Horticulture

EXTENSION UtahStateUniversity

extension.usu.edu

January 2019 Horticulture/Vegetable/2019-01

Vegetable Irrigation: Leafy Greens

Dan Drost and ***Tiffany Maughan***

Proper irrigation is critical for leafy green production. Optimal irrigation management leads to healthy plants and maximum, high-quality yields. Under-irrigation results in a reduction of yield. Irrigation can be used to combat the negative effect of high temperatures on leafy greens but over-irrigation increases disease susceptibility, nutrient leaching, and water use inefficiency. A consistent moisture supply throughout all growth stages, but particularly during rapid growth is important for reducing tip-burn in leafy greens. Tip burn is characterized by brown spots or tissue breakdown along the margins of young leaves and is caused by localized calcium deficiency in the tissue. This occurs even when calcium levels in the soil are high. It is commonly due to water stress and low evapotranspiration.

Different irrigation methods are commonly used to irrigate leafy greens, each with different management considerations. Furrow irrigation is quite common but many growers are converting to use drip irrigation to save water, improve plant growth, and optimize productivity. Regardless of the irrigation system used, there are some basic principles to understand that will help ensure proper irrigation. This fact sheet will discuss these basic principles.

Properly managing irrigation is analogous to managing money. In addition to knowing your current bank balance (soil water content), it is important to track both expenses (evapotranspiration) and income (rainfall and irrigation).

Bank Balance (Soil Water Content)

How big is my bank account? – Water holding capacity

First, some terminology:

- Field Capacity is the amount of water that can be held in the soil after excess water has percolated out due to gravity.
- Permanent Wilting Point is the point at which the water remaining in the soil is not available for uptake by plant roots. When the soil water content reaches this point, plants die.
- Available Water is the amount of water held in the soil between field capacity and permanent wilting point (Figure 1).
- Allowable Depletion (readily available) is the point where plants begin to experience drought stress. Depending on soil type, the amount of allowable depletion leafy greens is about 25% of the total available water in the soil (Figure 2).

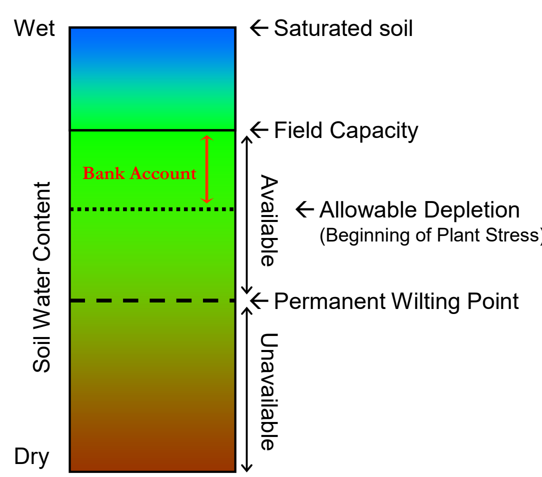

Figure 1. Soil water content from saturated to dry. Optimal soil moisture levels for plant growth are between field capacity and allowable depletion.

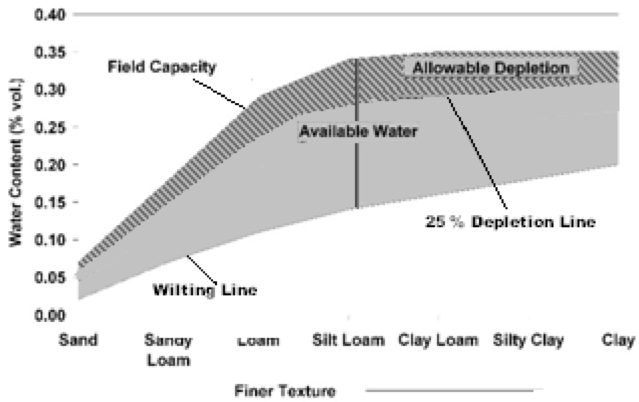

Figure 2. The amount of allowable depletion, or the readily available water, represents about 25% of the total available water.

The goal of a well-managed irrigation program is to maintain soil moisture between field capacity and the point of allowable depletion, or in other words, to make sure that there is always readily available water and that plants do not experience water stress.

The amount of readily available water is related to the effective rooting depth of the plant, and the water holding capacity of the soil. The majority of leafy greens are very shallow rooted. About 95% of spinach and 90% lettuce roots are in the top foot of soil. The water holding capacity within that rooting depth is related to soil texture, with coarser soils (sands) holding less water than fine textured soils such as silts and clays (Table 1). A deep sandy loam soil at field capacity, i.e., would contain 0.6 to 0.75 inch of readily available water in an effective rooting depth of 1 foot.

