C. Irrigation Management

1. Basic Principles

Moisture management throughout the growing season is a critical factor for the production of high-quality vegetables. Even relatively short periods of inadequate soil moisture can adversely affect crops. Supplemental irrigation is beneficial in most years since rainfall in the Mid-Atlantic region is rarely uniformly distributed throughout the growing season, even in years with above-average precipitation.

Moisture stress has varying effects on plants depending on developmental stage and type of stress. Moisture deficiencies occurring early in the crop cycle may delay maturity and reduce yields and quality. Shortages later in the season often decrease produce quality, as well as yields, or even result in irreversible crop damage. Over-irrigation, especially late in the season, can reduce the quality and post-harvest life of the produce. Table C-1 shows the periods of crop growth when an adequate supply of water is critical for high-quality vegetable production.

Applying the proper amount of water at the correct time and location is critical for achieving the optimum benefits from irrigation. The crop water requirement, termed evapotranspiration, or ET is equal to the quantity of water lost from the plant (transpiration) plus that evaporated from the soil surface. Knowledge of ET is the most important factor for effective irrigation management. Many factors must be considered when estimating ET. The most important factor is the amount of solar radiation (sunlight), which provides the energy to evaporate moisture from the soil and the plant. Other important factors are air temperature, wind speed, and humidity level. Different crops also have different transpiration rates.

Instruments that measure soil moisture content or soil water potential are commonly used to measure changes in soil moisture and adjust irrigation schedules (see “Scheduling Irrigation with Soil Moisture Sensors” in section C 2. Drip (Trickle) Irrigation below).

Table C-1. Most Critical Periods of Water Needs by Crops

Crop	Most Critical Period		Crop	Most Critical Period
Asparagus	Brush (period following fern mowing)		Onions: dry	Bulb enlargement
Beans: lima	Pollination and pod development		Peas	Seed enlargement and flowering
Beans: snap	Pod enlargement		Peppers	Flowering and fruit development
Broccoli	Head development		Potatoes: white	Tuber set and tuber enlargement
Cabbage	Head development		Potatoes: sweet	Root enlargement
Carrots	Root enlargement		Radishes	Root enlargement
Cauliflower	Head development		Strawberries	Establishment, runner development, fruit enlargement
Corn: sweet	Silking and tasseling, ear development			
Cucumbers	Flowering and fruit development		Squash: summer	Bud development and flowering
Eggplants	Flowering and fruit development		Tomatoes	Early flowering, fruit set, and enlargement
Lettuce	Head development		Turnips	Root enlargement
Melons	Flowering and fruit development			

Crop Water Requirement

Plant factors affecting the crop water requirement are crop species and variety, canopy size, leaf characteristics (size, shape, wax coating, and orientation), plant population density, rooting depth, and stage of growth and development of the crop. The plant canopy size and shape influences transpiration, light absorption, reflection, and the rate at which water evaporates from the soil. Crops that feature a canopy with more surface area for transpiration and sunlight interception (mature sweet corn, potatoes, snap beans) use more water than crops that do not have an extensive canopy (onions, immature plants, recently transplanted crops). Rooting depths vary with crop species and may be affected by soil compaction, hard pans, and pH. Rooting depth determines the volume of soil from which the crop can draw water and is important when determining to what depth the soil must be wetted by irrigation. For most vegetables, the effective rooting depth is approximately 12 inches.

Plant growth stage influences vegetable susceptibility to moisture stress. Irrigation is critical when establishing newly seeded or transplanted crops. During the first 1-2 weeks of seedling or transplant growth, the root system is not yet established in surrounding soil and irrigation can significantly increase plant survival, especially when soil moisture is marginal. Irrigation can also increase the uniformity of emergence and final stand of seeded crops. For seeded crops, reduce the rate of application and the total volume of water per application to avoid crusting (cohesion of soil particles at the surface). If crusting is present, continue to apply low rates at high frequency while seedlings are emerging. Keeping the soil surface moist will reduce the force necessary for seeding emergence. Water use by vegetable crops increases up to full canopy and then will decrease thereafter. For warm season crops, peak water use can be as much as 0.30 inches per day in mid-summer.

Cultural practices also influence ET. Cultivation, mulching, weed growth, and method of irrigation are factors to consider. Cultivation generally increases soil evaporation, but if crop roots are pruned or damaged by the cultivator, water uptake and transpiration may be reduced. Shallow cultivation may help eliminate soil crusts and improve water infiltration from rainfall or irrigation. Weeds compete with the crop for water and increase the volume lost through transpiration. Sprinkler irrigation wets the entire crop area and results in greater evaporation loss than trickle/drip irrigation, which wets only the area in the region of the plant root system. Trickle/drip irrigation systems require more frequent operation to prevent plant stress due to the relatively small, wetted area.

