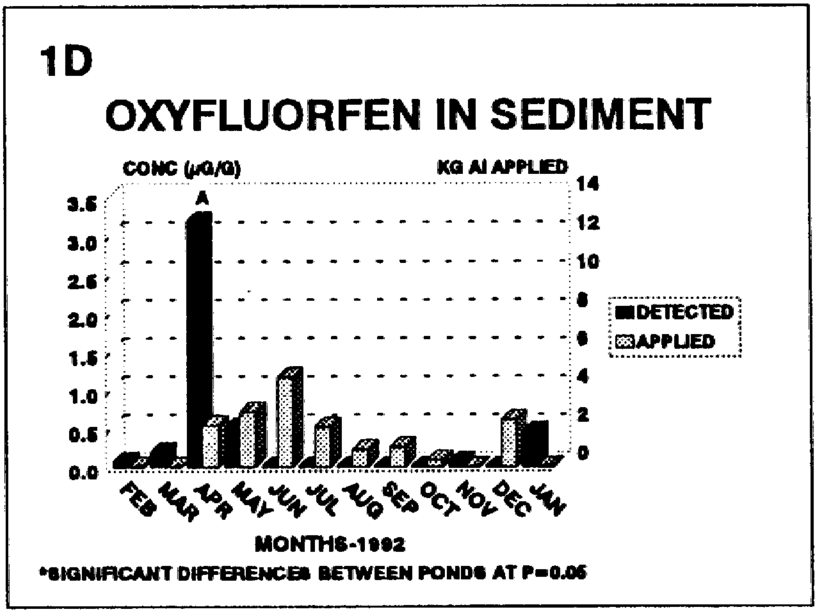
Figure 1. Concentrations of oxyfluorfen detected in containment pond water (ug/ml for 1991 - A and for 1992 - B) and in sediment (ug/g for 1991 - C and for 1992 - D) and the amount of formulated material applied (kg ai).






1C
OXYFLUORFEN IN SEDIMENT
CONC (µG/G)
KG AI APPLIED
DETECTED
APPLIED
FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN
MONTHS-1991


1D
OXYFLUORFEN IN SEDIMENT
CONC (µG/G)
KG AI APPLIED
DETECTED
APPLIED
FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN
MONTHS-1992
*SIGNIFICANT DIFFERENCES BETWEEN PONDS AT P=0.05

Comparison of Herbicide Application and Residues in Pond Water During a Two-Year Study

M. B. Riley, R. J. Keese, N. D. Camper, T. Whitwell, and P. C. Wilson
South Carolina

Nature of Work: Herbicides are used extensively in ornamental nurseries for control of weeds both in and around containers. In general, herbicides are applied as broadcast sprays or granules to plants in containers and part of the formulation falls directly on the adjacent soil or bed-cover material. This material, and also material which is leached from the containers (2), may occur as herbicide residues in runoff water. Herbicide residues were detected in containment ponds (5) and in runoff water as a result of direct application followed by irrigation (3). In general several herbicide applications are made during the year. Two of the most commonly used materials are Rout (oryzalin and oxyfluorfen, Grace-Sierra Chemical Co.) and OH-2 (pendimethalin and oxyfluorfen, Scotts) (1). Repeated application of these materials concern nurserymen because of the potential for phytotoxicity of recycled irrigation water and pollution of surface and ground water. Herbicide runoff is dependent on many factors including chemical and physical properties of the herbicides, soil and container media properties, bed construction and slope, and timing of application in relation to rainfall or irrigation (4).

A two-year study was conducted at a commercial nursery to determine the presence of herbicide residues following normal commercial procedures and where the runoff water was contained on the premises and reused for irrigation. The nursery consisted of approximately 150 acres (60 ha) with two ponds. Herbicide application information was provided by the nursery. Water samples were collected from both ponds monthly beginning February 1991. All glassware used for collection and analysis was silanized to prevent herbicide adsorption. The pH of water samples was recorded, adjusted to pH 2.2-2.3 with 6N HCl, and herbicides were extracted from the water (200 ml) after filtering using a C_{18} solid phase extraction column. Herbicides were eluted with 2 ml acetone, filtered and stored (-20 C) prior to analysis. Herbicide residues were determined using a Varian HPLC equipped with a C_{18} column and a variable wavelength UV detector (206 nm). Running conditions consisted of a gradient of 60:40 acetonitrile:water to 75:25 in 25 minutes at 1 ml/min. Retention times were 7.4, 20.2, and 21.2 min for oryzalin, oxyfluorfen and pendimethalin, respectively. Detection limits were 1 ng/ml (1 ppb). Confirmation of oxyfluorfen and pendimethalin was obtained utilizing gas chromatography-mass spectrometry.

