

# Subirrigation for production of native plants in nurseries—concepts, current knowledge, and implementation

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## ABSTRACT

Subirrigation, a method whereby water is allowed to move upward into the growing medium by capillary action, has been the focus of recent research in forest and conservation nurseries growing a wide variety of native plants. Subirrigation reduces the amount of water needed for producing high-quality plants, discharged wastewater, and leaching of nutrients compared with traditional overhead irrigation systems. Recent research has shown additional benefits of subirrigation, such as enhanced crop uniformity and improved outplanting performance. With these advantages and successful operational use in some locales, it seems likely that subirrigation would be of use to a greater number of native plant nurseries. In this article, we provide an overview of ebb-and-flow subirrigation technologies including potential benefits, summarize the current state of research knowledge for native plant production, present special considerations for these systems, and offer a basic framework on how growers can implement such a system.

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## KEY WORDS

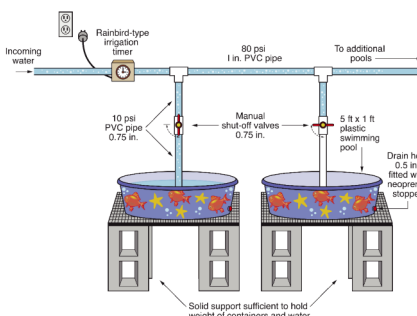
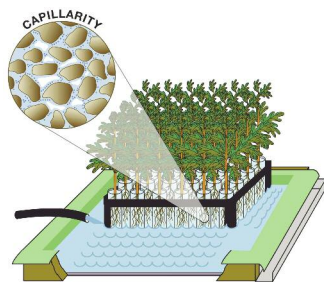
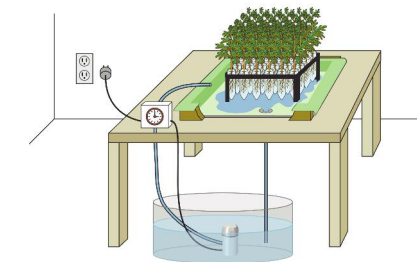
controlled-release fertilization, electrical conductivity, fertilizer-use efficiency, irrigation, nitrogen-use efficiency, water-use efficiency

## NOMENCLATURE

Plants: USDA NRCS (2011)

Insects: ITIS (2011)

Fungi: IFP (2011)



Nursery managers, striving to produce quality seedlings, face government regulations on water use (Oka 1993) and wastewater discharge (Grey 1991), and mounting public concern about environmental contamination (Neal 1989). One area in which managers can simultaneously address all these concerns is through irrigation water management. Use of subirrigation has shown promise in overcoming these challenges without compromising crop quality and may concurrently provide other benefits (for example, Dumroese and others 2006, 2007, 2011; Landis and others 2006; Bumgarner and others 2008; Davis and others 2008; Pinto and others 2008). Specifically, growers can reduce the quantity of water used during crop production, the amount of water discharged from irrigation, and the fertilizers and chemicals present in discharged water.

Overhead irrigation systems can cover large areas, prevent fertilizer salt accumulation in medium (Argo and Biernbaum 1995), and be installed with relatively little expense (Landis and Wilkinson 2004). From a water and nutrient management perspective, however, these systems can be inefficient, may result in significant fertilizer leaching, and are difficult to use on small areas containing diverse species and (or) stocktypes. For example, Dumroese and others (1995) found between 49 and 72% of water and 32 and 60% of nitrogen (N) applied using an overhead irrigation system were discharged from a container nursery. Additionally, a study examining nutrient uptake efficiency and leaching fractions in western white pine (*Pinus monticola* Douglas ex D. Don [Pinaceae]) culture found that irrigation water was leached at a rate of 1.3 l/m<sup>2</sup> per d with N losses of 8 mg N/m<sup>2</sup> per d from leachate (Dumroese and others 2005). In another conifer seedling container study, Juntunen and others (2002) recovered 11 to 19% of applied N and 16 to 64% of phosphorus in collected leachate. These examples of discharged nutrients within wastewater demonstrate the impacts to the environment and the nursery budget. Culturally, overhead irrigation also results in water interception and deflection (that is, “umbrella effect”) by the leaves of broad-leaved plants (Figure 1). This effect may lead to uneven water distribution (Landis and Wilkinson 2004), crop variability, mortality in dry cavities (Dumroese and others 2006), and reduced irrigation application efficiencies (Beeson and Knox 1991). Yet despite these potential disadvantages, overhead irrigation systems are still standard practice in forest and conservation nurseries (Landis and others 1989a; Leskovar 1998).

The benefits of subirrigation have been demonstrated for a variety of species and nursery systems (Dumroese and others 2006, 2007, 2011; Landis and others 2006; Bumgarner and others 2008; Davis and others 2008; Pinto and others 2008). Recent work with northern red oak (*Quercus rubra* L. [Fagaceae]), koa (*Acacia koa* A. Gray [Fabaceae]), pale purple coneflower (*Echinacea pallida* (Nutt.) Nutt. [Asteraceae]), ‘ōhi‘a (*Metrosideros polymorpha* Gaudich. [Myrtaceae]), and