Soil factors must also be considered. Soils with high levels of silt, clay, and organic matter have greater available water-holding capacities than do sandy soils or soils that are compacted (Table C-2). Available water refers to the amount of water that a plant can withdraw from the soil. Soils with high available water-holding capacities require less frequent irrigation than soils with low available water-holding capacities. Low water-holding capacity soils like loamy sands and sandy loams require frequent irrigation in smaller amounts due to the low holding capacity.

Another soil factor that influences irrigation practices is the soil infiltration rate. Water should not be applied to soils at a rate greater than the rate at which soils can absorb water. This can be problematic in silt and clay loam soils, particularly with sprinkler irrigation. Excessive irrigation may lead to erosion from runoff and promote disease development. Table C-3 lists the typical infiltration rates of several soils.

Table C-2. Available Water-Holding Capacity Based on Soil Texture

Soil Texture	Available Water-Holding Capacity (inch of water/ inch depth of soil)
Coarse sand/compacted sands	0.02 - 0.06
Fine sand	0.04 - 0.09
Loamy sand	0.06 - 0.12
Sandy loam	0.11 - 0.15
Fine sandy loam/compacted loams	0.14 - 0.18
Loam and silt loam	0.17 - 0.23
Clay loam and silty clay loam	0.14 - 0.21
Silty clay and clay	0.13 – 0.18

Table C-3. Soil Infiltration Rates Based on Soil Texture

Soil Texture	Soil Infiltration Rate (inch/hour)
Coarse sand	0.75 - 1.00
Fine sand	0.50 - 0.75
Fine sandy loam	0.35 - 0.50
Silt loam	0.25 - 0.40
Clay loam	0.10 - 0.30

Irrigation Principles

There is no simple method to accurately schedule irrigation events since all the above factors interact to determine actual ET. In the absence of reliable methods to estimate ET, the following should be kept in mind when deciding when and how much to irrigate:

1. Soils vary greatly in water-holding capacity and infiltration rate. Silt and clay soils and soils high in organic matter can hold much more water than sandy soils low in organic matter.
2. Water loss from plants and the soil surface is much greater on clear, hot, windy days than on cool, overcast,

humid days. During periods of hot, dry weather, when the crop is at full canopy, ET rates may reach 0.3 inch/day or higher.

3. Research shows that irrigating to maintain soil moisture levels in a narrow range, just below field capacity (60 to 80% available soil moisture), results in better crop performance than if the range is broader. Soil moisture monitoring is therefore a more accurate way to determine irrigation needs.
4. Plastic mulches reduce evaporation from the soil but also reduce the amount of water that can reach the root zone from rain. Thus, much of the natural precipitation should be discounted when scheduling irrigations for crops grown using plastic mulch.
5. On moderate moisture-holding capacity soils, apply 0.25-0.75 inches of water per irrigation event. This will ensure that water reaches active areas of the root zone. The exception is during early crop growth and establishment when lower rates may be appropriate. With sandy soils, daily irrigation applying only what can be used that day is best. Splitting or pulsing the daily application with a 2+ hour break between applications has shown benefits, particularly in very coarse soil.
6. If irrigation water has a high salt content (for example, wells in coastal aquifers or tidal streams), excess water should be applied during each irrigation event to leach any salts before they are concentrated by evaporation. It is necessary to regularly measure the salinity of tidal surface water to prevent crop damage.
7. Total weekly water needs for vegetable crops will increase to full canopy and decrease thereafter. Irrigation rates should be adjusted accordingly. Critical crop stages such as fruiting, or tuber bulking should also be considered in determining weekly irrigation rates.

2. Drip (Trickle) Irrigation

Drip (or trickle) irrigation is used on a wide range of vegetable crops. Drip irrigation is a method of slowly applying small amounts of water directly to the plant root zone. Water is applied frequently, often daily or several times a week, to maintain favorable soil moisture conditions. The primary advantage of drip irrigation systems is that water use is more efficient than with overhead sprinkler irrigation systems. In many cases, one-half or less of the water applied with sprinkler or surface systems is required with drip systems because there is no evaporation loss from the soil surface. Most of the water conservation from drip irrigation occurs in the early season. The difference in water use between drip and sprinkler is negligible once a full canopy is achieved. In addition, substances applied through the drip irrigation system, such as pesticides and fertilizers, can be conserved along with water, provided the drip system is managed correctly.