Results and Discussion: Oxyfluorfen and pendimethalin residues were regularly detected in pond water during the two-year study (1991-2) with higher residue levels generally observed in the month of or the month following significant applications (Fig. 1-2). During 1991 oxyfluorfen and pendimethalin were applied in essentially three major applications (April, August, and January) (Fig 1a, 2a). In 1992, approximately twice as much herbicide was applied throughout the year, with major applications in January and June. Detected herbicide residues were closely related to the application rates, with higher residue levels occurring in the month of or following application. Herbicide residue levels did not accumulate during the study period, but peaks and valleys were observed indicating that herbicides were being degraded and/or washed through the system. The highest level of oxyfluorfen detected was 0.037 ug/ml (ppm) and pendimethalin was 0.008 ug/ml (ppm). Overall results do not indicate a significant accumulation of herbicides in water during the growing season. If accumulation did occur, it could present problems where water is subsequently used for irrigation or is leaving the nursery site. A definite correlation exists between the pendimethalin levels applied and the residues detected. Herbicide applications which are applied continuously throughout the year would be less likely to result in residue problems when compared to application of herbicides in two or three major events.

Significance to Industry: Knowledge concerning the presence of herbicides in water from containment ponds and its relationship to application is important to nursery operators in determining if: injury may occur when using the water to irrigate plants, injury may occur to non-target organisms in the aquatic system, and herbicide residues are present in water leaving the nursery site. Results from the two-year study indicate that careful consideration should be taken prior to herbicide application since cumulative application was directly related to herbicide residue detection, even though no accumulation of herbicides occurred over the long-term and residues were less than 50 ng/ml (50 ppb) .

South Carolina Agricultural Experiment Station No. 3434. This research was supported in part by grants from Horticultural Research Institute, Scotts Chemical Company, and Grace-Sierra Chemical Company. Trade names and companies are mentioned with the understanding that no discrimination is intended nor endorsement implied.

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Figure 1. Quantities of pendimethalin applied and residues detected in water during 1991 (A) and 1992 (B). Letters indicate differences at P=0.05 between monthly herbicide residue levels.

Figure 1-A

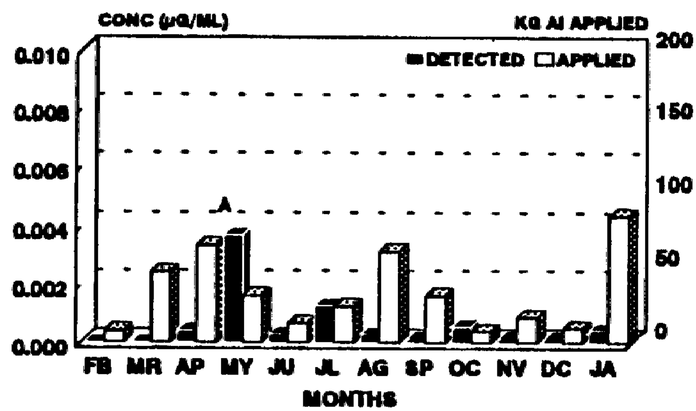


Figure 1-B

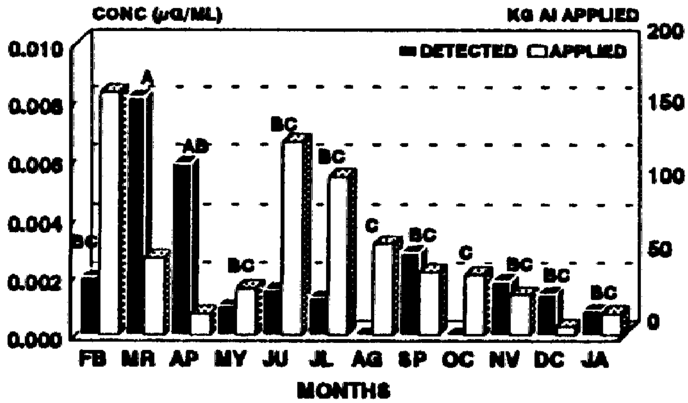


Figure 2. Quantities of oxyfluorfen applied and residues detected in water during 1991 (A) and 1992 (B). Letters indicate differences at P=0.05 between monthly herbicide residue levels.