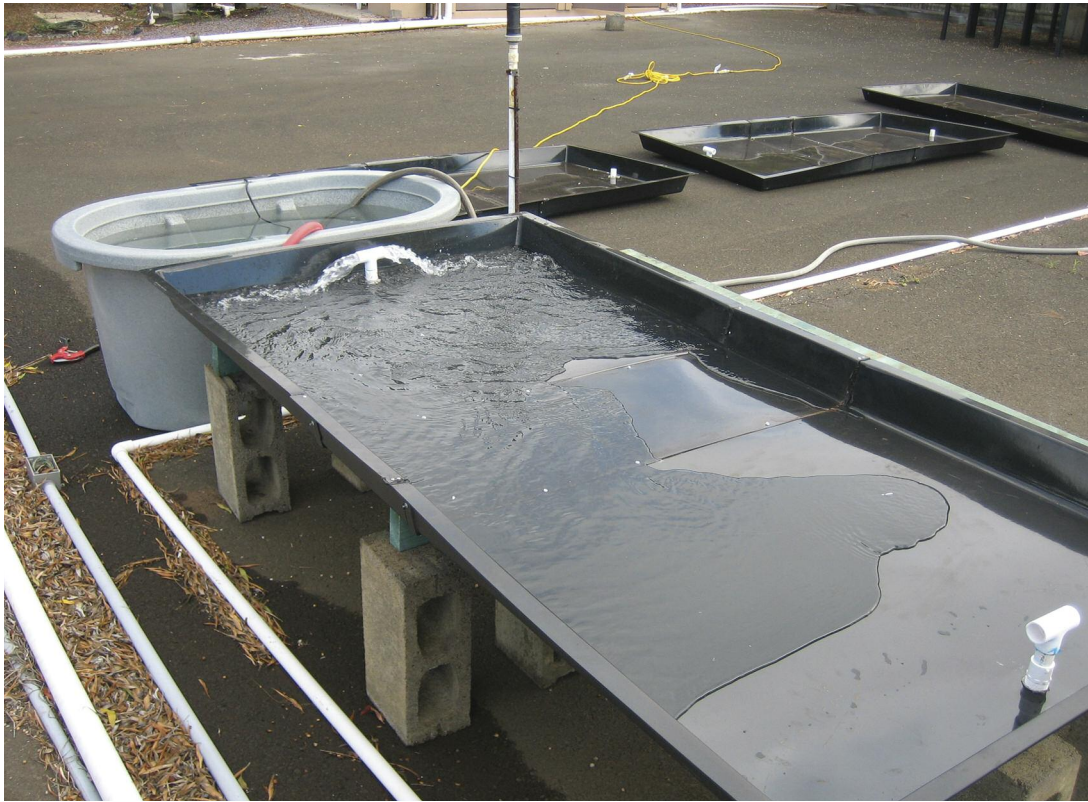
Figure 1. Northern red oak, with its large leaves that form an umbrella and prevent efficient overhead irrigation, can be readily grown with subirrigation. Photo by Anthony S Davis; reprinted from Dumroese and others 2007

blue spruce (*Picea pungens* Engelm. [Pinaceae]) demonstrates the benefits and versatility of subirrigation and increased interest in this system (Dumroese and others 2007). Such benefits may include less water use, reduced labor inputs, improved fertilizer efficiency, decreased liverwort and moss growth, plant quality improvements, and more uniform crop growth. Incorporating subirrigation systems into nurseries can be easy and low cost. Either commercially available equipment can be purchased to fit onto existing nursery benches, or custom, low-tech equipment can be constructed in-house to accommodate a multitude of specialized needs (for example, Schmal and others 2007). Although several types of subirrigation systems are available (for example, wick, trough, and flooded floor), we will focus our discussion on ebb-and-flow subirrigation.

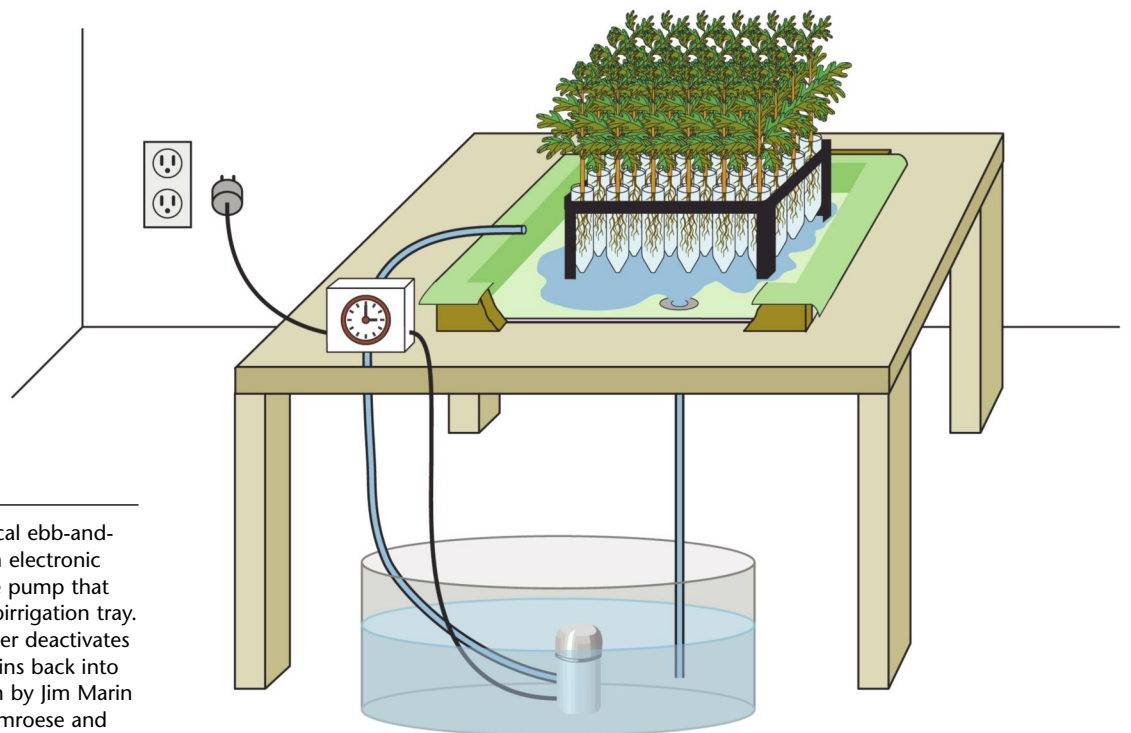
Although subirrigation systems are often used by the horticultural industry, this system, and its application in native plant nursery production, is relatively new. Our intent is to present an overview of the benefits of ebb-and-flow subirrigation as reported by recent research, examine special considerations with these systems, and provide practical information about commercial and custom systems.

