

AGRICULTURAL ALTERNATIVES

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Irrigation for Fruit and Vegetable Production



Precipitation in Pennsylvania averages about 37 inches each year. About 13 inches of this precipitation runs off land into streams, while 24 inches infiltrates into the soil, where it can be used by crops. The 24 inches of precipitation usually is sufficient for growing many agronomic and some horticultural crops. However, irrigation often is necessary because of the uneven distribution of precipitation throughout the year, especially during critical growth periods.

Uneven precipitation can cause plant stress during critical growth periods, which will affect both crop productivity and produce quality. Most horticultural crops require irrigation to minimize plant stress. Proper timing of water applications during appropriate periods can increase the yield and quality of most horticultural crops in Pennsylvania in most years. The critical periods for the irrigation of various vegetables, tree fruits, and small fruits are listed in Table 1.

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Table 1. Critical periods for irrigation of vegetables, tree fruits, and small fruits.

VEGETABLE CROPS	CRITICAL PERIOD(S)
Asparagus	spear growth, fern growth
Broccoli	transplanting, flower bud production
Cabbage	transplanting, head development
Carrot	root enlargement
Cauliflower	transplanting, curd development
Cucumber	pollination, fruit enlargement
Eggplant	transplanting, flowering, and fruit development
Lettuce	throughout growth
Lima bean	blossom and pod development
Muskmelon	pollination and fruit enlargement
Onion	transplanting and bulb enlargement
Pea	pod development
Pepper	fruit development
Potato	tuber development
Rhubarb	petiole formation for harvest
Snap bean	blossoming and pod enlargement
Spinach	throughout growth
Sweet corn	silking and tasseling, ear development
Sweet potato	when slips are set in the field
Tomato	transplanting, early flowering, fruit set and enlargement
Turnip	root enlargement
Watermelon	pollination and fruit enlargement

(Table 1, continued next page)

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Table 1. (continued)

TREE FRUITS	CRITICAL PERIOD(S)
Apple	The critical periods for these tree fruits are early fruit set, during flower formation, and during final fruit swell.
Pears	
Peaches	
Plums	
Nectarines	
Cherries	
SMALL FRUITS	CRITICAL PERIOD(S)
Blueberries	berry swell to end of harvest and at fruit bud formation for next year's crop (late July and August)
Raspberries	bloom and as berries are sizing before first picking
Blackberries	bloom and as berries are sizing before first picking
Strawberries	at planting, during runner formation, during flowerbud formation before harvest begins, and at renovation

Water Sources and Their Effect on Irrigation Costs

Water used for irrigation can come from one source or from a combination of sources. In Pennsylvania, most irrigation systems use untreated surface water or groundwater. In a few special cases, it is possible to irrigate cropland using a municipal water-supply system.

Surface water

Surface water runoff from local watersheds can be collected, stored in a pond, and used for irrigation during periods of lower than normal precipitation and for critical growth periods. In Pennsylvania, 2 acres of watershed tributary provide approximately 1 acre-foot of water annually. (An acre-foot is the volume that would cover 1 acre to a depth of 1 foot.) Much of this water (about 40 to 60 percent) is lost to seepage through the pond bottom and to evaporation on the pond surface. Therefore, you will need about 4 acres of watershed to supply 1 acre-foot of irrigation water per year.

If the area to be irrigated is located near a stream fed by a large watershed, it may be possible to draw water from the stream without building a storage pond. Water withdrawn from streams usually is free when used for irrigation. If stream flow in the Susquehanna and Delaware River basins drops below a prescribed level, however, irrigation may be legally restricted. Generally, drought emergency conditions occur toward the end of the growing season and should not be a serious limitation. Costs associated with using surface water for irrigation are determined by the size of the pump and power plant required to lift the water from the source (stream or pond) to the field where the water will be used.

Groundwater

Groundwater in Pennsylvania is generally of good quality and frequently is used to supply homes and farmsteads. It also can be a good source of irrigation water. However, locating and drilling a well that will provide adequate, high-quality water is a difficult and expensive task that may not always be successful. Because groundwater is stored in soil and rock below the soil surface where it cannot be seen, there is no guarantee that sufficient groundwater is available to meet irrigation needs.

