University of Kentucky
College of Agriculture,
Food and Environment
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Off the Grid: Ultra-low Pressure Drip Irrigation and Rainwater Catchment

for Small Plots and High Tunnels

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Under Pressure

All forms of irrigation need a push or pressure to move water from its source to its destination. Water sources include wells, springs, lakes, creeks, canals, rivers, cisterns, elevated tanks, or municipal water supplies. The amount of pressure or push required depends on many things including the height water must be lifted, length and size of the delivery pipe(s), crop and size of the area to be irrigated, and the distance water needs to be moved from the source to the field, greenhouse, or tunnel.

Pressure to move water and operate an irrigation system is created in several ways including all sorts of pumps. Pumps include diesel- or gasoline-fueled motorized pumps or electric pumps powered by an electricity grid, batteries, or directly from solar photovoltaic (PV) panels. Pumps vary greatly in size, power, pressure and capacity, so growers need to first estimate their crop size and water requirements and work backwards to determine power requirements, pump size and type.

Pressure can also be obtained by the weight of water itself and gravity-fed water delivery systems have been used in some parts of the world for centuries. Water creates pressure of 1 pound per square inch (1 psi or 0.068 atm) for every 2.3 feet (0.7 m) it is raised above the surface of the area to be watered or irrigated:

2.3 ft. elevated water = 1 psi

If, for example, we plan to irrigate from a pond that is on a hill so that the pond's water level is 25 feet above the field to be irrigated, water from the pond will have about 11 psi of pressure for irrigation (25 ft ÷ 2.3 ft/psi = 10.9 psi). And if a tank is filled to a level of 3 ft above the ground, that provides about 1.3 psi to irrigate a plot at ground level (3 ft ÷ 2.3 ft/psi = 1.3 psi). This is true regardless of tank size so that a 10-gallon tank with its water level at 3 ft will create the same pressure as a 500-gallon tank with its water level at 3 feet (**Figure 1**).

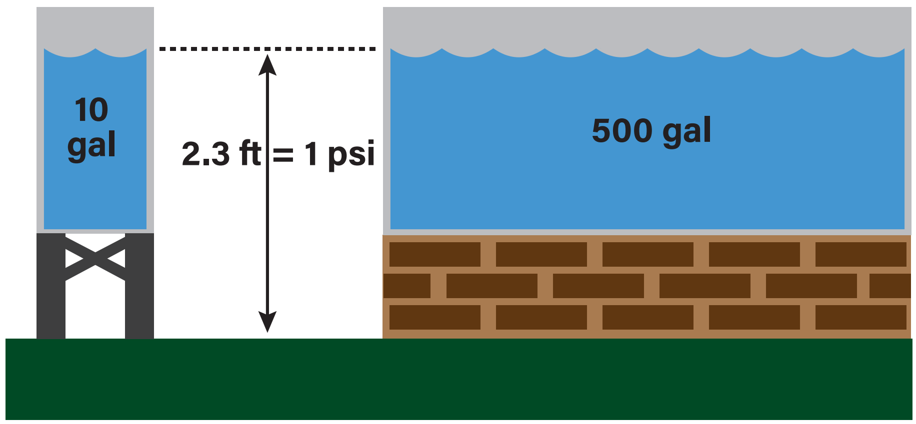

Figure 1. Large and small tanks at the same height will have the same pressure (about 1 psi in this example).

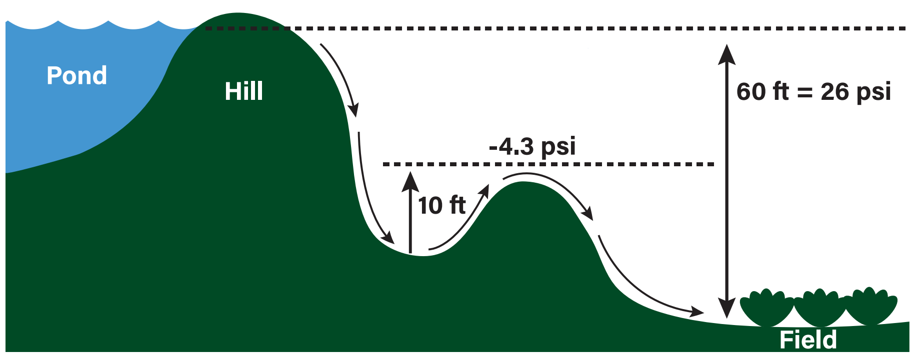

Figure 2. Gains and losses in pressure from a pond located above the field to be irrigated.

