# Examples of Using Subirrigation Systems for Both Growing and Storing Seedlings

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## Abstract

Subirrigation systems offer a water-efficient alternative to the industry standard of overhead irrigation. These systems can be used in growing environments, as well as during storage of overwintered seedlings. This article offers examples for using subirrigation in both the growing and storage environments. Additionally, detailed instructions are provided for creating a subirrigation tank to fit any nursery need.

## Introduction

Efficient water resource management is of increasing importance to industrial systems. Thus, it is critical to continually develop industrial systems that are more efficient in water usage (Ridoutt and Pfister 2010, Smakhtin 2008). Forest nurseries represent one of these industry systems, producing seedlings for both commercial and restoration purposes. With containerized nurseries producing more than 500 million seedlings in the United States alone (Hernández et al. 2017), an opportunity exists to make significant reductions of water usage in this industry.

Nearly all containerized nurseries use overhead irrigation systems for both irrigation and fertilization (Landis et al. 1989, Leskovar 1998). The efficiency of this system is poor, with a range of only 57 to 70 percent of irrigation water actually reaching the substrate surface (Beeson and Knox 1991). Additionally, overhead systems do not uniformly irrigate individual cells as a result of differences in spray patterns and interception from plant foliage, especially with broad-leaved plants (Dumroese et al. 2007). Moreover, water that is intercepted by foliage is prone to spreading foliar diseases (Oh and Kim 1998). These negative outcomes of overhead irrigation systems have created a need to explore alternative irrigation methods.

Subirrigation is one such system that offers opportunities to increase water use efficiency. The first documented subirrigation system was through an 1895 Ohio Experimental Station bulletin (Green and Green 1895). Since the description of this first system, a variety of subirrigation systems have been developed, such as ebb-and-flow benches, flood-floor, trough-tray, wick system, mobile or Dutch trays, and capillary mat (Ferrarezi et al. 2015, Landis and Wilkinson 2004). However, all use the same basic principle of watering plants from below using a combination of atmospheric air pressure on the water source and capillary action inside the container medium to saturate the medium.

Water use is significantly reduced in a subirrigation system compared with overhead irrigation systems. For example, Dumroese et al. (2006) found that subirrigation systems used only 44 percent of the water that conventional overhead irrigation systems use. Additionally, they found that subirrigation systems reduced moss growth 33 percent and eliminated nitrogen leaching from the media (based on controlled-released fertilizer incorporated into the medium). With respect to plant performance, subirrigated plants have been shown to be morphologically similar or superior to those receiving overhead irrigation (Davis et al. 2008, Dumroese et al. 2006, 2007, Landis et al. 2006, Schmal et al. 2011).

This article describes examples of subirrigation systems used in a growing and a storage environment. The examples are based on a medium-sized nursery at the John T. Harrington Forestry Research Center (JTH FRC) with New Mexico State University in Mora, NM.

## Growing Environments Using Subirrigation

Subirrigation systems can be employed across the spectrum of growing environments, each with unique advantages and difficulties. Most fully enclosed traditional greenhouses could be readily adapted to use either benchtop subirrigation tables or ground-based subirrigation tanks. A high degree of climate control in a greenhouse, moreover, allows for year-round production and avoids the potential for seedling damage due to harsh weather events (Landis et al. 1992). Advantages to using subirrigation compared with overhead irrigation in a fully enclosed greenhouse environment may include improved water-use efficiency, improved nutrient-use efficiency, improved irrigation control and uniformity, and reduction of foliar diseases and insects. Potential disadvantages to using subirrigation compared with overhead irrigation in a fully enclosed greenhouse environment may include increased concentrations of soluble salts in the upper portion of the plug (potentially requiring periodic flushing via overhead irrigation), the need to monitor dissolved solute concentrations in plugs, fewer opportunities for evaporative cooling of seedlings during the hot summer months, the potential difficulty of retrofitting greenhouse plumbing to accommodate a new irrigation method, and potentially increased transmission of root diseases via shared irrigation water.