Drip irrigation systems have several other advantages over sprinkler and surface irrigation systems. Low flow rates and operating pressures are typical for drip systems. These characteristics lead to lower energy and equipment costs. Once in place, drip systems require little labor to operate, can be automatically controlled, and can be managed to precisely apply the amount of water needed by the crop, which also reduces operating costs. With most drip systems, disease and insect damage is reduced because leaves are not moistened by irrigation water. In addition, the areas between rows remain dry, which reduces weed growth and water use, as well as pests and pathogens in these areas of the field. Another advantage is that field management operations can continue during irrigation.

There are also potential problems with drip irrigation systems. Most drip irrigation systems require a higher level of management than other irrigation systems. Moisture dispersal throughout the soil is limited, and usually a smaller soil water reserve is available to plants. Under these conditions, the potential to stress plants is greater than with other types of irrigation systems. Drip systems must be carefully managed to avoid localized moisture stress.

The equipment used in drip systems can present potential problems. Insects, rodents, and people can damage drip irrigation equipment. Pressure regulation is critical, and filtration is required. The drip system, including the pump, headers, filters, and connections, must be checked and ready to operate before planting. Failure to have the system operational could result in costly delays, poor plant survival or irregular stands, and reduced yield. Drip systems cannot be used for frost control. Calculating the length of time required to apply a specific depth of water with a drip irrigation system is more difficult than with sprinkler systems. Drip systems add an additional cost for processing vegetables, are not adapted to drilled crops such as peas, and, therefore, may not be economical for these crops.

Drip irrigation is especially effective when used with plastic or organic mulches. Unlike sprinkler systems, drip systems apply water to only a small portion (wetted zone) of the total crop acreage. Usually, a fair assumption to make is that the mulched width approximates the extent of the plant root zone and should be used to calculate system run times for most vegetables. Table C-4 shows the amount of water applied per hour with a drip irrigation system based on the drip tube flow rate and the total cropped area (excluding drive rows). The use of this table requires that the drip system be operated at the pressure recommended by the manufacturer.

Table C-4. Irrigation Applied per Hour per Cropped Acre (Inches)

Drip Tape Flow Rate (gpm/100')	Tape Spacing (ft)						
	2.5	**3**	**4**	**5**	**6**	**7**	**8**
0.22	0.08	0.07	0.05	0.04	0.04	0.03	0.03
0.34	0.13	0.11	0.08	0.07	0.05	0.05	0.04
0.45	0.17	0.14	0.11	0.09	0.07	0.06	0.05
0.67	0.26	0.21	0.16	0.13	0.11	0.09	0.08

Table C-5 presents the maximum recommended irrigation period for drip irrigation systems. The irrigation periods listed assume that 50% of the available water in the root zone is depleted (see next section on the use of soil moisture monitoring equipment for determining when this occurs). Soil texture directly influences the water-holding capacity of soils and, therefore, the depth reached by irrigation water.

Table C-5. Maximum Number of Hours per Application for Drip Irrigated Vegetables
Based on a 12-inch-deep root zone and irrigation at 50% soil moisture depletion during the day.
Cut the maximum run times in half for nighttime irrigation and when active crop water use is not occurring.

Soil Texture	Estimated Wetted Width (in)	Maximum Run Time (hours) by Tape Flow Rate (gpm/100')			
		0.22	**0.34**	**0.45**	**0.67**
Coarse Sand	**8**	1.5	1.0	0.7	0.5
Fine Sand	**10**	3.3	2.1	1.6	1.1
Loamy Sand	**12**	5.1	3.3	2.5	1.7
Sandy Loam	**16**	9.8	6.4	4.8	3.2
Fine Sandy Loam	**20**	15.1	9.8	7.4	5.0
Loam and Silt Loam	**24**	22.7	14.7	11.1	7.4
Clay Loam	**24**	19.3	12.5	9.4	6.3
Silty Clay and Clay	**24**	17.0	11.0	8.3	5.6

Scheduling Irrigation with Soil Moisture Sensors

Irrigation scheduling is a management practice used to determine how often to irrigate and how much water to apply with each irrigation event. Irrigation duration was discussed in the previous section and should be based on soil available water-holding capacity and soil moisture depletion level. Soil moisture sensors are tools used to measure soil water. This can then be used to determine how much soil moisture has been depleted and when irrigation should be scheduled.

