Field Production

Major Update by Liz Maynard and Ben Phillips – Apr 2022

Vegetable Classifications

EPA Vegetable Crop Groups

EPA Crop Group	Crop
Group 1 (Root and Tuber Vegetables)	Beet, Carrot, Celeriac, Horseradish, Parsnip, Potato, Radish, Rutabaga, Sweet Potato, Turnip
Group 3 (Bulb Vegetables)	Garlic, Leek, Onion, Shallot
Group 4 (Leafy Greens and Leafy Petioles)	Arugula, Asparagus, Chicory, Chives, Celery, Cress, Endive, Escarole, Florence Fennel, Lettuce, Mizuna, Parsley, Radicchio, Rhubarb, Spinach, Swiss Chard
Group 5 (Cole Crops and Brassica Leafy Greens)	Broccoli, Brussels Sprouts, Cabbage, Cauliflower, Kale, Kohlrabi, Mustard Greens, Turnip Greens
Group 6 (Legume Vegetables)	Beans, Peas, Southern Peas/Cowpeas, Lima Beans
Group 8 (Fruiting Vegetables)	Eggplant, Pepper, Okra, Tomato
Group 9 (Cucurbit Vegetables)	Cantaloupe/Muskmelon, Cucumber, Pumpkin, Squash, Watermelon
Group 15 (Cereal Grains)	Sweet Corn
Group 19 (Herbs and Spices)	Basil, Cilantro, Coriander, Dill, Fennel, Florence Fennel, Lavender, Marjoram, Oregano, Parsley, Rosemary, Sage, Savory, Tarragon, Thyme

Botanically Related Vegetables

Plant Family	Crops
Amaranthaceae	Beet, Spinach, Swiss Chard
Amaryllidaceae	Chives, Garlic, Leek, Onion, Shallot
Apiaceae	Carrot, Celeriac, Celery, Cilantro, Coriander, Dill, Fennel, Florence Fennel, Parsley, Parsnip
Asparagaceae	Asparagus
Asteraceae	Chicory, Endive, Escarole, Lettuce, Radicchio, Tarragon
Brassicaceae	Arugula, Broccoli, Brussels Sprouts, Cabbage, Cauliflower, Cress, Horseradish, Kale, Kohlrabi, Mustard Greens, Mizuna, Radish, Rutabaga, Turnip, Turnip Greens
Convolvulaveae	Sweet Potato
Cucurbitaceae	Cantaloupe/Muskmelon, Cucumber, Pumpkin, Squash, Watermelon
Fabaceae	Beans, Peas, Southern Peas/Cowpeas, Lima Beans
Lamiaceae	Basil, Lavender, Marjoram, Oregano, Rosemary, Sage, Savory, Thyme
Malvaeae	Okra
Poaceae	Sweet Corn
Polygonaceae	Rhubarb
Solanaceae	Eggplant, Pepper, Potato, Tomato

Temperature Tolerances of Selected Vegetables

Warm-season		Cool-season	
Very Tender	Tender	Semi-Hardy	Hardy[1]
Cantaloupe, Cucumber, Eggplant, Lima Bean, Okra, Pepper, Pumpkin, Squash, Watermelon	Snap Bean, Sweet Corn, Tomato	Carrot, Cauliflower, Chinese cabbage, Lettuce, Potato	Asparagus, Broccoli, Cabbage Horseradish, Onion, Pea, Spinach

[1]Hardy crops are most tolerant of cool temperatures and frost. Very tender crops are most susceptible to frost and cool temperatures.

Using Plastic Mulch

Black plastic mulch laid before planting helps control weeds, reduce root pruning, and give profitable increases in early yields of warm-season crops. Wavelength- selective and clear mulches typically lead to greater early yields than black plastic, but weed growth under these mulches may be a problem. This is particularly true for clear mulch. Because leaching is retarded, less fertilizer is lost, and nitrogen sidedressing is often unnecessary with the plastic mulch. If nitrogen needs to be added, it can be applied later through the irrigation system.