Special procedures, such as the fracture-trace technique, have been developed to locate wells where they will penetrate into zones of fractured rock beneath the surface. Wells located in such fractured rock zones will produce larger quantities of water than wells drilled into zone where the rock is not fractured. Finding the fractured rock zones or, better yet, finding the intersection of two fractured rock zones can be a time-consuming and expensive procedure. If you plan to develop a groundwater supply, you should consult a hydrogeologist. Local well drillers also can be a source of information on well yields in your area.

The costs associated with using groundwater for irrigation are determined by the cost of drilling the well and the cost of the well casing, the pump, and the power plant. Pumping costs are a function of elevation differences between the source and the field and, to a small degree, the distance between the source and the field.

Municipal water

Depending on your location, you may be able to purchase water from a municipal water supplier. Municipal water is of high quality and usually is delivered at a minimum pressure of 40 pounds per square inch (psi). However, municipal water suppliers may place limits on how much water can be used and when. These limits are established to protect the other users of the system. Generally, it is very costly to use municipal water to irrigate agricultural crops.

Laws Affecting Irrigation Water Use

You must verify whether you have the legal right to withdraw water for irrigation. Water-use rights in the eastern United States are called riparian or landowner's rights because landowners are entitled to the reasonable use of water flowing through or adjacent to their lands. In some western states, water is available only to owners with specific rights. In some areas, permits are required before surface water or groundwater can be withdrawn for irrigation.

When you use water in Pennsylvania, you may be depriving others of the right to use the same water. Consumptive uses of water within the Susquehanna and Delaware watersheds are carefully regulated. Consumptive use includes withdrawing water from surface water or groundwater sources and consuming it through the processes of

evaporation and transpiration in irrigated crop production. If you plan to withdraw water from either surface water or groundwater for consumptive use, you should contact your watershed commission and the Pennsylvania Department of Environmental Protection before spending any money on plans or equipment. Agencies and commissions that you might need to contact are listed at the end of the publication.

The Pennsylvania Fish and Boat Commission also may be interested in your use of surface water. If your water withdrawal reduces stream flow rates to the point that the health of sport fish is endangered, you can be held responsible. Contact your local office of the Pennsylvania Fish and Boat Commission if you have any questions.

Water Requirements

The irrigation water source must be large enough to provide sufficient water when it is needed. Because irrigation is not totally efficient, the water supply rate must exceed the rate of crop use. Water requirements depend on your climate, crop, and the amount of available soil moisture. Water use changes during the growing season and is difficult to predict. Therefore, water supply systems generally are evaluated using two criteria—seasonal water demands and daily water demands. The water supply must be sufficient to satisfy the requirements of the irrigation system and supply enough water to meet crop needs. Because stream flow and shallow groundwater sources are strongly influenced by climate, they might not provide enough water during the dry part of the year, when irrigation is needed most.

Choosing an Irrigation System for Vegetables and Small Fruits

Farmers who are considering the purchase of an irrigation system for their vegetables or small fruits must consider many factors. These may include issues relating to: 1) field considerations such as soil type, drainage, erosion potential, location of power sources, topography (including pumping lifts), and distance from water supplies, 2) water considerations such as availability, quantity, quality, costs to develop a water supply, and annual crop water requirements, 3) crop considerations such as yield potential, frost protection requirements, and cultural practices relating to planting, pest management, and harvesting, and 4) system considerations such as the type of power supply, labor requirements and availability, and initial capital and annual operating costs.

Growers use basically six types of irrigation systems: hand-moved sprinklers, solid-set sprinklers, hand-moved big guns, traveling big guns, center pivots, and trickle/drip. Each irrigation system type has its own advantages and disadvantages for a given application. Once a particular type of irrigation system is chosen, it will need to be customized for

the particular field and crop application. This should be done in consultation with an irrigation equipment dealer or a qualified agricultural engineer.