Determining Soil Moisture Levels:

Hand-Feel Method

This is the easiest and cheapest method to determine soil moisture levels for irrigation scheduling. Soil samples are collected using a soil probe or shovel, and the moisture level is estimated by "feeling" the soil and comparing it to known conditions. This method can allow for multiple depths of samples and is not susceptible to equipment failures; however, it does require an experienced operator to get consistent results. The United States Department of Agriculture Natural Resource Conservation Service, USDA-NRCS, provides an excellent guide to using the hand feel method, available at your local NRCS office or at *https://nrcs.usda.gov/sites/default/files/2022-09/Estimating%20Soil%20Moisture%20by%20Feel%20and%20Appearance.pdf*.

Tensiometers

Tensiometers are excellent tools for determining irrigation frequency because they indirectly measure water available in the crop root zone. Tensiometers are glass or plastic tubes filled with water hermetically sealed with a porous ceramic tip submerged in the soil at one end and a vacuum gauge at the other end. As the soil dries, its capillary action will try to suck the tensiometer water through the ceramic tip creating a vacuum. This vacuum is a measure of soil tension or "soil suction" or "matric potential." Soil tension is a measure of how tightly water is held in the soil and is measured in pressure units of centibars (cb) or kilopascals (kPa). These are different units of measurement of the same condition: soil vacuum. The soil tension measured with tensiometers is an indirect indication of soil moisture content and can be used as an indicator of irrigation need.

Table C-6 contains guidelines for using soil tension data to schedule irrigation events. Field capacity is the moisture content at which a soil is holding the maximum amount of water it can against the force of gravity. This moisture content is reached 24 to 72 hours after saturating rain or irrigation. Field capacity corresponds to soil tension levels ranging from 5 to 10 cb in coarse-textured soils and as high as 40 cb in fine-textured soils.

Table C-6. Irrigation Guidelines for Tensiometers

Soil Texture	Soil Tension (cb)	Soil Moisture Status and Irrigation Requirement
Sand, Loamy Sand	5 – 10	Soil at field capacity; no irrigation required
Sandy Loam, Loam, Silt Loam	10 – 20	
Clay Loam, Clay	20 – 40	
Sand, Loamy Sand	20 – 40	50% of available water depleted; irrigation required
Sandy Loam, Loam, Silt Loam	40 – 60	
Clay Loam, Clay	50 – 80	

The soil tension range corresponding to the time when irrigation should begin is also influenced by **soil texture**. In coarse-textured soils, irrigation should begin at soil tensions of 20 to 40 cb. In extremely coarse-textured soils, irrigation may be necessary at even lower tensions (see Table C-6). Conversely, medium- and fine-textured soils do not need to be irrigated until soil tensions reach higher values, as shown in Table C-7. For all soil types, irrigate when a maximum of 50% of available water has been depleted. Lower depletion allowances may be used depending upon specific crop and management needs.

The utility of tensiometers in fine-textured soils is limited due to the range of detection. When soil dries beyond the 80 cb tension level, the column of water in the tensiometer "breaks," allowing air to enter the device. After breaking tension, the device ceases to operate correctly until it is serviced. Thus, tensiometers are the most practical in sandy or coarse-textured soils where normal soil tension levels are well below the point of breaking tension. In sandy soils it is often desirable to use ½ bar gauges that read in the 0-50 cb range rather than the standard 0-100 cb.

Ideally, four tensiometers per management zone should be used to account for variability in soil texture and other factors within the field. Install at least one tensiometer in the area that will likely require water sooner than other areas of the field (*e.g.*, sandier soils and high areas). The remaining tensiometers should be placed to inscribe a triangle within the area to be irrigated but inside field edges. The inherent variability of the irrigation system should also be considered as the overlaps of sprinklers or the reduced output of drip emitters due to run length or slope will affect the reading. Irrigation decisions are based on the average of all the readings.

Tensiometer placement influences measured soil tension levels. Tensiometers should be placed where plant roots are actively growing. It is appropriate to monitor soil tension 6-12 inches below the soil surface and within 6-12 inches from the plant base. If using drip irrigation, place the tensiometer axis close to the drip tape and the sensor (tip) buried 6-12 inches below the soil surface. This ensures that readings reflect moisture in the root zone and decrease when irrigation occurs. Placement near the drip tape is even more important when growing in coarse-textured soils and on raised, mulched beds. In these situations, the bed shoulders often remain very dry and placing tensiometers there will not give an accurate measure of soil tension in the active crop root zone.

Tensiometers can also be used in other ways. Placing tensiometers at various soil depths at the same location is useful for determining whether an irrigation or rainfall has reached a certain depth. Placing tensiometers at various depths is also useful for determining the depth from which plants draw the most water.