Try to lay plastic mulches as early in the season as possible. Mulches should be laid as soon as the ground can be worked after a heavy rain. Irrigate the field if soil moisture is not adequate prior to laying the mulch. Plastic mulches should be laid over moist soil. If the plastic is laid over dry soil, it will actually delay subsequent transplant growth. It is better to lay out plastic at midday so it can be stretched tight. However, do not overstretch the plastic because cool nights may actually cause it to tear.

The seedbed should be as fine as possible in order to get a good covering. The plastic is laid by burying about 6 inches of each edge. Black plastic mulch is most effective in warming the soil when it is in direct contact with the soil.

A disadvantage of plastic mulch is disposal at the end of the season. Many landfills do not accept plastic mulches. Photodegradable plastic mulches, which degrade into small pieces of plastic that remain in the environment, are available. Biodegradable plastic mulches that break down completely are also available. Fully biodegradable mulches are currently more expensive, but do not need to be removed and disposed of at the end of the season, and do not leave long-lasting contamination in the environment. For more information on biodegradable mulches, see information from a nationally funded project at biodegradablemulch.tennessee.edu.

With plastic mulch, yields of pepper, eggplant, and summer squash are higher most years, and harvest can be up to seven days earlier than unmulched plantings. Clear plastic mulch is common in early sweet corn production. Growers can plant sweet corn in hills, single rows, or double rows, and apply herbicides before laying the plastic. Clear plastic mulch warms the soil and contributes to early harvest and quality produce.

Herbicides that were applied before the mulch was laid may break down before the crop matures. Unless otherwise advised, never apply herbicides over the top of plastic mulch. An alternative to the clear mulch/herbicide system is the Infra-red transmitting (IRT) or wavelength selective mulch system. IRT mulches provide similar soil warming to clear film while controlling most weeds like black plastic.

Apply all fertilizer before laying the plastic, but reduce the total amount applied by 10% to 15%, or apply some of the required fertilizer and plan to provide the rest through fertigation.

Mulch layers are available in various widths. They also can be adapted for raised beds and for the laying of trickle irrigation tubes all in one operation. Trickle irrigation combined with plastic mulch offers several advantages: it uses water economically, requires less energy for pumping, wets leaf surface less, allows for easy fertilizer application, provides a uniform moisture supply, and allows the application of certain insecticides and fungicides.

Irrigation and Water Management

Vegetables require an adequate supply of moisture throughout their entire growth. While the frequency and amount of water varies according to individual vegetable crop, its age, current soil moisture, soil type, and weather conditions, generally 1 to 1.5 acre inches of water are required each week. One acre-inch is 27,154 gallons of water.

Effective Rooting Depth of Selected Vegetables

Shallow (6-12 inches)	Moderate (18-24 inches)	Deep (> 36 inches)
Beet	Cabbage, Brussels sprouts	Asparagus
Broccoli	Cantaloupe	Lima bean
Carrot	Cucumber	Pumpkin
Cauliflower	Eggplant	Sweet potato
Celery	Pea	Watermelon
Greens & herbs	Potato	Squash, winter
Onion	Snap bean	
Pepper	Squash, summer	
Radish	Sweet corn	
Spinach	Tomato	

Vegetable Crops and Growth Period Most Critical for Irrigation Requirements

Crop[1]	Most Critical Periods
broccoli, cabbage, cauliflower, lettuce	head development
carrot, radish, beet, turnip	root enlargement
sweet corn	silking, tasseling, and ear development
cucumber, eggplant, pepper, melon, tomato	flowering, fruit set, and maturation
bean, pea	flowering, fruit set, and development
onion	bulb development
potato	tuber set and enlargement

[1]For transplants, transplanting and stand establishment represent a most critical period for adequate water.

The total available water holding capacity (AWHC) for a given location depends on soil texture, organic matter, and rooting depth. AWHC estimates are best obtained from the county soil survey or the local Soil and Water Conservation District office. The table 'Available Water Holding Capacities for Several Soil Types' shows AWHC estimates for some typical soil textures in the upper Midwest.