Hand-Moved Sprinklers

This system involves the setup of aluminum pipe to distribute water from the source to the field. A 4- to 6-inch mainline is often used, which is connected to a header pipe (with lateral valves) that stretches across the top of the field. For each irrigation set, one or more 2- to 4-inch lateral pipes are run the length of the field. After water is applied to one section of the field, the lateral pipes are moved down the header pipe (usually 40 to 60 feet) and the next section is irrigated. Relatively small sprinklers, ranging from 3 to 30 gallons per minute (gpm) each, are spaced every 40 to 60 feet down the entire length of each lateral. Sprinkler pressures usually range from 50 to 70 pounds per square inch (psi). Small capacity pumps up to 600 gpm are used with this system.

The major advantage of this system is that total system capital cost is relatively inexpensive. The primary drawback is that it is a very labor-intensive irrigation system. This type of system is suitable for strawberries and vegetables. The capital costs are relatively low when compared to other types of sprinkler systems. A system set up to irrigate one acre (mainline and header pipe, one lateral with 12 sprinklers, and a 10 horse power (hp) gasoline pump) could cost as little as \$2,000 to \$3,000. Additional acreage could be added fairly inexpensively because only additional header pipe would be required. Because the lateral pipes must be moved to get water to the entire crop, labor costs to operate the system are relatively high.

Solid-Set Sprinklers

With this system, the entire field is covered with laterals that are set in the field for the entire growing season. A 4- to 8-inch mainline and header pipe is commonly used to deliver water to the laterals. Enough 2- to 4-inch lateral pipes to cover the entire field are used, spaced 40 to 90 feet apart depending on sprinkler size and system operating pressure. Relatively small sprinklers, ranging from 4.5 to 45 gpm each, are spaced every 40 to 90 feet down the length of each lateral. Sprinkler pressures usually range from 50 to 70 psi. Medium capacity pumps, up to 1,000 gpm or larger, are required.

The major advantages of this type of system are its suitability for frost protection, its ease of operation (because pipes are not moved once they are set in the field and individual lateral lines can be controlled by the header valves), and its adaptability to fertigation. The major disadvantages are that it is a very capital-intensive system, and the presence of the pipes can impede certain field operations such as spraying, cultivation, and harvest. This system is typically used on strawberries and vegetables. Capital costs are approximately \$3,500 per acre. Labor requirements are relatively low compared to hand-moved

sprinklers, because the pipes are not moved to irrigate. Labor is usually only required for setting up the system at the start of the season and removing it at the end of the year.

Hand-Moved Big Guns

This system is similar to the hand-moved sprinkler system, except that a dozen or more small, low-volume sprinklers are replaced with one or two high-volume big gun sprinklers. Many farmers who previously used hand-moved laterals with small sprinklers switched over to hand-moved big guns because they could cover more ground with less labor.

A 6-inch mainline and header are typically used with this system. Lateral pipes (commonly 4 inches) are connected to the header pipe at the lateral valves spaced from 150 to 240 feet apart. The big guns (ranging from 100 to 500 gpm each) are spaced 150 to 240 feet along the lateral lines. Big gun nozzle pressures generally range from 70 to 100 psi. Pumps up to 500 gpm are needed to operate each big gun.

The principal advantage of this system is that large areas can be irrigated fairly quickly compared to hand-moved small sprinkler systems. The primary disadvantages are that it is labor intensive to set up and operate, produces a large droplet size that may injure tender crops, and causes adverse wind effects on water distribution patterns due to its high-stream trajectory. This system is typically used on crops grown on large acreages like potatoes, onions, sweet corn, and pumpkins. Capital costs can range from \$5,000 to \$15,000 for two guns, some mainline, laterals, and a PTO-powered pump. Labor costs are less than with a hand-moved sprinkler system, but are still relatively high compared to other systems.

Travelling Big Gun Sprinklers

A travelling big gun system consists of a big gun sprinkler mounted on a wheeled cart connected to a hard plastic hose on a mechanical reel. These systems are used by growers to irrigate large acreages with relatively little hand labor. The pump, with 6-inch mainline and header, are set in the field. After the reel is set up beside the header, the big gun cart and hose are pulled to the end of the field with a tractor. The reel uses the extended hose to slowly pull the big gun cart across the field, irrigating a strip as the hose is retracted. After the strip is irrigated, the reel is moved 150 to 240 feet farther down the header and the process is repeated. Hose diameters range from 2 to 5 inches and hose lengths are up to 1,250 feet. The big gun can have a capacity ranging from 100 to 500 gpm operating at 70 to 100 psi.

