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Fertilizer Application and Management for Micro (Drip)-Irrigated Vegetables in Florida[1]

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Microirrigation and fertigation refer to applying irrigation water (and) fertilizer nutrients through small emitters placed on or in the soil near the plants. Drip or trickle irrigation is a type of microirrigation where the water and nutrients are dispensed to the crop via small plastic tubes with drip-type emitters that are placed near a row of plants. Drip irrigation is an important irrigation method in many crop production areas of the world, particularly in arid areas or regions which have a high competition for available water resources. Currently, approximately 40% of Florida's vegetable crops produced with polyethylene mulch culture are irrigated with drip irrigation (Figure 1). Vegetable crops throughout Florida grown with drip irrigation include strawberries, tomatoes, watermelons, muskmelons, cucumbers, squash, eggplants, and peppers.

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 the capability to conserve water and fertilizer compared to overhead sprinklers and subirrigation with conventional fertilization systems. Research has shown that water savings with drip irrigation can amount to as much as 80% compared to subirrigation and 50% compared to overhead sprinkler irrigation (Locascio et al., 1981b; Elmstrom et al., 1981; Locascio et al., 1985). This benefit of drip irrigation is extremely important for vegetable producers trying to grow vegetables in urbanizing areas of the state, such as the Tampa Bay area and the lower east coast, and in areas with inadequate water supplies for subirrigation or sprinkler irrigation.

Figure 1. Tomato culture with plastic mulch and stakes involves large amounts of costly inputs. About 40% of mulched vegetables in Florida are drip irrigated.

Figure 1

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Drip irrigation also helps reduce foliar disease incidence compared to overhead sprinkler systems. 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 as compared to applying all fertilizer preplant (Dangler and Locascio, 1990b).

Drip irrigation provides for precise timing and application of fertilizer nutrients in vegetable production. Fertilizer can be prescription-applied during the season in amounts that the crop needs and at particular times when those nutrients are needed. This capability of drip helps growers increase the efficiency of fertilizer application and should result in reduced fertilizer applications for vegetable production. The 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 (Locascio and Smajstrla, 1989; Locascio et al. 1989; Dangler and Locascio, 1990a). Small, controlled applications not only save fertilizer but they can also reduce the potential for groundwater pollution due to fertilizer leaching from heavy rainstorms or periods of excess irrigation.

Placing small amounts of fertilizer in the production bed only at times 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 and is particularly important when using water sources that are high (greater than 1500 parts per million) in soluble salts. Extra salt levels imposed on the production system by high levels of dry fertilizer in the bed can thus be reduced if the bulk of the fertilizer is applied in small amounts through the drip irrigation system.

Drip irrigation can be better than subirrigation in production systems which must use low quality water with high soluble salt contents for irrigation purposes. This is because the water applied by drip irrigation moves the salts away from the dripper, rather than moving the salts up and concentrating them near the plant as subirrigation does.

Although drip irrigation has many benefits that are important in modern vegetable production, many challenges exist with this technology. 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 legal, uniform, and efficient manner. Drip irrigation systems are expensive and should be designed and installed by competent irrigation industry representatives to ensure an operable and cost efficient system. Significant amounts of technical skill and management labor are required to properly operate these systems so that peak efficiency and benefits are realized. This means that trained personnel should be involved with the design, installation, and operation of the system. Proper training and management skills are very important to the success of any drip irrigation operation.

Most vegetable crops produced in Florida are adaptable to drip irrigation. The crops most easily adaptable are those crops that are currently produced on bedded systems using polyethylene mulch. These crops include tomato, pepper, eggplant, strawberry, and cucurbits including watermelon, muskmelon, squash, and cucumber. The cole crops including cabbage, cauliflower, and broccoli also are easily adapted to production with drip irrigation.

System Design Considerations

Proper design of the drip irrigation system for efficient operation cannot be over-emphasized. Benefits are quickly lost in poorly designed irrigation systems. Growers should carefully investigate companies with whom they will contract for the system installation. These companies should have experience and understanding of drip irrigation systems and especially be able to design systems for the particular needs of a specific production system. It is beyond the scope of this publication to discuss the specifics of complete drip irrigation design and installation. There are numerous publications dealing with drip irrigation design, installation, and operation; Smajstrla et al., 1985a; Haman and Izuno, 1987; Smajstrla et al., (1994); Clark et al. (1993); Smajstrla et al. (1992). Several specific design considerations concerning fertilizer management are described in this publication.

Fertilizer injector. One important component of the drip irrigation system which is to be used for fertilizer management is the fertilizer injector. Several types of injection systems are available to apply fertilizers through a drip irrigation system. The major groups include positive displacement (hydraulic or electric powered) pump injectors, pressure differential systems, and venturi injectors. The choice of a particular injector depends on the desired longevity of the piece of equipment, the required accuracy of injection, the required injection rate, and whether or not corrosive chemicals such as acids will be injected.