It is the elevation of the water column rather than capacity of the tank that determines pressure.

We use this simple principle when planning a pump-driven or gravity-fed irrigation system. Let's assume we are installing drip irrigation and our water source is a pond that is 60 feet higher than the field we want to irrigate (**Figure 2**). We can use pressure from the pond, which is equal to 26 psi (60 ft ÷ 2.3 ft/psi = 26 psi). But between the pond and field there is a small hill which rises 10 feet. This will reduce our 26 psi operating pressure by 4.3 psi (10 ft ÷2.3 ft/psi = 4.3 psi) so that our remaining available pressure at that point is 26 – 4.3 = 22 psi (**Figure 2**). That 4.3 psi of lost pressure from going up the small hill is regained, however, as the water descends again from the small hill to the field. This does not take into account additional pressure losses from a filter or pipe fittings, friction in the delivery pipes, etc.

Conversely, water pressure can be expressed as the height of a water column. If we know that a pump or a city water supply generates 30 psi of pressure, that's equivalent to water in a tank that's almost 70 feet above ground level (30 psi x 2.3 ft/psi = 69 ft). Pump manufacturers usually provide this information in the form of feet or meters of pressure or "head" generated.

Low and Ultra-low Pressures for Drip Irrigation

Manufacturers of drip irrigation tubing publish operating pressures for their products and commonly recommend pressures in the 8-15 psi range. This is equivalent to a water tank that is 18 to 34 feet high (8 psi x 2.3 ft/psi = 18 ft; 15 psi x 2.3 ft/psi = 34.5 ft). These are considered low pressures compared with pressures required for other forms of irrigation like sprinklers. The main advantage of using low pressure forms of irrigation is that less energy is required from pumps and therefore less fuel is required. Smaller pumps can be used including solar-powered pumps. In addition, less expensive thin-walled delivery pipes and simpler fittings can be used.

While 8-15 psi is considered the normal range for drip, some companies have tested their drip lines at pressures as low as 3 psi which is equivalent to water levels about 7 feet high. Extension workers in Asia, however, recently discovered that, if the system is designed correctly, commercial drip irrigation tubing (i.e., drip "tape" or drip laterals) will function well for small plots up to ¼ acre (10,890 sq. ft or 1012 sq. m) at "ultra-low" pressures of only 1 to 2 psi. This is equivalent to water levels in tanks that are only 2 to 5 ft above ground level (**Figure 3**). This reduces initial pump costs, pump operating costs, and the difficulty of elevating and supporting heavy water tanks[1].

In a project to develop simple, low-cost drip irrigation systems for small farmers in Southeast Asia, hundreds of field tests demonstrated that water could be applied uniformly on small plots up to a quarter-acre using elevated tanks and pressures of only 1 to 2 psi. Carefully controlled tests at the University of Kentucky in 2014 and in Colorado by Robert Yoder (Affordable Village Solar) and Ryan Weber (iDE[2]) confirmed that the uniformity of water application through commercial drip tubing[3] is not significantly reduced on small plots at pressures of 1 to 2 psi compared with a standard drip pressures of 8 to 12 psi. The application uniformity tests in Kentucky were carried out on an area equivalent to the size of a commercial high tunnel (70 ft x 18 ft) with a total of 210 drip emitters (three 70-ft laterals, **Figure 4**).