What's in the bank? Measuring Soil Moisture

In order to assess soil water content, monitor soil moisture at two depths: 6 inches deep and near the bottom of the effective rooting depth (12 to 18 inches deep). One of the more cost effective and reliable methods for measuring soil moisture is by electrical resistance block, such as the Watermark^{TM} sensor (Irrometer Co., Riverside CA). These blocks are permanently installed in the soil, and wires from the sensors are attached to a handheld unit that measures electrical resistance. Resistance measurements are then related to soil water potential, which is an indicator of how hard the plant roots have to "pull" to obtain water from the soil. The handheld unit reports soil moisture content in centibars, where values close to zero indicate a wet soil and high values represent dry soil. The relationship between soil water potential and available water differs by soil type. The range of the sensor is calibrated to 0 to 200 centibars (higher values indicate drier soil), which covers the range of allowable depletion in most soils. The sensors are less effective in coarse sandy soils, and will overestimate soil water potential in saline soils. Remember that allowable depletion is approximately 25% of available water, which roughly corresponds to soil water potentials of 20 centibars for a loamy sand soil, and 30 centibars for a loam (Table 2, 25% depletion values for each soil texture). Allowable depletion varies slightly by crop. For example, allowable depletion for spinach is 20% of available water whereas lettuce is 30%.

Table 1. Available water holding capacity for different soil textures, in inches of water per foot of soil. Total available water is the amount of water in the soil between field capacity and permanent wilting point. Allowable depletion (readily available water) is the amount of water the plant can use from the total available before experiencing drought stress. Allowable depletion for leafy greens is approximately 25% of total available.

Soil Texture	Total Available Water *inch/foot*	Allowable Depletion *inches* (Readily available) In top1'	In top1.5'
Sands and fine sands	0.5 - 0.75	0.13 - 0.19	0.19 - 0.29
Loamy sand	0.8 - 1.0	0.2 - 0.25	0.30 - 0.38
Sandy loam	1.2 - 1.5	0.3 - 0.38	0.45 - 0.57
Loam	1.9 - 2.0	0.48 - 0.5	0.72 - 0.75
Silt loam, silt	2.0 - 2.1	0.5 - 0.53	0.75 - 0.79
Silty clay loam	1.9 - 2.0	0.48 - 0.5	0.72 - 0.75
Sandy clay loam, clay loam	1.7 - 2.0	0.43 - 0.5	0.65 - 0.75

Table 2. Recommended Watermark™ sensor values at which to irrigate.

Soil Type	Irrigation Needed
	(*centibars*)
Loamy sand	20 - 25
Sandy loam	22 - 27
Loam	25 - 30
Silt loam, silt	28 - 32
Clay loam or clay	30 - 35

™Watermark is a registered trademark of Irrometer, Co., Riverside, CA.

Expenses – Evapotranspiration

Water is lost from the field through surface runoff, deep percolation (moving below the root zone), evaporation from the soil surface, and transpiration through the leaves of the plant. Of these, the biggest losses are typically due to evaporation and transpiration, collectively known as "evapotranspiration" or ET. Deep percolation from excess irrigation can be another large loss. Estimates of ET are based on weather data, including air temperature, relative humidity and wind speed. Table 3 lists average daily reference ET values

Table 3. Daily total alfalfa reference evapotranspiration (ET_r) for nine Utah cities expressed in (A) inches per day, (B) gallons per acre per day, and (C) drip-irrigated gallons per 100 feet of bed length per day.