Subirrigation systems have also been successfully employed in open-air growing environments (Davis et al. 2011). When used in open-air growing environments, subirrigation still offers advantages in improved water-use efficiency and improved nutrient-use efficiency and potential disadvantages in increased soluble salt concentrations and fewer opportunities for evaporative cooling of seedlings during the hot summer months. In an open-air growing environment, seedlings are still subject to potentially damaging or lethal weather events, such as heavy rains, hail storms, and high winds. Pathogen transmission is largely unrestricted in such growing environments, with inoculum moving between the aboveground portion of plants by wind and rain splashes, while moving between root systems through shared irrigation water. Additionally, the growing season of open-air growing environments will always be limited by the local climate (i.e., the system can only be used seasonally unless used in subtropical or tropical climates). Open-air growing environments, however, have the advantage of having little to no energy cost associated with the operation.

Partial greenhouses or shelterhouses present a versatile hybrid between the traditional fully enclosed greenhouse and the open-air growing environment (figure 1). A partial greenhouse may consist of a greenhouse roof and frame with detachable or retractable walls rather than fixed, permanent walls. When combined with subirrigation tanks, a partial greenhouse system offers all the advantages described previously for a fully enclosed greenhouse, with the additional advantage of natural ventilation during summer to eliminate energy costs associated with cooling a greenhouse. Although a partial greenhouse growing environment cannot efficiently support winter production in most climates, its retractable walls can still appreciably lengthen the growing period in most climates by being closed to retain heat or opened to promote cooling as needed (Landis et al. 1994). In addition to serving as a primary growing environment, partial greenhouses equipped for subirrigation can serve as a transition area in which to acclimate seedlings between production in a fully enclosed greenhouse to an open air growing environment or outplanting.

### Example: Subirrigation Growing Environment

At the JTH FRC, seedling production begins within a fully enclosed, climate-controlled greenhouse using overhead irrigation. Seeds are sown into Ray Leach "Cone-tainer"™ SC10 (Stuewe and Sons, Tangent, OR) containers and then misted for 3 to 5 minutes at an interval of five times a day. Approximately 5 weeks after germination (depending on the species), seedlings are moved to the subirrigation structure. This structure is roofed with retractable walls (figure 1). Inside the structure are 19 subirrigation tanks at ground level that can hold 56 SC10 racks each (5,488 seedlings per tank based on SC10s). The roof provides protection to the seedling crop from potentially damaging rain and hail events. The retractable walls are lowered during these precipitation events, as well as during periods of cold (cloudy days and at night). The roof collects rainwater that can be used for as an irrigation source in the greenhouse (filtered and sterilized) or any other location.

The subirrigation tanks take about 20 minutes to fill, after which containers are irrigated or "soaked" for 10 min. Once complete, the water is drained from the tank into a catchment pond that is used for irri-

**Figure 1.** Partially enclosed (roof and retractable walls) greenhouse using a subirrigation system. (Photo by Tammy Parsons, 2015)

gation and fertilization of riparian tree species used for rooted cuttings. If desired, however, this drained irrigation water could be collected in additional tanks after filtration and sterilization for future use. Methods for reusing subirrigation water with containerized seedlings have not been fully developed and require additional research. Fertilization is applied via the subirrigation water (i.e., fertigation). Overhead risers are installed on each tank to flush the containers from the buildup of soluble salts via fertigation and reduce electrical conductivity. Certain species can tolerate these increases in fertilizer salts. To err on the side of being safe, however, flushing occurs once a month for most species.

Exposure to the outdoor environment enables plant material to acclimate to the natural growing environment. As the season progresses into fall, temperature and light begin to decline. To speed the hardening-off process, shade cloth is installed on wires that span all sections of the growing structure. Seedlings can be lifted for planting while still actively growing (i.e., hot planting) or continue to dormancy for either planting or storage.