This has significant implications for designing gravity-fed and low energy drip systems here in the United States and in developing countries. The only caution with such low pressures is that the uniformity of watering can be reduced considerably by small changes in elevation within the field to be irrigated, so ultra-low pressure drip systems are most suited to level fields and high tunnels.

In a Ball Aerospace and University of Kentucky-assisted project in Gujarat,

Figure 3. A low tank used to irrigate a small high tunnel with rainwater.

Figure 4. Test setup for measuring uniformity of watering from drip irrigation with only 1 psi system pressure.

[1]One gallon of water weighs 8.34 lbs. (3.78 kg), so a 300-gallon (1136 liter) tank full of water will weigh well over a ton.

[2]International Development Enterprises, Denver, CO. https://www.ideglobal.org/

[3]Toro Aqua Traxx™ (Toro Irrigation, Bloomington, MN: www.toro.com) drip tape with 12-inch emitter spacing was tested at Univ. of Kentucky and Azud drip tape (Murcia, Spain: www.azud.com) was tested in Colorado.

India[4], low-powered DC solar pumps of about 1 hp were successfully combined with ultra-low pressure drip irrigation in 2014-15 (**Figure 5**). Ten pumps were installed on 10 different farms where each easily and uniformly irrigated an acre of commercial vegetables. In these systems the solar pumps raised water from open wells to tanks which were raised 5 ft (1.5 m or 2.2 psi) above the surface of the fields to be irrigated; crops were irrigated by gravity from the tanks.

The systems in India were designed in part based on thousands of ultra-low pressure drip systems installed on high value fruit, vegetable, and flower crops in Myanmar (Burma) from 2009 to 2014. Several similar but smaller systems have been installed in high tunnels in Kentucky and are described below.

[4]Project supported by Affordable Village Solar, Delhi, India: http://www.paulpolak.com/_slide/affordable-village-solar/

Figure 5. One-acre field in Gujarat, India, irrigated using a combination of a 1 hp solar-powered DC pump and ultra-low pressure drip from a gravity tank (background); system pressure was 2-3.5 psi.

Figure 6. Three "tote" tanks joined together to collect rainwater from a small outbuilding in Wilmore, Ky. The tanks have a total capacity of 825 gallons and are used to irrigate an adjacent vegetable garden and high tunnel.

Water for Free—Rainwater Collection

As climate change and irregular rainfall patterns affect more U.S. states and countries around the globe, rainwater collection and storage are becoming increasingly important. Surprising quantities of rainwater can be collected from a high tunnel, greenhouse, home, barn, or outbuilding. An inch of rainfall on a rooftop of only 500 square feet (about 20 ft x 25 ft, or 46 sq. m), for example, produces about 300 gallons of water, or:

1 inch rainfall from 1000 sq. ft rooftop = 600 gallons

A high tunnel that is 90 ft long and 30 ft wide (2,700 sq. ft) has the potential to capture 1620 gallons of water from each 1-inch rain. If a catchment system on the tunnel captures 90 percent of the first half-inch of rainfall, that results in about 730 gallons of water. It's obvious from these numbers that the limitation is usually not the amount of water from rainfall but the available water storage capacity in the form of tanks, cisterns, retention ponds, etc. (**Figure 6**). Collected rainwater should be considered a supplemental rather than the primary source of irrigation water.

Untreated rainwater collected from rooftops, high tunnels, or greenhouses should only be used with drip irrigation. It should not be used for washing produce, hand washing, drinking, or come into direct contact with edible portions of vegetables (i.e., sprinkling onto leafy greens, etc.).

Collecting Rainwater from High Tunnels

It is relatively simple to attach gutters to the sides of high tunnels to collect rainwater. While professionally-installed seamless guttering is recommended, it is also possible to install gutters yourself using simple tools and sectional gutters available at home improvement stores (**Figure 7**).

