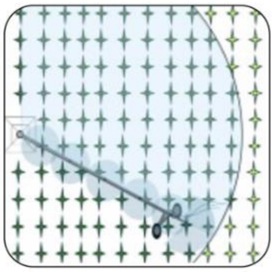
IRRIGATION: TURNING GALLONS INTO INCHES

We typically think of crop water requirements in inches since evapotranspiration and rainfall are reported as depths of water with no regard to area. In some cases, the volumetric measurement (gallons) for an irrigation application can be directly converted into linear measurement of depth (inches). Unfortunately, the calculation of an irrigation application's volume is not always this simple. Knowing the output of your irrigation system and the area it is applied to is essential for matching your irrigation application to the requirements of your crop!

Center-Pivot Irrigation



In many instances, irrigation covers broad areas of a field. Assuming the application is uniform, the volume of irrigation can be calculated as a linear depth (inches), solely based on the pumping rate of the well and area of application. In center-pivot irrigation, this requires matching the machine's rate of travel to cover the field within the time it takes to pump the total volume of water required. This is typically the simplest case where gallons applied, divided by the area under irrigation, results in the depth of the application. To convert the gallons to inches, an appropriate conversion factor that translates volume to surface area (square feet) and depth (inches) must be used.

$$1\ Gallon = 231\ in^3 \ \rightarrow \ \frac{231\ in^3/Gal}{144\ in^2\ /ft^2} = 1.604\ \frac{in\ ft^2}{Gal}$$

This conversion factor is often accompanied by a factor for efficiency to compensate for the water that does not end up making it to the plant's roots. It is common to assume 10% losses, or 90% efficiency, for an overhead irrigation application. This factor can be included into the conversion directly, as seen below, and may be written as a reciprocal so long as it is applied to the equation appropriately.

$$1.604\ \frac{in\ ft^2}{Gal} * 90\%\ \text{Efficiency} = 1.44\ \frac{in\ ft^2}{Gal}$$

Or in its reciprocated form:

$$\frac{1}{1.604\ \frac{in\ ft^2}{Gal}} = 0.62\ \frac{Gal}{in\ ft^2} * 90\%\ \text{Efficiency} = 0.56\ \frac{Gal}{in\ ft^2}$$

Note: Irrigation applications are unlikely to ever be 100% efficient. Highly efficient center-pivot and drip applications may be more than 90% efficient, indicating that more than 90% of the water arrives in the soil under the plant in some cases. The efficiency value used above accounts for the evaporative losses incurred during application due to wetting the crops leaves and the soil's surface. Do not confuse this with irrigation uniformity! This efficiency value can be underestimated by a small percentage to incorporate a small buffer.

In most cases, a chart on the inside of the center-pivot's control panel will indicate a setting to achieve a desired application depth. This is the amount of irrigation, precipitation or evapotranspiration is often referred to as "inches". However, in cases where the values are unknown or incorrect, the following equation can be used to estimate application parameters.

$$Application\ \boldsymbol{depth}\ (in) = \frac{Flow\ rate\ (GPM) * 60\ \frac{min}{hour} * Application\ duration\ (hr) * 1.44\ \frac{in\ ft^2}{gal}}{Irrigated\ area\ (Ac) * 43{,}560\ \frac{ft^2}{Ac}}$$

Example #1: A center-pivot with a well producing 500 gallons per minute (GPM) when the irrigation system is operating, took 24 hours to complete irrigating the 25-acre area. How many inches were applied?

$$Application\ \boldsymbol{depth}\ (in) = \frac{500\ (GPM) * 60\ \frac{min}{hour} * 24\ (hr) * 1.44\ \frac{in\ ft^2}{gal}}{25\ (Ac) * 43{,}560\ \frac{sq.ft}{ac}} = 0.95\ (in)$$

It is often more practical to know the desired depth of irrigation and assess for the total run time for the application. To do this, the equation is rearranged as follows:

$$Application\ \boldsymbol{duration}\ (hr) = \frac{Irrigated\ area\ (Ac) * 43{,}560\ \frac{ft^2}{ac} * Application\ depth\ (in)}{Flow\ Rate\ (GPM) * 60\ \frac{min}{hour} * 1.44\ \frac{in\ ft^2}{Gal}}$$

Example #2: A scheduling program indicates that 0.75 inches of irrigation need to be applied to keep up with evapotranspiration. The center-pivot has 50 acres under its coverage and a well producing 700 gallons per minute (GPM) when the irrigation system is operating. How many hours should it take the center-pivot to cover the irrigated area?

$$Application\ \boldsymbol{duration}\ (hr) = \frac{50\ (Ac) * 43{,}560\ \frac{sq.ft}{ac} * 0.75\ (in)}{700\ (GPM) * 60\ \frac{min}{hour} * 1.44\ \frac{in\ ft^2}{Gal}} = 27\ (hr)$$

Drip Irrigation (Estimated per Plant)