## THE SUBIRRIGATION SYSTEM

In subirrigation, a water-containing structure is flooded (Figure 2) until the water level contacts the medium (Figure 3). Once contact is made, capillary action (the attraction of water molecules for one another and other surfaces) moves water up through the medium and throughout the container (Figure 4A)



*Figure 2. Flooding of subirrigation trays at Hawai'i Division of Forestry and Wildlife Kamuela (Waimea) State Tree Nursery, on the Island of Hawai'i. Photo by Douglass F Jacobs*



*Figure 3. Schematic of a typical ebb-and-flow 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 drains back into the reservoir tank. Illustration by Jim Marin Graphics; reprinted from Dumroese and others 2007*



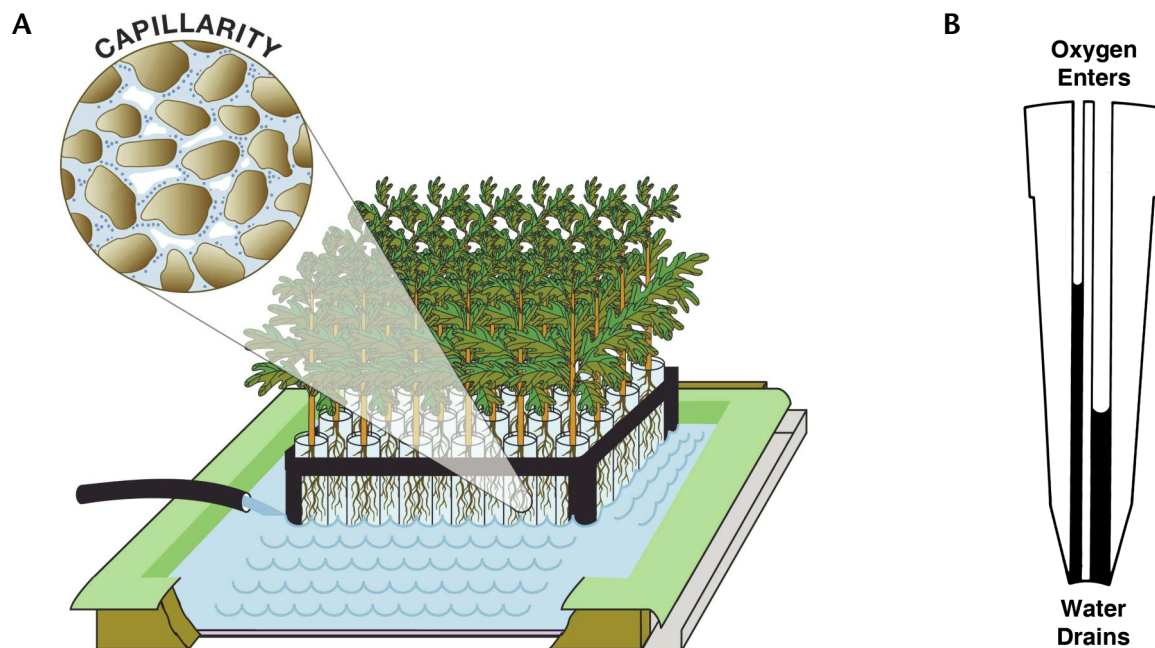


Figure 4. Subirrigation works because water is drawn upward into the containers by capillary action of water (A). The amount and speed of water uptake will depend on the porosity of the growing medium—the smaller the pores, the more that will be absorbed (B). Illustration by Jim Marin Graphics; reprinted from Landis and Wilkinson 2004

(Landis and Wilkinson 2004). Growing medium pore space and medium type (for example, Sphagnum peat) are the primary factors dictating saturation height and speed (Figure 4B) (Landis and Wilkinson 2004). For a very well-drained medium, it may be that capillary action alone is insufficient to maintain moisture levels at the medium surface during germination; therefore, subirrigation may need to be supplemented with overhead irrigation to keep seeds and medium adequately moist (Dumroese and others 2007). As with any new irrigation system, it is essential to test and troubleshoot a subirrigation system before going fully operational because of variability in media, equipment, container types, and the moisture demands of different species.

Several types of subirrigation systems are available on the market (Landis and Wilkinson 2004); a closed system (Dumroese and others 2007) is one of the most promising systems for forest and conservation nurseries. In a closed system, water is pumped from a reservoir tank into a subirrigation tray (Figure 2); when the irrigation cycle is completed, the water returns to the reservoir tank (Figure 3). Typically, water is held in the tray until the medium is brought to field capacity; however, a range (that is, low to high cost) of equipment is available to facilitate and fine-tune this process. Many growers use automated pumps with programmed flood cycles in which the pump fills the tray, turns off for several minutes to allow the tray to completely drain, and repeats the process until the medium is brought to field capacity. Alternatively, systems utilizing solenoid valves, which close the irrigation line for a specified dura-

tion, can have a separate drain component where water is released after a certain amount of time. The USDA Forest Service, Missoula Technology and Development Center has demonstrated the effective use of remote soil moisture probes for determining when to water bareroot nursery beds (Davies and Etter 2009). Integrating this technology into subirrigation systems would further decrease water usage, labor inputs, and prevent crop overwatering. Minimal maintenance is needed throughout the growing season to keep a subirrigation system working properly; however, water losses through evaporation and crop transpiration require periodic refilling of reservoir tanks.

## SEEDLING QUALITY AND MORPHOLOGY

Subirrigated plants are morphologically similar or superior to those receiving overhead irrigation (Figure 5) (Coggeshall and Van Sambeek 2002; Dumroese and others 2006, 2007, 2011; Landis and others 2006; Bumgarner and others 2008; Davis and others 2008). Pinto and others (2008) used subirrigation to propagate pale purple coneflower seedlings that exhibited better nutrition (that is, 11% greater N content per seedling), 13% greater nitrogen-use efficiency (NUE), less mortality, and greater growth (15% taller and 14% more total dry weight) than overhead irrigated seedlings receiving the same nutrient rates (Figure 6). Subirrigated northern red oak seedlings had increased aboveground biomass production and greater root and shoot N contents during nursery culture when compared

with overhead irrigated seedlings (Figure 7) (Bumgarner and others 2008).

Greater crop uniformity and outplanting performance have also been noted with subirrigated seedlings. Bumgarner and others (2008) showed that subirrigated northern red oak seedlings had greater stem diameter growth following outplanting compared with overhead irrigated seedlings. Increased stem diameter was also noted in an outplanting trial of koa seedlings (Davis and others 2011). Although not quantified, Landis and others (2006) noted that stem heights and diameters were very uniform in seedlings propagated using subirrigation. Crop uniformity is easily attainable with subirrigation systems because the “umbrella effect” is eliminated and an equal amount of water and nutrients are supplied to each container. These results affirm that a correctly used subirrigation system yields similar or better seedling morphology, quality, and outplanting success than does overhead irrigation.

