An Introduction to Subirrigation in Forest and Conservation Nurseries and Some Preliminary Results of Demonstrations

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Abstract: We are successfully using subirrigation to grow a variety of native plants. Subirrigated plants have grown at least as well as their cohorts irrigated with a fixed or traveling overhead system, but with less water inputs, less discharge of waste water, and less discharge of nitrogen fertilizer. So far, we have not been troubled with high levels of accumulated salts in the upper portions of root plugs watered from below, nor have we seen any incidence of disease transferred through the recycled water. As our demonstrations are completed, we will be able to provide managers of forest and conservation nurseries more specific recommendations for using subirrigation in their facilities.

Keywords: irrigation, fertilization, *Metrosideros polymorpha*, *Quercus rubra*, *Picea pungens*, *Acacia koa*, *Echinacea pallida*, electrical conductivity, container

In forest and conservation nurseries and probably most other horticulture settings, overhead irrigation is the most common type of irrigation system (Landis and others 1989; Leskovar 1998). These systems have several advantages: (1) they are relatively easy and inexpensive to install; (2) large areas can be treated; and (3) they prevent accumulation of fertilizer salts that can harm crops (Argo and Biernbaum 1995). Overhead irrigation has some disadvantages, too, namely: (1) they can be fairly inefficient in terms of water use (Dumroese and others 1995); (2) large amounts of fertilizer can be leached and (or) discharged from the nursery (Dumroese and others 1992; Juntenen and others 2002; Dumroese and others 2005); and (3) it can be difficult to effectively treat small areas containing a diversity of species and (or) stock types. Because container production uses high rates of fertilizer (Molitor 1990), nitrogen levels in the soil beneath production areas can be very high (McAvoy and others 1992). Undesired movement of unused fertilizers into surface and ground water has led some states to impose restrictions on how much water can be discharged (Grey 1991). Conversely, some states are also restricting water use during dry seasons (Oka 1993). These factors, and increased public concern about water quality and conservation (fig. 1), are causing proactive growers to look at new ways to manage water (Skimina 1992).

One way to reduce water usage as well as the amount of water discharged from a container nursery is to use subirrigation. Although several types of subirrigation systems are available (Landis and Wilkinson 2004), one of the most promising for use in forest and conservation nurseries is a closed system where irrigation water moves from a reservoir tank into an application

Figure 1—Sign of the times. More communities are taking proactive steps to protect their water supplies (photo by R. Kasten Dumroese).

tank (fig. 2). In the application tank, capillary action (resulting from the attraction of water molecules to each other and other surfaces) allows the irrigation water to move upward into the growing medium (Coggeshall and Van Sambeek 2002). Originally, subirrigation was considered to have good potential in forest and conservation nurseries because it was a way to irrigate species with large canopies—canopies that deflected, and therefore wasted, appreciable amounts of irrigation water. Subirrigation, however, has several other advantages as compiled by Landis and Wilkinson (2004):

- A wide range of commercial systems are available.
- Systems can be made locally with affordable materials.
- Foliar disease is reduced because foliage remains dry (see Oh and Kim 1998).
- Less water is needed per application (see Ahmed and others 2000).
- Water is applied more uniformly so crops are more uniform (see Neal 1989).
- Unused water is recycled.
- Less fertilizer is needed because none is discharged from the nursery (nutrients are recycled with the irrigation water).
- Different species and stocktypes can be grown in the same area.
- Some species grow better (see Yeh and others 2004).

With funding from the USDA Forest Service, State and Private Forestry, we have been demonstrating the effectiveness of subirrigation against either fixed or traveling overhead irrigation to grow native plants. We are evaluating 'ōhi'a (*Metrosideros polymorpha* Gaud. [Myrtaceae]) and koa (*Acacia koa* Gray [Fabaceae]) in Hawai'i; northern red oak (*Quercus rubra* L. [Fagaceae]) in Indiana; and blue spruce (*Picea pungens* Engelm. [Pinaceae]) and pale purple coneflower (*Echinacea pallida* (Nutt.) Nutt. [Asteraceae]) in Idaho. We

