Fertilizer Management for Drip-irrigated Vegetables in Florida

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Summary. Fertilizer application by drip irrigation is becoming a common practice for many vegetable crops, especially in Florida. Vegetable producers view drip irrigation as a tool to reduce water use, increase fertilizer efficiency, and improve profits, while simultaneously reducing the potential risk to the environment due to nutrient enrichment of surface and groundwater. This paper presents the current Univ. of Florida recommendations for fertilizer management with drip irrigation for vegetables in Florida. These recommendations are based on more than 15 years of research on water and nutrient management with drip irrigation. Although these recommendations were developed for largely sandy soils from mostly Florida research, they should be easily adaptable for other U.S. vegetable regions on sandy soils.

Microirrigation (fertigation) refers to application of irrigation water and fertilizer nutrients through small emitters placed on or in the soil near the plants. Drip irrigation is a type of microirrigation where water or nutrient solution is dispensed to the crop via small

plastic tubes or drip-type emitters that are placed near rows of plants. Drip irrigation is an important irrigation method in many crop production areas of the world, particularly in arid areas or areas that have a high competition for available water resources. Currently, $\approx 15\%$ to 20% of Florida's vegetable crops produced with polyethylene mulch culture are drip-irrigated. The major vegetable crops in Florida for which drip irrigation is used include strawberry, tomato, watermelon, muskmelon, cucumber, squash, eggplant, and pepper.

Benefits

Drip irrigation has many benefits, some of which are becoming more important in today's environmentally conscious world. One of the major benefits of drip irrigation is its ability to conserve water and fertilizer compared with other irrigation and fertilization systems. Water savings with drip irrigation can amount to as much as 80% compared with other irrigation methods (Bogle and Hartz, 1986; Elmstrom et al., 1981; Locascio et al., 1981 b, 1985). This benefit of drip irrigation is extremely important for vegetable producers trying to grow vegetables in urban areas, and in areas with inadequate water supply.

With drip irrigation, water is not applied to plant foliage, maintaining drier plants and reducing susceptibility to disease outbreak with an associated reduction in the need for fungicides. Fruit quality of tomatoes may be improved when N and K are applied by drip irrigation compared with applying all fertilizer preplant (Dangler and Locascio, 1990b).

Drip irrigation provides for precise timing and application of fertilizer nutrients. Improved fertilizer application efficiency results from small, controlled amounts of fertilizers that are applied throughout the season in contrast to large amounts of fertilizer placed within or on the bed under the plastic mulch at the beginning of the season (Dangler and Locascio, 1990a; Locascio and Smajstrla, 1989; Locascio et al., 1989). Increased efficiency not only saves production costs but also can reduce the potential for groundwater pollution due to fertilizer leaching from large amounts of rain or periods of excess irrigation.

Applying small amounts of fertilizer when the crop requires them results in reduced potential for soluble salt injury to crops. This benefit of drip irrigation can improve plant stands and overall crop uniformity and yield. It is particularly important when using water sources that are high in soluble salts.

Drip irrigation has many benefits and challenges. Drip irrigation systems must be carefully designed and installed so that they operate with proper efficiency and so that fertilizers and chemicals can be applied in a safe, legal, and efficient manner (Clark, 1992; Clark et al., 1988, 1990b). These systems are expensive and should be designed and installed by competent irrigation in-

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dustry representatives to ensure an operable and cost-efficient system. Significant technical skill and management are required to operate these systems for peak efficiency.

Most vegetable crops are adaptable to drip irrigation, especially those produced on bedded systems using polyethylene mulch. These crops include tomato, pepper, eggplant, strawberry, watermelon, muskmelon, squash, and cucumber. Cabbage, cauliflower, and broccoli also are easily adapted to production with drip irrigation.

Nutrient requirements

Well-managed fertilizer programs begin with nutrient recommendations based on a calibrated soil test (Kidder et al., 1989; Hochmuth and Hanlon, 1989). Significant portions of nutrient requirements can be satisfied by the soil in many situations. Soil testing can predict response to added nutrients, and a calibrated test can be used to calculate amounts of fertilizer needed to satisfy the nutrient requirement of the crop. The Mehlich-I (double-acid) soil test (Hanlon and DeVore, 1989; Hanlon et al., 1990) has been calibrated for Florida vegetables. Nutrient needs should be determined well enough ahead of planting so that the fertilizer application program can be in place when the crop is started.