REDUCED WATER USE

Closed subirrigation systems allow for increased water-use efficiency because the only losses from the system are through transpiration and evaporation. A study in Hawai‘i with ‘ōhi‘a reported a 56% reduction in irrigation water using a subirrigation system; application values per container were 36 ml of water per d using fixed overhead irrigation and 16 ml/d with subirrigation (Dumroese and others 2006). The same study illustrated the inefficiency of overhead systems because only 17% of the applied water from the fixed overhead system was “used” by the crop, as nearly 70% was errant spray and 13% of the applied water leached from the pots. Moreover, this study was conducted at a remote site with very limited management; subirrigated seedlings were probably watered more than necessary, indicating that additional water savings could have been made. Similarly, the Tamarac Nursery in Ontario, Canada, experienced a 70% savings in water and fertilizer use (Landis and Wilkinson 2004). These reductions in water use are attributable to the absence of lost leachate in closed subirrigation systems, the lack of errant spray, and the elimination of the “umbrella effect” and its subsequent need for extended irrigation periods to make up for nonuniform irrigation coverage.

IMPROVED FERTILIZER-USE EFFICIENCY

Most research with subirrigation in forest and conservation nurseries has used controlled-release fertilizer (CRF). Incorporating CRF into the medium of nursery crops has many benefits including improved fertilizer-use efficiency, less fertilizer pollution in discharge water, and the elimination of a need to rinse foliage (Landis and Dumroese 2009). Combining the use of

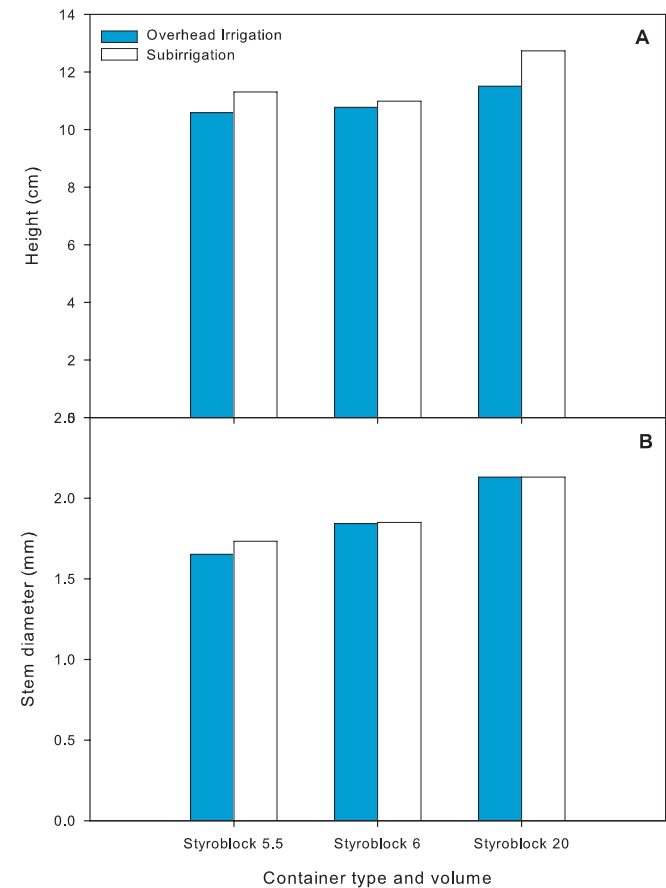


Figure 5. Blue spruce seedlings were slightly larger with subirrigation compared to sprinkler irrigation in all 3 container types in height (A) and diameter (B). Reprinted from Landis and others 2006

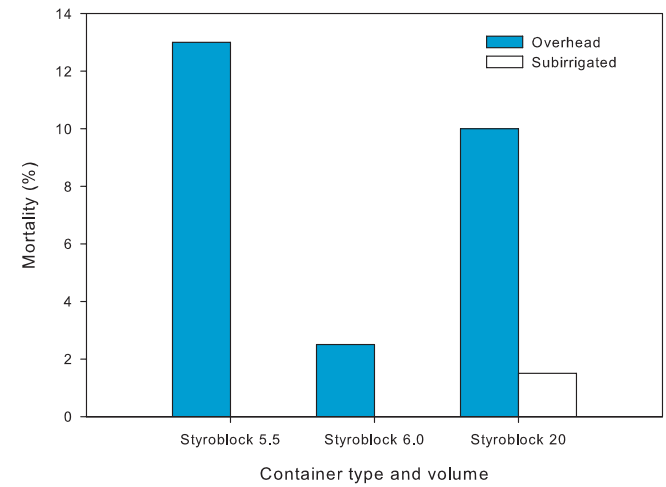


Figure 6. Mortality of pale purple coneflower seedlings grown with subirrigation and fixed overhead irrigation. Reprinted from Dumroese and others 2007

