Research Reports:

Effect of Pot Lip Shape on Soil Surface Evaporative Losses[1]

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Abstract

Small pots containing a loam soil were monitored in a growth chamber and wind tunnel to determine the effect of 13 different lip shapes on evaporation from the soil surface. In the growth chamber, pots with modified lips showed evaporative losses ranging from 52-95% of the unmodified control during the first 24 hrs following watering. The same trend was observed during the second 24 hrs following watering but not during the third 24 hr period. In the wind tunnel, nine treatments showed significant reductions in evaporation in comparison to the control 24 hrs after watering; no differences were observed after three days of drying.

Index words: container design, soil boundary layer, evaporation

Introduction

Efficient water management in the nursery can decrease the amount of water to be pumped, labor costs, nutrient and pesticide runoff contributing to groundwater contamination, plant vulnerability to drought stress, and ultimately contribute to the production of healthier and higher grade plant materials. Water management research for nurseries has been directed primarily at water delivery systems and has cffectively demonstrated the potential for net water savings (5). While there is literature concerning the evapotranspirative losses from crops affected by large-scale structures such as wind breaks (1, 2, 3, 5, 6, 8, 11), to our knowledge no one has examined evaporative losses from plant containers or the potential for reducing these losses using small-scale modifications to the containers themselves. The purposes of this study are 1) to develop a protocol for empirically assessing the effect of wind on surface water loss from pots, and 2) to use this method to quantify the effect of pot lip shape on evaporation from a soil surface inside a pot.

The outdoor container nursery presents unique water management challenges. Nursery pots are individual

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units, isolated from the bulk soil, and are therefore subject to energy fluxes from all sides. Though there is wide variation among crops, frequently the canopy is open in comparison with row crops, turf, and forest plantations because plants are small and the production cycle is too short to allow for full canopy closure. Between irrigations the growing medium in the pots is generally not permitted to dry to the same degree as field soils and the surface of the medium may stay continually damp. Under this set of conditions the soil would be expected to contribute a high proportion of the total evapotranspiration of the system. Despite these unique attributes of pot culture systems, we have little empirical data quantifying the effects of system components on the water budget. Wind-induced turbulence would be expected to be especially important in determining the rate of surface evaporation in this system. At the scale of the pot, the potential exists for altering wind speed and turbulence through minor aerodynamic changes to the pot itself.

Materials and Methods

Pots. Round green plastic pots 80 mm (3.1 in) high with a 76 mm (3.0 in) inside top diameter were used. These are easy to modify and transport in large quantity and are small enough to permit replication of lip treatment in the confined spaces of a growth chamber and wind tunnel. These pots are approximately 1/2 scale in relation to a #1 nursery container.

Air flows around and in #1 nursery containers and 1/2 scale models were visualized in the Cornell Environmental Wind Tunnel using a Sage Action helium bubble generator. Over a range of wind speeds, turbulence (as opposed to laminar flow) was observed over the soil surfaces in both containers. Thus it is reasonable to conclude that transfer processes affected by turbulence (such as evaporation) will be similar in both full size and scaled containers as long as the ratio of lip length to pot diameter is maintained (4, 9). A 3 x 4 factorial of lip length and angle was used (lengths = 10, 15 and 20 mm (.39, .59 and .79 in); angles = 0, 30, 60 and 90 degrees) along with a lipless control. Lips were fabricated from flexible clear Lexan plastic which was either cut into flat "doughnuts" or rolled and taped into frustums (truncated cones) (Fig. 1). All lips were painted green to match the pots and were then taped to rims of the pots.

Soil. We covered the bottom of the pots with paper towel to prevent soil from spilling through the drain holes. Pots were then filled with 175 g (.39 lb) of air dry loam soil (32% sand, 50% silt, 18% clay, 51% total porosity) which had been sieved twice through a 6.4 mm (.25 in) screen). This quantity of soil was sufficient to fill the pots to the shoulder, 12 mm (1/2 in) below the unmodified lip edge. Soil is preferable to potting medium in this initial investigation for several reasons. First, conventional potting mixes for outdoor nurseries vary widely in composition and frequently include soil along with peat, sand and other amendments. Second, bouyant mix components float to the top during watering, introducing pot-to-pot surface variation which would affect transfer processes and confound our results. Finally, literature on soil gas exchange contains many studies using a variety of field soils. The ability to