## Storage Environment Using Subirrigation

When plants produced in the nursery have reached outplanting size but cannot be outplanted immediately, they must be stored or overwintered. Successful storage requires careful planning to avoid cold injury to the seedling and limit moisture stress and consumption of stored carbohydrates during the storage period. Although all storage methods result in net carbohydrate loss because of continued respiration and metabolic activity, not all methods are equally effective at limiting those processes and maintaining long-term seedling viability. The best storage methods eliminate light and reduce temperature within the storage space, either within a freezer at 28 °F (-2.2 °C) or in a walk-in cooler at 34 °F (1.1 °C). These two systems provide the added benefit of requiring little to no water inputs during the storage period. Despite their effectiveness and the elimination of water demands, the cost of constructing and running freezers and walk-in coolers can be prohibitive.

The most economical method for both small- and large-scale storage that gives the grower some control over the storage environment is to employ a shade house or cold frame (Landis and Luna 2009). This control is largely confined to control over light levels and buffering of daytime temperatures. Daytime temperatures are buffered because of reduced solar radiation but nighttime temperatures are largely unaffected and can result in potentially damaging nighttime temperatures, because the porous shade cloth likely does little to reduce radiative cooling at night (Ghosal et al. 2003). Fluctuations in temperatures affect plant dormancy, especially toward the end of the storage period when warm spring weather can trigger an end to dormancy before optimal outplanting times. A permeable roof can result in a storage environment that is too dry (e.g., in arid regions with low relative humidity) or too wet (e.g., in humid regions where rain can enter).

Control over temperature fluctuations can be improved by adding liners to the shade house (Perry 1990), effectively creating a modified cold-frame environment with reduced light levels, and using heaters to increase temperatures during extreme weather. A pilot trial was performed at the JTH FRC in the winter of 2015 to examine temperature fluctuations for four environments: (1) double wall plastic, (2) shade cloth

+ double wall plastic, (3) reflective material + double wall plastic, and (4) no liner control. Temperatures were measured using Thermochron iButtons (Maxim/Dallas, Dallas, TX). This trial showed that adding plastic lining as a double layer and using a fan to maintain a layer of air between the plastic liners can provide a buffer against both daytime and nighttime temperatures (figure 2). The use of a reflective barrier outside the double plastic liner can increase the reflectance of the structure, thereby reducing conductance of heat and concurrently creating a fully dark environment within the storage area.

Nevertheless, these improvements for overwintering in a cold frame do not eliminate the need for occasional water inputs to the stored plants. Especially true for evergreens, the plants will continue to transpire during the storage period. Overhead irrigation, in addition to inefficiently providing water to the seedling, can lead to proliferation of fungal pathogens and storage molds, such as Botrytis cinerea, on the leaves wetted in the process of providing water to the root system. A subirrigation system, consequently, is preferable to effectively and efficiently provide water directly to the roots of the stored seedlings. When combined with a fan system, the seedling's water demands are satisfied without creating an environment where pathogens can flourish.

## Example: Subirrigation Storage Environment

The storage facility at the JTH FRC is a modified cold frame (figure 3) to overwinter more than 60,000 seedlings. This facility is an excellent alternative to using the more expensive walk-in cooler or freezer for overwintering. The structure consists of a hoop house design with a roof made of a double-walled plastic liner filled with air via a small air pump. This double plastic layer provides insulation for the structure. The heating source is a propane heater connected to a flexible convection tube. Cooling is accomplished using a large, external fan to draw outside air into the structure. Additionally, the side walls are made of corrugated polycarbonate panels. The last element to ensure minimal temperature fluctuation is an EcoFoil solid radiant barrier (EcoFoil, Urbana, IL) placed over both the side walls and roof. This radiant barrier eliminates most light and reflects 96 percent of radiant heat.

The internal environment does not completely eliminate plant respiration, transpiration, metabolic activity, and water loss from the media due to evaporation. As a result, the inside structure includes subirrigation tanks as described previously and in the next section. These tanks are used to irrigate seedlings when growing medium reaches a predefined maximum dry down level. Conifer seedlings are irrigated once a month on average. Deciduous