<u>Resistance Meters</u>

Electrical resistance meters determine soil water by measuring the electrical resistance between two wire grids embedded in a porous matrix such as gypsum, ceramics, glass fibers, or nylon cloth. To measure soil moisture, sensors are buried in the crop root zone in the soil. The electrical resistance of sensors varies with water content, which in turn is dependent upon the water content of the soil in contact with them. As the soil dries, the sensor loses water and the electrical resistance increases. Therefore, resistance changes within the sensor as measured by the meter can be interpreted in terms of soil water content. New generation “matrix” sensors are more accurate and consistent than are older “gypsum” sensors. The sensors, which have embedded stainless steel electrodes, are installed at desired locations and depths in the soil during the growing season. Insulated wires from each sensor are brought above the soil surface where they can be plugged into a portable meter for reading.

Resistance sensors are generally calibrated in terms of soil water tension so that readings are applicable across soil textures. Sensors should be calibrated for each soil type. The way different commercial sensors respond to changes in soil water tension varies considerably, and manufacturers provide calibration curves for their equipment. When sensor readings are expressed as soil water tension, the irrigation chart in Table C-6 can be used as a guide.

Prepare resistance matrix sensors according to manufacturer’s recommendations before installation. This normally requires soaking in water. Soaking removes air from the sensors and ensures accurate meter readings.

Using a soil probe or auger, bore a hole in the row slightly larger than the sensor. Make a separate hole for each sensor to the desired depth. Crumble up at least 3 inches of soil removed from the hole and put it back into the hole. Pour about ½ cup of water into the hole to form a slurry of mud at the bottom. Push the sensor firmly to the bottom of the hole, forcing the slurry to envelop the sensor. A good way to do this is to use a section of ½-inch electrical conduit or pipe and slip the conduit over the lead wire and against the top of the sensor. Backfill the holes with soil 3 or 4 inches at a time, tamping firmly as the hole is filled. Drive a stake midway between the filled holes and tie the wire that leads to the stake. Be sure to mark the wires in some manner so that you can identify which one is for the shallow sensor and which one is for the deeper sensor. Install and locate resistance sensors and meters in a similar manner to tensiometers to give accurate information on soil water depletion.

Volumetric Soil Moisture Sensors

Volumetric soil water sensors such as TDR (Time Domain Reflectometry) and FDR (Frequency Domain Reflectometry) sensors can measure soil water accurately. They require power sources to operate (battery, solar, wired) and are typically much more expensive than tensiometers and resistance blocks. For irrigation scheduling, sensors at various depths and locations in the field are installed and monitored. Soil moisture is recorded as volume of water per volume of soil. This then can be related to the available soil water percent based on a specific soil type by calibration to produce a soil water curve.

Maintaining Drip Irrigation Systems

Water is carried through plastic tubing and distributed along the tubing through orifices or small holes called emitters. The emitters dissipate the pressure from the system by forcing the water exiting from an emitter through orifices, tortuous flow paths, pressure reducing flow paths, or long low paths, thus allowing a limited flow of water to be discharged. The pressure-reducing flow path also allows the emitter diameter to remain relatively large, allowing particles that could clog an emitter to be discharged.

Insect damage to thin-walled polyethylene drip tubing or “tape” can be a major problem. Ants, wireworms, earwigs, mole crickets, field crickets, grubs and other insects typically damage drip tape by chewing holes through the side walls. This damage destroys the integrity of the tape, resulting in small to massive leaks that may result in poor moisture distribution and soil erosion.

Other types of drip tape damage may be mistaken for insects. For example, rats, mice, gophers, and birds can chew, gnaw, or peck holes in thin-walled polyethylene tapes. Damaged tape should be inspected under magnification to provide clues to the source prior to taking action to remediate the responsible agent.

Although modern emitter design reduces the potential for trapping small particles, emitter clogging remains the most serious problem with drip irrigation systems. Clogging can be attributed to physical, chemical, or biological contaminants. Filtration and occasional water treatment may be necessary to keep drip systems from clogging.

Bacteria can grow inside drip irrigation tubes and form a slime, known as a biofilm, that can clog emitters and can serve as a source of plant and human disease-causing pathogens. Algae present in surface waters and in high iron wells can also clog emitters. Biofilms and algae can be effectively controlled by chlorination of the trickle system. Periodic treatment **before** clogging develops can keep the system functioning efficiently. The frequency of treatment depends on the quality of the water source. Generally, two or three treatments per season are adequate.

Irrigation water containing high concentrations of iron (greater than 1 ppm) can also result in clogging problems due to the types of bacteria that "feed" on dissolved (ferrous) iron. The bacteria secrete a slime called ochre that may combine with other solid particles in the drip tape and plug emitters. The precipitated (ferric) form of iron, known commonly as rust, can also physically clog emitters. Treating water containing iron with chlorine will oxidize the dissolved iron, causing the element to precipitate so that it can be filtered and removed from the system.

