Rainwater Harvesting for High Tunnel Irrigation Using Solar and Gravity Power

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Quick Facts

- High tunnels help extend the growing season of high-value crops, but they always require irrigation because they prevent rain from reaching the crop and soil.
- Rainwater harvesting off the high tunnel can alleviate the need for an external source of water to irrigate the crop.
- Tank storage of 1.55 gallons per square foot of high tunnel area was able to meet most of the irrigation needs of the crops grown in Tennessee high tunnels. A supplemental water source may be required during extended periods of drought.
- Harvested rainwater can be delivered to the crop using drip tape without an external source of power, keeping a high tunnel off the electricity grid or from using fossil fuel driven pumps.
- Three self-contained irrigation delivery systems were tested: 1) gravity power alone, 2) solar-charged battery pumping, and 3) direct-solar transfer pumping to higher-elevation delivery tanks.
- It is important to understand the requirements and characteristics of these delivery systems options to determine the best approach for your operation.
- Rainwater harveting systems can be very expensive. Therefore, it is critical to find ways to reduce the cost of water storage to make rainwater harvesting more cost effective in high tunnel production.

High Tunnels

High tunnels are simple greenhouse-like structures. Because they effectively trap solar radiation, the rise in internal temperature allows producers to extend the growing season of high-value crops. High tunnels are a less expensive alternative to the traditional greenhouse and use plastic films instead of rigid glazing. Crops are grown in natural soil, and houses do not generally utilize external power for heating and ventilation. However, high tunnels block out all rainfall making irrigation inside the structure necessary.

Rainwater Harvesting

Rainwater harvesting is a possible solution for irrigation in high tunnels because it does not require an external source of water or power — an important consideration for some producers. Rainwater harvesting is a common practice on a backyard scale as seen in Figure 1. In these small-scale systems, rainwater is most often collected using gutters and stored in tanks for hand watering. UT Extension developed and tested larger scale rainwater harvesting for high tunnels using drip irrigation. Tanks and gutters were used, but harvested rainwater was delivered to high tunnels by three different methods:

1. Gravity driven.
2. Solar-charged battery pumping.
3. Solar-transfer pumping to delivery tanks.

This publication will evaluate the effectiveness of rainwater harvesting for high tunnels in Tennessee while describing these three internally powered irrigation methods. The characteristics and costs of these approaches will also be compared.

Figure 1: *Small-scale rainwater harvesting is becoming more common in residential areas.*

Figure 2: *Collection tanks that were used to store rainwater. The holding capacity of these tanks was 1,100 gallons each. The dark color was chosen to inhibit microbe growth within the tank.*

Tank Sizing, Gutters and other Considerations

An important consideration when designing a rainwater harvesting system is the size of the storage containers. Container size is determined by rainfall and crop-water use amounts for the surrounding area. The storage volume needs to be large enough to supply water for an extended period without rainfall. Local rainfall data indicated that tanks would need to supply irrigation for a two weeks to cover a majority of dry periods in East Tennessee.

Next, a peak evapotranspiration rate for common vegetable crops was estimated at 1.5 inches/week from outside weather data. However, this rate was considered higher than actual rates because inside a high tunnel, wind, solar radiation and wetting of the soil surface are reduced while drip tape under plastic mulch also inhibits evaporation from the soil surface. Therefore, an evapotranspiration rate of 1.25 inches/week was multiplied by the two-week dry period to determine a test storage volume of 2.5 inches per high tunnel area. This equals 1.55 gallons for every square foot of high tunnel footprint. For a 30-by-48-foot-high tunnel, this translates to 2,200 gallons of tank storage as shown in Figure 2. It should be noted that this criteria was our best estimate for testing rainwater havesting in East Tennessee and more or less water storage may be required depending on actual conditions and the location of the high tunnel.

Initially plastic gutters were used for rainwater harvesting but later changed to heavier metal gutters. One advantage of using plastic snap together gutters (shown in Figure 3) is that they detach easily from the high tunnel to facilitate snow removal while heavier metal gutters can remain on the high tunnel when snow is dragged off the roof using a loop of rope. Another snow removal option is a powerful leaf blower that potentially reduces the chances of damage to thin-walled aluminum gutters. Finally, solid wall plastic tanks were common to all rainwater harvesting systems tested. Black tanks were used to cut out light and inhibit biological growth in stored water.