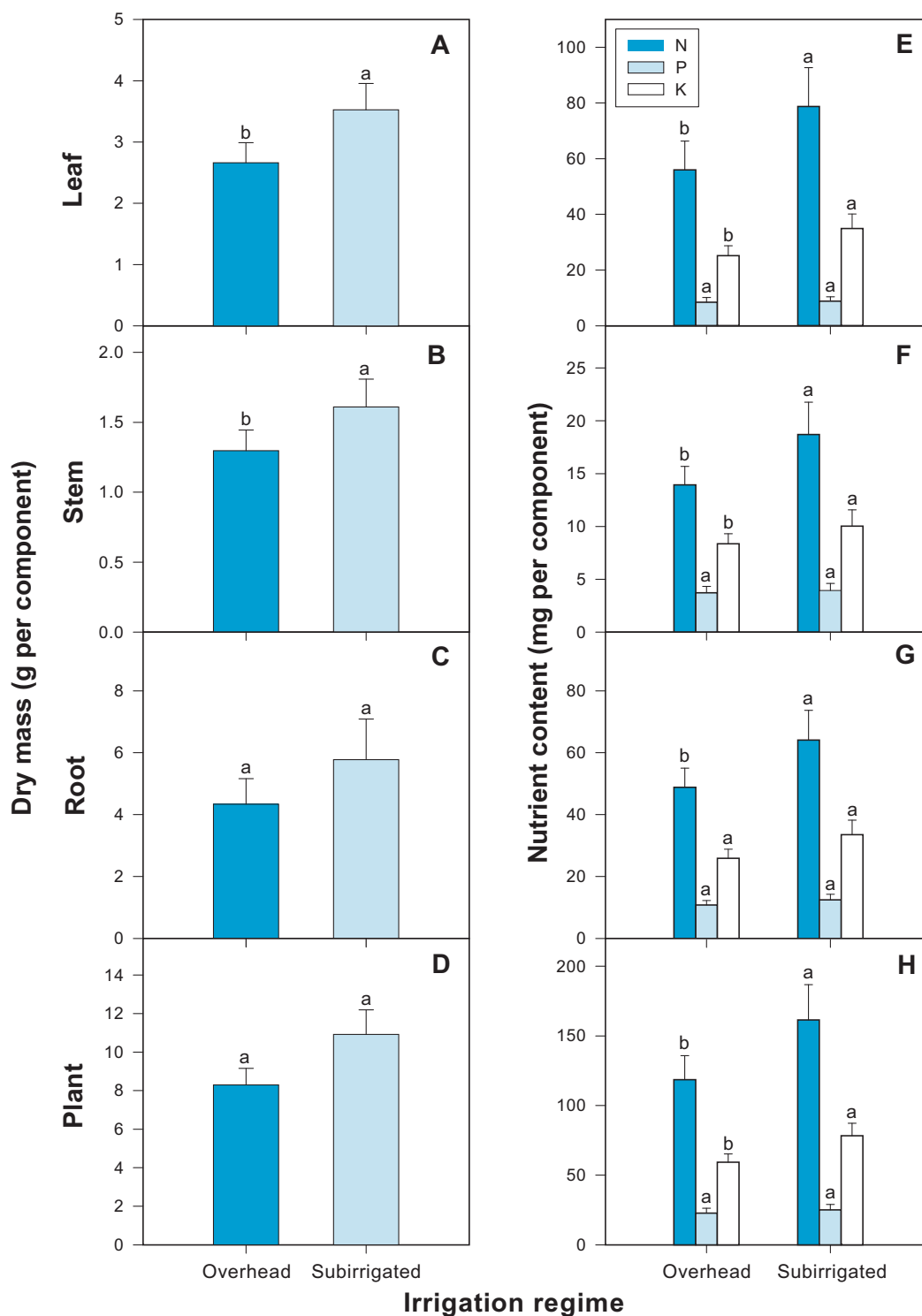


Figure 7. Effects of irrigation method on northern red oak component dry weight (A–D) and nutrient content (E–H) sampled 4 mo after sowing under controlled greenhouse environments. Treatments marked with different letters are statistically different according to Tukey's honestly significant difference test at  $\alpha = 0.05$ . Reprinted from Bumgarner and others 2008

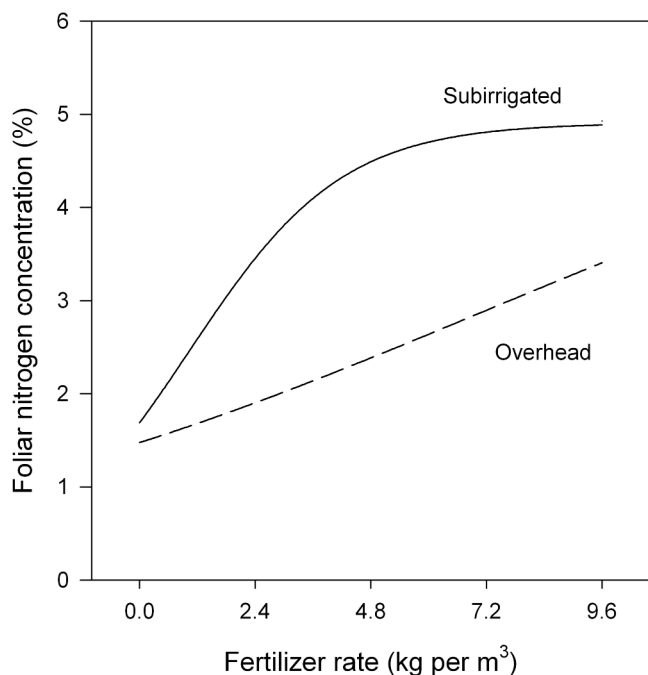


Figure 8. Foliar nitrogen concentrations in subirrigated koa seedlings were higher than in overhead irrigated seedlings; concentrations continued to rise with increasing rates of fertilization. Reprinted from Dumroese and others 2011

CRF with a subirrigation system further enhances these benefits. To illustrate, the aforementioned study with ‘ōhi‘a (Dumroese and others 2006) used CRF in both overhead irrigated and subirrigated treatments. The average concentration of N in leachate from overhead irrigation was 43 ppm (24 g [0.85 oz] N per replicate; equivalent to 5 g [0.18 oz] N leached per m<sup>2</sup>), representing a 3% loss of the total applied, which is very low when compared with 32 to 60% losses with standard fertigation systems (Dumroese and others 1992, 1995). In spite of this, the average N concentration in subirrigation reservoir tanks was even lower at 5 ppm (0.7 g [0.025 oz] N per replicate tank) (Dumroese and others 2006). Thus, a subirrigation system allows nursery growers to save money by using less fertilizer.

Another added benefit of subirrigation is the persistence of residual fertilizer salts in the medium and holding tanks (Dumroese and others 2006, 2011). For example, after 9 mo of irrigation using a 6-mo release CRF, electrical conductivity (EC) in the medium of subirrigated seedlings was higher than that of overhead irrigated plants (Dumroese and others 2006). These residual fertilizer salts improve plant nutrient availability and fertilizer-use efficiency, while also serving as a source of nutrient reserves during field establishment (Dumroese and others 2006; 2011). The capture of leachate in closed subirrigation systems allows for recycling of nutrients that would otherwise be lost with overhead systems, leading to subsequent improvements in nutrient-use efficiency and seedling nutrient

content (Figure 7E–H and 8) (Bumgarner and others 2008; Pinto and others 2008; Dumroese and others 2011).

## DECREASED PRESENCE OF DAMAGING AGENTS

Given the constant recycling of irrigation water in subirrigation systems, the potential proliferation of disease is of concern and has prevented some growers from experimenting with and (or) using subirrigation systems. This concern is justified, as water mold fungi, such as *Phytophthora* Bary (Pythiaceae) and *Pythium* Pringsh. (Pythiaceae), have been shown to spread in various subirrigation systems, including the ebb-and-flow system used in floriculture and ornamental horticulture (Sanogo and Moorman 1993; van der Gaag and others 2001; Oha and Son 2008), especially when surface water sources are used (Hong and Moorman 2005). Whether or not disease ensues depends on the plant and the pathogen (van der Gaag and others 2001), and in several experiments, placement of diseased plants within subirrigation areas spread less disease than when inocula were added directly to the subirrigation reservoir (Sanogo and Moorman 1993; van der Gaag and others 2001).