Figure 2-A

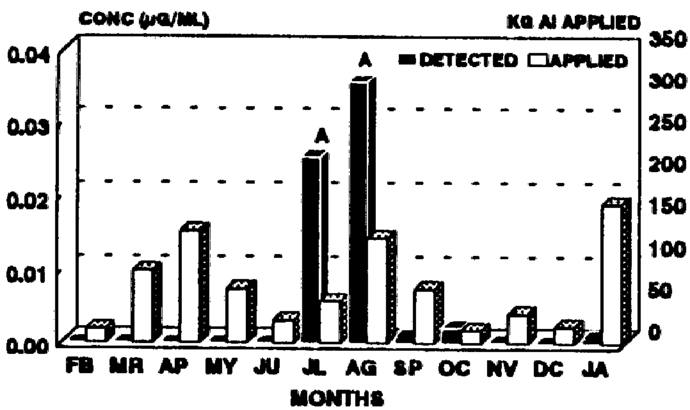
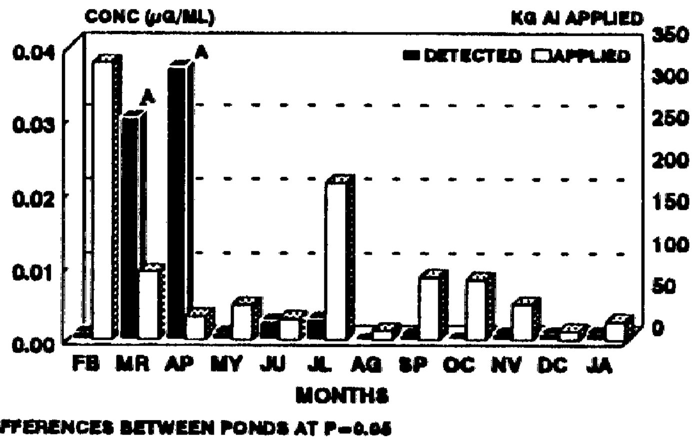


Figure 2-B



Cold Storage Method and Duration Affects Water Stress in Bare-root Trees

Rick Bates and Alex X. Niemiera
Virginia

Nature of the Work: In many parts of the country deciduous shade trees are harvested during autumn and early winter, placed in cold storage and shipped in the spring. Storage conditions can increase the likelihood of desiccation stress. The desiccation tolerance of bare-root nursery stock differs dramatically among species (4). For example, *Crataegus phaenopyrum* is sensitive and many *Acer* species are tolerant. Mist irrigation of pre-bud break Yoshino cherry trees resulted in decreased water stress (1). However there are few reports on the impact of shipping, storage methods and duration on stress accumulation in bare-root deciduous nursery stock. The objectives of this study were to determine the influence of shipping, plant part exposure during storage and storage length on shoot xylem water potentials of Norway maple and Washington hawthorn bare-root seedlings.

Seventy-two *Acer platanoides* and seventy-two *Crataegus phaenopyrum* two-year-old branched bare-root liners were received from Lawyer Nursery, Plains, Montana on 14 Jan. 1993. One-hundred-forty-four two-year-old Norway maple and Washington hawthorn liners grown at the VPI&SU nursery, Blacksburg, Va. were also lifted from pine barkfilled beds on 14 Jan. 1993. Eighteen trees of each species remained in VPI&SU nursery beds as controls to be lifted through the spring. Shipped and locally grown trees were immediately placed into 2C (35F) storage and approximately 70% relative humidity. At the time of placement into cold storage, trees were randomly allocated to one of the following four packaging treatments: 1) whole plant covered (entire seedling enclosed in Union Camp 3-layer poly bags) 2) roots covered (roots only sealed in poly bags with shoots exposed) 3) shoots covered (shoots only sealed in poly bags with roots exposed) 4) whole plant uncovered (entire seedling exposed). On 28 Jan., 11 Feb., 28 Feb., 27 Feb., 11 March, 28 March, and 11 April three hawthorn and three maple trees from each treatment and each source (shipped and locally grown) were removed from cold storage and stem xylem and root water potential was measured using a portable pressure chamber on a 10.2 cm (4 in.) stem section and a 7.6 cm (3 in.) root section excised from each tree. At each of the above times three maple and three hawthorn controls were lifted from nursery beds and water potential measurements were taken. Sixty days after treatments terminated tree marketability was assessed. Species, storage treatment and time were arranged in a factorial combination. Tree source (local vs. shipped) data was analyzed seperately.