Compared to hand-moved big guns, this system has several advantages including 1) lower labor requirements to set up and operate, 2) improved water distribution uniformity, 3) ability to irrigate larger acreages with less labor, and 4) adaptability to almost any shape, size, and contour of field. Disadvantages of travelling big guns include 1) a high relative capital cost, 2) high operating costs due to the high operating pressure required (200 psi) and pressure losses in

the system, 3) the unsuitability for frost protection, 4) a large droplet size that may injure tender crops, 5) the adverse effect of wind on the water distribution pattern, and 6) the potential for water runoff and soil erosion if not operated properly. These systems are used on crops grown on large acreages such as potatoes, onions, sweet corn, and pumpkins. Depending on size, new travelling big gun sprinklers cost \$25,000 to \$35,000 each. A system including the reel, big gun cart, mainline, header, and PTO pump often costs \$40,000 to \$50,000. Compared to hand-moved systems, labor costs are relatively low because as much as 8 acres can be irrigated at one time before resetting the system.

Center Pivots

Center pivots are a moving irrigation pipeline, where water is distributed along the length of the pipe, which pivots around a central, fixed water supply. Center pivots are most suited for fields in which a single crop is being grown. Sprinklers on the pivot spans, mounted on wheeled towers, apply water as the unit turns around the pivot base. Depending on the pivot's speed of rotation, 1/4 to 1 inch of water is applied in a single pass.

Center pivots can be as short as a single span of 130 to 210 feet or much longer to irrigate very large fields. The size of the mainline (which can either be portable or buried) and pivot pipe are usually either 6 or 8 inches. A typical operating pressure for center pivot sprinklers is 50 psi. Mid-size pumps of 400 to 1,600 gpm are used to operate the pivot. End guns are often added to irrigate the corners of fields.

Some of the advantages of center pivots are: 1) after initial set up very little labor is required to operate the system, 2) medium operating pressures that save energy, 3) easy to apply small amounts of water frequently, 4) excellent water application uniformity, even in windy conditions, 5) an ability to cover large areas, and 6) its adaptability to fertigation.

Although center pivots can have a relatively low capital cost per acre when compared to other permanent irrigation systems like solid-set small sprinklers, the total capital cost to set up the system is high. The capital cost to set up a center pivot depends on the length of the system and the distance from the irrigation water supply. The cost per acre for irrigating a small field with a center pivot can be several times the cost of a large field. For example, a small center pivot system set up to irrigate only 10 acres may cost as much as \$50,000 (or \$5,000 per acre). For a larger system (like those used for irrigating a quarter section of agronomic crops), the cost is about \$75,000 (or \$500 to \$700 per acre). The labor cost to operate the system is relatively low with usually only one person required to start and oversee the operation of the system.

In recent years many center pivots have been modified by removing the medium to high-pressure sprinklers and replacing them with low-energy precision application

(LEPA) nozzles, which go a good job of uniformly applying the water, but at pressures of only 10 to 20 psi. LEPA conversions greatly reduce the energy required to run a center pivot irrigation system.

Trickle/Drip Irrigation

Trickle irrigation, also referred to as drip irrigation, applies water to only the soil. With row crops such as vegetables or strawberries, this type of irrigation most often is delivered via a tube that runs the length of the row. With larger crops, individual emitters (water delivery devices) located at intervals along the tube are often employed to avoid watering between plants.

Trickle systems are more efficient than sprinkler systems because water is applied directly to the soil, so less water is lost to evaporation. Under typical operating conditions, trickle systems are about 95 percent efficient, while sprinkler systems are only about 70 percent efficient. Water application efficiency is an important factor when considering irrigation systems, and probably will become more important as access to water becomes more limited.

Compared to sprinkler nozzle sizes, trickle system emitters have very small openings, normally about the size of a pinhole. Various emitters have different internal flow characteristics that determine how sensitive they are to pressure changes and quality of the irrigation water. A 150-to-200-mesh screen or a sand filter is usually required for water filtration. Emitters are either self-cleaning or are taken apart for cleaning. Periodic chlorine injections are used to keep the system free of algae and bacterial slime. Acid injections, along with periodic system flushes, help remove mineral buildup in some systems. Backflow prevention devices should be used to keep the water supply from becoming contaminated.