Month	Logan	Brigham City	Ogden	Farmington	Salt Lake City	Spanish Fork	Richfield	Cedar City	St. George
(A) Inches per day									
Mar	0.09	0.10	0.10	0.12	0.11	0.12	0.14	0.13	0.15
Apr	0.15	0.16	0.17	0.19	0.17	0.16	0.20	0.18	0.22
May	0.20	0.22	0.22	0.25	0.22	0.21	0.23	0.24	0.28
Jun	0.24	0.27	0.28	0.30	0.28	0.26	0.30	0.31	0.32
Jul	0.29	0.32	0.32	0.27	0.30	0.28	0.29	0.29	0.31
Aug	0.26	0.28	0.29	0.23	0.27	0.25	0.27	0.27	0.28
Sep	0.18	0.20	0.20	0.19	0.19	0.18	0.20	0.21	0.21
Oct	0.09	0.12	0.12	0.12	0.11	0.10	0.13	0.14	0.14
(B) Gallons per acre per day. Irrigation amounts need to be adjusted by Crop Coefficient and Irrigation Efficiency. [1]									
Mar	2444	2716	2716	3259	2987	3259	3670	3451	4073
Apr	4073	4345	4617	5160	4617	4345	5386	5006	5974
May	5431	5974	5974	6789	5974	5703	6360	6412	7604
Jun	6517	7332	7604	8147	7604	7061	8102	8500	8690
Jul	7875	8690	8690	7332	8147	7604	7937	7788	8418
Aug	7061	7604	7875	6246	7332	6789	7385	7306	7604
Sep	4888	5431	5431	5160	5160	4888	5522	5739	5703
Oct	2444	3259	3259	3259	2987	2716	3609	3741	3802
(C) Drip-irrigated gallons per 100 feet of bed length per day based on 3-foot bed spacing. Irrigation amounts need to be adjusted by Crop Coefficient and Irrigation Efficiency. [2]									
Mar	16.8	18.7	18.7	22.4	20.6	22.4	25.3	23.8	28.1
Apr	28.1	29.9	31.8	35.5	31.8	29.9	37.1	34.5	41.1
May	37.4	41.1	41.1	46.8	41.1	39.3	43.8	44.2	52.4
Jun	44.9	50.5	52.4	56.1	52.4	48.6	55.8	58.5	59.8
Jul	54.2	59.8	59.8	50.5	56.1	52.4	54.7	53.6	58.0
Aug	48.6	52.4	54.2	43.0	50.5	46.8	50.9	50.3	52.4
Sep	33.7	37.4	37.4	35.5	35.5	33.7	38.0	39.5	39.3
Oct	16.8	22.4	22.4	22.4	20.6	18.7	24.9	25.8	26.2

[1]Conversion to gallons per acre per day (B) = (A) x 7.481 * 43560 / 12.
[2]Calculation for drip-irrigation: (C) = (B) x 3 ft. (bed spacing) / 435.6. If different bed spacing is used, adjust calculation accordingly.
Calculated from long-term monthly evapotranspiration values from Hill, 2011.

for several cities across Utah. Many more sites are monitored in the state. If your city is not listed, visit climate.usurf.usu.edu to find a location near you.

Some weather stations in Utah are programmed to calculate and report the ET estimates for alfalfa as a reference crop (ET_{ref} or ET_r). The ET of your crop can be determined by multiplying the ET_r by a correction factor or crop coefficient (K_{crop}) that is specific to your crop and its stage of development.

$$ET_{crop} = ET_r \times K_{crop}$$

The K_{crop} for several common leafy greens are shown in Table 4. The K_{crop} varies as the plant grows, represented in Table 4 as percent ground cover. Ground cover is determined by evaluating a representative section of a planting bed and either estimating or measuring how much bare soil is exposed when looking directly down at the section. If 60% of the soil is exposed, use the 40% ground cover value. In general, water use increases gradually as the crop develops until the full canopy is established. Leafy greens are typically cool season crops. In Utah, many greens are primarily grown in the spring and fall to avoid summer heat. Some differences between spring and fall production should be considered for irrigation scheduling. For example, spring production time for a lettuce crop takes approximately 70 to 80 days. In the fall this production window shortens to 50 to 60 days.

Table 4. Description of percent ground cover and crop coefficient estimates for several leafy green crops.

		% Ground Cover				
Crop		**20**	**40**	**60**	**80**	**100**
Beets/Chard[1]	**Kcrop**	0.26	0.35	0.55	0.77	1
Broccoli/Mustard[2]	**Kcrop**	0.24	0.5	0.79	1.02	1.08
Cabbage[1]	**Kcrop**	0.35	0.45	0.65	0.84	0.95
Lettuce (head)[2]	**Kcrop**	0.24	0.38	0.58	0.77	0.9
Lettuce (looseleaf)[1]	**Kcrop**	0.4	0.55	0.85	1.01	1.02
Spinach[1]	**Kcrop**	0.25	0.4	0.6	0.75	0.9

[1] From AgriMet Cooperative Agricultural Weather Network with alfalfa as the reference crop.

[2] From California Agriculture (Gratten et al., 1998) with grass as the reference crop.

Income – Irrigation and Rainfall

In Utah's high elevation desert climate, rainfall only contributes a small fraction of the in-season water requirements of the crop. Therefore, regular irrigation is needed to supply plant water needs. This irrigation water can be supplied by furrow, sprinkler, or drip lines.