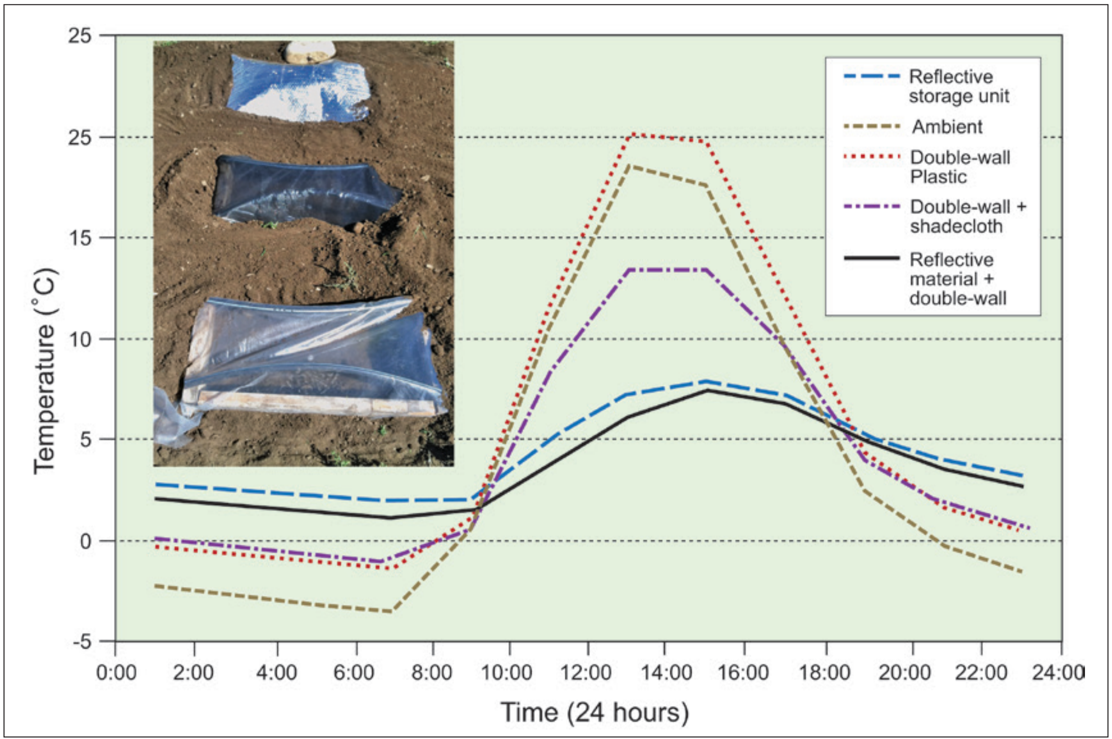


**Figure 2.** Average hourly temperatures (December–March 2014) of the operational reflective storage unit at the John T. Harrington Forestry Research Center, ambient outside temperature, and three test units (double wall plastic, shade cloth + double wall plastic, and reflective material + double wall plastic). The inset photo shows examples of the three test units (double wall plastic, shade cloth + double wall plastic, and reflective material + double wall plastic from top to bottom). (Photo by Owen Burney, 2013)

**Figure 3.** Modified cold frame using EcoFoil radiant barrier during winter at the John T. Harrington Forestry Research Center in Mora, NM. (Photo by Owen Burney, 2013)

seedlings require less water and are irrigated every other month while in storage.

## Constructing a Commercial Subirrigation System

This section describes the process for building a wooden tank structure with a pond liner designed to hold container racks or styroblock containers for the purpose of subirrigation (figure 4).

The 16-ft by 8-ft (5-m by 2.5-m) tank described here is designed to accommodate the Ray Leach Cone-tainer™ SC10 racks with 56 racks per tank. This configuration allows for air space every few rows so air can travel between racks to prevent moisture from collecting on the bottom of the tank. Tank size can be adjusted to meet requirements of containers, space available, or both. The tanks must be sloped so they can drain after each irrigation.

[Conversions: 1 in = 2.54 cm; 1 ft = 30.48 cm]

**1. Framework assembly—**

a. The frame of the subirrigation tank is built like the subfloor of a house (figure 5).

b. To assemble the frame, cut two 2-in by 12-in by 8-ft treated boards to exactly 8 ft in length, these boards will be the two side rims. Use two 2-in by 12-in by 16-ft treated boards for the length.

c. Assemble the four rims into a box shape by securing the corners with four 3-in decking screws in each corner. Make sure the 8-ft boards are inside of the longer boards. Square the box up.