Regardless of who does the installation, you may need to attach a supplemental wooden board below the tunnel's "hip board" in order to support the gutter (**Figure 8**). The hip board alone may not provide enough attachment surface to allow adequate sloping of the gutter from one end to the other. Gutters should be sloped 6 to 8 inches per 100 feet of length. This slope can be marked on the board with a chalk line before installing the gutter and can be checked before final installation by pouring water in the gutter at the high end. Make sure that the outlet or low end of the gutter is at least a few inches above the top of the water collection tank.

The supplemental board can be as simple as a 2 x 6 or 2 x 4 installed with pipe straps and self-tapping screws that secure straps to the tunnel bows (**Figure 9a and b**). The supplemental support boards may need to be cut at a diagonal for mounting on Quonset style tunnels

Professional gutter mounting brackets like the ones shown in **Figure 10** are far superior to those sold with do-it-yourself gutter systems (**Figure 11**)--we learned this the hard way. Professional sealants like the one shown in **Figure 12** are also recommended and available from home and roofing supply companies.

(see the Iowa State University publication and video listed under **References**).

In the simplest systems, the ends of gutters are fitted with endcaps, downspout outlets, and short flexible downspouts leading to the opening in the top of the tank (**Figure 7**). A small section of gutter leaf guard or other screen can be cut out and placed over the downspout opening in the gutter to act as a simple removeable filter (**Figure 13**). If the end of the gutter is more than an inch or so above the tank it may also require a simple supporting structure like the one shown in **Figure 14**. This is a "quick and dirty" system and other more elegant arrangements can be made for handling overflow such as the floating ball valve used in a system developed at Iowa State University (see **References**).

Water Tanks and Fittings

Second-hand 275-gallon plastic "tote" tanks like those in **Figures 3** and **6** are available for $40-$100 and make good water storage tanks for small plots and tunnels. Some irrigation and tank dealers also sell outlet fittings designed for these tanks (**Figure 15**). You can also make your own outlet adapter using Fernco™ or similar flexible adapters (**Figure 16**). It is essential not to significantly reduce the tank's outlet diameter, which should be at least 1½ in. (inside diameter) if you are going to use low tank heights for ultra-low pressure drip.

Figure 7. While seamless gutters are preferred, sectional gutters sold in home improvement stores can also be used.

Figure 8. Hip board and gutter support board.

Figure 9a. Inside view of hip board and gutter support board.

Figure 9b. Bracket and self-tapping screw attach gutter support board to tunnel bows.

Figure 10. Professional grade gutter brackets.

While tote tanks usually have sufficiently large outlets, rain barrels and other tanks may come with a ¾-inch outlet that is usually too small for ultra-low pressure drip. In this case use a portable electric drill and hole saw to cut a larger opening for a bulkhead fitting. Bulkhead fittings (**Figure 17**), available in different sizes from irrigation dealers and tank suppliers, can also be used to make outlets in plastic tanks and barrels. When these are not available, inexpensive plastic fittings designed for electrical work (gray in color) can be used to make outlet fittings (**Figure 18**). These should be fitted with flat rubber washers or o-rings. Standard white PVC pipe fittings similar to the electrical fittings shown in **Figure 18** cannot be used because their tapered threads do not permit snug fits against tank walls.

Figure 11. Gutter brackets (not recommended) for use with do-it-yourself sectional gutters.

Figure 12. Professional grade gutter sealant.

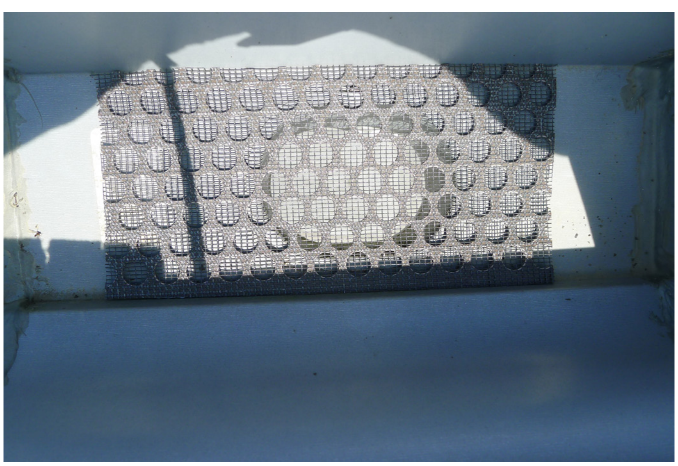

Figure 13. Small section of "gutter guard" used to filter debris at the gutter outlet.

