Effect of Irrigation on Crabapple Growth and Water Relations During Field Production with In-Ground Fabric Containers[1]

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Abstract

Growth and water relations of irrigated and non-irrigated *Malus sieboldii* var. *zumi* produced with and without in-ground fabric containers in a field-nursery setting were investigated. Predawn and midday leaf water potential and midday stomatal conductance were measured periodically through the season, and trunk increment, leaf area, root growth, and osmotic potential were measured in late season. Water potential became more negative and stomatal conductance decreased in non-irrigated treatments during an extended mid-summer drought that resulted in less trunk diameter growth and leaf area. Trees grown in fabric-containers, both irrigated and non-irrigated, exhibited no detectable differences in water relations over the season. These trees did have fewer roots and less leaf area than the trees grown without fabric containers, indicating that in-ground fabric containers can limit growth even when irrigated. Non-irrigated trees in fabric containers were nonetheless affected by water stress as they had the least trunk growth and most negative osmotic potential of all treatments. Careful management practices would suggest increased irrigation frequency during production with in-ground fabric containers to avoid water stress.

Index words: *Malus sieboldii* var. *zumi*, stomatal conductance, water potential.

Significance to the Nursery Industry

This study indicated that, even when irrigated, trees produced in field nurseries with in-ground fabric containers grow less than those conventionally produced without fabric containers. Trees in fabric containers appear to be subject to more severe water stress during periods of low rainfall due to fewer roots exploiting soil water outside the container, which can further limit growth. These results suggest that more frequent irrigation may often be necessary for trees produced in fabric containers to compensate for a diminished volume of available soil water and sustain optimum growth.

Introduction

In-ground fabric containers are proposed as an enhanced method for producing field-grown nursery stock (13). In contrast to conventional production by direct planting of plant material into the field, the non-woven, synthetic-fabric container encloses the root system with soil in the field. This confinement constricts large-root penetration into soil outside the container and promotes root branching inside the container (6). Consequently a tree produced in a fabric container has a smaller root ball that is easier to harvest and handle than conventionally-produced plants of similar size.

In-ground fabric containers appear, however, to be an alternative to, rather than an enhancement of, conventional field production. Planting with fabric containers is more difficult because of the need for specialized equipment (10), and different management is needed to avoid reported reductions in top growth (2, 4, 9). Fertilization practices may needed to be adjusted (3), but whether irrigation practices too may need adjusting has not been examined.

Root restriction would logically affect the volume of soil roots can exploit, likely creating a smaller reservoir of extractable soil water. In turn this could lead to more rapid soil-water depletion, more frequent tree water stress, and potential growth limitation when other conditions are managed for optimim growth (4). More frequent depletion of soil water to stressful levels can be avoided by nurseries with permanent irrigation systems, but for those in moderate-to-high rainfall regions that rely on temporary irrigation systems on an as-needed basis, more frequent irrigation could increase costs. In either case knowledge of the potential for water stress can be used to make informed management decisions regarding tree production with in-ground fabric containers. The objective of this study was to determine if trees produced with in-ground fabric containers in a field-nursery setting are more subject to water stress than those conventionally produced without fabric containers.

Material and Methods

This study was conducted on a Hosmer silt loam (fine-silty, mixed, mesic, Typic Fragiudalf) with a water holding capacity of approximately 0.2 m/m (2.4 in/ft) in the 0.6 m (2 ft) topsoil layer. The experiment was laid out in a complete-block, split-plot design with five replications, and randomly assigned treatments were +/– irrigation main plots and +/– in-ground fabric-container subplots. Three-year old, clonally-propagated *Malus sieboldii* var. *zumi* grown in 11 l (3 gal) containers in a peat:perlite (1:1 by vol) mix were transplanted into either 0.36 m (14 in) fabric bags located in a 0.6 m (2 ft) wide weed-free tree row in early September 1990 and backfilled with native soil, or were planted directly into native soil to emulate conventional production.