Irrigation should be initiated for most crops before 50% of the available water is removed by the plants in the active root zone. In most vegetable crops, the majority of the roots are usually within the top 6 to 18 inches of soil. When using a trickle irrigation system on shallow-rooted, water sensitive crops (lettuce, peppers, etc.), the allowable depletion is generally 20% to 25% of AWHC and the system is run more frequently. With deeper rooted, more drought-tolerant crops (pumpkin, watermelon), a higher depletion allowance can be used without loss of yield orquality.

Available Water Holding Capacities for Several Soil Types

Soil Texture	Available Water Holding Capacity	
	In Inches per Inch of Soil	In Inches per Foot of Soil
Loamy fine sand	0.08-0.12	0.96-1.44
Sandy loam	0.10-0.18	1.20-2.16
Loam	0.14-0.22	1.68-2.64
Silt loam	0.18-0.23	2.16-2.76
Clay loam	0.16-0.18	1.92-2.16

Soil Water Monitoring

Two common ways of estimating soil water deficit to assist irrigation scheduling are:

1. Measuring soil water tension with soil moisture sensors.
2. Observing the feel and appearance of soil samples collected using a soil probe or shovel.

Soil water tension can be monitored at a given point in the active root zone by electrical resistance moisture blocks or tensiometers. Soil tension or suction is a measurement usually expressed in centibars that describes how tightly water is held to the soil particles. The larger the value the drier the soil.

Tensiometers directly read soil tension between 0 and 80 centibars and work best in sandy loam or lighter textured soils. Resistance blocks work in a wider range of soil textures, and some types, such as Watermark sensors, work as well in lighter textured soils, as do tensiometers. If the soil texture is known, use the Soil Water Deficit Estimates for Different Soil Textures and Selected Tensions table to estimate the inches of soil water deficit for a given tension reading; use the Soil Tension Values for Different Soil Textures For Use in Scheduling Trickle Irrigation table to estimate the point of 20% to 25% depletion.

For example, let's say you have a sandy loam soil that has an AWHC of 1.5 inches per foot. A tomato crop would be irrigated before 50% (or about 0.7 inch) has been depleted in the upper foot of soil, or when a 6-inch tensiometer reads 45 centibars (Soil Water Deficit Estimates for Different Soil Textures and Selected Tensions). If we use the same soil for another example, a trickle-irrigated pepper crop would be irrigated when 20% to 25% (or 0.3 inch) has been depleted in the upper foot soil, or a 6-inch tensiometer reads 22 centibars (Soil Tension Values for Different Soil Textures For Use in Scheduling Trickle Irrigation).

To obtain representative soil tension readings with any sensor, the sensors should be left installed throughout the irrigation season and preferably at two or more locations in the field. Two depths are generally desired at each location. These depths should be about one-third and two-thirds of the active root zone, or about 6 and 12 inches for a rooting depth of 18 inches.

Estimating soil moisture by feel and appearance takes some practice. The Natural Resource Conversation Service (NRCS) provides instructions in *Estimating Soil Moisture by Feel and Appearance,* available at nrcs.usda.gov, or through your local NRCS office. A soil probe or shovel is used to collect samples from the desired depths. By observing the color and texture of the soil, squeezing it into a ball, pinching it between thumb and finger to form a ribbon, noting how well the ball holds together and how long a ribbon can be made, and comparing to photos or charts, it is possible to estimate soil water depletion and the% of available water remaining.

Soil Water Deficit Estimates for Different Soil Textures and Selected Tensions

Soil Texture	Soil Tension in Centibars (cbs)						
	10	30	50	70	100	200	1,500[1]
	Soil Water Deficit - Inches per Foot of Soil						
Coarse sands	0	0.1	0.2	0.3	0.4	0.6	0.7
Fine sands	0	0.3	0.4	0.6	0.7	0.9	1.1
Loamy sands	0	0.4	0.5	0.8	0.9	1.1	1.4
Sandy loam	0	0.5	0.7	0.9	1.0	1.3	1.7
Loam	0	0.2	0.5	0.8	1.0	1.6	2.4

[1]1,500 cbs refers to the permanent wilting point and the soil deficit value is equal to the soil's total available water capacity.