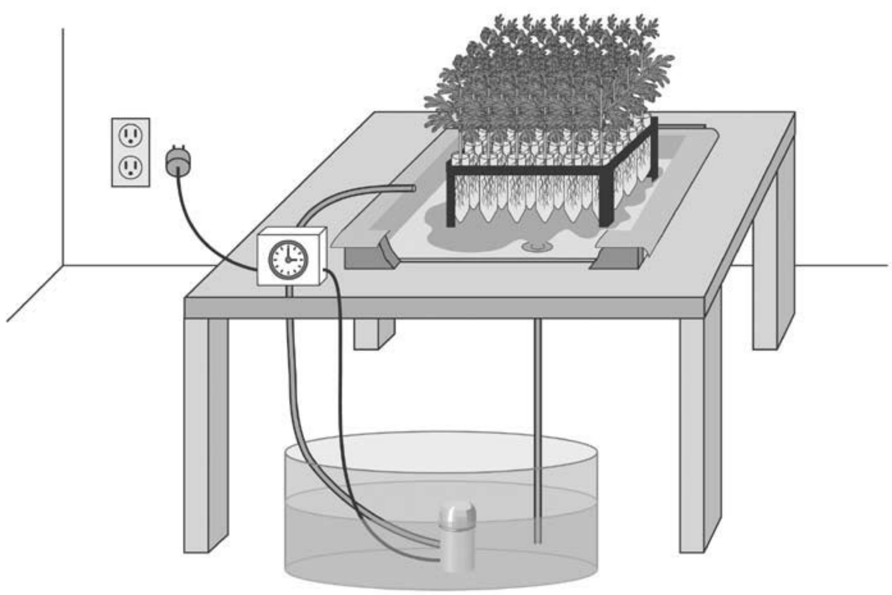

Figure 2—Schematic of a typical subirrigation system. An electronic timer activates a submersible pump that pushes water up into the subirrigation tray. When the tray is full, the timer deactivates the pump and the water slowly drains back into the reservoir tank (illustration by Jim Marin Graphics).

have included subirrigation systems in our demonstrations. The first is the Ebb-Flo system manufactured by Midwest GROmaster Inc (St. Charles, IL). The trays for this system are available in many dimensions, but all trays are only 5 cm (2 in) deep. Trays can be placed directly on top of existing benches and can be purchased with a leveling system. The second is the FlowBench™ system manufactured by Spencer-Lemaire Industries Limited (Edmonton, Alberta). FlowBench™ trays also come in a variety of styles, but we have been using units that are 58 cm wide by 114 cm long by 13 cm deep (23 by 45 by 5 in).

Both systems work the same way (fig. 2). Under each tray (or two) we positioned a plastic reservoir tank (generally about 285 l [75 gal]) filled with water. Inside the tank is a submersible pump connected to an electronic timer. At designated intervals, the pump pushes water up into the subirrigation trays—the timer is set so that the pump runs just long enough to fill the tray. Once the tray is full, the pump cycles off and the irrigation water drains back through the pump into the reservoir. It generally takes just a few minutes to fill the subirrigation trays, and about three to five times longer for the water to drain out. If necessary, the timer could be set so that two or three consecutive cycles occurred on the same day to ensure the medium was returned to field capacity.

In all of these demonstrations, we incorporated controlled release fertilizer (CRF) into the media. Usually, we followed the label rates on the product as well as using a zero rate control. Using CRF allowed us to avoid the problem of having to fertigate over the subirrigation trays, and it also allowed us to be consistent with application rates in both (overhead and sub) irrigation systems. The media used were essentially standard types used in forest and conservation nurseries (for example, Premier Pro-Mix®). Variables included height, root collar diameter, mortality, biomass, water usage, leachate volume, nitrogen concentration and content in the plants or leachate, moss development, medium electrical conductivity (EC), CRF prill weight, temperature, and photosynthesis (all variables not necessarily measured in each demonstration). All of these studies are still ongoing, but here is what we have discovered so far.

Results By Species

'Ōhi'a

'Ōhi'a plants were grown in 10-cm (4-in) square pots inside the U.S. Fish and Wildlife Service, Hakalau Forest National Wildlife Refuge native plant nursery on the Big Island of Hawai'i (fig. 3). Nursery manager Baron Horiuchi was our collaborator. Using the GROmaster system, it appears that plants produced similar biomass whether grown with fixed overhead irrigation or subirrigation. Nitrogen lost to leaching was greatest with fixed overhead irrigation and essentially zero with the closed-system subirrigation application method. Because all of the applied water was available to plants, less than half the amount of water was used for subirrigation when compared to fixed overhead irrigation. Surprisingly, the amount of moss growing in the containers, and the sexual development of moss plants, was greatly reduced with subirrigation (fig. 4)—alleviating the deleterious effects of moss growth is paramount for some growers (Landis and Altland 2006). Although EC levels were higher in subirrigated containers, the values were well below those considered deleterious, thereby avoiding problems associated with salt accumulation in the upper portions of the containers. In fact, overall, the EC levels in

Figure 3—A nice looking 6-month-old 'ōhi'a seedling grown with subirrigation (photo by R. Kasten Dumroese).