Figure 14. Simple gutter support structure made from treated pine.

Water left standing in tanks for a week or more could harbor mosquitoes and should be treated with *Bacillus thuringiensis* (Bt) tablets or "dunks."

Components for Ultra-low Pressure Drip

While water pressure at the tank outlet may be sufficient for using gravity-fed low-pressure drip in high tunnels and small plots up to about ¼ acre (**Figure 19**), that pressure is easily lost by using delivery pipe and fittings that are too small. Pressure is also lost though filters commonly used for drip irrigation.

Besides using a large diameter tank outlet, it is important that large diameter delivery pipes are used from the outlet to the drip lines. One and a half-inch or larger layflat or polyethylene flexible pipe works well and drip line "take-off" connectors can be attached directly to these pipes (**Figure 20**). The large inside diameter of these pipes eliminates most pressure losses due to friction. Any bends, kinks, or sharp turns in the pipe also cause pressure losses, so these should be as few and as smooth as possible.

A main shut-off valve, usually a simple ball valve, is required at the tank outlet (**Figure 21**); some second-hand tote tanks come already fitted with a valve (**Figure 16**). This valve and any valves for irrigation zones should be about the same inside diameter as the delivery pipes.

Although screen or disc filters (**Figure 22**) are routinely used for drip irrigation at higher pressures, they cause significant pressure losses, and it's not possible to use a standard filter with ultra-low pressures of 1 psi or less (3.2 ft tank height). Large diameter screen filters worked well with

Figure 15. 1½-inch outlet fitting designed for a 275-gallon tote tank.

Figures 16a and 16b. Tote tanks with ball valves fitted to PVC pipe with Fernco™ couplings.

Almost all research and testing to date of ultra-low pressure drip has been with lateral lengths of 100 feet (30 m) or less and longer laterals are not recommended without additional uniformity testing. Use of ultra-low pressures and solar pumping is just beginning and improvements are possible; the authors welcome your feedback and suggestions.

ultra-low pressure drip in India with tank outlet heights as low as 3½ ft. Greater losses may occur with disc filters which have not yet been tested at these low pressures; it may not be possible to use ultra-low pressure drip with unfiltered surface water. Filter size should not be much smaller than the delivery pipe diameter.

Fortunately, it is possible to filter out most large particles using a simple screen in the gutter outlet (**Figure 13**) or tank inlet when collecting rainwater from high tunnels. Some settling of finer particles also occurs in the tank itself and tanks will need to be cleaned periodically.

We have used unfiltered rainwater with drip for two seasons in a high tunnel at the UK Horticulture Research Farm without significant clogging. Algae will grow in the tanks, however, if water is allowed to stand for more than a few days, and algae can result in clogging of drip lines. Long-handled brushes and mixture of a soapy water and a little bleach solution (about 1 part bleach to 8-10 parts water) can be used to clean the inside of the tanks (**Figure 23**).

Sun Power

While the system described below is still in its testing stages and can certainly be improved upon by new users, we have successfully used small, inexpensive solar-powered direct current (DC) pumps with drip in a few high tunnels in Kentucky. Even though gravity can pro-

Figure 17. 2-inch bulkhead fitting for water tanks.