Soil Tension Values for Different Soil Textures For Use in Scheduling Trickle Irrigation

Soil Texture	0% Depletion of Available Water Holding Capacity (Field Capacity)[1]	20-25% Depletion of Available Water Holding Capacity[2]
	Soil Tension Values (in centibars)	
Sand, loamy sand	5-10	17-22
Sandy loam	10-20	22-27
Loam, silt loam	15-25	25-30
Clay loam, clay	20-40	35-45

[1]At field capacity the soil contains 100% of AWHC; any excess water in the rootzone has drained away.
[2]Start trickle irrigation for shallow-rooted crops at this point.

Information adapted from *Mid-Atlantic Commercial Vegetable Production Recommendations*, New Jersey Ag Expt. Station, Rutgers; and *Water Management in Drip-irrigated Vegetable Production* by T.K. Hartz, UC-Davis, Calif., HortTechnology 6:165-67.

Water Quality for Irrigation

Test irrigation water sources for suitability for irrigation. Many commercial labs provide this service. It is important to test for food safety; see the Food Safety chapter of this guide for information on these tests. It is also important to test for chemical characteristics including pH, alkalinity, salinity, and mineral content. If water is not suitable for irrigation it may be possible to treat it so it can be used.

In high tunnels and greenhouses where the soil or growing medium doesn't receive rainfall, one of the most common issues is high alkalinity in irrigation water. In the Midwest the alkalinity is caused by high levels of calcium and magnesium. Over time the high alkalinity leads to increases in soil or growing medium pH and eventually pH-related nutrition problems show up in crops. In greenhouses where this is a problem, treating irrigation water with acid is often used. The acid neutralizes most of the alkalinity. Acid is automatically injected into the irrigation system. The amount of acid required depends on the type of acid used and the alkalinity of the water.

The online calculator "ALKCALC" at e-gro.org provides recommendations for various concentrations of phosphoric, nitric, and sulfuric acid based on user-entered alkalinity. It is important to account for the nutrient contribution of the acid – P from phosphoric acid, N from nitric acid, and S from sulfuric acid – in the overall fertilizer plan. These acids are highly corrosive and must be handled with care. Always add acid to water; never water to acid. Wear proper face, hand and body protection. Other ways to deal with rising soil pH due to alkaline irrigation water include using sulfur to reduce soil pH (see the Soil Fertility and Nutrient Management chapter in this guide) and finding alternative water sources, for instance rainwater, to supply all or part of the irrigation need.

Chemical and Fertilizer Application Using Irrigation

Chemigation–applying ag chemicals with irrigation–and fertigation–applying fertilizers with irrigation–can be efficient ways to get materials into the root zone. See the Chemical Application and Safety chapter in this guide for more information about equipment and required safety measures.

Frost Control Using Irrigation

Irrigation can help protect vegetable crops from frost, although it is not a common practice in the Midwest. With the proper equipment, growers must begin sprinkling as soon as the temperature reaches 34 F. Place a calibrated thermometer at the lowest elevation in the field at plant level, facing skyward. Continue sprinkling plants until the air temperature is greater than 30 F and the ice has melted from the plants.

To be effective, you need approximately 0.1 inch of water per hour, the sprinkling must be continuous, and the sprinklers should rotate at least once per minute. If conditions become windy and temperatures drop, it may be necessary to increase the amount of water to as much as 0.5 inch per hour. It is the process of the water freezing that gives off the heat to protect the crop. Therefore, liquid water must be present during the freezing period to protect the plants.

Production Tables

Yield of Vegetable Crops

Crop	Expected Yields in Tons per Acre		
	Average	Good	Excellent
Asparagus	1	1.5	2
Bean, snap	2	3	4
Cabbage	13	15	20
Cantaloupe	10	15	19
Cucumber (slicing)	9	12	15
Cucumber (pickling, hand harvest)	6	10	12
Onion	13	18	23
Pepper, green	14	17	20
Potato (fall)	10	15	20
Pumpkin	10	15	25
Spinach	6	8	10
Summer squash	10	13	16
Sweet corn	4.5	8	10
Sweet potato	7	12	15
Tomato (fresh market)	11	13	15
Tomato (processing)	25	29	33
Watermelon	15	20	25

This table only provides general yield estimates for new or prospective growers. The USDA-National Agricultural Statistics Service Vegetable Survey provides more accurate information.