Trees were spaced at 1.5 m (5 ft) within the row, and main plots were separated by three border trees to limit subsurface water movement. The tree row was mulched to 0.1 m (4 in) depth with wood chips and further weed appear-

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ance was controlled with a directed post-emergent, non-selective herbicide (Glyphosate). All trees were fertilized with 56 g (0.125 lb) of actual N per tree applied as ammonium nitrate in mid-November 1990. Both treatment and border trees in the irrigated treatment were drip irrigated daily during the 1991 growing season with one emitter located at the base of each tree. Initially 3.9 l (1 gal) were applied, but after detecting incipient water stress in late June we increased this to 7.8 l (2 gal) per day. The border trees were not irrigated in the non-irrigated treatments.

We measured seasonal changes in water relations of the treatments to assess development of water stress. Starting in mid-June predawn water potential (Ψ) was monitored every 1.5–2 weeks during the growing season. A single leaf was excised from each tree before dawn, immediately sealed in an aluminum bag (7), and returned to the laboratory for measurement with a pressure chamber, usually within an hour (model Arimad II, Kfar Charuv-Water Supply Accessories, Ramat Hagolan, Israel). At midday, between 12 noon and 2 PM, we also measured stomatal conductance (g_s) on three dates, and Ψ on two of those three dates. Water potential was measured as previously described, and g_s was measured with a steady-state porometer (Model 1600, LI-COR Inc., Lincoln NE) on four representative, fully illuminated, mature leaves per tree. During the study period we collected daily rainfall amounts from a weather station approximately 4 km (2.5 miles) away from the experimental site.

Integrated tree responses to irrigation and fabric-container treatments were measured in late summer and early fall. In late August osmotic adjustment was determined from pressure volume curves. Approximately 0.3 m (1 ft) shoot of current-year's growth was excised from each tree predawn and then recut underwater to remove cavitated vessels in the lower 0.1 m (4 in) of stem (11). Foliage was then enclosed with plastic wrap and allowed to rehydrate. After 24 hours of rehydration we took paired weight and Ψ measurements on a single excised leaf from each treatment until the range of the pressure chamber was exceeded. Osmotic potential Ψ_π at saturation was calculated as the y-intercept of the linear portion of the resulting pressure-volume curve.

In early October all trees were cut at the soil line, and current-year trunk growth was measured on a 25 mm (1 in)-thick basipetal cross section. All foliage was harvested and leaf area of a random 25-leaf subsample was measured with a leaf area meter (Model 3000 LI-COR, Lincoln, NE), and the subsample and bulk foliage sample were dried at 60°C