Most emitters normally operate at pressures of 5 to 20 psi, with flow rates of 0.5 to 2.0 gallons per hour. Emitter spacing depends on the discharge rate and soil type because most of the water will be distributed through the soil. The low pressure requirements of emitters result in a greater sensitivity to pressure losses along a lateral line or an elevation gradient. Pressure-compensating emitters may be necessary to achieve uniform water application on rolling terrain. Because the pressure and discharge requirements for emitters are usually not as great as for sprinklers, the annual operating costs of these systems tend to be lower.

Small plastic mainlines and header pipes, ranging in size from 1 to 4 inches are common. These pipes are often buried on permanent crop types. Trickle emitter lines are run down the rows to provide water to the plant roots. Often fields are broken into zones to minimize the pump and mainline sizes. Typically, small electric pumps of less than 100 gpm are used. The pump, filter, mainline, headers, and trickle lines are laid in the field annually, or the system may be permanently installed for perennial crops. Typically, the system is run for 1 to 4 hours each day, to provide the amount of water required during the growing season. These systems are quite easy to automate and are often controlled by a timer.

Many advantages of using trickle/drip irrigation include: 1) more efficient water usage than sprinkler systems, 2) adaptability for fertigation, 3) reduced disease problems because leaves are not wetted, 3) low energy requirement because of the low pump pressures required, and 4) low labor requirements and high degree of automation. Some disadvantages are blocked emitters and broken lines and connectors caused by machinery operations or freezes. Trickle and drip systems are not suitable for frost protection. These systems can be used on most any horticultural crop including row crops, small fruits, and tree fruits. Capital costs range widely from as little as \$200 to \$300 to as much as \$2,500 per acre, depending on the amount and quality of dripper line required and the number and types of emitters used. Other cost factors include type of water source and distance from field, power supply, pumps, level of automation, and method of installation. Labor costs to operate the system can be quite low, depending on the level of automation.

Choosing a Tree Fruit Irrigation System

Tree fruit growers use two types of irrigation systems: solid set sprinklers and drip. Both irrigation systems have their own advantages and disadvantages for a given application. Once a particular type of irrigation system is chosen, an irrigation equipment dealer or a qualified agricultural engineer can help you customize it for the particular orchard block and fruit crop.

Solid Set Sprinklers

With this system, laterals are buried in the tree rows with a riser and impact sprinkler exposed above ground. These systems are full coverage systems that apply water to the entire tree and orchard floor. They are well suited to applications where frost protection is needed. The initial investment cost of this system is high because of the cost of trenching and placement of the PVC laterals and sprinkler heads. Annual operating costs are high because of pumping costs.

Drip Irrigation

Drip irrigation uses polyethylene laterals with emitters to deliver water directly to individual trees. In practice, only about 40–50% of the orchard floor will be wetted. With drip irrigation the PVC submain and main water supply are usually buried to facilitate machinery operations. These systems are easily adapted to chemigation and because they do not wet the entire tree, they facilitate conventional pesticide applications. Drip systems are not suitable for frost protection.

Scheduling Irrigation

Once you have acquired an irrigation system, you must decide when to irrigate, how much water to apply, and how you will use and maintain the equipment. Irrigation systems must be designed to ensure that both the water supply and the irrigation system can meet peak demand. Figure 1 shows estimated time amounts for infiltrated rain in Pennsylvania.

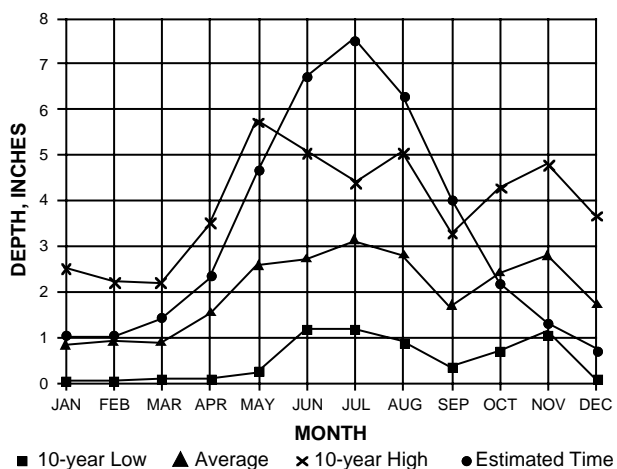


Figure 1. Pennsylvania infiltrated rain and estimated time amounts.