Some positive displacement injectors are water powered, requiring a portion of the irrigation water to drive the injection pump. Some types of pumps discharge this water onto the ground. Other pumps reinject it back into the irrigation system. All injection systems which do not have an external power supply (usually an electric motor) suffer a pressure loss across the injector or proportioner. Sometimes this pressure loss is great enough to eliminate the use of a particular injection system. More information on fertilizer injectors and pumps can be found in Agriculture Engineering publications (Haman et al., 1989; Haman et al., 1990).

Location of the fertilizer injector or proportioner should be carefully considered in the design of an irrigation system. It is important to locate the injector so that relatively small amounts of water are delivered to the field before the fertilizer reaches the crop. Irrigation systems that have long or large mainlines and submains that must be filled with water before the irrigation water finally reaches the irrigated crop, may experience problems when the fertilizer is injected in frequent, small doses. In these systems, the main lines and sublines must be filled with water to bring the system up to pressure before the fertilizer is injected. Therefore, a large amount of water must be delivered to the crop before the fertilizer can reach the crop. The potential for overwatering a crop is high when the fertilizer injector is not located near the point where water is finally delivered to the crop. It is convenient to locate the injector near the pump and irrigation controller so that all of the components can be easily monitored. However, injection points remote from the control station may be required to obtain an adequate uniformity of fertilizer application.

Backflow prevention. Irrigation systems that will be injecting fertilizers or pesticides must, by state law, have proper backflow and antisiphon equipment installed in the system. A backflow prevention system is needed to prevent the movement of water containing fertilizer or other injected chemicals back into the well or water source when the system is not operating. Antisiphon equipment is also needed to prevent the flow or suction of the fertilizer stock solution back into the irrigation lines when the system is not operating. More information on backflow prevention systems for Florida is available (Smajstrla et al., 1985a).

Irrigation controllers. Drip irrigation systems are easily controlled and managed with field computers or controllers (Figure 2). Management of a drip irrigation system with a controller reduces labor requirements and allows precise measurements and applications of water and fertilizer. Controllers are especially effective labor savers for drip irrigation systems with several zones. Controllers also provide the capability of recording and storing data on amounts of water and fertilizer applied to each zone in the system. This information can be valuable for tracking the operation of the system, for diagnosing problems, and for scheduling water and fertilizer applications for future crops.

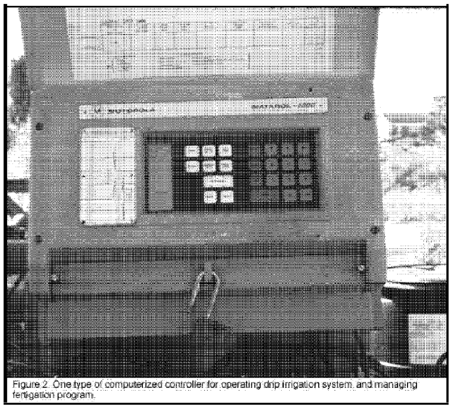

Figure 2. One type of computerized controller for operating drip irrigation system and managing fertigation program.

Figure 2

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There are various types of controllers for drip irrigation management. To select a controller for a specific system, field managers should first determine their management objectives and what types of information and data they want collected and stored. Costs of computer controllers can range from a few hundred dollars to several thousand dollars. Most drip irrigation systems use controllers that cost from two to six thousand dollars. The investment in a controller for a drip irrigation system is usually a wise investment. Without a controller, a system must be manually operated and labor requirements will be high because of the frequent, short-duration irrigation events.

Filtration. A critical component of all drip irrigation systems is the filtration system (Haman et al., 1986; Haman et al., 1988a; Haman et al., 1988b). Filtration systems differ depending on the quality and source of the irrigation water (well water or surface water). When pumping from wells, screen or disk filters are usually adequate to remove particulate matter such as sand or limestone. For surface water systems, sand media filters may be required to trap particulate matter such as algae, bacteria, larvae, and organic matter that could be pumped from the pond or lake.

In systems where fertilizers are injected, they must be injected before the filters. Then the filters will remove any particulate matter or precipitates that occur as the fertilizer materials are injected into the system.

Filtration is extremely important in drip irrigation systems to prevent plugging and clogging of the small drip irrigation emitters, and to maintain design levels of uniformity in water and fertilizer application to the crop. For most drip irrigation systems, filtration on the order of 150-180 mesh is satisfactory. However, growers should consult with the particular irrigation tubing manufacturer to determine recommendations for exact filtration requirements.

Tubing Type and Placement

Tubing. There are two basic types of drip irrigation tubing available to the vegetable grower. These are reusable and disposable types of tubing. The reusable tubing consists of heavy-wall polyethylene and normally is at least 20 mil thick. This tubing is designed to be reused for several (5 to 10) seasons. It typically is three to five times more expensive than disposable tubing, but the higher cost may be justified for use over multiple seasons. Reusable tubing is applied from large spools and recaptured onto those spools for storage at the end of the season (Figure 3). Reusable tubing requires considerable attention to maintenance and clogging prevention to achieve a 5-10 season life span. If the tubing and the emitters become clogged, the uniformity of water and fertilizer application decreases with each successive crop.