Drip or trickle irrigation allows producers to apply water directly to the root zone. This is ideal since evaporative losses are minimized and water is not applied to areas of the field that are not covered by the crop. While this is great for water conservation, you need to omit the area not covered by the crop and irrigation. This can be done by dividing the irrigation output by the estimated area of the crop. Since evapotranspiration is relative to canopy area, calculations for irrigation should also be based on canopy area. Even though irrigation is often applied to a smaller area within the canopy's footprint, using the crop's canopy area allows for direct comparison between irrigation supplied and removals due to evapotranspiration. Applying the irrigation for a plant that has a large canopy relative to the estimated area the irrigation is applied to can cause the irrigation to reach excessive depths. To prevent this, the total desired application depth may be divided into smaller applications and spaced out over a period of time. For a system in which gaps exist between rooting and or irrigated areas, the following equation focuses on a single plant to calculate the depth of irrigation applied by a drip irrigation system.

$$Plant - based\ application\ \boldsymbol{depth}\ (in) = \frac{Emitters\ per\ plant * Flow\ rate\ (GPH) * Duration\ (hr)}{0.62\ \frac{Gal}{in\ ft^2} * \pi * radius\ of\ plant\ canopy^2\ (sq.ft)}$$

Example #3: A drip line with two 0.5 (GPH) emitters irrigating each plant was turned on for 4.5 hours. The plants had an average canopy radius of 1.5 feet. How many inches were applied?

$$Plant - based\ application\ \boldsymbol{depth}\ (in) = \frac{2\ Emitters\ per\ plant * 0.5\ (GPH) * 4.5\ (hr)}{0.62\ \frac{Gal}{in\ ft^2} * 3.1415 * 1.5^2\ (sq.ft)} = 1.02\ (in)$$

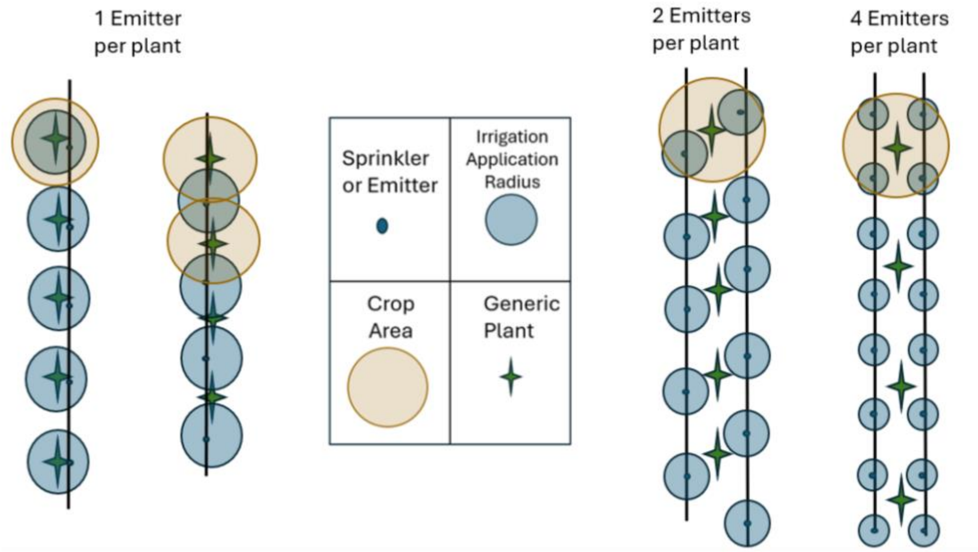
Just as with center-pivot irrigation, it is often beneficial to know the duration that the irrigation system should run for. Application depth is a target value that should be determined by a method of irrigation scheduling. Using the equation for plant-based duration, you can use a suggested application depth, generated by an irrigation scheduling program, as an input and calculate the duration your irrigation system should run for. Keep in mind that this duration may be broken into multiple smaller periods. This prevents the application from reaching depths below the root zone and allows time between the sub-applications for the crop to use the water. This is especially common in drip irrigation since application efficiency is high and the irrigation for a whole plant may be concentrated to a single emitter.

$$Plant - based\ \boldsymbol{duration}\ (hr) = \frac{0.62\ \frac{Gal}{in\ ft^2} * \pi *\ plant\ canopy\ radius^2\ (sq.ft) * Application\ depth\ (in)}{Emitters\ per\ plant\ *\ Flow\ rate\ (GPH)}$$

Example #4: A drip line with two 0.5 (GPH) emitters irrigating each plant and the plants had an average canopy radius of 3 feet. How many hours should the system run if the desired depth of irrigation is 0.75 inches?

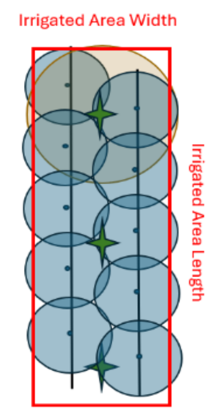
$$Plant - based\ \boldsymbol{duration}\ (hr) = \frac{0.62\ \frac{Gal}{in\ ft^2} * 3.1415 * 3^2\ (sq.ft) * 0.75\ (in)}{2\ Emitters\ per\ plant * 0.5\ (GPH)} = 13.1\ (hr)$$

Note: If irrigation water is likely to reach excessive depths (over 75% of the crop's maximum rooting depth), this application could be broken down into two 6.5-hour applications (13.1 (hr) / 2 = 6.5 (hr)) with the second half applied at a later time. This helps to keep the water higher in the root zone since it allows time for dispersion and utilization by the crop. This is an especially important consideration in sandy soils where water-holding capacity is low.