Preplant fertilizer

Usually, P, Ca, Mg, and micronutrients can be applied to the soil as a dry blend or liquid rather than injected through the drip system. The preplant fertilizer can be broadcast in the mulched bed area or banded. It would be better to band fertilizer in situations where small amounts of nutrients are needed or where the nutrient-fixing capacity of the soil is high (Barber, 1984).

Inconsistent results have been reported with regard to the portion of N and K to apply in the preplant fertilizer. Some research shows a benefit to the addition of 20% to 40% of the N (and K if needed) in the preplant fertilizer (Locascio et al., 1982, 1985). However, successful crops were possible when all N and K was injected, especially where the soil already contained some N (from high organic matter content) and some K (Clark et al., 1991). A portion of N and K applied preplant would have a benefit of supplying early nutrition during conditions that did not require irrigation. The added N with the preplant P will function as a starter fertilizer promoting root growth (Marschner, 1986).

Injected fertilizer

Theoretically any soluble fertilizer can be injected into a drip irrigation system that is properly designed to handle a wide variety of fertilizers and acids. Phosphorus and micronutrients are not recommended widely for application in drip irriga-

tion systems because of problems with precipitation (Rolston et al., 1981); however, P can be applied successfully through drip irrigation systems, even when Ca is present, with certain precautions (Mikkelsen, 1989; Rolston et al., 1981). If application of P is required during the season (such as during cold periods), it can be injected as phosphoric acid alone. Further acidification of the irrigation water might be needed to minimize P precipitation during fertilizer application.

Problems similar to those with P injection also are present for micronutrient injection. If micronutrients must be injected, then soluble forms, less subject to precipitation, can be used (Hall, 1986; Rolston et al., 1981).

Although there are problems and considerations with injecting P and micronutrients, there are several potential benefits from a properly conducted injection. Phosphorus and most micronutrients are immobile in the soil, so that generally only one or two applications would be needed. Also, in most old vegetable soils only small amounts are needed. Plant recovery of these nutrients can be increased when they are applied through the drip system (Mikkelsen, 1989; Rolston et al., 1981). This is probably due to the resultant band-like application by drip irrigation, where the nutrients are not widely mixed with the soil where fixation can occur.

One criticism of P and micronutrient application has been that these nutrients did not move from the point of application (the emitter). Although only small portions of the root zone (near the emitter) would be exposed to the nutrients, not all of the root system needs to absorb the nutrient to benefit the plant (Drew, 1975; Drew and Saker, 1978).

Zero preplant. In some production systems where soils are relatively high in organic matter or that test high in micronutrients, P, and K, it is possible to grow successful crops with no preplant fertilizer, i.e., all fertilizer (N) applied through the drip-irrigation system. This might be particularly attractive for areas where crops are adversely affected by high soluble salt concentrations. Reducing the amount of fertilizer applied in the bed potentially could reduce problems from soluble salt injury to young seedlings or transplants.

Amounts. In most situations, injected fertilizers will consist only of N and K. The amount of N basically is determined by the N requirement for that particular crop. These amounts of N are found in the various extension recommendations specific for each state, e.g., Circular 806 for Florida (Hochmuth and Hanlon, 1989).

The amount of K to be injected is based on the soil-test-predicted amount of K required for the crop minus the amount of that soil-test-predicted K that is applied in the bed as a starter. For example, if the soil tested medium in K, then perhaps 80 lb K/acre (90 kg K/ha) would be required for the season. If 20% of this K, i.e., 16 lb

(18 kg) K were applied in the bed as starter fertilizer, then 64 lb (72 kg) would be injected through the season.

Sources. There are several sources of N and K that can be used for drip irrigation injection (Fiskell and Locascio, 1983; Locascio and Fiskell, 1979; Locascio and Martin, 1985; Locascio et al., 1978, 1981a, 1982, 1984). All sources must be highly water soluble. Nitrogen sources, such as ammonium nitrate, calcium nitrate, potassium nitrate, and various N solutions, can be used to supply N. Potassium can be supplied from potassium chloride or potassium nitrate.

There is no definitive research that points to an importance for any particular N : K ratio in the fertilizer for vegetables. As long as soil-test-predicted amounts of K are added, then the crop nutrient requirements for K will be satisfied.

A portion, $\approx 25\%$ to 50% of the N, can be applied in the nitrate form, especially for crops planted in cool soil conditions (Hochmuth and Hanlon, 1989). For crops planted in warm seasons, the bulk of the N can be supplied in the ammoniacal form. This is possible because under warm soil conditions ammoniacal N is converted rapidly by nitrification to nitrate. Ammoniacal fertilizer is less expensive than nitrate and, in most situations, would be suitable for supplying N to the crop.