Figure 3: *Plastic snap together gutters on a high tunnel. Repair tape was used to fill the gap between the gutter and the structure.*

1. The Gravity Driven System

Gravity causes water to flow downhill and the same principle can be used to move water from the high tunnel roof to the crop inside without using a pump as shown in Figure 4. The weight of water also creates water pressure which is highest in the drip system when the tank is full. In this application, the tanks had to fit under the gutters to capture rainwater and be elevated to ensure water pressure was high enough to operate the drip system as the tanks empty. Gravity pressure is developed at 1 pound per square inch (psi) for every 2.31 feet of water elevation. Therefore, the maximum pressure for this high tunnel application was around 2 psi when the tank was full and around 1 psi when the tank emptied. These pressures were well below recommended pressures to operate drip systems, yet the water distribution was adequately uniform when using short lengths of drip tape on flat to moderate slopes. At these low pressures, the drip system had to be operated longer than normal to apply the desired amount of water. The gravity-powered system required minimal maintenance due to its simplicity and because the low-pressure did not create many leaks. Therefore, the quantity, cost and complexity of repairs was low in comparison to the other systems.

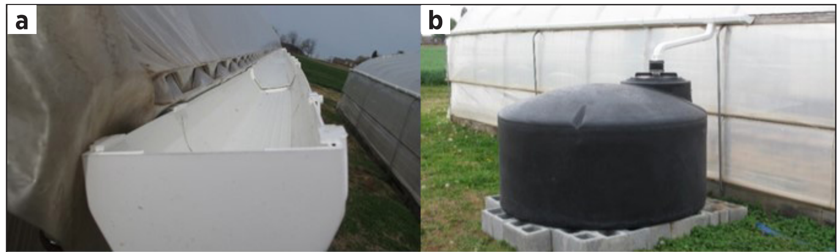


Figure 4a: Rain fed from the plastic film into the gutters

Figure 4b: Rain fed from the gutters into the tank

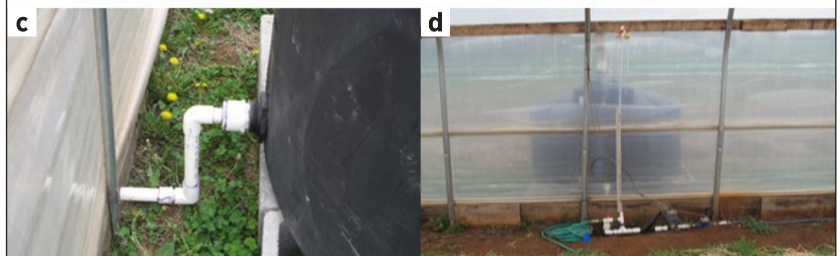
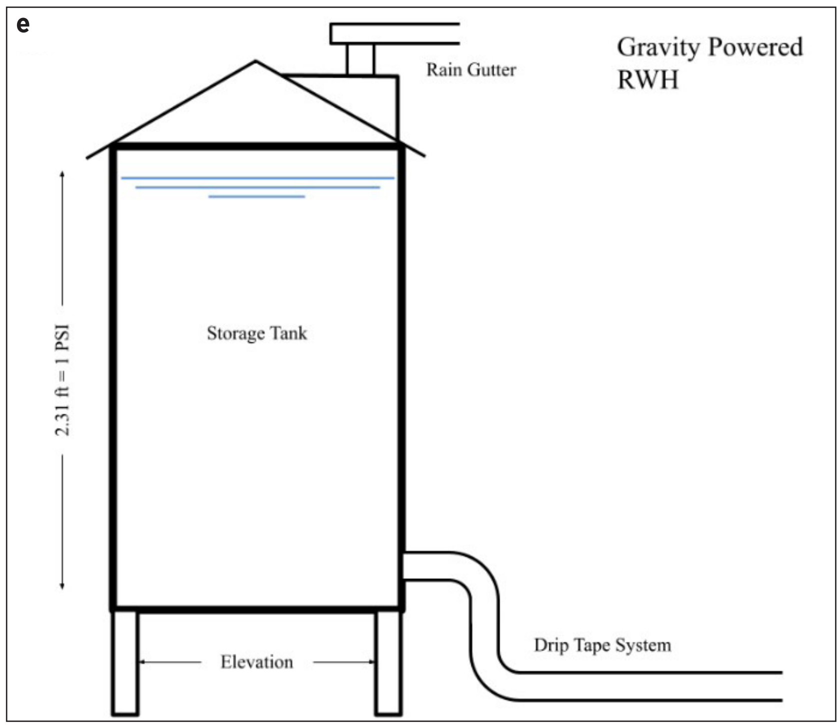


