Ball Redbook 2021 – Subirrigation

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What is Subirrigation?

Subirrigation is a method used in horticulture which relies on capillary action to deliver water and nutrients to the plant root zone from the bottom of their containers. This approach improves sustainability and is environmentally responsible as it maximizes water reuse with no runoff.

Subirrigation has many styles commonly including benches, troughs, and floors. It also has alternative names including ebb-and-flood, ebb-and-flow, flood/flow/cascade floors, flood benches and gutter/trough irrigation.

Subirrigation relies on different water movement in the potted media than overhead watering with considerable impact on growing practices and results.

Table 5-10: Subirrigation vs. Overhead Irrigation

	Subirrigation	Overhead
Water distribution	To bottom of container	To top of potted media
Water movement	Up	Down
Water uptake	Capillary action	Downward seepage
Watering volume	Less	More
Substrate pores	Smaller pores filled with water	All pores temporarily filled risking oxygen starvation
Leaching	None but may lead to salt accumulation when over-fertilizing	Excess water leaches. Wasteful but can be used to manage salt content
Disease transfer through watering	Possible but rare	Through splashing

How Does Subirrigation Work?

The two basic types of systems are flooding and flowing. In flooded systems (such as trays or floors), the plants are placed on contained surfaces which temporarily fill with a fixed amount of water that is pumped from a storage tank. After the desired water depth is reached (commonly between ½” (13mm) to 2” (51mm)), water is immediately drained. While one zone drains, another zone fills. This allows large areas to be watered in a short period of time (such as several acres per hour) while conserving water.

In flowing systems (such as troughs or floors), plants sit on a positively sloped contained surface while water is delivered to the high point and flows downward in a continuous uniform thin stream. When the desired watering is achieved, flow is stopped, and watering of another zone begins. Like the flooding method, large areas can be watered in a short period of time.

[5-09 photo of flood floor]
Figure 5-9. Concrete flood floors serve as a bench, heat, and irrigation system all in one. Shown here is a flood floor partially filled with plants.

It is generally accepted that plants may intake up to 90% of their water-holding capacity within the first two minutes of subirrigating. Consequently, an average water exposure time of six to ten minutes per zone allows containers to reach full capacity resulting in uniform watering of the crop.

Managing irrigation cycle time is critical to prevent oversoaking. It is important to drain excess irrigation water during plant uptake to minimize potential for pathogen infiltration and distribution. Also, faster irrigation cycles improve control of nutrient uptake.

Water Storage

Irrigation water is most effectively stored in closed containers such as reservoirs or tanks. Closed containers protect the water from outside contaminants while minimizing evaporation. Filling an irrigation zone requires large amounts of water supplied in a short time commonly ranging from 50 gallons per minute (189 liters per minute) to 1500 gallons per minute (5678 liters per minute). Most plants intake 5% to 25% of the water delivered to the zone. The remaining water drains back to the storage tanks to be filtered and recycled to another zone. Most subirrigation systems are designed with two to four tanks, each containing different solutions which can be selected according to the crops needs.

Tanks can be installed above or below grade. Above grade tanks typically have a lower installed cost and are advantageous where there is high groundwater or when local soils are not cost effective to remove. These tanks are best located in a heated or insulated area to limit heat loss and prevent freezing. Smaller tanks are commonly molded plastic while larger tanks are often constructed from corrugated steel panels with plastic liners (that must be handled with care when cleaning).

Below grade tanks usually have a higher installation cost but have several advantages. Irrigation water can return to the tanks by gravity which saves energy because no pumps are required to transfer the water. During a power outage, crops will not oversoak as the growing surfaces are still able to drain. The unoccupied space above the tanks can be utilized. Small below-grade tanks are often precast concrete or plastic in contrast to larger below-grade tanks which are typically cast-in-place concrete.

[5-10 photo of above-grade subirrigation tank system]
Figure 5-10. Subirrigation systems may require above-grade storage tanks to hold the system's irrigation water.

[5-11 photo of below-grade subirrigation tank system]
Figure 5-11. Below-grade storage tanks require considerable excavation and formwork during construction.

