

WATER MANAGEMENT IN DRIP-IRRIGATED VEGETABLE PRODUCTION

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Summary:

Many factors influence appropriate drip irrigation management, including system design, soil characteristics, crop and growth stage, environmental conditions, etc. The influences of these factors can be integrated into a practical, efficient scheduling system which determines quantity and timing of drip irrigation. This system combines direct soil moisture measurement with a water budget approach using evapotranspiration estimates and crop coefficients.

Drip (trickle) irrigation offers the potential for precise water management and divorces irrigation from the engineering and cultural constraints that complicate furrow and sprinkler irrigation. It also provides the ideal vehicle to deliver nutrients in a timely and efficient manner. However, achieving high water- and nutrient-use efficiency while maximizing crop productivity requires intensive management. Central to that management is appropriate irrigation scheduling, both in terms of timing and volume applied. This discussion focuses on the practical aspects of drip irrigation management for commercial vegetable production.

There are two basic approaches to scheduling drip irrigation: soil-moisture-based scheduling and a water-budget-based approach that estimates crop evapotranspiration. There are limitations to both methods, but when used together they are a reliable way to determine both quantity and timing of drip irrigation.

Estimating evapotranspiration

The amount of water evaporated from the soil surface and lost through transpiration of the crop is collectively called evapotranspiration (ET). With drip irrigation, evaporation from the soil is minimized, particularly in plastic mulch production systems, leaving crop transpiration as the main component of water loss.

Environmental variables, primarily solar radiation, air temperature, relative humidity, and wind, are the driving forces behind evapotranspiration. There are two widely used systems which integrate the effects of these variables into a daily reference value. Reference evapotranspiration (ET_0), calculated from the aforementioned environmental variables, estimates ET from a well-watered, uniform-height, actively growing turf, alfalfa or similar crop (Pruitt *et al.*, 1987). Historical mean daily ET_0 is available for many locations; for example, California has a network of computerized weather stations which provide real-time daily ET_0 (Snyder *et al.*, 1987).

The other common technique used to estimate relative evaporative demand is pan evaporation (E_p), the daily loss of water from a standardized open, water-filled pan. E_p is a

common measurement made at many weather stations across the country, and historical mean daily E_p values are widely available. Both ET_o and E_p are reported as inches of water lost.

Neither pan evaporation nor ET_o calculated by empirical equations accurately reflects actual crop ET in all climates; these ET estimates commonly require modification based on local conditions (Pruitt *et al.*, 1987; Burman *et al.*, 1980). Although it differs somewhat among climates and pan locations (over bare soil vs. green crop), E_p averages 20-30% higher than comparable ET_o estimates (Doorenbos and Pruitt, 1977). For an in-depth discussion of ET estimation see Burman *et al.* (1980).

Utilizing crop coefficients

E_p or ET_o values provide an estimate of relative evaporative demand. The amount of water actually lost from a particular field is mostly a function of crop growth stage; as the crop canopy expands water loss increases. To account for crop growth stage, crop coefficients (K_c) are used to adjust either E_p or ET_o to fit current field conditions. K_c values are available for the common vegetable crops, mostly from regional sources which have compiled local research results or have adapted published information to local conditions.

Several words of caution are appropriate regarding the use of published crop coefficients. They are specific to a particular evapotranspiration estimate (ET_o or E_p). They are also specific to a particular field configuration, because they are based on an assumed maximum degree of crop canopy coverage; the importance of this can be illustrated by a simple example. A K_c system developed for double-row pepper on a 40-inch bed (where, at maturity, the foliage almost completely covers the ground area) will overestimate the water requirement of drip-irrigated double-row pepper on 60-inch beds, where even at maturity considerable open ground will exist between beds.