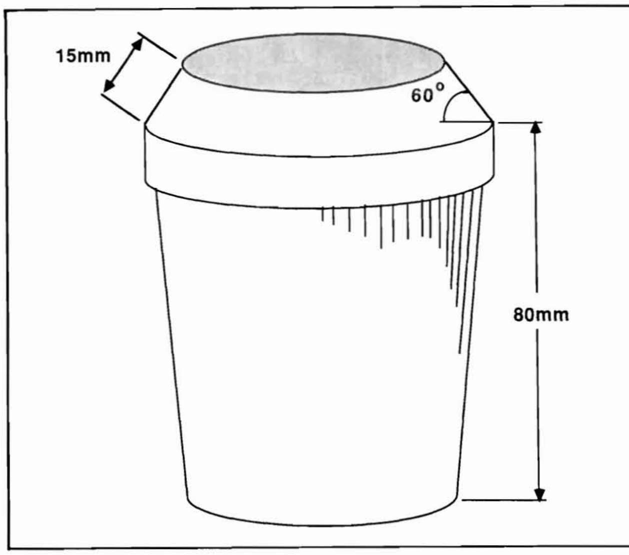

Fig. 1. Schematic drawing of a plastic pot with a 15 mm (.6 in), 60° lip.

relate our findings to these studies will facilitate future work.

No plants were used in the present study.

Growth chamber. The growth chamber was a conventional walk-in chamber used for plant growth studies. For both experiments a 3.6 x 2.5 m (11.8 x 8.2 ft) growth chamber was set for a 14-hr photoperiod with a 25°/18.5°C day/night (77/65°F) temperature regime and a constant 50% RH. A combination of incandescent and fluorescent lights provided a total radiation input of 105 Wm^{-2} (approximately 10% of the radiant flux at the mid-latitudes on a clear summer day). Wind speed was less than 0.45 m s^{-1} (1.48 ft s^{-1}) but the air was not stagnant. Fans circulated the growth chamber air and created vertical eddies which encompassed the portion of the chamber used. Pots were placed on an expanded metal bench (to minimize flow restrictions) 82 cm (2.7 ft) above the floor.

Wind tunnel. A laminar flow environmental wind tunnel in the Department of Mechanical and Aerospace Engineering at Cornell University was used. A constant wind speed of 4.95 m s^{-1} (16.24 ft s^{-1}) was established. This is classed as a "gentle breeze" under the International System for wind (10). Wind speed was monitored with a Met-One cup anemometer and relative humidity and temperature with a Campbell Scientific 201 probe. Both instruments were positioned downwind and slightly above the pots. A Campbell CR-21 micrologger averaged measurements over 5-minute intervals. Control over temperature and relative humidity in the wind tunnel was not feasible, but variation in these factors was accounted for statistically by considering each experiment run as a block. No direct lighting was provided in the wind tunnel hence radiant energy inputs were minimal and were not monitored. Pots were spaced in the wind tunnel so that blockage of the cross sectional area by the pots and pot stands was less than 10%. In addition, interference among pots was eliminated by placing the center of each pot at least 3 pot diameters from all other pots in the same cross sectional plane. All pots were placed in a free stream well outside the boundary layers of the wind tunnel. A Sage Action bubble generator and vortex filter with an arc lamp were used to visualize and measure air flows in the wind tunnel and to verify that each pot was subjected to similar laminar free stream velocities.

Experiment 1. In this experiment each of 13 lip shapes were replicated 6 times, yielding a total of 78 pots in the experiment. On day 0 all pots were placed randomly in a 6 x 13 pot rectangle on the bench in the growth chamber and at 0900 hours were watered with 50 ml of deionized water. This was sufficient to just saturate the soil volume and give slight through flow. When drainage had ceased we weighed each pot on an electronic top loading balance with a resolution of 0.01 g (2.2 X 10^{-5} lb). Each pot was reweighted at 0900 hours on the 3 following days. We calculated water loss as the weight difference between successive days.