Some growers become concerned about relative salt indices of fertilizer materials. This concern is generally not critical if soil-test-predicted and crop nutrient-requirement amounts of N and K are applied to the crop.

Commercial liquid fertilizer materials for injection often are mixed N and K solutions. Concentrated materials are easier to inject because shorter injection cycles are required to inject the same amount of fertilizer compared with a more dilute fertilizer solution. The basic attempt should be to purchase the highest analysis liquid fertilizer available. In some situations, particularly those where the soil already contains large amounts of nutrients such as K, it is possible to inject single-nutrient solutions such as 19% or 28% N solutions, which are usually mixtures of ammonium nitrate and urea.

High temperatures increase the solubility of fertilizer materials. For example, fertilizer solutions used in the early fall or late spring might be as high as 10% or 12% N and K. However, under lower winter temperatures, fertilizer solutions should be lower in concentration, e.g., 6% N and K. This salting-out potential must be taken into consideration when fertilizer solutions are purchased. Growers may want to purchase smaller amounts more frequently for injection in winter so that the solution does not remain in a field tank too long.

Some growers may want to investigate the possibility of formulating their own nutrient solutions. This approach might be especially feasible for growers with an extensive acreage of drip-

irrigated vegetables. For large acreages formulation of fertilizers on site might be less expensive compared with purchasing premixed solutions with their associated transportation costs. Growers wishing to consider the possibility of formulating their own fertilizers should thoroughly investigate this option. This investigation should include the cost of the facility to mix and possibly heat the solutions. Mixing one's own fertilizer would have an additional benefit of providing same-day mixing and use, avoiding the need for long-term storage of nutrient solutions.

Injection frequencies. For many growers it is most convenient to think of rates of injection in terms of amount of a particular nutrient per acre (ha) per day or week. Foreexample, the recommended rate of N injection for a particular crop might be to start early in the season with 1 lb N/acre per day ($1.12 \text{ kg} \cdot \text{ha}^{-1} \cdot \text{day}^{-1}$), then increase to 1.5 lb N/acre per day ($1.68 \text{ kg} \cdot \text{ha}^{-1} \cdot \text{day}^{-1}$) and finally inject 2 lb N/acre per day ($2.24 \text{ kg} \cdot \text{ha}^{-1} \cdot \text{day}^{-1}$) when the crop is at its peak growth rate. Rates are calculated based on the recommended amount of cropped row length in an acre or hectare. For example, for tomatoes the typical bed spacing might be 6 feet (1.8 m) between centers, or 7260 linear bed feet (LBF) of crop in an acre ($5510 \text{ m} \cdot \text{ha}^{-1}$). Calculation of application rates based on row length minimizes confusion over area rates under production systems using variable bed (row) spacings. More information on calculating rates of nutrients is available (Hanlon and Hochmuth, 1989).

Nutrients can be injected at various frequencies. Basically the frequency (daily, weekly, monthly) depends on system design constraints, soil type, and grower preference. Frequent injection might be needed on sandy soils that do not retain large amounts of nutrients and for growers who want to minimize injection pump size and cost.

The frequency, in most situations, is not as important as achieving a correct rate of application of nutrients to the crop during a specified period (Cook and Sanders, 1991; Locascio and Smajstrla, 1989). Some growers find it easy, with computer-controlled systems, to inject as often as once every day, which places smaller amounts of nutrients at risk of leaching during any single leaching event. Since leaching is possible with drip irrigation (Bar-Yosef, 1977) nutrients applied in any irrigation must not be subject to excess irrigation either during that same irrigation or by subsequent irrigations (Locascio et al., 1989).

In sandy-soil areas, several small applications of water may be needed during the day to supply adequate water to a particular crop. This occurs when the crop is at a period of high water demand and the soil has a low water-holding capacity. In these situations, fertilizer can be injected in one or more of these irrigations during the day.

It is possible to inject nutrients in

noncontinuous (bulk) or continuous (concentration) fashion. For bulk injection, drip irrigation systems always should be brought up to operating pressure before injecting any fertilizer or chemical. Fertilizer should be injected in a period such that enough time remains to permit complete flushing without overirrigation. On sandy soils in Florida, an overall irrigation cycle of 45 min (young crop) up to 1.5 h (mature crop) would be sufficient (assuming today's typical drip tube flow rates) to apply the amount of water required by the crop during anyone irrigation cycle (Clark et al., 1990a; Smajstrla et al., 1985). Irrigation cycles >1.5 h for a mature crop on sandy soils run the risk of leaching nutrients and moving water below the root zone. More detail on injection calculations and periods is available (Clark et al. 1990a; Hochmuth and Clark, 1991). It is very important to design the system and fertilizer injector so that injection and flushing can be achieved in a reasonable amount of time without running the risk of overwatering the crop to apply the fertilizer.