Results and Discussion: In general shoot water potentials decreased (became more negative) with increased storage duration regardless of storage treatment, plant source or species (Table 1). The exception to this trend was hawthorn and maple field lifted controls in which water potentials increased over time. Englert (1992) obtained similar results with field grown red oak, Norway maple and Washington hawthorn (2).

The shoot water potentials for locally grown hawthorn were highest for the whole plant covered storage treatment followed by roots covered, shoots covered, and whole plant uncovered treatments for all sample dates. Root water potential values showed a similar trend (data not shown). In general, stem water potential for locally-grown and shipped hawthorn trees for all treatments decreased (increased water stress) through the experiment (Table l).By the end of the experiment (11 April), the degree of water stress for locally-grown and shipped trees in the whole plant covered treatment was much lower than other storage treatments. This implies that water loss occurs via shoots as well as roots.

For locally grown and shipped maple, shoot water potentials were highest for the whole plant covered and roots covered treatments compared to shoots covered and whole plant uncovered treatments for most dates (Table 1). The fact that only covering maple roots did not result in relatively low stem water potentials indicates the stress tolerant nature of Norway maple. In contrast, only covering hawthorn roots resulted in relatively low water potential values thereby indicating a desiccation stress intolerant nature.

Marketability ratings for hawthorn and maple (data not shown) showed a trend similar to water potential values. Hawthorn tress that were totally covered had the highest ratings whereas tress of other treatments had significantly lower values. For maple, whole plant covered and roots covered had the highest ratings. In general, there were no consistent marketability differences between local and shipped trees for both species.

Significance to Industry: These results indicate that water stress increases with storage duration regardless of species. Water loss from stems of desiccation sensitive Washington hawthorn was greater than that of the more tolerant Norway maple. While it is imperative to protect roots of all bare-root stock, sensitive species such as hawthorn need both root and shoot protection to minimize water stress. In certain cases shipped trees exhibited a greater degree of water stress than locally grown trees, however this did not translate into any consistent decrease in marketability (data not shown). Stem water potential has been shown to be an excellent indicator of water stress in woody species (3). Additional work needs to be done to develop screening procedures to assess the condition of bare-root trees during storage using pressure chamber techniques.

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Table 1. Influence of cold storage duration and plant part exposure on shoot xylem water potential of Washington Hawthorn and Norway Maple.[Z]

Storage Treatment	Plant Source	Shoot Water Potential (-MPa)						
		Date						
		1/28	2/11	2/27	3/11	3/28	4/11	LSD
		Hawthorne						
Field Lifted (No Storage)		1.16	.74	.45	.52	.45	.51	
Whole Plant Covered	Local	.97	.98	1.04	1.37	1.68	1.64	.19
	Shipped	1.53	2.23	2.00	1.75	1.98	2.25	.24
Roots Covered	Local	1.11	1.11	1.37	1.74	2.71	3.54	.31
	Shipped	1.31	2.09	2.40	2.73	2.80	3.24	.28
Shoots Covered	Local	1.63	2.18	2.28	2.49	2.75	3.41	.28
	Shipped	1.50	1.88	2.86	2.83	3.00	4.00	.30
Whole Plant Uncovered	Local	1.81	2.32	2.48	2.71	3.25	3.82	.35
	Shipped	1.59	2.28	2.94	3.10	3.11	4.00	.33
		Maple						
Field Lifted (No Storage)		1.27	.87	.94	.92	.73	.47	
Whole Plant Covered	Local	.63	.79	.87	1.33	1.45	1.25	.18
	Shipped	.75	1.00	1.07	1.58	1.76	1.77	.22
Roots Covered	Local	.95	1.10	1.00	.99	1.86	1.97	.31
	Shipped	.71	1.51	1.40	1.66	2.27	2.04	.27
Shoots Covered	Local	1.06	1.35	2.51	2.60	2.85	3.16	.31
	Shipped	1.39	2.13	2.30	2.88	3.19	3.17	.28
Whole Plant Uncovered	Local	1.81	2.35	1.92	2.73	3.00	3.00	.20
	Shipped	1.45	1.97	3.14	3.10	2.76	3.07	.25

[Y]LSD values at the P=0.05 level.
[Z]Each value is the mean of three observations.