**1. Joist assembly—**

a. Joists are secured to a rim board, and a 0.75-in oriented strand board (OSB) decking is attached to the joists for the floor.

b. Because the floor must have a slope for drainage, the joists need to be cut to create an angle in the floor.

c. Take a 2-in by 8-in by 8-ft treated board and rip from 3.25-in to 2.25-in wide to obtain a minimum ⅛ in per 1-ft slope for drainage (figures 4 and 5).

d. Using a 2-in by 8-in board will enable you to get two joists from each board. Attach the joists to the long rim boards.

e. Start by attaching one joist to the 8-ft side rim and at 16-in on center across the length. Make sure the ripped sides of the joists are facing up and that all the joists are angled the same direction.

f. Attach joists to the rim with 2-in to 3-in decking screws in each end. The high side of the joists should be about 8 in down from the top edge of the rim, and the low side should be about 9 in down.

g. A joist should be attached to each side rim, as well as to support the floor decking.

**2. Flooring and predrainage assembly—**

a. Set the bench in its permanent location and make sure all four sides are level so the slope will drain properly. Setting the box on level concrete blocks for support is a good method. You will need to have access to where the drain will exit from underneath.

b. Install a block to support the drain assembly between two joists on the low side.

c. Three drains are installed on the 16-ft tank (figures 4 and 6). A 1-in by 6-in board planed down to approximately 0.5-in thick is used as the block attached up against the long rim and even with the top edge of the joists. Attach blocks using decking screws going through the joists into the ends of the blocks.

d. Install 4-ft by 8-ft by 0.75-in OSB sheets on top of the joists and attach with 1½-in decking screws every 12 in. Make sure the screws are set and not sticking above the surface.

e. At the location of each drain block and approximately 2 in from the rim joist, use a 3-in hole saw to drill only through the OSB layer—do not drill through the support block (figure 6).