Recycling Water

Water is fully recirculated between the storage tanks and contained irrigation zones. Water is filtered prior to returning to the storage tanks. Gravity filters (such as cascade filters, roll-media filters, and drum filters) can handle large volumes of water containing some plant growing media (which has a tendency to clog up most other types of filters). This type of filtration can handle particulate as small as 5 microns and is the standard of care in mid-size to large greenhouses. It has proved to sufficiently protect crops from disease in addition to effectively manage water quality.

Water sanitation may be required for susceptible crops or specialized research facilities. High water flow rates of subirrigation systems make fine filtration, UV, ozone, heat pasteurization, and other water treatment systems rather costly. An economical option is to batch treat the water at reduced flow rates at the end of a multi-zone irrigation cycle. This may not eliminate the possibility of contamination as sanitation will not occur during the irrigation of each individual zone, but it does prevent accumulation of pathogens in the system. Hydrogen peroxide, chlorination, and copper ionization, (etc.), are common treatment options but require careful monitoring to be effective and safe. There are also methods to mitigate the development of plant pathogens and algae using aeration or oxygen infusion which helps prevent the water from becoming anaerobic.

Replenishing Water

Because subirrigation systems are recirculating, returning water to the storage tanks decreases as plants take-up water. As a result, stored irrigation water should be replenished. Tank capacity should be able to contain and manage a full irrigation cycle.

There are two basic approaches to manage nutrient concentration and pH of irrigation water:

1. Supply a fixed fertilizer mix solution to each tank. This may be appropriate for systems with short watering times, as the return water may be nearly unchanged from its initial mix concentration and risk of dilution is minimal. It is appropriate to use computer-controlled systems to deliver different recipes on demand where multiple recipe tanks exist.
2. Maintain a fixed fertilizer concentration (which is measured by the water's electrical conductivity or EC) and pH within each tank. For systems with longer watering times, return irrigation water may significantly change from its original concentration. To avoid dilution, additional fertilizer mix must be added to the solution to maintain a constant nutrient concentration. This can be achieved by monitoring EC and pH levels within each tank and injecting a variable mix (as needed) to balance the concentration.

Where concrete storage tanks are used, extra care in monitoring pH levels is necessary due to the presence of lime in concrete.

Heat

Except for very warm climates, heating growing surfaces is essential for quick drying after irrigation and provides a dry microclimate in the foliage. Separate control over root and foliage temperatures provide important tools to control and enhance the growth of the crops. Floor heating is commonly in the slab. Bench heating is commonly on, in or under the bench. Trough heating is commonly under the trough.

Automation

Automation of subirrigation systems is an opportunity for the grower to improve control of their subirrigation system while increasing system efficiency and reducing the amount of labor required for monitoring. Simple control schemes may use preset timers and level control switches to turn irrigation systems on and off, allow phasing of irrigation cycles, help replenish irrigation water and warn of system overflows.

More complex control schemes can accommodate remote control of the entire irrigation system from a centralized location. System components may include a computer, local control panels, variable flow control to each irrigation zone (to accommodate a variety of crops), weather stations (to adjust irrigation cycling as a function of exterior climate), water quality monitoring, and automated fertilizer dosing (to name a few).

Automated systems can proactively adjust subirrigation system requirements in addition to reactively use system feedback to fine tune system set points. Because greenhouses can have fully automated climate control systems, it makes sense to take advantage of this and integrate subirrigation systems into this control scheme.

Growing Systems: Benches, Troughs, and Floors

Each growing system has unique subirrigation advantages and should be selected based on the grower's preferences and budget.

Fixed benches

These consist of a wood or metal frame that supports a plastic or aluminum pan with a depth up to 2" (51mm). Pans are typically flooded to a depth of 0.5" (13mm) to 1" (25mm). The bottom of the pan is usually grooved to promote drainage and reduce algae growth. Bench widths are commonly between 4' (1.2m) to 6' (1.8 m) or less for easy handling of the crop. Lengths of up to 100' (31 m) are common. Fixed benches are filled and drained from the bottom of the pans by pipes or hoses that connect to irrigation mains and drains. These pipes run under the benches, overhead, or under the floor to avoid being an obstruction. Depending on the number and size of the benches, one or several benches are filled or drained at a time. Control valves (electrically operated solenoid valves, air-operated or manual/gravity operated) switch between fill and drain mode.