Whichever irrigation system you utilize, it is important to calibrate your system so that you know precisely how much water is being applied. When trying to determine application uniformity, it is best to measure output at both ends of your irrigation system. Also, if your planting is on a slope, you should measure output at the highest and lowest points of your field. Elevation differences and the distance the water travels through the irrigation lines both affect water pressure, and consequently the flow rate at the nozzle.

Drip irrigation tape comes with recommended operating pressures, a variety of emitter spacing, and various flow rates. Most drip tapes operate at 10 psi. Emitters may be spaced from 4 to 36 inches apart and come in a variety of flow rates. Leafy greens do well with 4 to 12 inch emitter spacing. Flow rates are commonly reported in gallons per100 feet of tape per hour (GPH) or gallons/emitter/hr. For a tape with a 12-inch emitter spacing, 24 gallons/100ft/hr = 24/100 = 0.24 gallons/emitter/hr. Pressure compensating emitters (PC) provide the best uniformity. Flow rate from each emitter and emitter spacing can be used to calculate rate per area (Table 3). Drip irrigation systems are usually operated every day or every few days to maintain optimal soil moisture.

The efficiency of your system is a measure of how much you have to over-water the wettest spots in the field to get adequate water to the dry spots. Efficiency is related to the uniformity of application and to the amount of evaporation that occurs before the water can move into the soil. A well-designed drip system can be 70 to 90% efficient. Overhead sprinkler systems are typically 60 to 75% efficient, while flood and furrow irrigation is typically 30 to 50% efficient. If your water supply is limited, a more efficient system can make a large difference in water savings and crop productivity.

Case Study

Following is an example of how to calculate water needs for a head lettuce crop in Farmington, Utah, with a full canopy (100% ground cover) in June. The soil is a deep sandy loam with drip irrigated beds every 3 feet.

- Water use (Expenses)
  - ETr values are 0.30 inch/day (Table 3, weather station data).
  - Crop coefficient is 0.90 (Growth stage = 100% ground cover, from Table 4).
  - $ET_{crop} = ET_r \times K_{crop}$
  - ET_{crop} = 0.30 inch/day * 0.90 = 0.27 inches/day
- Soil storage capacity (potential bank balance)
  - The total storage capacity for readily available water over the 1.5 foot effective rooting depth is 1.5 inches (Table 1).
  - 1.5 inches / 0.27 inch per day = 5.55 (5) days between irrigations. In 5 days replace 1.5 inches.
- Restated, the soil moisture in the rootzone will go from field capacity to plant stress levels in 5.55 days.
- To recharge the soil profile, you will need to add a net of 1.5 inches of water every 5 days. Assuming a drip irrigation system with an efficiency of 90%, 1.67 inches of water application will be required for each watering. If you are operating your drip system on a daily basis you would set your system to apply 0.30 inch per day (0.27/0.90). For a 2 day irrigation interval, apply 0.60 inch (2*0.27/0.90).

Summary

Good irrigation management requires:

1. An understanding of the soil-plant-water relationship
2. A properly designed and maintained irrigation system, and a knowledge of the efficiency of the system
3. Proper timing based on
   a. Soil water holding capacity
   b. Weather and its effects on crop demand
   c. Stage of crop growth.

Each of these components requires a commitment to proper management. Proper management will lead to the maximum yields per applied irrigation water, and will optimize the long term health and productivity of your crop.

Irrigation Application Rates

• Surface Irrigation (flow usually in cubic feet per second)
Inches/hour = cubic feet per second (cfs) / acres
Example: 4 cfs / 5 acres = 0.8 inches/hour

• Drip Irrigation (flow per emitter is usually in gallons per hour)
Inches/hour = 1.6 * gallons per hour (gph)/emitter spacing (feet^2)
Example: 1.6 * 0.5 gph / (1 feet * 4.5 feet) = 0.18 inches/hour

• Irrigation Set Times
Set time (hours) = Gross Irrigation Need (inches) / application rate (inches/hour)
Example: 3 inches / 0.28 inches/hour = 10.7 hours

•Conversions
1 cfs = 448.8 gpm
1 gpm = 60 gph
1 acre = 43,560 feet^2

Additional Resources

AgriMet Crop Coefficients. Pacific Northwest Regional office of the Bureau of Reclamation.US Dept. of the Interior www.usbr.gov/pn/agrimet/cropcurves/crop_curves.html

Crop coefficients for use in irrigation scheduling. Water Conservation Factsheet. No. 577.100-5. British Columbia Ministry of Agriculture and Food. October 2001. www.agf.gov.bc.ca/resmgmt/publist/500Series/577100-5.pdf.

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This project is funded in part by USDA-Risk Management Agency under a cooperative agreement. The information reflects the views of the author(s) and not USDA-RMA.

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