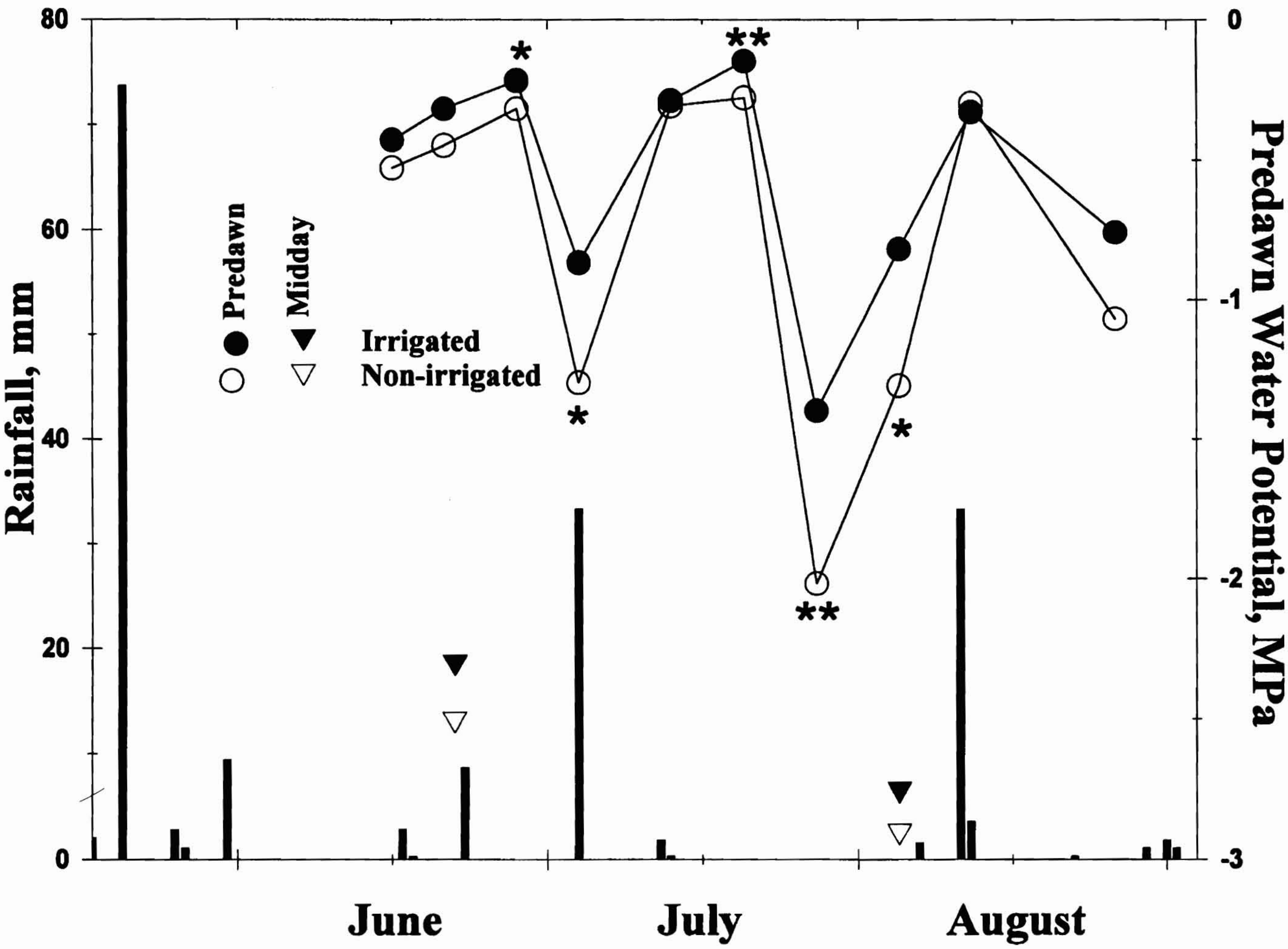

Fig. 1. Rainfall and predawn water potential for crabapples grown with in-ground fabric containers with and without irrigation. Asterisks (*, **) above or below the data points indicate significant (P = 0.05, 0.01, respectively) differences between irrigation treatments corresponding to the data collection date along the X-axis. On dates with no asterisks there were no significant differences between irrigation treatments. Data from fabric-container treatments are not shown because significant differences were not detected.

Table 1. Midday stomatal conductance on three dates, osmotic potential at saturation, and final leaf area, diameter increment, and root growth for irrigated/non-irrigated crabapples grown with/without in-ground fabric containers.

	Stomatal conductance			Osmotic potential[z]	Trunk increment	Total leaf area	Root number[y]
	June 20	July 25	Aug 2				
	mmole/m²-s			MPa	mm	m²	#
Irrigated							
With container	250 ± 57	273 ±12	248 ± 12	−1.88 ± 0.2	14.8 ± 2.2	3.78 ± 0.68	71 ± 20
Without	221 ± 17	250 ± 39	248 ± 31	−1.57 ± 0.3	14.9 ± 0.9	5.00 ± 0.88	120 ± 29
Non-irrigated							
With container	25 ± 13	23 ± 15	30 ± 11	−2.35 ± 0.1	8.4 ± 0.5	2.79 ± 0.99	41 ± 15
Without	32 ± 13	18 ± 13	26 ± 13	−1.65 ± 0.6	10.2 ± 0.8	3.43 ± 0.30	84 ± 39
Irrigated[x]	**	**	**	ns	**	*	ns
Container	ns	ns	ns	**	ns	*	**

[z]At saturation.