Experiment 2. Evaporative losses from soil will be affected by wind turbulence. As the soil dries, wind would be expected to have a decreasing effect on evaporation. Also, pot lip configuration would be expected to have a decreasing effect on evaporation as soil dryness becomes rate limiting. To address the question of duration of pot lip effectiveness after watering under windy conditions, we monitored water loss from pots in a wind tunnel after the soil had been allowed to dry in the growth chamber for 1 or 3 days.

First, pots without lips were filled with soil and placed in the growth chamber as previously described. Watering in the growth chamber was staggered over time to achieve the desired period of drying (1 or 3 days) prior to the wind tunnel runs. During these initial drying periods in the growth chambers, lips were omitted to allow all pots to dry under homogeneous conditions. Immediately prior to placing a block of pots in the tunnel, appropriate lips were attached, the pots were weighed, and then placed in the wind tunnel for 1 hour. The pots were then re-weighed to determine the evaporative losses while in the wind tunnel.

The experiment had 26 treatments (13 lip shapes and 2 drying periods) and each treatment was replicated 6 times. Because the wind tunnel could accommodate only 12 pots at one time, we used a randomized incomplete block design and assigned the treatments to 13 blocks (block = wind tunnel run) prior to placing the pots in the growth chamber. Pots were arranged by block in the chamber. Statistically, the block effect includes location in the growth chamber, day of watering, and wind tunnel cycle.

Results and Discussion

Experiment 1. In the growth chamber, all lip treatments result in decreased water loss during the first day after watering in comparison with the lipless control (Table 1). There are two distinct patterns of loss: either a decreasing rate of loss over the three-day drying cycle or a constant rate of loss over the same period. The first group is typified by the control (0/0). This treatment lost water faster than any other treatment on Day 1 but slower than any other treatment on Day 3. The second group is typified by the 20 mm (.8 in) long, flat lip (20/0), which lost water at a uniform rate throughout the experiment.

Response surface analysis was used to describe the simultaneoud effects of length and angle (Figure 2A). Linear effects were significant at the .0011 level or better; no quadratic effects were significant. The prediction equation for Day 1 water loss is:

$$g = 22.92 - .615 (L) - .034 (A) + .006 (L \times A)$$

where g refers to grams of water evaporated during the preceding 24 hours, L refers to lip length and A refers to lip angle. Figure 2 shows that *as lip length increases, water loss decreases* while *as lip angle increases, water loss also increases.* The 20/0 treatment lost only 53% as much as the 10/90 treatment.

The prediction equation for Day 2 water loss is:

$$g = 21.76 - .528 (L) - .061 (A) + .006 (L \times A)$$

with the same letter conventions as above. Again, only linear effects were significant. The response surface corresponding to this equation is shown in Figure 2B and again, increasing lip length decreases water loss while increasing lip angle increases water loss. The directions of the lip and angle effects are the same as Day 1 but are lower in magnitude, indicating that the effects of lip configuration decrease over time.

Table 1. Average evaporation from soil surfaces under 13 different pot lip shapes after 1, 2, or 3 days of drying in the growth chamber. n = 6 replicates per treatment. Lip treatments designated as length/angle, eg 10/90 indicates a lip length of 10 mm at a 90 degree angle.

		DAY 1		DAY 2		DAY 3			
Rank After 1 Day of Drying	Lip Treatment	Av. Water Loss g/day	se	Av. Water Loss g/day	se	Av. Water Loss g/day	se	Total Av. Water Loss	Rank Based on Total Water Loss
1	0/0	20.74	0.38	17.41	0.84	7.56	1.31	45.71	4
2	10/90	19.67	0.34	17.62	0.33	10.60	1.60	47.89	1
3	20/90	18.60	0.25	17.36	0.43	9.62	1.62	45.58	5
4	15/90	18.45	0.23	17.09	0.24	9.06	1.57	44.60	7
5	10/60	18.03	0.20	15.56	1.34	13.89	1.04	47.48	2
6	10/30	17.17	0.25	16.49	0.25	10.16	1.50	43.82	9
7	15/60	17.06	0.36	15.94	0.33	11.63	1.26	44.63	9
8	10/0	16.83	0.22	16.48	0.42	13.62	0.58	46.93	3
9	20/60	15.91	0.22	15.36	0.20	12.03	0.87	43.30	10
10	15/30	15.43	0.07	15.70	0.13	12.75	1.02	43.88	8
11	15/0	13.99	0.48	13.88	0.61	12.12	0.44	39.99	11
12	20/30	12.81	0.21	13.43	0.49	13.32	0.63	38.56	12
13	20/0	10.52	0.25	10.74	0.42	10.13	0.40	31.39	13