In some systems, fertilizer is injected continuously (concentration injection) so that all irrigation water applied contains nutrients. This is acceptable as long as no irrigation cycle is so long that nutrients are leached below the root zone. During rainy periods a bulk injection of a larger amount of fertilizer might be needed to fertilize a crop when no irrigation is needed.

Nutrient injection scheduling

Crop growth curve. Injecting fertilizer into a drip-irrigation system offers the benefit of nutrient application to the crop in amounts and at times when fertilizer is most likely to be absorbed by the plant. Generally this means beginning early in the crop cycle with small amounts of nutrients, then increasing the rate of application of the nutrients as the crop growth rate and nutrient demand increases. Once the crop has reached maturity, e.g., tomatoes at first harvest, nutrient applications can level off and even decrease slightly toward the end of the crop.

Accounting for preplant N and K. When N and K are applied as preplant fertilizer at the rate of $\approx 20\%$ of the total N and K crop nutrient needs, then the N and K injections can be delayed. This delay may be up to ≈ 2 weeks after transplanting for a tomato crop. When N and K are added to the soil before planting by banding near the transplant or seed, then this amount of N and K will suffice for early seedling development. If no fertilizer is placed in the bed, then nutrient injections will need to begin immediately after planting.

Length of season. Another consideration in nutrient scheduling with drip irrigation is the length of the growing season. For example, the season for Florida tomato crops may be 14 to 15 weeks long in the spring but only 12 weeks long in the fall. Plant growth rate is rather slow early in the season in spring crops because the crop is estab-

lished under low temperatures compared with the high temperatures for fall crop establishment. It follows that nutrient applications should be slightly higher for any particular period in the fall compared with the spring. This would be especially true for early season injections. The total amount of nutrients injected for a spring or fall crop should be similar to obtain similar yields.

Florida schedules. The schedules for injecting N and K for vegetables in Florida appear in Table 1. These schedules are based on research and experience in commercial production fields (Dangler and Locascio, 1990a; Hochmuth, 1990a, 1990b, 1990c; Hochmuth et al., 1989; Kidder et al., 1989). For some crop groups, such as melons, extrapolations of nutrient programs for one crop to another are possible. The schedules in Table 1 assume that the soil will be supplying none of the K crop nutrient requirement. The actual K amount used in a grower situation will depend on the soil-test index for K, and in many situations the actual K amount that the grower needs to apply would be less than those amounts specified in Table 1.

Situations for expanded or compressed injection schedules

The schedules in Table 1 are for a typical season's duration and may need to be adjusted slightly depending on specific cultural practices and growing season conditions. Crop development rate can be increased by transplanting in contrast to direct-seeding. For example, watermelons may produce fruit 7 to 10 days earlier when transplanted than seeded. Transplanted crops might require slightly greater amounts of nutrients early in the season than seeded crops. Injection rates could be increased by 0.5 lb/acre per day ($0.6 \text{ kg} \cdot \text{ha}^{-1} \cdot \text{day}^{-1}$) for the first 4 to 6 weeks compared with a seeded crop. Since transplanted crops mature more quickly than seeded crops, rates of injection can be reduced or discontinued earlier than seeded crops. Although scheduling may change slightly for seeded and transplanted crops, the total amount of nutrients injected by the end of the season should be similar.

The crops and schedules reported here are for vegetables produced on polyethylene mulch. Mulch generally has a growth-enhancing effect. Some growers use drip irrigation without mulch. Where mulch is absent, the growth cycle might be lengthened by 7 to 10 days. Therefore, injection schedules could be expanded by reducing the amount injected in the early weeks by 0.5 lb/acre per day ($0.6 \text{ kg} \cdot \text{ha}^{-1} \cdot \text{day}^{-1}$).