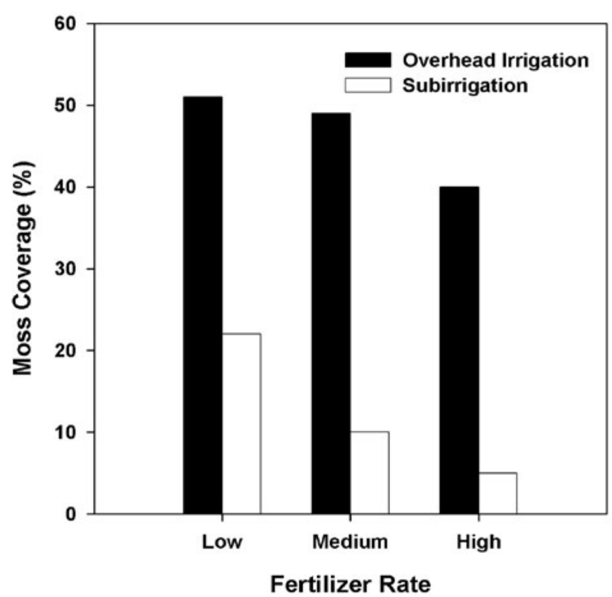

Figure 4—Moss growth on the surface of pots after 3 months of fixed overhead- and sub-irrigation (see Dumroese and others 2006).

subirrigation were higher, indicating some residual fertilizer was still available to plants at the end of the demonstration, whereas all of the fertilizer was essentially gone (it had leached) from the fixed overhead. A problem at this facility was its remoteness, which did not allow continual tweaking of the subirrigation frequency and duration. The result was overwatering plants early in the demonstration, which caused problems with fungus gnats and aphids. The pests were easily controlled with biological and chemical pesticides and once the timing issue was resolved, these pests were no longer pests. Complete details on this study are available in Dumroese and others (2006).

Koa

Our koa demonstration included a factorial design of four container types (table 1) and four fertilization levels (none, low, medium, high) placed into the FlowBench™ system. Fertilizer rate caused differences in seedlings growth. Regardless of irrigation method, koa heights and root collar diameters were similar within fertilizer rates (fig. 5). These seedlings were grown in an outdoor compound operated by the State of Hawai'i Division of Forest and Wildlife at Waimea on the Big Island of Hawai'i—Ian Shigematsu was our collaborator. Because they were outside, the fixed overhead irrigated and subirrigated seedlings received rain and, subsequently, EC values were fairly consistent throughout the container profile as rainwater percolated through the medium. EC values at the end of the demonstration were higher with subirrigation, indicating some residual fertilizer was present (less leaching had occurred), but like 'ōhi'a, these EC values posed no concern. In collaboration with Mike Donoho, Pu'u Wa'awa'a Ahupua'a Coordinator, Division of Forestry and Wildlife, Hawai'i Department of Land and Natural Resources, we have outplanted seedlings at Pu'u Wa'awa'a to compare survival and growth between the two irrigation systems (fig. 6).

Table 1—Locations and containers used in subirrigation demonstrations.

Location	Container	Number per container	Volume	Density	Depth
			Cavity or pellet characteristic		
			ml (in^3)	*m^2 (ft^2)*	*cm (in)*
Waimea	Plug Trays		50 (3)	474 (44)	10 (4)
	Ray Leach “Cone-tainers”™ SC 10	98	164 (10)	528 (49)	21 (8)
	Deepots™ D16	25 or 50	262 (16)	323 (30)	18 (7)
	Deepots™ D40	20	656 (40)	215 (20)	25 (10)
Purdue	Beaver Styroblock™ or Copperblock™ 60/220—Styro 15 (512A)	60	220 (13)	284 (26)	12 (5)
	Jiffy® 50100	32	250 (6)	224 (21)	10 (5)
	Jiffy® 50150	32	350 (20)	224 (21)	15 (6)
Moscow	Beaver Styroblock™ 160/90—Styro 5 (315B)	160	90 (5.5)	756 (70)	15 (6)
	First Choice® 112/105—Styro 6 (415B)	112	105 (6.5)	530 (49)	15 (6)
	Beaver Styroblock™ 45/340—Styro 20 (615A)	45	340 (20.5)	213 (20)	15 (6)

Figure 5—Subirrigated, 12-week-old koa seedlings growing in a plug tray (left) and in Deepots™ D40 (right) (photo by Anthony S. Davis).