Chlorine treatment should take place upstream of filters in order to remove the precipitated iron and microorganisms from the system. Take care when adding chlorine to drip irrigation systems, however, since concentrations at or above 30 ppm can be toxic to growing plants.

Chlorine is available in either gas, liquid, or solid forms. Chlorine gas is extremely dangerous and not recommended for agricultural purposes. Solid chlorine is available as granules or tablets containing 65 to 70 percent calcium hypochlorite. Liquid chlorine is available in many forms, including laundry bleach and post-harvest wash materials. Liquid forms typically contain between 5 and 15 percent sodium hypochlorite. **Use chlorine only if the product is labeled for use in irrigation systems**.

Because chlorination is most effective in water at pH 6.5 to 7.5, some commercial chlorination equipment also injects buffers to maintain optimum pH for the effective killing of microorganisms. This type of equipment is expensive but more effective than simply injecting a sodium hypochlorite solution. The rate of chlorine injection required is dependent on the number of microorganisms, the amount of iron in the water source, and the method of treatment being used.

For managing dissolved iron and microbes in the water source, one of the following basic strategies is suggested as a starting point:

For iron treatment:

- Inject liquid sodium hypochlorite continuously at a rate of 1 ppm for each 1 ppm of iron in irrigation water. In most cases, 3 to 5 ppm is sufficient.

For bacteria and algae treatment:

- Inject liquid sodium hypochlorite continuously at a rate of 5 to 10 ppm where the biological load is high.
- Inject 10 to 20 ppm during the last 30 minutes of each irrigation cycle.
- Inject 50 ppm during the last 30 minutes of irrigation cycles one to two times each month. Super chlorinate can be used (injected at a rate of 200 to 500 ppm) once per month for the length of time required to fill the entire system with this solution and shut down the system. After 24 hours, open the laterals and flush the lines.

Chlorine can be injected using many types of fertilizer/pesticide injectors, including positive displacement injection pumps. These types of pumps are powered by gasoline or electric motors and include piston, diaphragm, gear or lobe, and roller (or peristaltic) types.

The injection rate for positive displacement injection pumps can be calculated from the following equation:

Injection rate of chlorine solution in gallons per hour =
[(0.006) x (desired chlorine concentration in ppm) x (irrigation gal per minute)] **/** % chlorine in bleach or concentrate

As an example, assume household bleach (5.25% sodium hypochlorite) is being used as a chlorine solution, that a treatment level of 5 ppm of chlorine is desired, and that the trickle system has a 200 gal per minute flow rate.

Injection rate of chlorine solution in gallons per hour =
[(0.006) x (5 ppm) x (200 gal/minute)] / 5.25% = 1.14-gal chorine per hour

Proportional injectors are also commonly used to inject chlorine. Proportional injectors are powered by the water pressure of the irrigation system and inject materials at a rate which is proportional to the irrigation system flow rate or system pressure. Injection rates are often adjustable and are usually specified as ratios, percentages, or ppm. Table C-7 lists equivalent values of these injection rate units.

For proportional injectors, the following equation can be used to calculate the required chlorine solution injection rate:

Injection rate of chlorine solution in ppm concentrate=
[(100) x (desired chlorine concentration in ppm)] / % chlorine in bleach or concentrate

As an example, assume post-harvest wash material (12.5% sodium hypochlorite) is being used as a chlorine solution and that a treatment level of 10 ppm of chlorine is desired.
Injection rate of the chlorine solution in ppm concentrate = [(100) x (10 ppm)] / 12.5% = 80 ppm

It is important to note that both liquid and solid forms of chlorine will cause water pH to rise. This is critical because chlorine (sodium hypochlorite) is most effective in water at pH 6.5-7.5. If water pH is above 7.5, it must be reduced to 6.5-7.5 for chlorine injection to be effective as a disinfectant.

Important Notes

1. **Approved backflow control valves and interlocks must be used in the injection system to prevent contamination of the water source. This is an absolute requirement if a public water source is used.**
2. **Chlorine concentrations above 30 ppm may cause phytotoxicity.**

Table C-7. Equivalent Injection Proportions

Ratio	ppm	Percent
1:10,000	100	0.01
1:5,000	200	0.02
1:2,000	500	0.05
1:1,000	1,000	0.1
1:500	2,000	0.2
1:200	5,000	0.5
1:100	10,000	1
1:50	20,000	2
1:20	50,000	5
1:10	100,000	10

3. Fertigation

Drip-irrigated crops are usually fertilized during the growing phase through the irrigation system, termed fertigation. Before considering a fertilization program for mulched and drip-irrigated crops, have the soil pH checked. If a liming material is needed to increase the soil pH, the material should be applied and incorporated into the soil as far ahead of mulching as practical. For most vegetables, adjust the soil pH to around 6.5 (see Table B-1).