Rolling benches

Rolling benches or "moving-aisle" benches are like fixed benches; except they are able to laterally move a fixed distance to accommodate temporary access. Because they can move, they do not require a dedicated access aisle for each individual bench which increases the available growing space. Consequently, rolling benches require flexible plumbing connections to each bench.

[5-13 photo of rolling benches]

Figure 5-13. Rolling benches have a "moving- aisle" allowing maximum use of the growing area while providing temporary bench access as needed.

Container benches/mobile trays

This system uses smaller containers (or trays), usually 4' (1.2m) to 6' (1.8 m) wide and 12' (3.7m) to 20' (6.1m) long which reside on a system of conveyance tracks. They can be rolled throughout the greenhouse and can serve as a growing and transport system all in one. Since these containers or trays do not stay in a fixed location, fill and drain piping cannot be connected to them. Containers are filled from the top by network of distribution piping rigidly connected to the greenhouse structure. Containers drain into a system of fixed gutters that are rigidly attached to the conveyance track structure. Because of the usually large number of rolling benches in a system, they are typically filled and drained in larger groups.

[5-14 photo of containers]

Figure 5-14. Mobile trays are transported through the greenhouse on a series of conveyance tracks.

Trough/gutter systems

These come in similar configurations as benches. However instead of a flat bottom tray, the plants sit in mildly sloped narrow gutters. The irrigation water discharges at the upper end of the gutter and drains to the lower end. A thin stream of water moves across the bottom of the pots along the way. Growers cite the vertical airflow between the gutters and a reduced risk of oversoaking as advantages. Although these systems limit the sizes of containers that can be grown, usually they are optimized for potted crops.

[5-15 photo of troughs]

Figure 5-15. Troughs are limited in container sizes but have a variety of advantages

Flood floors

Plants are grown on concrete floors which are typically flooded to a depth of 0.5" (13mm) to 2" (51mcm). Flexible rubber water barriers along the perimeter contain the water while allowing free movement of people and carts across the floors in any direction. The watering sections usually correspond with the greenhouse bays, typically 1000 square feet (92 square meters) to 6000' (557 square meters). Smaller sections allow more flexibility with crop spacing and location, while larger sections allow faster watering of large areas but also require larger tanks, pumps, and piping.

The floors are pitched from the edge to the center at approximately 0.5% slope. This is just enough to allow puddle-fee drainage while minimizing water depth profile. Depending on the width of the bay, a single "V" or a "W" profile shape is customary. Multiple smaller "V" shapes will make a flatter floor, which is especially desirable for small pots and for bedding flats. A flatter floor means less water depth is needed to give all plants a full watering and helps prevent potential oversoaking of plants at the lowest floor elevation. Also, distribution piping can be smaller. Studies have been performed at the Connecticut Agricultural Experiment Station (Hamden, Connecticut) confirming the effectiveness of a multi-"V" floor in contrast to a single "V" floor.

At the bottom of each "V", a pipe (typically PVC) runs immediately under the floor. Typically, holes are drilled through the concrete into the pipe to allow filling and draining. It is critical that the subsurface piping be encased in concrete and anchored to the floor slab in addition to having a positive seal be maintained between the pipe and floor to prevent leakage under the slab.

Each floor is connected to the irrigation water storage tank system with a main fill and a main drain line. For larger commercial greenhouses, pipe sizes typically range from 4" (102mm) to 15" (381mm), allowing flow rates ranging from 300 gallons per minute (1136 liters per minute) to 1500 gallons per minute (5678 liters per minute).

Pouring a good concrete flood floor requires skilled installers with precision equipment (typically used in installing "super flat" floors) and an attention to detail. The surface of the floor should be a very smooth ("hard finish") for fast drying, free of cracks and resistant to corrosion from fertilizers. Once the concrete is poured, the transmission and distribution pipes become inaccessible, so proper engineering and installation of the system's plumbing is essential if the system is to perform as expected.

Flow/cascade floors

Flow or cascade floors are a relatively new subirrigation alternative to traditional flood floors. They have the same growing area advantages to flood floor systems. However, the primary difference between flow floors and flood floors is the transport of water across the floor in contrast to the more traditional fill and drain approach.