An alternative to using published K_c values is to develop coefficients based on the percentage of the soil surface covered by foliage. This ties the coefficient directly to the site-specific field configuration and plant vigor. The percentage canopy cover is estimated by measuring the average in-row plant width and dividing by the bed width. This system works reasonably well for most ground-grown vegetable crops (Hartz, 1993); where crops are staked or trellised this system is less appropriate. Since peak crop water demand may slightly exceed ET_o (Phene *et al.*, 1985), percentage canopy cover should be estimated liberally.

Using the water budget approach, crop water requirement is calculated:

$$[(E_p \text{ or } ET_o) - ER] \times K_c = D$$

where E_p , ET_o and ER (effective rainfall) are expressed as cumulative inches since the last irrigation, and D is depth of water. It is crucial to use K_c values developed specifically for either ET_o or E_p . If percentage canopy cover is used in lieu of published crop coefficients, the calculation is the same when ET_o is used; the water use characteristics of most vegetable crops are similar to that of the reference crop on which the ET_o estimate is based. When using a canopy cover estimate and E_p , an additional factor must be used to compensate for the difference between E_p and ET_o (Doorenbos and Pruitt, 1977). E_p is typically 20-30% greater than ET_o .

Accounting for nonuniformity

The estimate of irrigation requirement must be increased to account for the nonuniformity of the drip system; no system delivers water with complete uniformity, and irrigation should be geared to meet the crop need in the driest part of the field. In general, the basic irrigation calculation should be increased by 10-20% to compensate for nonuniformity of the system. If distribution uniformity of the system is less than 80% the cause of the nonuniformity (emitter plugging, design flaws, etc.) should be addressed rather than simply increasing the volume of water applied, since overirrigation in the high flow area can be as damaging as deficit irrigation.

Irrigation frequency

The water budget scheduling system outlined above estimates the volume of water required, but it does not suggest with what frequency it should be applied. It is difficult to generalize about drip irrigation frequency, because there are a plethora of factors to consider (crop, root depth and distribution, soil water holding characteristics, drip wetting pattern, degree of automation, etc.). However, two basic rules can simplify the issue:

1. Deplete no more than 20-40% of available soil moisture in the most active root zone. For sensitive crops (celery, lettuce, pepper, etc.) limit depletion to 20%; deep-rooting, stress tolerant crops (tomato, melon) allow greater depletion without loss of yield or quality.
2. Limit individual applications to approximately 0.5 inches or less. This limits the degree of root zone saturation after application and minimizes the amount of applied water likely to drain below the active root zone.

Irrigation frequency will vary, depending on crop growth stage and site specific variables. Typically, frequency may be once every 5-7 days early in the season, increasing to daily or every other day during peak water demand. Although some researchers have advocated multiple applications per day (Davis *et al.*, 1985; Phene *et al.*, 1985), that approach is not practiced widely except on very sandy soils during periods of high crop water use. However, in such situations multiple applications per day may be required to prevent unacceptable crop stress and/or significant leaching of water and nutrients.

Other considerations

The preceding discussion forms the framework for making decisions on drip irrigation volume and timing. There are other important site- and crop-specific considerations.

1. Early season irrigation scheduling

Early in the season when plants are small, it is beneficial to encourage roots to explore as much of the soil profile as possible. This maximizes nutrient uptake and maximize stress tolerance later in the season. The best approach to early season irrigation is to begin with a full soil profile and encourage deep rooting by not watering routinely, but rather waiting until the 20% depletion of available water is reached at the appropriate monitoring depth. This may mean going 5-7 days or longer between irrigations on spring plantings. Obviously, when establishing plantings in hot weather, the interval would be less; in this circumstance water may be applied for its cooling effects or seedbed salinity control, as well as for plant uptake. Once the crop is established and rapidly growing, you can switch to the scheduling technique outlined. Many growers have found that, despite the added costs, sprinkling to establish the crop is a useful

practice, particularly for shallowly planted crops such as lettuce. In addition to maximizing plant stand, sprinkling wets the entire soil profile, encouraging more extensive rooting and improving capillary movement of water from drip lines once drip irrigation begins.