[y]Number of roots greater than 2 mm diameter exceeding 180 mm away from trunk

[x]**, *, ns= significance at P = 0.01, 0.5, and non-significant, respectively

(140°F) for two days and then weighed. Total tree leaf area was calculated as the sum of subsample leaf area plus the product of subsample specific leaf area (m^2/g) and bulk foliage weight. Finally, we excavated root balls and counted the number of roots ≥2 mm (0.08 in) in diameter that exceeded the 0.18 m (7 in) radius of the fabric container. For trees not in fabric containers a root ball larger than the radius of the fabric container was dug and then the roots that passed through a vertical plane equal to the container radius were counted. Water relations and growth measurements were compared among treatments with analysis of variance (SAS Inst. Inc., Cary NC) appropriate for a split-plot design.

Results and Discussion

Rainfall in 1991 during the study period was characterized by extended dry periods during the growing season (Fig.1). June was particularly dry, as only 12 mm (0.5 in) of rain fell, and July and August were slightly more moist with 36 mm (1.4 in) and 42 mm (1.7 in), respectively. This region on average receives 100–150 mm (3–5 in) of rain per month during the summer, and low rainfall during 1991 affected tree water relations. All crabapples depleted soil water to deficient levels in late June as predawn Ψ declined from initial levels of –0.3 MPa to between –1.0 and nearly -1.5 MPa. Following rain in early July another rain-free period extended into early August where predawn Ψ fell below –2 MPa in the non-irrigated trees.

While more negative predawn Ψ in the irrigated trees indicated that the initial application rate was not fully adequate, during both dry cycles the non-irrigated trees were under significantly greater water stress by –0.3 to –0.5 MPa. We did not detect any effect of the fabric containers on predawn Ψ within either irrigation treatment, which ostensibly suggested that trees in fabric containers did not deplete their available soil water more rapidly than those not in containers. Similarly, we did not detect any significant differences in midday Ψ between fabric-container treatments in early August during the rain-free period when midday Ψ approached –3.0 MPa in all treatments. There was also, however, no significant effect on midday Ψ between irrigation treatments, probably due to reduced g_s in the non-irrigated trees (Table 1) that reduced transpiration and moderated internal water deficits (12).

Midday g_s variation among treatments was similar to that of predawn Ψ (Table 1). Irrigated treatments exhibited g_s levels nearly an order of magnitude higher than those in the non-irrigated treatments, but again we did not find any effect of the fabric containers. Incipient water stress is most evident in midday stomatal closure, and due to progressive closure midday g_s becomes insensitive to increasing water-stress severity (5). Consequently stomatal sensitivity to soil-water status is then much more apparent during cooler mid-morning hours (5). Low g_s of the non-irrigated trees in June indicated that they were already under moderate water stress as a result of low rainfall the previous three weeks. It is possible that we missed potential effects of the fabric containers on mid-morning g_s on all three dates, particularly considering that several growth responses of trees in fabric containers were lower than those of trees not grown containers (Table 1).

Irrigation and fabric-container treatments both had significant effects on integrated plant responses (Table 1). Trunk growth, and to a lesser extent leaf growth, of non-irrigated trees were less than the irrigated trees, consistent with the high sensitivity of expansive growth to water stress (1). Fabric containers reduced total leaf area and the number of roots above 2 mm in size, consistent with the results of Harris and Gilman (4), and resulted in more negative Ψ_π. Less penetration of large roots through the container was expected because of the constricting effect of the fabric on radial root growth. Significantly more negative Ψ_π in both irrigated and non-irrigated trees trees grown in fabric containers indirectly indicated less root growth. Fewer roots as a result of the impeding fabric probably meant a weaker sink for carbohydrates, and the consequent solute build-up in the foliage could acount for the decreased Ψ_π(8). Lower Ψ_π in the fabric-container trees may have resulted in higher predawn turgor potential from nighttime resaturation that obscured differences in predawn Ψ.