Plants are placed on a precision sloped concrete floor and are irrigated by a constant thin stream of evenly distributed water which travels from the high end of the floor to the low end of the floor (typically widthwise across the bay). Water uptake occurs by capillary action until the irrigation water is shut off. The remaining water is recycled during the process. Flow floors can handle large and small scale growing given the containers are able to accept the flow of water from the floor.

Like a traditional flood floor, flow floor irrigation cycle time ranges between 6 to 10 minutes to ensure the plants are watered sufficiently. Flow floors require constant pump run time to irrigate in contrast to a traditional flood floor that only requires the pump to run during the fill cycle. The remaining irrigation water returns to the storage reservoirs and is available for reuse before the irrigation cycle is complete. Flow floors tend to have a lower installed cost than flood floors as water is recycled back to each floor during each irrigation cycle. This reduces the required storage tank volume, eliminates the need for drainage valves at each floor and may reduce subsurface distribution piping.

Which Subirrigation System is most appropriate?

Flood bench and gutter/trough systems

- Practical where plants need to be at working height.
- Small irrigation units adapt to small batches of varied crops.
- With benches and troughs, plants are typically transported by hand (unless a monorail or conveyor system is installed).
- Container benches are a fast and flexible transport system.
- Maintenance can be higher as more equipment and hardware is used.
- Life expectancy before major renovation needs is approximately ten to fifteen years.

Flood/flow/cascade floors

- Appropriate for large and small-scale growing. Various size containers with similar watering needs can be grown on the same floor section.
- Well suited for crops that do not require work (such as disbudding) during the growing period.
- Best use of greenhouse space, with maximum flexibility to adapt to a wide variety of crops.
- Handling plants on floor is cumbersome, but easy access allows for fast crop movement. Plant handling equipment, such as gantries, forklift attachments for spacing and transport, and conveyor carts, are used.
- Combines a bench system, an irrigation system, and a heating system all in one.
- Maintenance is low
- System life expectancy can be over twenty years.

Growing on Subirrigation Systems

Despite relatively high initial investment costs, subirrigation systems are attractive to growers because they work well for practically all potted crops and for most bedding plants. Watering is highly uniform; labor for watering is minimal; and flood floors (and benches, to a slightly lesser degree) allow great flexibility in crop spacing, choice of containers, and efficient use of space. (Gutter or trough systems can have additional limitations and require work to adjust gutter spacing.) Foliage does not get wet, so you have fewer problems with the spread of foliar diseases, reducing fungicide use. Pots of different sizes can be grown in the same watering zone since capillary uptake naturally regulates the uptake. Water recirculation saves fertilizer and water costs. Plus, full recirculation of the irrigation water means zero runoff, and growers are under increasing pressure to reduce or eliminate irrigation water discharge.

However, subirrigation systems have their own peculiarities to consider. With traditional flood floors and bench systems (but not with troughs, flow floors or multi "V" flood floors), each irrigation cycle is a full watering, so partial watering to hold back the crop does not work. But due to the even watering, crops can be allowed to dry out more between irrigation cycles before the first plants suffer damage. Many, if not most growers combine subirrigation with an overhead system (such as booms or overhead sprinklers) for maximum flexibility. Potting mixes must promote good capillary action while maintaining air volume. Standard peat-lite mixes with a wide range of pore sizes work well, while a high bark content in a mix can restrict water uptake.

[5-16 photo of plants growing on a flood system]

Figure 5-16. With traditional flood subirrigation systems, every watering is a full watering so there is no way to "lightly water." That is why demand by growers has led to development of alternative watering *methods such as flow floors, troughs in addition to equipping their bays with boom irrigators for overhead watering.*

The Future

In the Netherlands, reportedly up to 80% of crops are grown on subirrigation. In North America, subirrigation systems are fast becoming the predominant mode of irrigation. Greenhouse operations continue to grow and level of automation. The initially high investment in subirrigation systems is recovered through labor savings, improved crop quality, and increased flexibility to adjust to fast-changing markets. Plus, with environmental concerns and regulations becoming a key issue for growers' long-term planning, recycling and zero runoff is insurance that will keep growers in business.