Figure 6—Outplanting koa seedlings grown with either fixed overhead irrigation or subirrigation at Pu'u Wa'awa'a on the Big Island of Hawai'i (photo by Anthony S. Davis).

Northern Red Oak

Seedlings were grown in Beaver Plastics Styroblock™ and Copperblock™ 512A containers or Jiffy® Forestry Pellets (table 1) inside a greenhouse at Purdue University using the Spencer-Lemaire FlowBench™ subirrigation system (fig. 7) or hand watered from above. As with the previous species, seedling height and root collar diameter were similar with both irrigation systems. Unlike koa, we did detect substantially elevated EC levels in the upper portions of the medium of subirrigated seedlings. This is probably a reflection of salts moving upward with the subirrigation water as well as a lack of fibrous roots in the upper portion of the plug that could absorb those ions. Although high, these values were still below those considered excessive (or potentially damaging to plants) and we found they were easily ameliorated by a single application of clear water applied with a hose. Regular monitoring of EC levels would quickly point out potentially dangerous levels and we now know that the remedy is as simple as a plain water application.

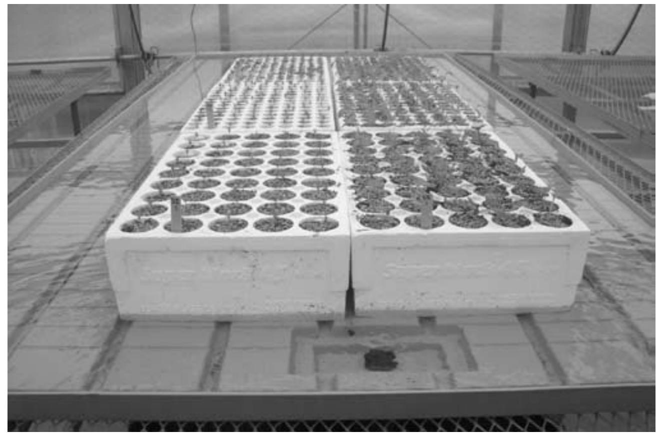

Figure 8—Sytrofoam® containers with blue spruce and pale purple coneflower seedlings being subirrigated (photo by Rhiannon Chandler).

Blue Spruce

Blue spruce seedlings were grown in three types of Styrofoam® containers (table 1) inside a greenhouse at the USDA Forest Service Rocky Mountain Research Station facility in Moscow, ID (fig. 8) for 3 months. This greenhouse was equipped with a typical traveling boom irrigation system. GROmaster trays were used for subirrigation. Regardless of container size, seedling height, root collar diameter, and biomass were similar between irrigation systems (fig. 9; see Landis and others 2006). Like red oak, we did detect fairly high EC levels in the upper portions of the medium

Figure 7—Northern red oak, with its large leaves that form an umbrella that prevents efficient overhead irrigation, can be readily grown with subirrigation (photo by Anthony S. Davis).

Figure 9—A nice looking, 4-month-old subirrigated blue spruce seedling (photo by R. Kasten Dumroese).

of subirrigated seedlings, but the values were within an acceptable range and we did not feel compelled to add clear water. In this particular demonstration, we did note that roots had egressed from the bottoms of some containers and were growing between the bottom of the container and the surface of the subirrigation tray, probably because there was no air gap between the container and tray. Although a simple remedy is probably to elevate the containers, care will be needed because the trays are shallow and raising them too much may disrupt capillarity in some cavities. We also detected appreciable amounts of nitrogen being leached from the overhead-irrigated containers when compared to the subirrigated ones.

Pale Purple Coneflower

This wildflower is the only species we have looked at so far where an increase in growth was detected with subirrigation. These were grown in the same type of containers as the blue spruce (table 1) and in the same greenhouse. Subirrigated coneflowers accumulated more biomass than those irrigated overhead. Interestingly, more coneflowers died in the overhead irrigation treatment—mortality averaged about 9% compared with 0.4% in the subirrigation (fig. 10). Coneflowers have a lot of canopy that may have deflected the irrigation water, or the plants may be susceptible to crown rots exacerbated by moistening the root crowns with overhead irrigation. Like blue spruce, appreciably more nitrogen was leached by the overhead irrigation system. EC values were, however, low throughout the medium profile, probably because of the aggressive, fibrous root system of this forb in the upper portions of the root plug.

What About Salts?