Reduced root growth resulted in less leaf total area of trees grown in fabric containers, consistent with other reports of reduced growth (2, 4, 7) with production in fabric containers. This observed reduction in growth is possibly due to restricted nutrient uptake (3). Trunk growth, however, in the irrigated-container treatment was not affected, in contrast to Harris and Gilman (4). With adequate water for normal photosynthesis, a reduced root sink could have resulted in increased carbohydrate allocation to trunk development.

There was evidence that trees grown without irrigation in fabric containers were more subject to water stress, despite the absence of differences in water relations. The interaction between irrigation and fabric containers in midday g_s, growth responses, or Ψ_π was not significant at $P = 0.05$, ostensibly indicating that non-irrigated trees in fabric containers were not under greater water stress. The data exhibits a trend, however, towards all growth responses and Ψ_π of the non-irrigated trees in fabric containers being lower than the other three treatments. In particular the Irrigation × Container interaction term for trunk growth and Ψ_π were both significant at $P = 0.2$. While the test for significance in this study did not achieve the prevailing 95% level of certainty, a cautious approach towards this trend in the data is necessary.

Viewed another way, these data indicate that there was still an 80% probability that fabric containers caused less trunk growth in non-irrigated trees during the particularly dry year of this study. Over time, especially during consecutive dry years, such a trend would probably be compounded. Potentially a feed-forward cycle could be established where the smaller root system of trees in fabric containers without adequate irrigation would be less able to supply water to top growth. In turn less water would reduce leaf area and trunk growth, reducing carbohydrate production and further limiting root growth. Ultimately limited growth would likely extend the production cycle and add to grower costs. Production uncertainty with in-ground fabric containers could be reduced by greater irrigation frequency to compensate for the truncated volume of extractable soil water.

Literature Cited

1. Bradford K.J., and T.C. Hsiao. 1982. Physiological responses to moderate water stress. p. 263-324 *In*: Lange O., P. Nobel, C. Osmond, H. Zeigler. (Editors) Encyclopedia of Plant Physiology, NS, Vol 12b Springer, Berlin.

2. Chong. C., G.P. Lumis, R.A. Cline, and H.J. Reissmann. 1987. Growth and chemical composition of *Populus detoides* x *nigra* grown in field-grow fabric containers. J. Environ. Hort. 5:45–48.

3. Chong, C., G.P. Lumis, and R.A. Cline. 1991. Shade tree growth and nutritional status as influenced by fabric containers and trickle irrigation. J. Environ. Hort. 9:187–191.

4. Harris, J.R., and E.F. Gilman. 1993. Production method affects growth and post-transplant establishment of 'East Palatka' holly. J. Amer. Soc. Hort. Sci. 118:194–200.

5. Hinckley, T.M., J.P. Lassoie, and S.W. Running. 1978. Temporal and spatial variations in the water status of forest trees. For. Sci. Monograph 20.

6. Ingram, D.L, U. Yadav, and C.A. Neal. 1987. Production system comparisons for selected woody plants in Florida. HortScience 22:1285–1287.

7. Karlic, H., and H. Richter. 1979. Storage of detached leaves and twigs without changes in water potential. New Phyt. 83:379–384.

8. Munns, R. 1988. Why measure osmotic adjustment. Aust. J. Plant Physiol. 15:717–726.

9. Remphrey, W., S. Rimmer, and M. Bouw. 1990. Nursery performance of selected shade-tree species grown in "Field-Grow" fabric containers. Can. J. Plant Sci. 70:337–343.

10. Rieger K. 1993. The buckeye planter. Amer. Nurseryman, Vol 177 (7), p. 49–53, April 1.

11. Schulte, P., and T.M. Hinckley. 1985. A comparison of pressure volume curve data analysis techniques. J. Exp. Bot. 36:1590–1602.

12. Thompson, D.R., and T.M. Hinckley 1977. A simulation of water relations of white oak based on soil moisture and atmospheric evaporative demand. Can. J. For. Res. 7:400–409.

13. Whitcomb, C.E. 1985. Innovations and the nursery industry. J. Environ. Hort. 3:33–38.