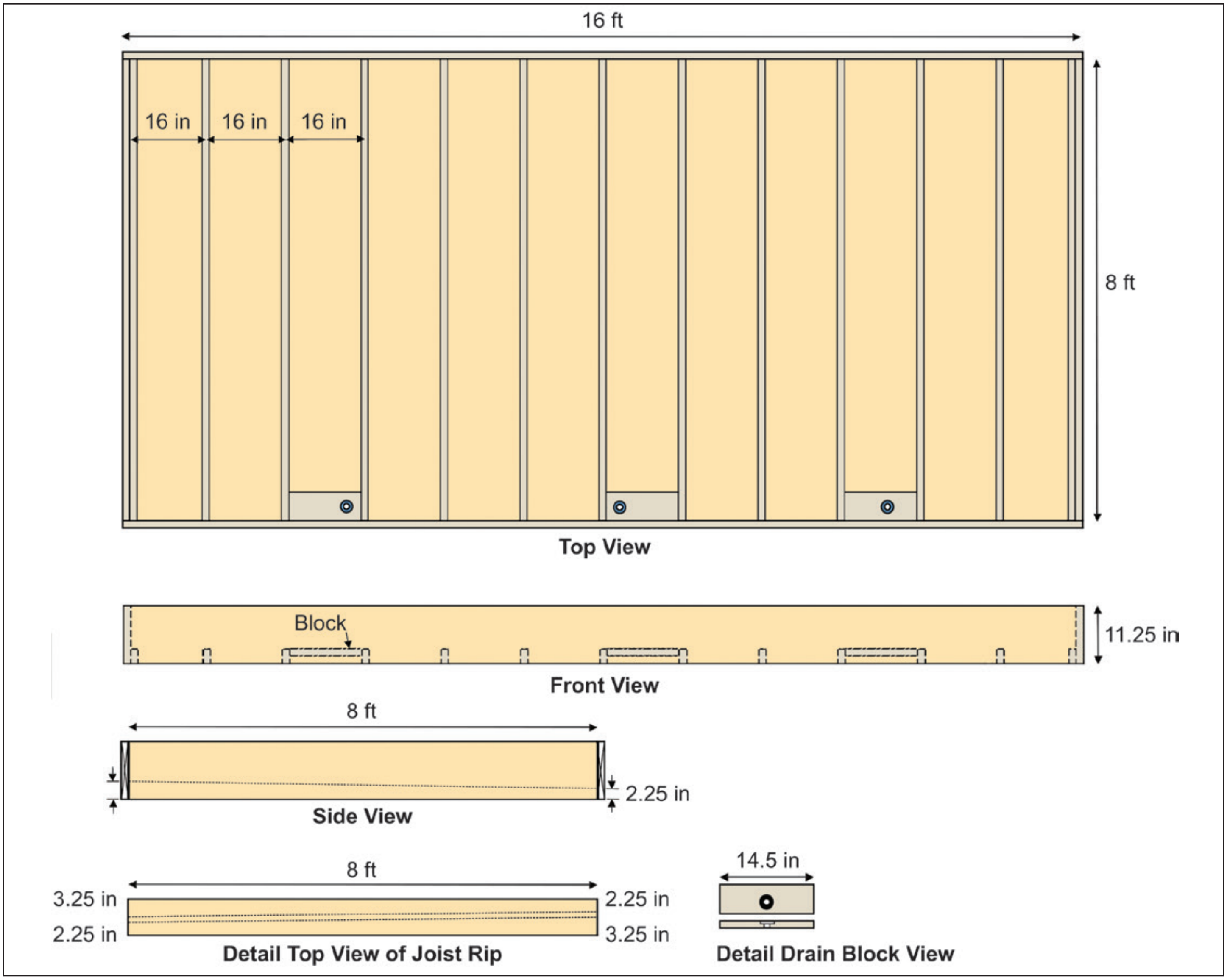


**Figure 4.** Schematic used at John T. Harrington Forestry Research Center to construct a 16 ft by 8 ft subirrigation tank designed to hold 56 racks of Ray Leach "Cone-tainer"™ SC10s

f. Change to a 2.25-in hole saw and drill through the support block.

**1.Tank liner assembly—**

a. Install the rubber pond liner—45-mil, 10-ft wide EPDM Pondgard (ethylene propylene diene monomer rubber). Make sure the inside of the box is clean so nothing will damage the liner.

b. Cut the length of the liner approximately 2 ft longer than the length of the tank (i.e.,10-ft wide by 18-ft length).

c. Roll the liner out and smooth into the bottom and up the sides of the tank. There should be 1 ft of liner to go up and over the edges on all sides.

d. Tuck the liner into the bottom and corners as tightly as possible. Fold up and over the top edge of the rim boards and secure with 2- by 6-in fence brackets by clipping onto the top edges of the rim boards.

**2. Final drainage assembly—**

a. Install the drain assembly using a 1-in heavy duty polypropylene tank fitting, 2.25-in hole size (figures 4 and 6).

b. Find the center of the drain hole in the OSB and carefully cut a small hole (approximately 1.25 in diameter) through the rubber liner.

c. Carefully push the drain assembly through the liner and hole in block with the rubber washer between the drain top flange and the liner. Make sure the liner does not tear. It should stretch around drain. Push down until the top flange is set into the recessed hole (the top of the drain should be flush with the tank floor).

**Figure 5.** Subirrigation frame and flooring during installation process at the John T. Harrington Forestry Research Center in Mora, NM. (Photo by Tammy Parsons, 2015)

d. Attach securely from the underside with the polyvinyl chloride (PVC) nut provided with the drain assembly.

Connecting the drain system will vary depending on the location of the tanks. The threaded drain assembly allows for an elbow to be attached at the bottom of the drain and then longer lengths of plastic pipe may be attached to carry water to a drainage area. Tanks can be drained using gravity or a pump. The tanks can be filled with a hose or a PVC pipe with a down spout. Irrigation can be automated and connected to injectors to regulate water pH and to apply fertilizer.

**Figure 6.** Drain assembly for subirrigation tank using a 1-in heavy duty polypropylene tank fitting with a 2.25-in hole size. (Photo by Tammy Parsons, 2015)

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