2. Irrigating shallowly-rooted crops

Many drip irrigation systems now in use for vegetable production utilize buried lines, typically 6-12 inches deep, which are reused for subsequent crops. Deep-rooted crops like tomato and melon can be managed efficiently, but shallow-rooted crops such as celery and lettuce may not be able to 'reach' all applied water. This problem can be minimized by:

- a) using low beds that minimize the depth of the drip lines.
- b) forming tightly pressed beds, which improves capillary water movement.
- c) irrigating often, using high-flow tape or tubing if possible. It is particularly important on heavy soils not to let the soil above the drip line dry out, because reestablishing capillary wetting is difficult.

3. Imposing moisture stress

There are circumstances where it may be desirable to withhold water at the end of the season, either to aid harvest or to improve quality. With melons or processing tomatoes for example, soluble solids content of the fruit is an important quality factor; a controlled degree of moisture stress as fruits ripen may be beneficial, although the relative degree of improvement will be modest. There are no firm guidelines established, but the general rule for processing tomatoes would be to supply water adequately through fruit set then begin deficit irrigation 4-5 weeks before harvest, completely cutting off water about 2 weeks before harvest. Since melons are usually harvested over several weeks, completely cutting off water before harvest begins may sacrifice yield. An alternative would be to reduce applications by 50-75% starting roughly 7-10 days before initiation of harvest. A recent study showed that melon quality was not compromised by drip irrigation during harvest, provided that irrigation was applied daily at low rates (Hartz, 1997). For either melons or processing tomatoes, these guidelines assume that the season began with a full soil profile to encourage deep rooting. Crops grown in very sandy soils tolerate less water stress than those on soils with higher available water-holding capacity. Also, deficit irrigation may induce root intrusion into the drip emitters; appropriate steps should be taken to manage this problem.

4. Accounting for rain

Drip irrigation scheduling will be influenced by rain, but not always in the obvious way. In general, less than 0.10 inches of rain can be ignored since most of it will evaporate from the soil surface rather than be used by the plant. Rainfall between 0.10-0.75 inches can be considered effective, in the sense that much of it may reach, and stay, in the root zone. However, there can be a hidden danger in a rain of this magnitude. With buried drip systems, the top few inches of soil will tend to collect salts (originally added by water or fertilizer inputs), sometimes to very high levels. A light rain can push this concentrated band of salts into the root zone. In such circumstances, actually irrigating during and/or immediately after the rain will help dilute this salt load and leach it away from the roots. This problem is confined generally to areas of high ET_0 and marginal water quality. Precipitation over 0.75 inch usually will be sufficient to minimize this problem.

5. Use of plastic mulch

Drip irrigation is commonly used in conjunction with polyethylene bed mulch. Significant effects of mulch on irrigation demand are relatively modest and generally confined to the early weeks of a growing season, before the plant canopy covers the wetted soil surface, if any (with buried drip systems the wetting pattern may or may not reach the surface). Scheduling early-season irrigation based on soil moisture depletion will work equally well for mulched or bare-soil cropping systems. Once a substantial crop canopy is established, mulch effects on crop water demand will be negligible. However, mulch can change the wetted area of the bed. By nearly eliminating evaporation from the soil, and by trapping condensate, mulch tends to keep the surface soil moist; by comparison, with buried drip systems on bare soil beds, the top 2-4 inches of soil may dry over time, even though crop water demands are being met. This has implications for fertilizer management because the surface soil is generally the richest in P and K availability.

6. Leaching for salinity control

Experienced growers recognize the danger of high soil or water salinity in vegetable crop production. Drip irrigation can minimize salinity problems in two ways: (1) by reducing evaporation from wet soil surfaces (which concentrates salt) and (2) by continually moving soluble salts to the edge of the wetting pattern, away from roots. Consequently, in-season leaching requirements are minimal for most drip-irrigated vegetable crop operations. The exceptions are:

- a. Areas of high initial soil salinity, poor water quality (>1,200 PPM soluble salts) or poor soil structure and/or drainage.
- b. Areas of high ET_0 and low annual rainfall.