Plant root depth, canopy development, growth habits, and nutrient requirements in a given climate largely determine the irrigation schedule. Soil-infiltration characteristics determine maximum water application rates. Actual water use will vary daily throughout the season, so growers must develop a method for ensuring that the crop has a sufficient amount of water available.

Several methods are used to determine when to irrigate, and some of these methods are more reliable than others. By the time plants show signs of water deficiency, such as wilting, plants have been stressed and their growth slowed. Irrigation at this point may save the crop, but production already has been limited.

The appearance of the soil after being squeezed by hand can be used to estimate water content. With experience, this method can be quite reliable, and charts are available to describe how different soils with different moisture content should look and feel. A common mistake is to feel the soil on the surface rather than around the root tips, where most moisture is taken up. You can avoid this problem by using a soil probe to sample soil in the crop root zone.

Plant water demand also can be estimated daily (based on crop development and climate conditions) and then

compared to the soil's water-holding capacity. Irrigation should begin when the stored soil moisture approaches 50 percent of the available capacity or the plants will become stressed. Moisture content should be measured periodically to verify water use and moisture depletion estimates. With experience, this water budget method can be quite reliable and can be used to predict when irrigation should begin. Computer software programs using this method are available and can be adapted to particular site conditions. These programs also can be used to automate irrigation practices.

Another method to schedule irrigation for most crops in the northern United States assumes that 1.0 to 1.5 inches of water are required weekly (the pan evaporation amount). The irrigation schedule can account for average weekly precipitation and can help you plan irrigation to apply the difference. However, rainfall amounts are unpredictable, so this method can lead to deficits or excesses that can limit crop performance. For small-fruit crops, growers may wish to raise the water demand to 2 inches per week during fruit development, especially on well-drained soils.

Equipment Use and Maintenance

Appropriate use and maintenance of irrigation equipment, both during the irrigation season and while in storage, will increase its life span and reduce operating and maintenance costs. Irrigation equipment dealers can provide you with guidelines for operating and caring for your equipment.

The pumping unit and control head will require the most maintenance in terms of lubrication, cleaning, and protection from dirt, moisture, freezing, and animals. Leaking pump seals and pipe gaskets should be replaced when necessary. Sprinkler nozzles that have worn more than 1/16 inch larger than specified or emitters that are clogged should be replaced. Mains and laterals, particularly in trickle systems, should be flushed periodically to remove buildup of precipitates and sediment. Equipment used in freezing weather must be properly lubricated and should be self-draining. Careful use and continued maintenance of irrigation equipment will help ensure many years of trouble-free performance.

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For More Information

Selected Web sites:

Basics of Vegetable Crop Irrigation, Alabama Cooperative Extension System (<http://www.aces.edu/department/extcomm/publications/anr/anr-1169/anr-1169.html>)

Irrigation in Ohio: Eight Major Factors, Ohio State University Extension (<http://ohioline.ag.ohio-state.edu/aex-fact/0370.html>)

Irrigation Scheduling Methods, University of Georgia (<http://www.ces.uga.edu/pubcd/b974-w.html>)

Plasticulture for Commercial Vegetable Production, University of Georgia (<http://www.ces.uga.edu/pubcd/b1108-w.html>)

Selecting a Sprinkler Irrigation System, North Dakota State University Extension Service (<http://www.ext.nodak.edu/extpubs/ageng/irrigate/ae91w.htm>)

Using Soil Moisture Sensors for Making Irrigation Management Decisions in Virginia, Virginia Cooperative Extension, (<http://www.ext.vt.edu/pubs/rowcrop/442-024/442-024.html>)

Governmental Agencies:

Pennsylvania Organization for Watersheds and Rivers
PO Box 765
25 North Front Street
Harrisburg, PA 17108-0765
(717) 234-7910

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