When using drip irrigation with plastic mulch, apply the recommended amount of preplant fertilizer and incorporate it 5-6 inches into the soil before laying the mulch. If equipment is available, apply the preplant fertilizer only to the soil area the mulch will cover. This is more efficient than a broadcast application to the entire field.

The most efficient method of fertilizing an established mulched row crop is through a drip tape installed with the plastic layer (see below). Due to the very small emitters in the drip tape, a completely soluble fertilizer or liquid solution must be used through the irrigation system. While in the past, a 1-1-1 (N-P_2O_5-K_2O) ratio of completely soluble fertilizer, such as a 20-20-20, has been used successfully, in most cases, lower P concentrations are now recommended (for example, 2-1-2 or 4-1-4 ratio). Solutions are often used without P_2O_5 (1-0-1 ratio), and this is specifically recommended where there is a high likelihood of P precipitating out of the irrigation water and clogging drip emitters (hard irrigation water supplies). If water sources contain high levels of calcium, calcium phosphate may precipitate, which can clog drip emitters.

Including the essential micronutrients with the completely soluble N-P_2O_5-K_2O fertilizer has resulted in positive yield responses. Including boron with the completely soluble N-P_2O_5-K_2O fertilizer on sandy loam soils testing low to low-medium in boron is highly recommended for medium and high boron demand vegetable crops.

Liquid fertilizer concentrates are available for direct injection. Soluble fertilizer nutrients to be applied to plants through the drip irrigation system are first completely dissolved in water to produce a concentrate. These concentrates are usually introduced into the irrigation system following filtration using a fertilizer injector designed for this purpose.

Fertigation Rates for Drip Irrigated Plasticulture Crops

All rates of soluble fertilizers applied through the drip irrigation system are based on crop recommendations (see individual vegetable crops in Chapter F). Suggested fertigation programs for common drip irrigated crops are given in Chapter F for the standard linear bed feet contained in an acre of that crop. This is called the Linear Bed Foot (LBF) system for fertilizer application. Rates are adjusted if crops are planted in row widths different from the standard (more or less linear bed feet per acre). All fertigation recommendations are expressed in lb./A. The use of LBF as a fertilizer rate ensures that an appropriate rate of fertilizer will be applied, regardless of the total number of LBF in the cropped area. The use of lb./A to express the fertilizer rate requires an adjustment based on the actual cropped area. The goal is to provide a specific concentration of nutrients to plant roots or a specific amount of fertilizer within a certain volume of soil. This approach assumes that most plant roots are confined within the volume of soil comprising the bed under plastic mulch. Fertigation can occur with each irrigation event, weekly, or prior to important crop growth stages.

Calculating the fertilizer requirements for a fertigated acre based on 6-foot bed centers
a. Example for a soluble dry fertilizer to be dissolved and distributed through drip fertigation.
If 40 pounds of N, 40 pounds of P (P_2O_5), and 40 pounds of potash (K_2O) per 7,260 linear bed feet (standard acre) per application are recommended, select a dry, completely soluble fertilizer with a 1-1-1 ratio, such as a 20-20-20. To determine the amount of 20-20-20 needed per acre, divide the percent N, P_2O_5, or K_2O contained in the fertilizer into the quantity of the respective plant nutrient needed per acre and multiply the answer by 100:
[40 lb. nitrogen needed / 20% N in fertilizer] x 100 = 200 lb. 20-20-20 per acre

b. Example for a liquid fertilizer distributed through drip.
Assume the same 40 lb. N-P_2O_5-K_2O and a 6-6-6 liquid is used.
If one gal of this fertilizer weighs 10 lb., 67 gal of 6-6-6 liquid fertilizer per acre per application is required.
1 gal (10 lb.) of 6-6-6 contains:
10 lb. x .06 (6% N) = 0.6 lb. N in each gal
40 lb. N per acre needed / 0.6 lb. N per gal 6-6-6 = 67 gal of 6-6-6 needed per acre

4. Subsurface Drip Irrigation Systems

Sub-surface drip irrigation, most commonly known as SDI, is the practice of using drip tape buried at depth for multi-year irrigation applications. These systems are easily automated and can significantly decrease labor requirements. Water quality is a critical component of the success of an SDI system. Maintaining adequate water quality will maximize both system performance and longevity.