We have yet to observe any waterborne disease issues with subirrigation systems, probably because the growing media is allowed to dry between irrigations; in conifer nurseries in the Pacific Northwest, *Phytophthora* and *Pythium* are generally only a problem when soil or media are persistently excessively wet (Dumroese and James 2003). Moreover, the absence of disease in subirrigated seedlings may reflect plants that are healthier than those propagated by means of overhead irrigation. When disease problems do arise, the cause(s) will likely result from a failure to use clean propagules, disease-free medium, and (or) disease-free water; not the subirrigation system itself. Recent reviews discuss a myriad of cultural, physical, and chemical methods that can be used in subirrigation systems to control waterborne diseases (Newman 2004; Stewart-Wade 2011); control may be as simple as adding a surfactant to the water (Stanghellini and others 2000).

Subirrigation may actually reduce some nursery pests. In an ‘ōhi‘a crop, subirrigation decreased moss and liverwort cover on the medium to one-third that observed with overhead

TABLE 1

Average coverage of moss in each container with either fixed overhead or subirrigation and percentage of those containers with sporangium present (Dumroese and others 2006).

Irrigation	Moss coverage (%)	Sporangium (%)
Fixed overhead irrigation	50	86
Subirrigation	15	23





Figure 9. General lack of moss and liverwort growing on the surface of the medium of 6-mo-old subirrigated plants (A) versus that growing with fixed overhead irrigation (B). Photos by R Kasten Dumroese; reprinted from Dumroese and others 2007

irrigation (Dumroese and others 2006) (Table 1; Figure 9). Additionally, the moss growing in the fixed overhead containers was more mature (that is, had roughly four times more sporangium) than the moss in the subirrigation containers (Dumroese and others 2006) (Table 1; Figure 9). Because moss and liverworts compete with the crop for fertilizer and light, they can easily choke out small seedlings, reduce seedling growth, or foster other pests, such as fungus gnats (*Bradysia* species [Diptera: Sciaridae]).

The moistening of root crowns and foliage by overhead irrigation can encourage the growth of foliar diseases such as grey mold (*Botrytis cinerea* Pers. [Sclerotiniaceae]) (Landis and others 1989b). Because subirrigation keeps foliage dry, it lessens the potential for foliar diseases. Dumroese and others (2006) did observe that subirrigating too frequently (that is, overwatering) can lead to the proliferation of fungus gnat populations. Therefore, as previously mentioned, it is important to test, monitor, and fine-tune subirrigation systems to obtain optimal crop growth.

## SPECIAL CONSIDERATIONS

Subirrigation tends to result in elevated EC values in the upper regions of container medium compared to overhead irrigation (Figure 10) (that is, EC values are high toward the top of containers and low toward the bottom) (Dumroese and others 2006, 2011; Bumgarner and others 2008; Davis and others 2008; Pinto and others 2008). The high EC results from water evaporation at the medium surface that leaves behind soluble salts (Landis 1988). These salts may be dissolved fertilizer from the CRF or dissolved salts inherent in the water. Nurseries having irrigation water with high dissolved salts should be cautious with subirrigation due to the potential for elevated EC (Landis and Wilkinson 2004). Although medium EC values may be higher in subirrigation systems, research has shown that these elevated values have not been detrimental to crops (Dumroese and others 2006, 2011; Bumgarner and others 2008; Davis and others 2008; Pinto and others 2008). Because root architecture is strongly influenced by EC (Jacobs and



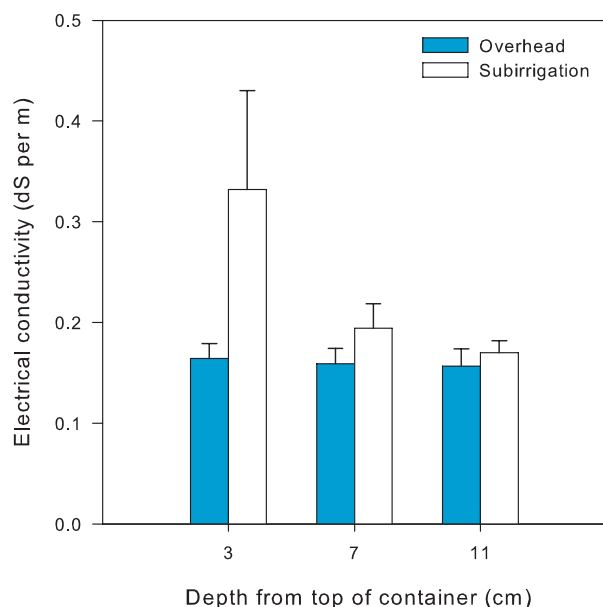


Figure 10. Electrical conductivity values for overhead and subirrigated pale purple coneflower seedling medium at three depths (3, 7, or 11 cm [1.2, 2.3, or 4.3 in]) from the top of the container. Measurements were taken 93 d after sowing. Reprinted from Pinto and others 2008

others 2003) and the upper layer of medium typically has the least amount of root dry mass (Todd and Reed 1998; Pinto and others 2008), the negative impacts from elevated upper layer EC are diminished.

Although EC thresholds for several conifer (Landis 1988; Jacobs and Timmer 2005) and herbaceous species (Scoggins 2005) exist, little information is available for many hardwood and other native plant species. Extracted medium solutions from subirrigated containers of northern red oak had EC values above recommended thresholds (Jacobs and Timmer 2005), but these levels did not negatively impact seedling growth (Bumgarner and others 2008). Medium EC at different depths can quickly be assessed with an electrical conductivity meter, such as a Field Scout™ (Spectrum Technologies Inc, Plainfield, Illinois). Because different measurement techniques can yield different values, we recommend that growers continually monitor crops and look at the overall trend in EC and subsequent plant response. Vigilant growers can then establish EC threshold values, based on their monitoring equipment and specific to their crops, and thereby avoid salt damage. If medium EC values exceed thresholds, an overhead application of clear irrigation water can immediately and drastically lower medium EC. For example, Davis and others (2008) had EC values in subirrigated containers that averaged 3.31 dS/m at a depth of 1 cm (0.39 in). Following overhead irrigation with clear water, average EC values dropped to 0.77 to 1.53 dS/m.

Observations during several research studies indicate that a lack of air space between the bottom of the containers and the subirrigation tray prevents seedling roots from “air pruning.”