Postharvest Handling and Storage Life of Fresh Vegetables

A lack of adequate refrigeration and cooling will shorten the shelf-life and lower the quality of fresh vegetables. Cucumber, eggplant, lettuce, green or ripe pepper, potato, snap bean, summer squash, and tomato are among the most susceptible vegetables to chilling or freezing injury. Some cold injury symptoms that can make vegetables unmarketable. The most typical include pitting, water- soaked spots, browning, surface decay, and, in pepper and tomato, failure to ripen.

The following list of recommended storage condition information is adapted from *The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks* (USDA-ARS Agriculture Handbook Number 66, ars.usda.gov), *Knott's Handbook for Vegetable Growers* (Donald N. Maynard and George J. Hochmuth, 5th ed., 2007), and *Properties and Recommended Conditions for Long-Term Storage of Fresh Fruits and Vegetables* (Marita Cantwell, University of California-Davis, Postharvest Technology website, postharvest.ucdavis.edu).

Vegetable	Storage Conditions		
	Temp (˚F)	Relative Humidity (%)	Relative Storage Life
Asparagus	36	95-100	2-3 weeks
Beans, snap	40-45	95	7-10 days
Beets & carrots, bunched	32	98-100	10-14 days
Broccoli	32	95-100	10-14 days
Cabbage, late	32	98-100	5-6 months
Cantaloupe	36-41	95	2-3 weeks
Cauliflower	32	95-98	3-4 weeks
Cucumber	50-54	85-90	10-14 days
Eggplant	50-54	90-95	1-2 weeks
Greens (collards, kale, & spinach)	32	95-100	10-14 days
Lettuce	32	98-100	2-3 weeks
Okra	45-50	90-95	7-10 days
Onions, dry	32	65-70	1-8 months
Onions, green	32	95-100	3 weeks

Vegetable	Storage Conditions		
	Temp (˚F)	Relative Humidity (%)	Relative Storage Life
Peas, in pods	32	90-98	1-2 weeks
Peas, southern	40-41	95	6-8 days
Pepper, green	45-55	90-95	2-3 weeks
Pepper, ripe	42-45	90-95	1 week
Potato, early	a	90-95	a
Potato, late	b	90-95	b
Pumpkin	54-59	50-70	2-3 months
Radish	32	95-100	1-2 months
Rhubarb	32	95-100	2-4 weeks
Squash, summer	40-45	95	1-2 weeks
Squash, winter	54-59	50-70	c
Sweet corn	32	95-98	2-5 days, up to 21 days for supersweet cultivars
Sweet potato	55-59	85-95	4-7 months
Tomato, light red	50-55	90-95	1 week
Tomato, mature-green	50-60	90-95	1-2 weeks
Tomato, firm-ripe	46-50	85-90	3-5 weeks
Turnip root	32	95	4-5 months
Watermelon	50-60	90	2-3 weeks

[a]Most summer-harvested potatoes are not stored. However, they can be held 4-5 months at 40 F if cured 4-5 days at 60-70 F before storage. They can be stored 2-3 months at 50 F without curing. Potatoes for chips should be held at 70 F or conditioned for best chip quality.

[b]Fall-harvested potatoes should be cured at 50-60 F and high relative humidity for 10-14 days. Storage temperatures for seed or table stock should be lowered gradually to 38-40 F. Potatoes intended for processing should be stored at 50-55 F. Those stored at lower temperatures or with a high reducing sugar content should be conditioned at 70 F for 1-4 weeks or until trial cooking tests are satisfactory.

[c]Winter-squash varieties differ in storage life. Acorn squash can be stored for 35-55 days, butternut squash for 60-90 days, and Hubbard squash for 180 days.