SDI is best addressed in two separate categories: Short-term SDI and Long-term SDI. Short-term SDI (ST SDI) is defined by a life expectancy ranging from 3 to 10 years. However, system life alone does not define Short-term SDI. These systems are typically used on mid-valued vegetable crops (for example, processed crops). ST SDI systems are commonly designed to deliver peak ET water demand to crops, giving greater control in meeting the crop's water needs. Typically, drip tape is installed between 3 inches and 10 inches deep along each crop row on a raised bed. The headers of the drip tape can be supplied with water via a surface hose or permanently buried PVC pipe; the other end of the drip lateral is typically left exposed for flushing. ST SDI offers many of the advantages of surface drip irrigation without the annual expense of drip tape replacement. After year one, insect damage from mole crickets and wireworms can be a problem with few chemical controls. These problems are reduced with deeper tape placement.

Long-term SDI (LT SDI) is characterized by a life expectancy of 10 years or greater. These systems are primarily designed for commodity crops (for example, corn and cotton). The LT SDI systems are designed to efficiently deliver water to large expanses of acreage. Due to limited water availability and high crop water demand, LT SDI systems are not typically designed to replenish peak volume needs but rather used to manage soil moisture profile during periods of peak water demand. Drip tape is installed from 12 inches to 18 inches in depth, depending primarily on soil characteristics. Drip tape is typically centered between rows of the crop. The drip tape is attached on each end to permanently buried PVC pipe, with one pipe serving as the water supply and the other pipe providing the flushing function. LT SDI offers many of the advantages of surface drip irrigation; however, water is applied in a manner to best economize the application while fulfilling the needs of crops. In sandy soils, LT SDI becomes less ideal as the capillary of the soil is low, thus limiting the ability of the deep tape to wick moisture to the surface. Disadvantages include the inability to activate surface-applied herbicides, the inability to irrigate the shallow root zone to improve germination, difficulty locating tape leaks in season, and the need to prevent field rutting by equipment during harvest.

5. Chemigation

Chemigation is the application of any pesticide through any irrigation system and includes furrow, border, overhead, and drip irrigation systems. Certain pesticides are labeled for application through irrigation systems (insecticides and fungicides commonly). Posting of areas to be chemigated is required when (1) any treated area is within 300 ft of sensitive areas such as residential, labor housing, businesses, hospitals, or any public zones such as schools, parks, and playgrounds, or (2) when the chemigated area is open to the public such as golf courses or retail greenhouses.

Prior to chemigation, first charge the irrigation system, then introduce the pesticide uniformly over the crop being irrigated. After chemigation, flush the irrigation system with fresh water. In drip systems, do not overwater during the flush phase to retain the pesticide in the root zone. The label must allow the use of chemigation before any pesticide can be applied in the irrigation system. **Consult the label for all rates and restrictions before use**. **Note that some labels specify that chemigation can be done only with certain types of irrigation, *i.e.*, drip or sprinkler.**

Chemigation Systems Connected to Public Water Systems

These systems must contain a functional, reduced-pressure zone, backflow preventer, or the functional equivalent in the water supply line upstream from the point of pesticide introduction. The pesticide injection pipeline must contain a functional, automatic, quick-closing check valve to prevent the flow of fluid back toward the injection pump.

- The pesticide injection pipeline must also contain a functional, normally closed, solenoid-operated valve located on the intake side of the injection pump connected to the system interlock to prevent fluid from being withdrawn from the supply tank when the system is automatically or manually shut down.
- A functional interlocking control to automatically shut off the pesticide injection pump when the water pump motor stops is also required, or in any situation where the water pressure decreases to the point where pesticide distribution is adversely affected.

Chemigation systems must use a metering pump, such as a positive displacement pump capable of being fitted with a system interlock.

Chemigation with Drip and Overhead Irrigation Systems

A safe and effective chemigation system must include the following components: a functional check valve, vacuum relief valve, and low-pressure drain on the irrigation pipeline to prevent water source contamination from backflow. The pesticide pipeline must contain a functional, automatic, quick-closing check valve to prevent the flow of fluid back to the injection pump.

- The pesticide injection pipeline must also contain a functional, normally closed, solenoid-operated valve located on the intake side of the injection pump and connected to the system interlock to prevent fluid from being withdrawn from the supply tank when the system is automatically or manually shut down.
- Further, the system must contain a functional interlocking control to automatically shut off the pesticide injection pump when the water pump motor stops.
- Finally, the water pump must include a functional pressure switch, which will stop the water pump when the water pressure decreases to the point where pesticide distribution is adversely affected.