For example, one subirrigation study conducted with blue spruce noted that roots were growing between the bottom of some containers and the surface of the subirrigation tray (Dumroese and others 2007). Several solutions to remedy the lack of root pruning with block-type containers exist and include using a copper coating within containers (for example, Copperblock containers), or applying copper to the tray (for example, Spin-Out), or covering the trays with copper mesh or copper impregnated fabrics. Another quick and inexpensive remedy for all container types is to use spacers to elevate the containers so that the subirrigation tray is able to dry out completely between irrigations.

## PERTINENT RESEARCH AREAS

Although recent studies have provided much beneficial information about the effects of subirrigation on the culture of plants in forest tree seedling and conservation nurseries, several pertinent areas still require investigation. First, while fertigation (fertilizer diluted with the irrigation water) is extensively used with overhead irrigation systems, we need more information about combining fertigation and subirrigation specific to forest tree seedling and conservation nurseries. Research in this area with horticultural species has shown the applicability of fertigation to subirrigation systems (Treder and others 1999; James and van Iersel 2001a, b), potentially allowing reduction of fertilizer application rates (Zheng and others 2005). Second, we need more information about the potential movement of waterborne diseases in subirrigation systems. Quantitative studies that compare disease spread, persistence, severity (for example, through inoculation of the crop with pathogens and spores), and possible remedies, such as biological controls and well-drained media, are warranted in forest tree seedling and conservation nursery subirrigated systems. Such studies may help eliminate a “fear-of-the-unknown” that may prevent some growers from realizing the benefits of subirrigation. Third, we need more information about the suitability of subirrigation for different plant types (for example, grasses, forbs, shrubs, trees) as well as the diverse number of species in those types; therefore, more trials with more species are necessary.

## IMPLEMENTING A SUBIRRIGATION SYSTEM

Subirrigation systems can be quickly installed, used for a variety of container types, and accommodate a wide range of production scales. The abundance of manufacturers offering subirrigation products combined with the inherent simplicity of basic subirrigation systems allow for large ranges in the complexity and price of these systems. The cost of some commercial systems may preclude their use in nurseries with budget constraints. Additionally, nursery growers may not be able to

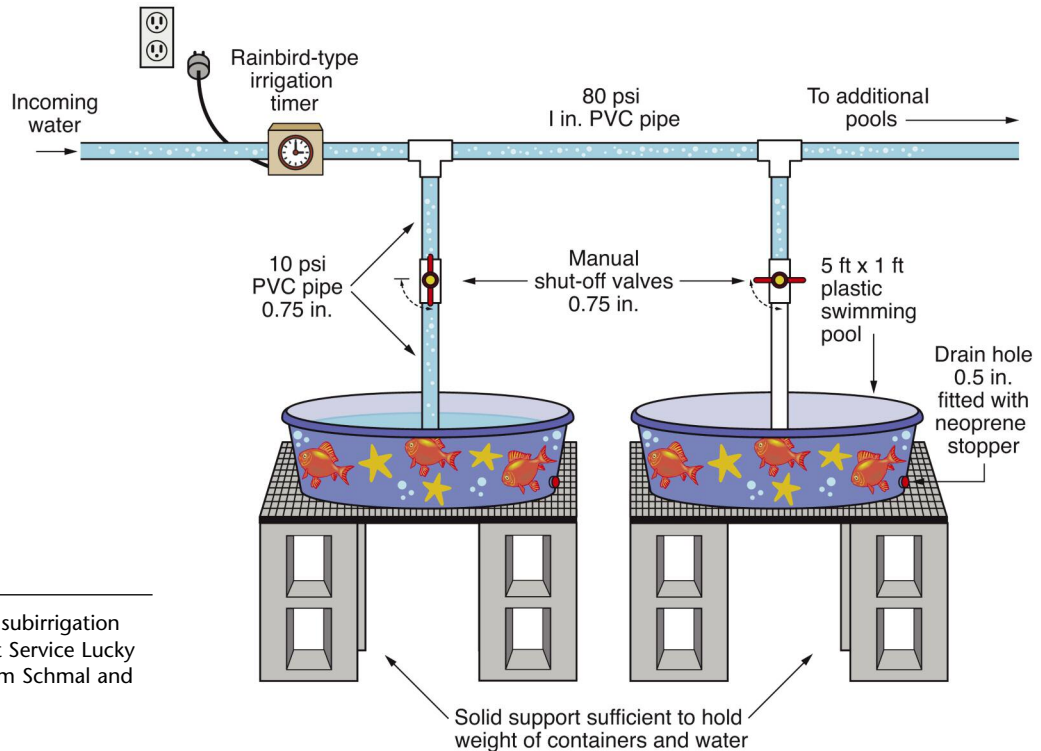


Figure 11. Schematic of the subirrigation system used at USDA Forest Service Lucky Peak Nursery. Reprinted from Schmal and others 2007

justify high up-front costs of a new system if they are initially skeptical of the cost versus benefits. Fortunately, materials to construct subirrigation systems in-house are readily available, and constructing custom systems can be a quick, cost-effective, and efficient way to subirrigate a variety of seedlings.

At the USDA Forest Service Lucky Peak Nursery, children's wading pools were used as part of a subirrigation system to water a variety of seedlings in 3.8-l (1-gal) Tree Pots (Schmal and others 2007). The system consisted of a main PVC irrigation pipe, a Rain Bird-type irrigation timer, and PVC distributor pipes with individual hand valves running to each pool (Figure 11). The pools were supported above the ground by metal cooler shelving placed on cinder blocks. About 130 containers fit into each pool (Figure 12), and plants were being grown in this system for 1 to 2 y. Approximate cost on a per pool basis was \$20 USD, not including the supporting structures. Other low-cost options for in-house constructed units include flood floor systems that consist of a raised perimeter of concrete blocks and lumber covered with pond liner (Landis and Wilkinson 2004).

Commercial subirrigation systems fall into 2 general categories: bench systems and flood floor systems. Both systems are highly customizable, accommodate practically any type and size of container, and can be configured to suit a variety of space and budget constraints. With bench systems, subirrigation trays, troughs, or bench liners are placed on top of nursery benches, and crop containers are subsequently placed within these structures. The benches must be sturdy enough to support the weight of the subirrigation water, the trays, and the

saturated containers. In addition to structural support, precise leveling is required to completely drain the water following an irrigation event; complete drainage facilitates air pruning and minimizes evaporative losses.