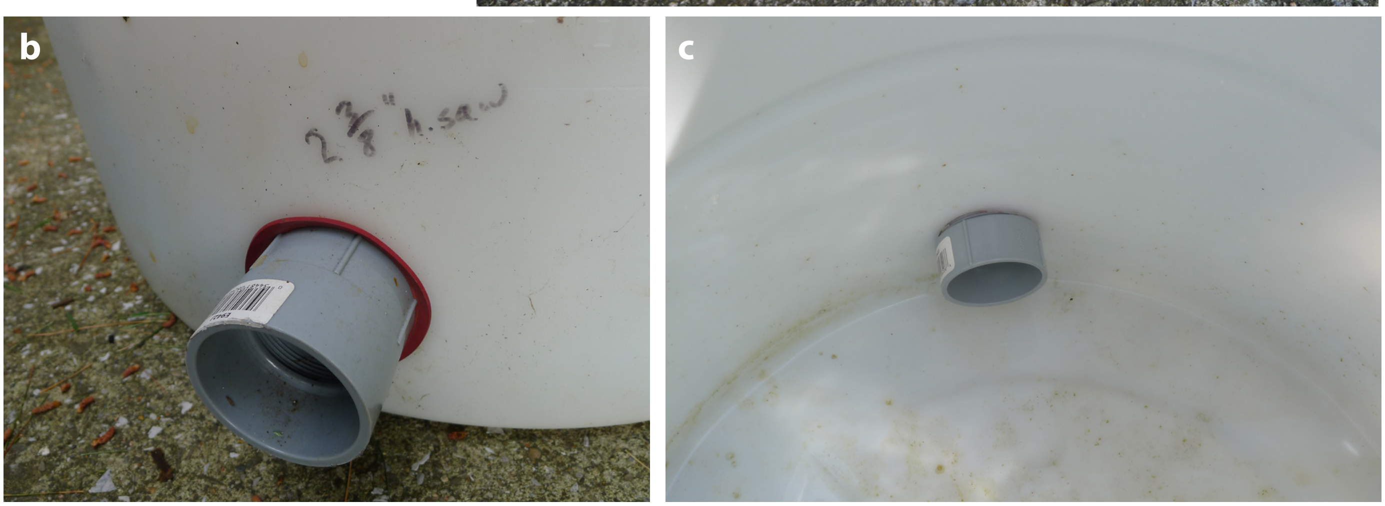

Figure 18a, b, c. Gray, 2-inch electrical conduit fittings (a) used to create a tank outlet which can be joined to standard white PVC pipe. A 2 3/8-inch hole saw was used to cut the hole in the tank (b). Different fittings are installed outside (b) and inside the tank (c).

vide sufficient pressure for drip when tanks are raised just a couple feet off the ground, there are cases when pumps must be used when tanks are on the ground and cannot be elevated. Sidewalls of high tunnels may be too low to use for rainwater catchment with an elevated tank (**Figure 24**). That said, however, one Kentucky grower discovered that gravity alone was sufficient to irrigate cut flowers uniformly with 10 drip lines in a 50-ft long tunnel when her ground tanks were at least half-full (**Figure 24**).

We installed an inexpensive (less than $200) solar pumping system to use together with ground tanks when water levels were too low to use gravity alone. This system consisted of a small 2-amp, 12 volt submersible bilge pump (for boats, **Figure 25**) coupled with a 9 amp-hour 12 volt battery, a 30 watt solar panel, and a small solar charge controller (**Figure 26**). Current (2017) costs for these components are shown in **Table 1**.

The solar panel simply keeps the battery charged while the battery powers the pump.[5] The controller is required to keep the panel from overcharging the battery in bright sunlight when power from the panel can exceed 19 volts.

We added an on-off switch, a 3-amp fuse, and placed the battery inside a cheap plastic "ammo box" which was mounted on a 4 x 4 treated post used for the solar panel

[5]While it is possible to use these pumps wired directly to the solar panel without a battery, this was not recommended by the manufacturer and may result in a much shorter service life of the pump.