Figure 4c: Gravity from the tank into the high tunnel

Figure 4d: Gravity into the drip irrigation system



2. The Solar Charged Battery System

The solar-battery system (Figure 5) was similar to a private well for a home except that the electricity was solar generated instead of connected to an electric utility. Solar panels charged the batteries, which then provided power to a submersible pump, the pressure switch and the pump controller. Four 12-volt batteries were connected in parallel and series to create a 24-volt DC system. The pressure switch was used to signal the pump controller to turn the pump on and off providing automatic operation as valves were opened and closed for irrigation. The pressure in this system was significantly higher than the other systems due to the pump with the pressure switch set to operate between 35 to 45 psi. Pressure regulators were used to maintain normal pressure in the drip system at around 12 psi, thus alleviating concerns about water distribution and uniformity. These high-pressures created many leaks requiring routine maintenance to avoid waste of harvested rain water. The complexity of the system incurred higher cost and required greater expertise for repairs as compared to the other systems.

Figure 5a: Capture tank with a submersible pump

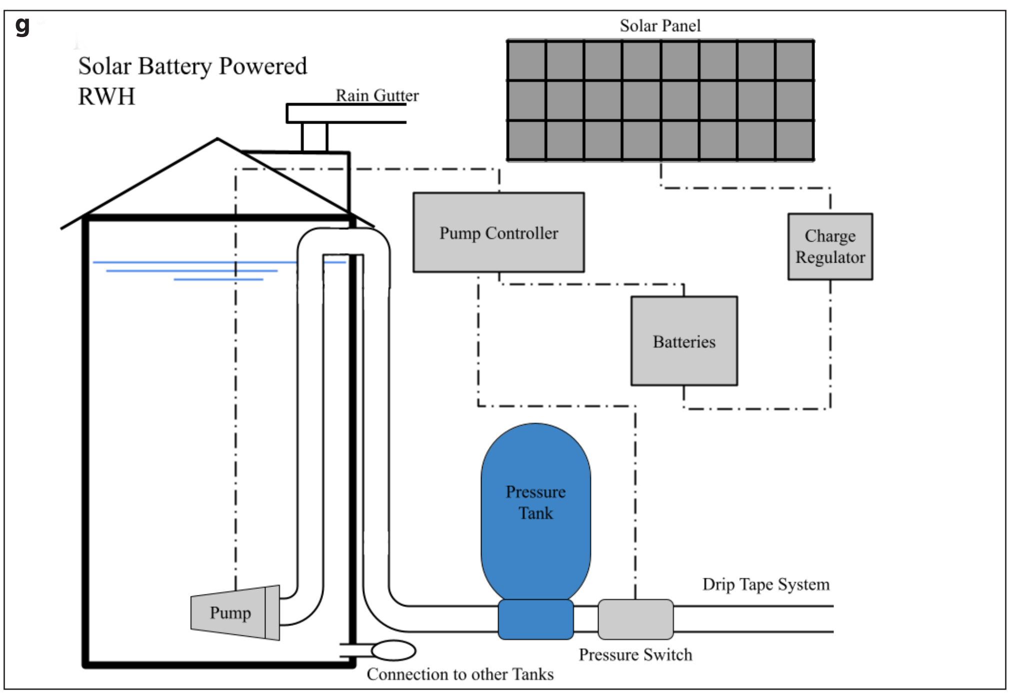
Figure 5b: Solar panels charge the batteries using a regulator