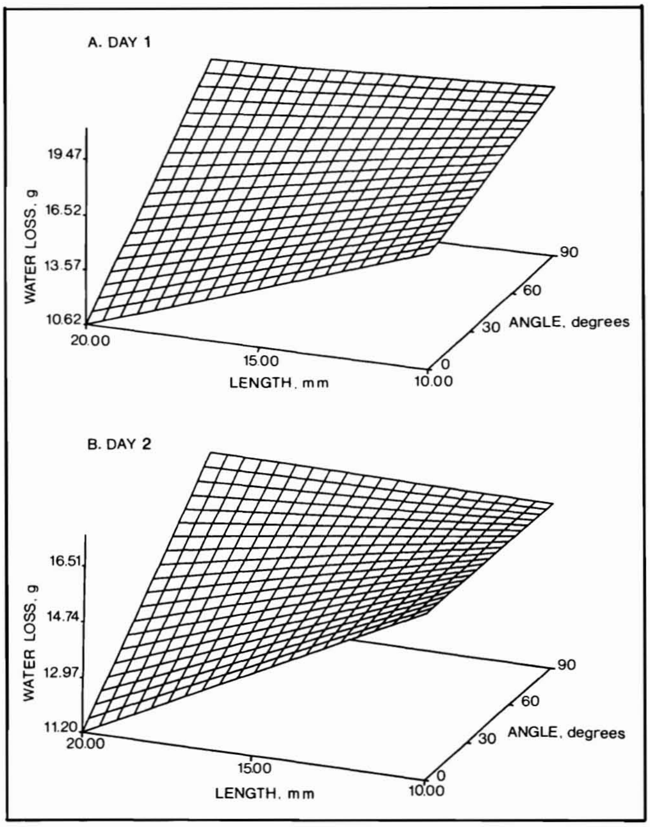

Fig. 2. Response surfaces for water loss as a function of lip length and lip angle during the first (2A) and second (2B) day after watering.

Neither main effects nor interactions were significant on Day 3, indicating that after three days of drying factors other than lip shape were controlling the rate of water loss. Most likely, the dry soil surface retarded evaporation and was rate limiting at this stage of drying.

Experiment 2. In the wind tunnel experiment, the incomplete block design precluded the use of response surface analysis for a single day's data, hence the conventional ANOVA and plots were used (Figure 3). After

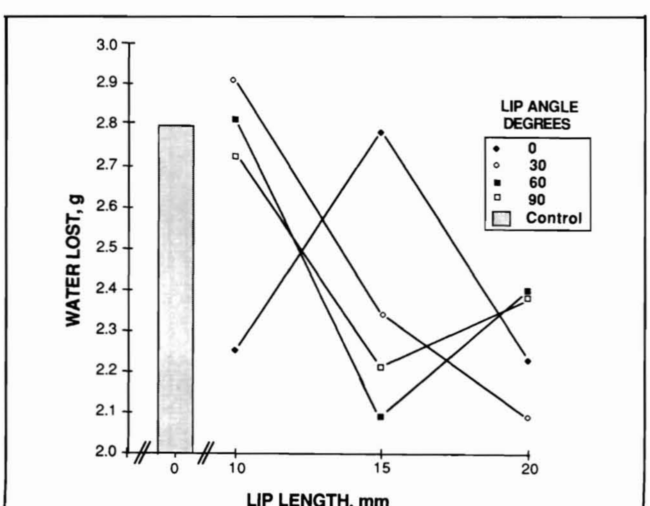

Fig. 3. Evaporation from pots with different lip angles as a function of lip length after 1 hour in the wind tunnel. Control treatment lacked any lip modification.

1 day of drying, both block and days since watering were statistically significant at the .0001 level and lip length was significant at the .004 level. Lip angle had no effect. Several trends are apparent after the first day of air drying. First, the control treatment is again among the group with the highest evaporation rates. In general, this group includes the 10 mm (.39 in) lips. Second, increasing lip length from 10 to 15 mm dramatically decreases water loss while further increases in length provide no apparent benefit. Third, the pattern of water loss in the flat, 0° angle treatment is inconsistent with all other treatments. For example at the 10 mm length (10/0), the flat lipped pots lost the least water while at 15 mm (15/0) they lost the most. This is perhaps due to increased turbulence in the wake of this particular lip, though bubble stream visualization does not suggest such a qualitative difference.