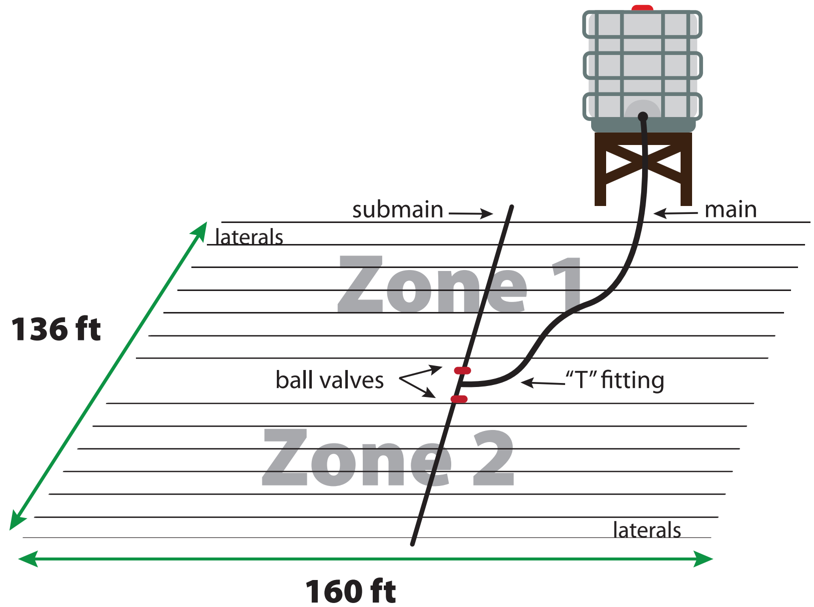

Figure 19. Larger plots up to an acre can be irrigated by dividing fields into ¼ acre zones using valves. A minimum height of 3 ft from the ground to the tank outlet and 2-inch diameter delivery pipe, valves, etc, are recommended for these larger plots.

Figure 20. Take-off connectors (with valves) for joining drip lines to a main or submain pipe.

Table 1. Costs for small solar pump & battery system for high tunnels

Rule™ 25S, 500 gallon per hour, 12-volt DC submersible bilge pump with automatic sensing	$65.00
12-volt 9 amp-hr sealed battery	$20.00
30 watt, 12-volt solar panel	$33.00
Morningstar Sunguard™ 4.5 amp 12V charge controller	$30.00
16-gauge landscape wire (10 ft @ $0.36/ft)	$3.60
waterproof wire nuts (6)	$2.50
3-amp fuse and fuse holder	$4.00
toggle switch	$8.55
plastic battery box ("ammo" box)	$5.00
4 x 4 x 8 ft treated post	$9.00
1/8 x 3/4 x 4 ft aluminum strip	$6.00
Total	**$186.65**

Figure 21. A main shut-off valve is required at the tank outlet.

Figure 22. Two-inch disc filter used for drip irrigation.

Figure 23. Cleaning a tote tank with detergent, chlorox, and a ceiling fan brush.

Figure 24. Tote tanks for rainwater collection from a high tunnel; the two tanks are joined by an underground PVC pipe. Drip lines in the tunnel are pressurized by gravity or the solar pump.

Figures 25a and 25b. Small 12-volt, 2 amp DC bilge pump used with a 12 volt battery and solar panel. The pump is attached to a scrap of Hardie™ board cut to fit inside the tank opening. Flexible marine bilge pump tubing is used as the pump's delivery pipe.

(**figures 24 and 27**). Several small holes were drilled into the bottom of the box to prevent rainwater accumulation, although this never became a problem. The fuse was wired between the battery and pump; we used 16-gauge outdoor lighting wire from the battery to the pump. Any exposed electrical connections were sealed with Liquid Tape™ and/or waterproof wire nuts.

The pump was attached to a piece of waterproof Hardie™ board which was cut small enough to fit through the opening on top of the tank (**Figure 25**). This board was attached to a 4-ft length of thin ¾-inch-wide flat aluminum stock available at home improvement stores. The aluminum strip could easily be fixed to the tank using a single bolt though a small hole drilled in the strip and lip of the tank opening (**Figure 28**).