The length of harvest can have an effect on extending the typical fertigation season from those in Table 1. For production areas where the crop can be continued through the winter, growers can inject 1 to 1.5 lb of N/acre per day (1.12 to $1.68 \text{ kg} \cdot \text{ha}^{-1} \cdot \text{day}^{-1}$) as a maintenance program for growing seasons longer than those in Table 1. The exact amount of N and K should be determined by

Table 1. *Injection schedules for mulched vegetables in Florida.*

Crop	Establishment method ^z	Typical bed spacing		Total nutrition (lb/acre) ^y		Crop development		Injection rate (lb/acre per day)	
		ft	m	N	K	Stage	Weeks ^{x,w}	N	K
Broccoli	TP	6	1.8	120 ^y	100 ^y	1	3	1.5 ^y	1.3 ^y
						2	2	2.0	1.7
						3	2	2.5	2.1
						4	2	2.0	1.7
Cauliflower	TP	6	1.8	120	100	1	3	1.5	1.3
						2	2	2.0	1.7
						3	2	2.5	2.1
						4	2	2.0	1.7
Collards	TP	6	1.8	120	100	1	3	1.5	1.3
Cucumber	S	5	1.5	120	100	2	6	2.0	1.7
						1	1	1.0	0.8
						2	2	1.5	1.3
						3	6	2.0	1.7
Eggplant	TP	6	1.8	120	100	4	1	1.5	1.3
						1	2	1.0	0.8
						2	2	1.5	1.3
						3	6	2.0	1.7
Lettuce	TP	6	1.8	120	100	4	3	1.5	1.3
						1	2	1.5	1.3
						2	1	2.0	1.7
						3	4	2.5	2.1
Muskmelon (cantaloupe)	TP	5	1.5	120	100	4	1	2.0	1.7
						1	2	1.0	0.8
						2	3	1.5	1.3
						3	3	2.0	1.7
Okra	S	6	1.8	120	100	4	2	1.5	1.3
						5	2	1.0	0.8
						1	3	1.0	0.8
						2	2	1.5	1.3
Onion (sweet bulb)	TP	5	1.5	120	100	3	2	2.0	1.7
						4	3	1.5	1.3
						5	3	1.0	0.8
						1	3	0.5	0.4
Pepper	TP	6	1.8	160	133	2	5	1.0	0.8
						3	3	1.5	1.3
						4	2	2.0	1.7
						5	1	1.5	1.3
Pumpkin	S	8	2.4	120	100	6	1	1.0	0.8
						7	1	0.0	0.0
						1	2	1.0	0.8
						2	3	1.5	1.3
Tomato	TP	6	1.8	160	133	3	7	2.0	1.7
						4	1	1.5	1.3
						5	1	1.0	0.8
						1	2	1.0	0.8

(Continued)

(Table 1. Continued)

Crop	Establishment method ²	Typical bed spacing		Total nutrition (lb/acre) ^y		Crop development		Injection rate (lb/acre per day)	
		ft	m	N	K	Stage	Weeks ^{z,w}	N	K
Strawberries	TP	4	1.2	180 ^y	150 ^y	1	2	0.5 ^y	0.4 ^y
						2	2	1.5	1.3
						3	24	1.0	0.8
Summer squash	S	5	1.5	120	100	1	2	1.0	0.8
						2	2	1.5	1.3
						3	2	2.0	1.7
						4	5	1.5	1.3
						5	1	1.0	0.8
Watermelon	S	8	2.4	120	100	1	4	1.0	0.8
						2	2	1.5	1.3
						3	2	2.0	1.7
						4	3	1.5	1.3
						5	2	1.0	0.8
Winter squash	S	8	2.4	120	100	1	3	1.0	0.8
						2	3	1.5	1.3
						3	2	2.0	1.7
						4	4	1.5	1.3
						5	1	0.0	0.0

²Choice of seed or transplant might affect the schedule. Transplanting shortens the growth cycle and the injection schedule by 1 to 2 weeks compared with seeding.

^yIncludes any starter fertilizer.

^zWhere 20% of N and K have been applied as starter, then first 1 or 2 weeks' injections can be omitted.

^wFor extended-season crops, N maintenance applications can continue at 1.0 to 1.5 lb/acre per day. Tissue testing should be used to fine-tune amounts.

plant tissue analysis. In most situations, the amount of K required in these maintenance programs will be less than the N requirement.

Finally, the cultivar (variety) can affect the crop development rate. In a given season, early cultivars might mature as much as 2 weeks ahead of later-maturing cultivars. The schedules in this paper are for the standard cultivars presently recommended in Florida. In general, most cultivars being grown will do well under these injection schedules.

Although drip irrigation is becoming more important in efficient vegetable production systems, there is still a need for research to refine its use for water and fertilizer management. The guidelines outlined in this paper are for sandy soils in warm, humid production areas, but many of the principles could apply to most summer production areas having sandy soils. Water and nutrient management programs need to conform to environmental protection requirements, and drip irrigation can be a tool to help accomplish this.

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