Figure 5c: Batteries power the pump using a charge regulator

Figure 5d: The controller turns the pump on and off

Figure 5e: A pressure switch and tank signal the controller

Figure 5f: The system runs when an irrigation valve is opened



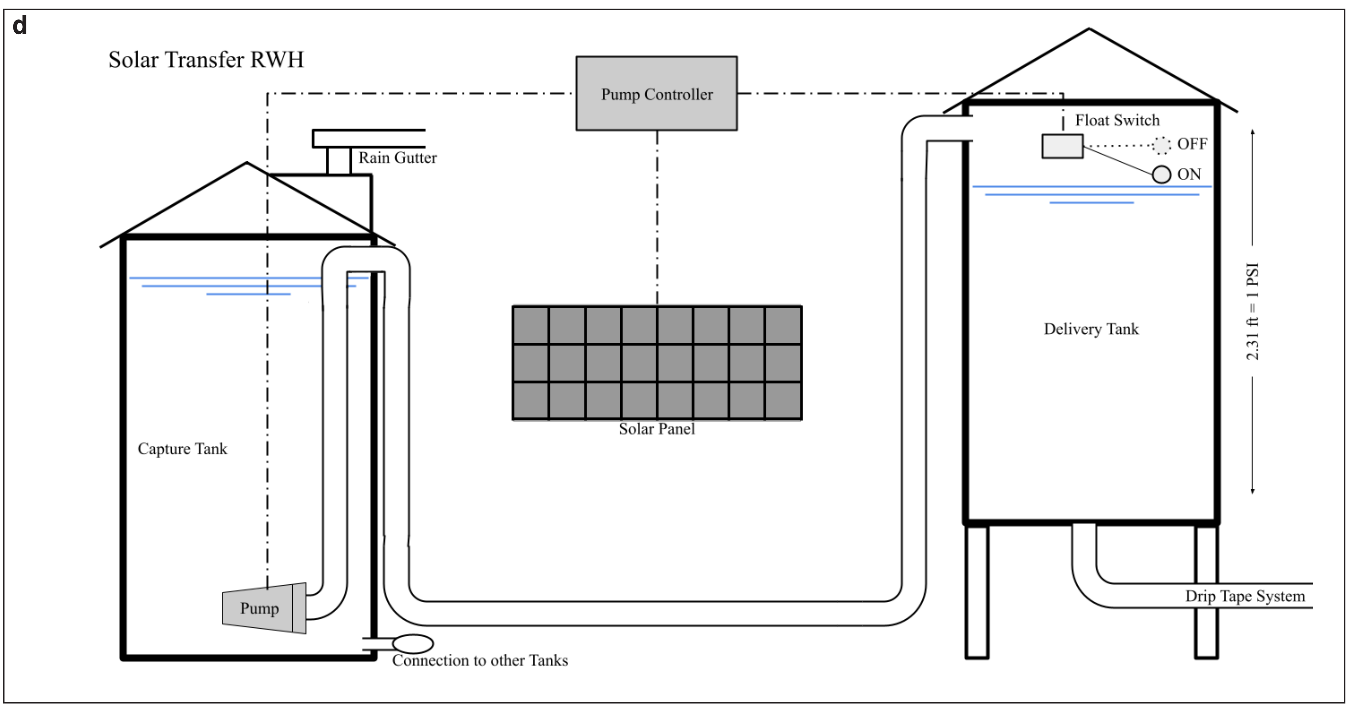
3. The Solar Transfer Pumping System for Gravity Watering

The solar-transfer system (Figure 6) used a capture tank much like the other two systems. However, the system was a combination of both gravity flow and solar pumping. The water was captured and then pumped to the delivery tank at a higher elevation to create higher pressure than the gravity powered system. Much like the gravity powered system, raising the elevation by just 2.31 feet corresponds to 1 psi of extra static pressure. Similarly, raising the tank 23.1 feet created 10 psi of static pressure. This system only transfered water from the capture tank when there was sunlight and the water level in the delivery tank dropped to the point of activating the float switch that allows the pump to turn on. In essence, this approach was always trying to keep the delivery tank as full as possible and the capture tank as empty as possible. Opening an irrigation valve allowed automatic operation of the drip system night or day as long as there was water in the delivery tank. By comparison, the solar-transfer system had a moderate number of leaks and intermediate complexity. This led to the maintence cost being higher than gravity power alone but lower than solar-battery powered pumping.

Figure 6a: Image of the capture tank with a submersible pump

Figure 6b: The solar panel along with the pump controller

Figure 6c: The delivery tank with the float switch. The gravity flows to the drip tape when a valve is opened



Rainwater Harvesting Effectiveness

The rainwater harvesting systems were evaluated for how well they supplied the irrigation requirements in high tunnels. Table 1 shows the percentage of rain water applied as compared to the total irrigation amount required when the 1.55 gallons per square foot storage capacity rule was used to determine tank size. The rainwater harvesting systems met nearly all the irrigation requirements during the fall growing season when crop-water use was very low. In the spring and summer months, crop-water use peaked at the end of June and beginning of July such that only 80 percent of the irrigation requirement was met in some years. Of course, the amount of irrigation water provided depended on four main factors: yearly rainfall patterns, seasonality of crop water use, tank size, and operator irrigation habits. During testing, the tank water lasted at least two weeks. However, there were some dry periods that lasted long enough to empty the tanks requiring the addition of municipal or well water. It may not be feasible to continue increasing tank size for these longer dry periods such that rainwater harvesting may require a supplemental source of water. Still, rainwater harvesting was able to meet a majority of the irrigation requirements for East Tennessee high tunnels. Tank capacity and dependence on supplemental water will need to be adjusted for rainwater harvesting in different climates.