Wires supplied with the pump had to be spliced and extended to reach the battery wires; these splices were soldered and then sealed (waterproofed) with shrink tubing and Liquid Tape™ (**Figure 29**). Although we first used the bilge pump in conjunction with a separate float switch from the same manufacturer, we later changed to a similar pump but with a built-in automatic switch for the system shown in **Figure 30**. This pump was easier to install and the point at which it switched on and off could be changed by moving it up or down within the tank using different mounting holes in the aluminum strip (**Figure 28**).

The solar-powered pump system in **Figure 30** was used to transfer water from the lower tank (foreground) to the higher tank at which point gravity was used to irrigate the tunnel.[6] The same type of solar pumping system was also used to irrigate a high tunnel directly from the tank at a site where tanks were on the ground (**Figure 24**). These tiny pumps supplied about 260 gallons per hour at pressures of 3 psi (2 m or 20 kPa) or enough for eight drip laterals in 90 x 30-ft tunnels.

[6]The pump could also have been used to irrigate the tunnel directly without gravity.

In Conclusion

Inexpensive ultra-low pressure gravity-fed drip systems have been developed which were adopted and successfully used by thousands of small farmers in Southeast Asia. These same simple design principles can be used in gravity-fed, solar, or a combination of gravity and solar-powered drip irrigation systems in small plots and high tunnels worldwide. It is also possible to combine such systems with rainwater catchment using tanks with outlets as low as 2 ft (0.6 m) above ground level (**Figures 30 and 31**).

Acknowledgement

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Figure 26. Small solar panel voltage controller.

Figure 27, Plastic "ammo" box used to house battery, solar controller, fuse, switch, and electrical connections.

Figure 28. Aluminum strip is bolted to lip of tote tank opening. Height of the pump in the tank can be adjusted using additional bolt holes in the strip.

References

Rainwater Catchment from a High Tunnel for Irrigation Use by Shawn Shouse and Linda Naeve. 2012. Iowa State University Extension and Outreach publication PM 3017. Available for download at: https://store.extension.iastate.edu/Product/13734 and as a video: https://www.youtube.com/watch?v=XsxRZQR_7VU

Design, Introduction, and Extension of Low-pressure Drip Irrigation in Myanmar by Brent Rowell and Mar Lar Soe. 2015. HortTechnology 25: 422-436 (August 2015). Summary: http://horttech.ashspublications.org/content/25/4/422.abstract. Pdf is available from the author.

For an in-depth review of drip irrigation experiences in developing countries see also *Drip Irrigation for Agriculture, Untold Stories of Efficiency, Innovation, and Development*. 2017. Jean-Phillipe Vernot *et al.* (editors). Routledge. New York. 384 p.

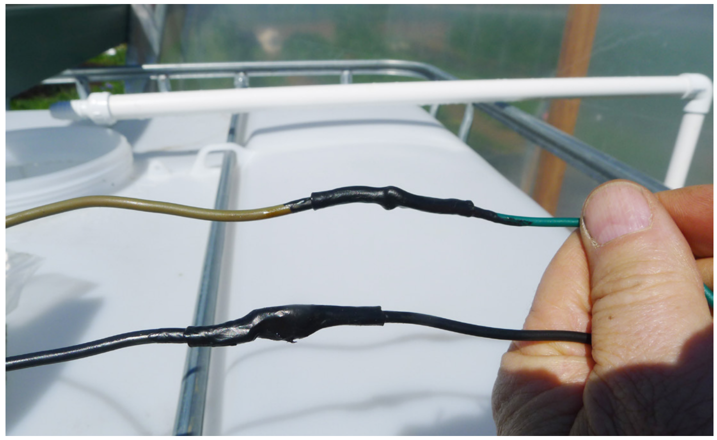

Figure 29. Waterproofed electrical connections soldered and sealed with shrink tubing and Liquid Tape™.

Figure 30. Rainwater collection and ultra-low pressure drip system on a tunnel at the UK Horticulture Research Farm. Solar pump is used to transfer water from the low tank (foreground) to the higher one.

Figure 31. Simple design principles can be used in gravity-fed, solar, or a combination of gravity and solar-powered drip irrigation systems.