Significance to the Nursery Industry

This study demonstrates a model system which allows objective examination of some factors influencing water balance in an individual pot. Our findings indicate that container lip shapes affect water loss. The system will allow future examination of other methods to control evaporative losses (such as mulches) and comparisons of the relative influence of mulch and lip shape on pot boundary layer resistance.

In a container nursery, frequently the plant canopy is not closed and soil will contribute significantly to the evaporative losses. Daily watering prevents formation of a dry surface crust so the pots will be constantly in "first stage" or early "second stage" drying where evaporation is controlled by the hydraulic properties of the soil (7). It is precisely under these conditions that reducing turbulence at the soil surface could be useful in reducing evaporative losses. Modified pot lips could help accomplish this goal.

Though the potential for reducing water losses clearly exists, further experimentation is needed to identify the range of circumstances in which reductions are practical and the approaches which are most effective. Results from studies of physical models such as those described here can serve as a basis for container design. Eventual application in the nursery industry will come in situations where water must be conserved, runoff minimized, or when plants may remain unwatered for brief periods, as during transport.

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Growth and Chemical Composition of *Populus deltoides* x *nigra* Grown in Field-grow Fabric Containers[1]

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Abstract

Growth and chemical composition of popular (*Populus deltoides* x *nigra,* DN 69) grown in field-grow fabric containers (FGFC) was evaluated. Unrooted hardwood cuttings were grown in 0.6, 2.4, 6.0, and 14.0 L (0.2, 0.6, 1.6, and 3.7 actual gal) custom-made FGFC inserted in 3, 6, 12 and 24 L (#1, 2, 3 and 6 trade size) plastic nursery containers, resp. A 3.5 cm (1.4 in) layer of the same medium was placed under the between the FGFC and the walls of the nursery container. Each bag was filled with a medium of pine bark; spruce bark (3:1 by vol.). Control plants were grown in containers of all sizes without FGFC in the same medium. Plant growth increased with increasing container size. Root dry weight of plants grown in FGFC were 21% less than plants without FGFC. However, there was no difference in top growth between FGFC and control plants. Soluble sugars concentration was 7% higher in leaves of FGFC grown plants, but leaf N, P, and K concentrations were similar. Roots outside the FGFC contained more N, P, and K than roots inside the FGFC. Soluble sugars and starch concentrations were greater inside the FGFC than outside.

Index words: Container culture, root studies, mineral nutrients, carbohydrates

Introduction

One of the newest techniques to be introduced to the nursery industry has been the production of trees and large shrubs in field-grow fabric containers (FGFC) or "root control bags" (3, 4, 5). These fabric containers have the same basic shape as commonly used nursery containers. Walls are constructed of a strong, black non-woven polypropylene geotextile fabric that allows water and nutrients to flow through freely. The bottom is a clear, low-density polyethylene which prevents root growth beneath the container. Plant roots penetrating the non-woven fabric are restricted, thus resulting in a more compact, fibrous root system (3).

This study investigated the relationship of top and root growth of poplar plants grown with and without FGFC nursery containers.

Materials and Methods

In early May, 1985, 23 cm (9 in) long, unrooted hardwood cuttings of hybrid poplar (*Populus deltoides* x *nigra,* DN 69) were planted in 0.6, 2.4, 6.0, and 14.0 L (0.2, 0.6, 1.6, and 3.7 actual gal) FGFC inserted inside 3, 6, 12 and 24 L (#1, 2, 3, and 6 trade size) plastic nursery containers under lath. The FGFC were custom-made (Fig. 1), so that a 3.5 m (1.4 in) of potting medium could be placed around the outside and under each bag. The potting medium used was 3 parts pine bark and 1 part spruce bark (by vol) screened through a 5 cm (2 in) mesh screen. Control plants grown in containers without FGFC were also included.

In late May, plants were moved to full sun and spaced 60 x 60 cm (24 x 24 in) to minimize inter-plant effects.

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