With flood floor systems, subirrigation water is contained by concrete or other impermeable material, and crop containers sit directly on the floor surface, leaving only as much room below as needed for air pruning. For many of these commercial systems, concrete must be poured and precisely leveled and enclosed plumbing routed, resulting in significant labor and



Figure 12. Top view of subirrigation using a children's wading pool filled with approximately 130 3.8-l (1-gal) Tree Pots™ at the USDA Forest Service Lucky Peak Nursery. Photo by Justin Schmal; reprinted from Schmal and others 2007

material costs. These systems may be a better option for nurseries planning to expand growing areas, rather than for those that already have an ample supply of suitable bench space, because many standard benches can be modified to accommodate subirrigation trays. Some advantages of flood floor systems are their inherent durability, allowance of unobstructed traffic, and the ability to combine floor heating.

In addition to the items mentioned above, most subirrigation systems require a few other elements. In a closed system where water will be stored and recycled, a reservoir tank is necessary. As a general rule, 3.78-l (1-gal) will flood 0.09 m<sup>2</sup> (1 ft<sup>2</sup>) to a depth of 4.1 cm (1.6 in). Livestock water tanks are a good, inexpensive option for subirrigation systems and are available at many local farm supply stores in a range of volumes. Because of the propensity for algal growth, it is important to use opaque materials that inhibit light penetration for all subirrigation components. Level (float) switches can be used to trigger the automatic “topping-off” of storage tanks when evaporation and transpiration have lowered water levels. Another essential item is a pump (for example, sump pump without a check valve) suitably sized for the subirrigation system’s volume and configuration. Manufacturers offering complete subirrigation systems can provide recommendations on the sizes of pumps needed for custom systems. For highly automated systems, a controller can be used in conjunction with solenoid valves to water different zones at different times. Below is a listing of several companies offering a wide range of commercial subirrigation products and systems.

**Beaver Plastics Ltd** carries FlowTrays™ for holding small numbers of containers and FlowBench™ sheets that come in a range of widths and can be joined together to accommodate any length bench. These products are constructed from sunlight-resistant ABS plastic.

Beaver Plastics Ltd  
7-26318-TWP RD 531A  
Acheson, AB T7X 5A3 Canada  
TEL: 888.453.5961  
FAX: 780.962.4640  
E-MAIL: growerinfo@beaverplastics.com  
WEBSITE: <http://www.beaverplastics.com>

**Stuewe & Sons Inc** offers a wide variety of containers and pots. They also have smaller flow trays that would be well suited to growers wanting to conduct subirrigation trials. Their largest flow tray (\$67 USD each) can hold 4 Ray Leach Cone-tainer™ trays, while their smallest (\$29.50 USD each) can hold a single tray. These flow trays are made of sunlight-resistant, 5 mm thick, black or white ABS plastic.

Stuewe & Sons Inc  
31933 Rolland Drive  
Tangent, OR 97389 USA  
TEL: 800.553.5331

FAX: 541.754.6617  
E-MAIL: [info@stuewe.com](mailto:info@stuewe.com)  
WEBSITE: <http://www.stuewe.com>

**Midwest GROmaster Inc** offers Ebb-Flo™ benches and trays that are pre-cut, pre-drilled, and ready for assembly. These custom-fit trays can be retrofitted to existing benches that are easily leveled using leveling bars. Tray widths are available from 45.7 cm (1 ft 6 in) to 1.98 m (6 ft 6 in) and range in price from \$6.92 USD/ft<sup>2</sup> to \$3.25 USD/ft<sup>2</sup> (not including leveling bars). The company also offers a variety of irrigation and fertigation controls.

Midwest GROmaster Inc  
PO Box 1006  
St Charles, IL 60174 USA  
TEL: 847.888.3558  
FAX: 630.443.5035  
E-MAIL: [sales@midgro.com](mailto:sales@midgro.com)  
WEBSITE: <http://www.midgro.com>

**Zwart Systems** designs, sells, and installs custom flood floor systems as well as flood trays. They also offer a full line of greenhouse and irrigation supplies, including water storage tanks.

Zwart Systems  
4881 Union Road  
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**TrueLeaf Technologies** designs and sells custom flood floor systems to fit any greenhouse or outdoor growing situation. They also design and provide complete flood bench system packages. According to the company’s website, cost of design, materials, and labor is on the order of \$4.50 to \$6.00 USD/ft<sup>2</sup>. TrueLeaf also sells water filtration and purification systems for large-scale nursery use.

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Although the upfront costs of subirrigation systems may appear high, nursery managers could quickly recapture the expense in the form of labor savings, reduced equipment maintenance, and improved plant quality. According to Midwest GROmaster’s website, a customer with nearly 0.4 ha (1 ac) of Ebb-Flo™ benches was able to recapture their upfront costs within 2 y from labor savings alone. When combining labor savings with reductions in water and fertilizer usage, investing



in a subirrigation system may prove a wise economical decision. Similarly, given the possible gains in crop quality, the alleviation of nursery noncompliance with water usage restrictions during dry periods, and increasing water quality legislation make the implementation of a subirrigation system an intelligent and timely decision.

## SUMMARY

Nursery managers require the most effective and efficient cultural practices available in order to produce uniform, high-quality stock for their customers while addressing public concern about, and increasing government regulations on, sustainability and environmental contamination. Subirrigating crops provides several proven advantages over the standard overhead irrigation systems used at most forest and conservation nurseries, specifically reduced water use, less labor inputs, improved fertilizer efficiency, decreased liverwort and moss growth, and greater crop uniformity. Subirrigation systems range from simple low-tech applications to high-tech, automated ones. Innovative nursery managers can probably fabricate their own systems, or they can seek the expertise of companies that offer a wide variety of quality subirrigation products to customize and integrate subirrigation systems into existing nursery infrastructures. Although not yet widely used at forest and conservation nurseries, more trials and demonstrations, particularly by growers, will likely lead to discovery of additional benefits and increase the use of subirrigation. Our environment as well as our nursery crops stand to benefit from increased use of subirrigation, because contamination is minimized and crop quality is enhanced by this system. With worldwide expansions in forest certification, more forest industries going “green,” and increasing demand for native plants for myriad reasons, nurseries using subirrigation can market their efforts to minimize their environmental footprint and to improve their sustainability.

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