As indicate above, we have noted that EC readings are higher toward the surface of subirrigated pots than those being irrigated from above. If the plants are being subirrigated in an outdoor nursery exposed to natural precipitation, we noted EC values at the surface can be quite low as the precipitation leaches salts downward in the profile. When grown indoors, EC values can be much higher—the highest EC values we have measured were still, however, within acceptable ranges (Fisher and Argo 2005; Jacobs and Timmer 2005) and could be lowered immediately and drastically with an application of clear water. This indicates that careful monitoring of the growth medium can alert growers to a potential danger that can easily be ameliorated with an overhead application of water.

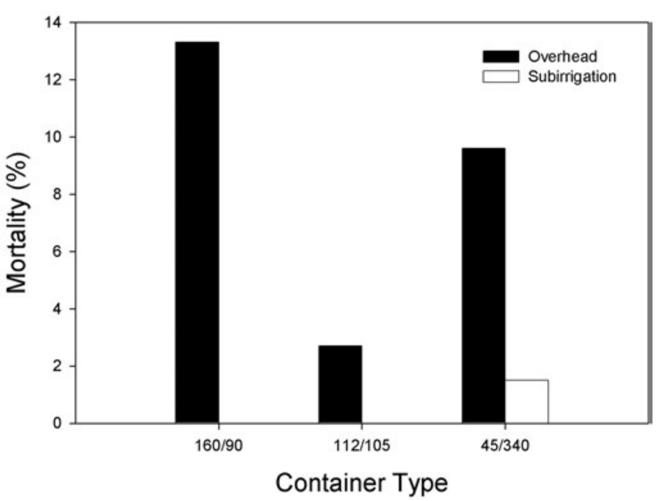

Figure 10—Mortality of pale purple coneflower seedlings grown with subirrigation and fixed overhead irrigation.

Unsolved Opportunities

As growers, we still have many questions concerning the use of subirrigation in forest and conservation nurseries. Landis and Wilkinson (2004) outlined several "disadvantages" that might be solved through our demonstrations and creative thinking:

- Overhead irrigation may be necessary to promote seed germination because the medium surface may not remain moist enough with subirrigation.
- No leaching occurs, so subirrigation cannot be used with poor quality water because of the build-up of salts.
- Roots may not air prune as effectively.
- More risk that waterborne diseases will spread.
- No data is available on how forest and conservation nurseries will respond to this treatment.

So far, a lack of root pruning has only been an annoyance in Styrofoam® containers. These containers lack legs and are positioned directly on top of the subirrigation tray surface, essentially leaving no air space. Apparently the space around the bottom of Ray Leach "Cone-tainers"™ and Deepots™ is sufficient for air pruning. For block-type containers, however, perhaps copper coatings within containers (for example, Copperblock™ containers), an application of copper to the tray (for example, Spin-Out™), or covering the subirrigation trays with copper mesh or copper impregnated fabrics may provide satisfactory pruning.

Although we have not seen any disease issues, it would seem that inoculum could float from cavity to cavity in the recycled water, especially so for the water mold fungi like *Phytophthora* and *Pythium*. Excluding these pests from the nursery by using clean propagules, disease-free medium, and a disease-free water source would be a prudent first step. Perhaps, if necessary, some type of in-line sterilization system could be used, similar to what is used in bottled water facilities.

In addition to the concerns raised by Landis and Wilkinson (2004), we have added a few problems that will need to be addressed as more plants are grown with subirrigation. First, a more automated subirrigation system is needed so plants are only irrigated when they need to be, not by a strict time clock. This would alleviate the problems we saw with over-irrigated 'ōhi'a, and would further decrease water usage in nurseries. Currently we are working with the USDA Forest Service Missoula Technology and Development Center to automate the pumps, perhaps by adapting sensors commonly used now in golf course and turf settings to regulate irrigation.

Second, we need to investigate the use of "fertigation" with subirrigation. To date, we have only demonstrated these systems with CRF. It should be possible to supply soluble fertilizers through the subirrigation system as well, although monitoring and maintaining appropriate fertilizer levels may be more difficult.

Third, we have discovered that if the medium in subirrigated containers becomes too dry, capillarity is lost. It would be interesting to see if addition of chemicals that disrupt water surface tension could be used to "restart" the capillarity—the alternative is to simply recharge the medium with water applied overhead.

Summary

Subirrigation is an effective way to produce native plants because less water is applied, less nitrogen is leached, plant growth is similar, moss growth is reduced, and sometimes seedling mortality is lower. Subirrigation inside greenhouses often causes EC values to be higher at the surface of the medium, but these values have been within acceptable ranges for normal plant growth. As our demonstrations are completed, we should have a clearer picture of the advantages and disadvantages of using subirrigation in forest and conservation nurseries.

Acknowledgments

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