	UT-Farm		Farmer 1		Farmer 2	
	Spring	Fall	Spring	Fall	Spring	Fall
2011	80%	100%				
2012						
2013	100%	100%				
2014	83%	100%	98%	100%		100%
2015	89%		100%	100%	87.5%	91%
2016			100%		<75%	

Table 1: *Percent of irrigation supplied by RWH.*

The Cost

The overall cost of the different rainwater harvesting systems was dominated by the price of the tanks used to store the water as shown in Table 2. The cost estimates were based on rainwater harvesting for two 30-by-75-foot high tunnels and will change depending on the size and number of the high tunnels. The cost of rain gutters and tanks was $12,000 and was the same for each of the alternative delivery systems. The additional cost for gravity flow, solar-transfer pumping and solar-battery powered pumping were $400, $2,750 and $3,950, respectively. The high cost of rainwater harvesting shows the importance of evaluating alternate water supplies. If a less expensive method of water storage were to be adopted, the cost of rainwater harvesting would dramatically decrease in all cases.

Item	RWH type	Description	Cost
Rain Gutters	GF, STP, SBPP	400 feet of installed aluminum or plastic. Material only for Galvanized	$2,000
Storage Tanks	GF, STP, SBPP	9,000 gallons of water, storage from rigid plastic tanks	$10,000
Elevate Tank	GF	250 concrete blocks to create 0.45 m of lift	$400
Solar Pumping	STP, SBPP	Solar panels, submersible 24 v solar pump, pump control, wire and conduit	$2,000
Battery Power	SBPP	4 deep cycle batteries, charge controller, pressure tank and switch, wire, conduit	$1,200
Water Lines	STP, SBPP	250 feet of 1-inch PVC Pipe with trenching	$750
Gravity-Only		TOTAL	$12,400
Solar Transfer		TOTAL	$14,750
Solar Battery		TOTAL	$15,950

Table 2: *Cost of the three rainwater harvesting irrigation systems tested during the UT experiment: gravity flow (GF), solar-transfer powered (STP) and solar-battery powered pumping (SBPP).*

Conclusion

When deciding whether to install a rainwater harvesting system, five questions should be asked:

- How important are energy and water sustainability for your high tunnels?
- What alternative water sources are possible or already available to you: wells, streams, ponds and municipal?
- Will rainwater harvesting be able to provide all or part of your high tunnel water requirements in your location?
- What type of rainwater harvesting will work best for your operation: gravity alone, battery-powered solar or solar-transfer pumping?
- Do the rainwater harvesting benefits justify the cost when comparing alternative water sources?

In Tennessee, rainwater harvesting was able to supply a majority of the high tunnel irrigation requirement when using the 1.55 gallon per square foot rule. It did not require an external source of power but did require some supplemental water. Keep in mind that Tennessee rainfall is substantial and well distributed. Rainwater harvesting in other regions and climates may require a different design criterion for water storage based on rainfall patterns, crop-water use, soil salinity, operator irrigation habits and the availability of supplemental water sources. Rainwater harvesting provides high-quality water that could help reduce soil salinity, but it can also harbor biological contamination from roof run-off. The biggest concern for rainwater harvesting in high tunnels is the large water storage volume that is very expensive when using rigid wall plastic tanks. Reducing water storage cost would increase the financial feasibility of rainwater harvesting.

Also, different approaches to rainwater harvesting must be considered. Gravity powered rainwater harvesting is characterized by simplicity, few leaks, lower cost and very low pressure. The restricted tank placement and low pressure can cause water distribution difficulties with gravity systems. In contrast, solar-powered battery pumping provides ample pressure to overcome water distribution and irrigation uniformity concerns. However, this approach is more technically complicated with frequent leaks and the highest cost to install and repair. Finally, solar-transfer pumping falls in between the other two delivery systems in terms of pros and cons.

A more detailed publication is available for those who require a more complete understanding of rainwater harvesting for high tunnels titled Rainwater harvesting with solar and gravity powered irrigation for high tunnels, *Applied Engineering in Agriculture* (2020), 36(4): 489-498 by Leib, B. G., W. C. Wright, T. Grant, A. Haghverdi, D. Muchoki, P. Vanchiasong, M. Zheng, D. M. Butler, and A. Wszelaki. https://elibrary.asabe.org/abstract.asp?aid=51680

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