Drip Irrigation (Estimated per Row)

In cases where fields are established with continuous rows of plants and irrigated with systems which have minimal gaps between emitter coverage areas, you can treat each row as a system with complete coverage. One example is high density apple plantings with drip tape that have nearly overlapping application radii. This simplifies the equation, making it resemble the first example with complete coverage of an entire field. Instead of dealing with gaps between rows, the calculation can be reduced to account for only the area that is irrigated. Total flow can be a flow rate feeding the line or calculated based on the total number of emitters. The number of emitters can be calculated by dividing the total length of line by the emitter spacing in feet.



$$Row - based\ application\ \boldsymbol{depth}\ (in) = \frac{Total\ flow\ rate\ (GPH) * Duration\ (hr) * 1.6\ \frac{in\ ft^2}{Gal}}{Width\ of\ irrigated\ area\ (ft) * Length\ of\ irrigated\ area\ (ft)}$$

Example #5: Two drip lines serve a row with 18” spacing and 0.5 (GPH) emitters. The row has a width of 4 feet and a length of 50 feet. If the system was turned on for 2.5 hours, how many inches would be applied?

$$Total\ flow\ rate\ (GPH) = \#\ of\ lines\ per\ row * Row\ length\ (ft) * \frac{12\ \left(\frac{in}{ft}\right)}{Emitter\ spacing\ (in)} * Flow\ rate\ (GPH)$$

$$Total\ flow\ rate\ (GPH) = 2\ Drip\ lines\ per\ row * 50\ (ft) * \frac{12"\ per\ foot}{18"\ spacing} * 0.5\ (GPH) = 33.3\ (GPH)$$

$$Row - based\ application\ \boldsymbol{depth}\ (in) = \frac{33.3\ (GPH) * 2.5\ (hr) * 1.6\frac{in}{Gal}ft^2}{4\ (ft) * 50\ (ft)} = 0.67(in)$$

Example #6: A single drip line serves a row with 24” spacing and 0.25 (GPH) emitters. The row has a width of 4 feet and a length of 50 feet. How many hours should the system run if the desired depth of irrigation is 0.75 inches?

$$Row - based\ \boldsymbol{duration}\ (hr) = \frac{Irrigated\ width(ft) * Irrigated\ length(ft) * Application\ depth(in)}{Total\ flow\ rate(GPH) * 1.6 \frac{in}{Gal} ft^2}$$

$$Total\ flow\ rate\ (GPH) = 1\ drip\ line\ per\ row * 50(ft) * \frac{12"\ per\ foot}{24"\ spacing} * 0.25(GPH) = 6.25(GPH)$$

$$Row - based\ \boldsymbol{duration}\ (hr) = \frac{4(ft) * 50(ft) * 0.75(in)}{6.25(GPH) * 1.6 \frac{in}{Gal} ft^2} = 15(hr)$$

All of these estimations rely on the irrigation system applying an even application. For more details on irrigation uniformity see the MSU Irrigation Uniformity Facts Sheet at https://www.canr.msu.edu/irrigation/upoads/files/16-Catch-Can-Stands-for-Rain-Gauges-and-Uniformity-Check-Evaluating-Irrigation-06.25.20.pdf.

Irrigation Scheduling: Meeting Crop Demands

The question of when to apply irrigation depends on the crop, soil, and environmental conditions. Many irrigation scheduling methods are available, including the checkbook scheduling and the MSU Irrigation scheduler https://www.canr.msu.edu/irrigation/upoads/files/FS03-IrrigationSchedulingTools07.19.pdf. Another great method is implementing a soil moisture monitoring system to track moisture levels in your field. The provided soil moisture allows you to project when and how much to irrigate based on evapotranspiration, crop type, and soil characteristics. The soil in the root zone may or may not be able to hold the total volume of water required by the crop over a given period. Knowing your root zone’s water-holding capacity is critical! To keep up with the crop’s water use and evaporation, you may need to break the total volume of irrigation into several smaller applications. For most crops, the majority of root functions occur in the upper portions of the root system. Smaller volume applications applied more frequently are often more efficient in drip-irrigated crops as there is minimal evaporative loss. Irrigation that induces drainage is not used by the plant and will push nutrients below where the plant can draw from. Leaching nutrients can contribute to contamination of groundwater and is a waste of valuable resources! The picture on the right is an infiltration demonstration using blue dye to trace the depth and spread of an irrigation application in relation to the root zone. Applications should ideally be adjusted to match the crop’s rooting area, while accounting for existing soil moisture and favoring the upper regions of the root zone. This leaves room for unexpected precipitation and a margin of error.

Link for **scheduling resources**: https://www.canr.msu.edu/irrigation/upoads/files/FS03-IrrigationSchedulingTools07.19.pdf

Link for **other Irrigation resources**: https://www.canr.msu.edu/irrigation/