In areas where salinity is a problem, it is best handled by leaching the soil profile before planting a vegetable crop, as is typically done in sprinkler- or flood-irrigated systems. When in-season leaching is required, a specific leaching fraction can be built into the calculation of the irrigation requirement.

Direct soil moisture monitoring

There can be several significant sources of error in the irrigation scheduling system previously described. Each site, soil type, and season is unique. Direct soil moisture measurement is the essential safeguard to avoid over- or under-watering, both of which can compromise the benefits of drip irrigation. Of the common soil moisture monitoring techniques available, the use of tensiometers is one of the best for monitoring drip irrigation. Despite substantial cost and the need for maintenance, tensiometers can provide crucial information.

The first consideration is tensiometer placement. One set of instruments should be placed in the zone of most active root uptake. Depth will depend on the crop; shallow-rooted crops like celery or lettuce should be monitored at 8-10 inches, whereas tomato and vine crops are evaluated best at 12-15 inches. It is also important to understand what is happening to soil moisture at lower depths; another set of instruments installed 8-12 inches below the shallow set will provide this information. To be sure that representative readings are obtained, tensiometers at each depth should be installed at several locations in a field, because no irrigation system is totally uniform, nor are field soils homogeneous.

Correct interpretation of tensiometer readings is critical. To understand exactly what the readings mean, one would need to know the soil moisture release curve for each field being monitored. Few growers have access to that information, so generalizations must be used. Optimum soil moisture usually is assumed to be near field capacity (the maximum amount of water a soil can hold against the force of gravity). In most sandy soils, soil matric potential at field capacity is between 7-12 centibars (cb), in loam soils between 12-20 cb. In coarse- to medium-textured soils, tensiometer readings at 20% available moisture depletion are 10-15 cb higher than at field capacity; this means that for stress-sensitive crops, irrigation should commence before tensiometers exceed 17-22 cb in sandy soil or 22-30 cb in loam or clay loam soil. Some studies suggest that in sandy soil, optimal drip irrigation management requires maintenance of soil moisture tension near field capacity (Pier and Doerge, 1995; Thompson and Doerge, 1995).

Shallow tensiometers indicate the moisture status of the active root zone; the deeper instruments indicate whether the amount of water applied is correct. After an irrigation, deep tensiometer readings should go down near, or even below, field capacity. If they do not, it means the application was too light. Between irrigations the deep tensiometer readings should come back up near, or slightly above, field capacity, indicating that deep roots are not permanently saturated. Failure of deep tensiometers to rebound between irrigations means that either the application is too heavy, too frequent, or there is restricted drainage which is preventing movement of gravitational water.

Another useful soil moisture monitoring tool is the portable soil capacitance probe. It works by emitting a radio frequency wave and measuring the attenuation of the wave by the soil around the probe tip. This instrument is best suited to compare the relative water content of different areas or soil depths, identifying under- or over-irrigated areas. It is a tool to augment, not replace, tensiometers. The major advantages of the soil capacitance probe is its portability and quick response time. A major limitation is that it can be difficult to insert the instrument deeper than 12 inches in many field situations, particularly in multiple crop drip installations where deep tillage is not practiced routinely.

Other soil moisture monitoring techniques are available, such as resistance blocks and the neutron probe, but they are not ideal for use in drip-irrigated vegetable production. Another technique which has achieved some acceptance for scheduling drip irrigation of cotton and other row crops is infrared thermometry (Jackson, 1982; Idso, 1982), which calculates a crop water stress index from crop canopy temperature and environmental variables. This approach has been used with some success with tomato and melon, but is poorly suited for use in other vegetable crops.

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