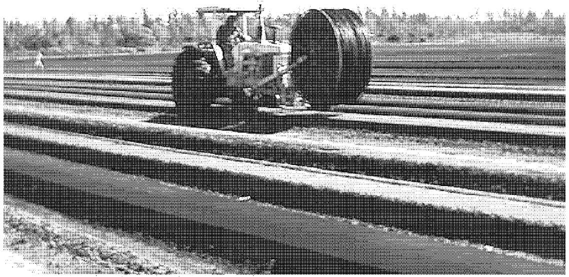

Figure 3. Applying reusable drip tubing from spools. Drip tubing is recovered onto these spools at end of season.

Figure 3

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Another problem with reusable tubing concerns the types and sizes of fields that the tubing is used in. With each successive season, the tubing must be cut if the row lengths of the fields vary from year-to-year or season-to-season. If row lengths vary, then there will be an accumulation of many cuts and splices in the tubing as it is used.

Because of cost and management considerations, reusable drip tubing is not commonly used in Florida vegetable drip irrigation systems. Rather, disposable drip tubing is most often used. Disposable drip tubing, sometimes referred to as drip tape, comes in various wall thicknesses normally ranging from 4 to 15 mil. Disposable tubing is designed to be used for a single season or for two or three seasons in a multi-cropping situation and then to be recycled or discarded. In most vegetable crops, 6 to 10 mil drip tape appears to be satisfactory. The heavier-walled material should be used in situations where multi-cropping will be practiced or where problems are likely from rodents or field crickets that might chew the tubing. Thin-walled tubing will also be more easily damaged by high pressure.

Depending on the size of the irrigation tubing, the water delivery rate, and field slopes, permissible lateral length may range from 200 to 600 feet. It is important in the design and management of the system to know the type of drip tubing and the discharge rate. Drip irrigation tubing is designed to have a certain uniformity of application flow rate within a specified length of run in the field. For some conditions, this maximum length of run may only be 200 feet. If lengths of laterals exceed those specified by the manufacturer, then nonuniform water and fertilizer applications will result.

Allowable lengths of run will also be dependent on the field topography. Fields with steep slopes will require special design considerations so that uniform applications of water and fertilizer can be achieved. Laterals should be placed across slope or down slope whenever possible because lateral lengths will need to be significantly reduced in areas of the field where water will be forced uphill.

Emitters. Emitters in drip irrigation tubing systems vary among manufacturers. Most emitters use mechanisms that provide a tortuous pathway for the water to pass before being emitted into the soil. Generally, emitter discharge increases with system pressure. However, some types of emitters may be pressure compensating so that water discharge does not change much with variations in pressure.

The lateral flow rate is important in the overall design and management of a drip irrigation system. Most drip irrigation tubing flow rates vary from 0.3 gallons per minute (gpm) per 100 feet of length to 0.65 gpm/100 ft with 0.5 gpm/100 ft being very common. Larger flow rate emitters irrigate the crop root zone quicker, and are less prone to clogging.

Conversely, low flow rate emitters allow longer lateral lengths, but are more prone to clogging. In some systems, high flow rate fertilizer injectors are needed to inject the desired amount of fertilizer within the run time constraints of the irrigation system. Therefore, it is important to consider the flow rate of the drip tubing when selecting a fertilizer injector for a drip irrigation system.

The emitter spacing required along the laterals depends on the type of soil and type of crop being produced. Closely spaced emitters are often required on typical sandy soils in Florida. Widely spread emitters (greater than 24 inches) can result in dry spaces in the bed, particularly when one emitter becomes clogged. Emitter spacings on the order of 9 to 12 inches are optimum for close spaced crops such as peppers, strawberries, squash, cucumbers, muskmelons, and cole crops. Emitter spacings may be as wide as 18 inches for wider spaced crops such as tomatoes, watermelons, pumpkins, winter squash, or eggplant. The emitter spacing is also important in multi-cropping situations. In these situations, it is normally better to choose a drip tubing with a relatively close emitter spacing, (no greater than 12 inches), so that the tubing would be applicable for nearly all multi-crop possibilities.

Flushing. Flush valves should be installed to allow a drip irrigation system to be flushed periodically during the season. Flush valves should be installed at the end of each mainline and lateral. During this draining process, accumulated precipitates and particulate matter are discharged from the tube. This valve can either be manual or automatic. Automatic flush valves automatically flush laterals at each irrigation. Most automatic flush valves are open when there is low pressure in the laterals but close when the pressure exceeds 1 or 2 psi. This means that a small amount of water is flushed through the valves as the pressure builds up.

The required frequency of flushing depends on the water quality and the amount of debris expelled. With poor water quality, flushing may be required daily or with each irrigation. With good water quality, flushing may only be required weekly or even less often.

Manual flush valves can be spring-loaded, a threaded cap, a crimped tube or other manual valve. For some systems, the ends of the laterals can be folded back on themselves using a short piece of drip irrigation tubing as a sleeve to hold the crimp in place. Removing this sleeve allows the lateral to be flushed manually.

Manual flushing should only be used on systems with good water quality so that frequent flushing is not required. It is normally not feasible to manually flush laterals daily because of the labor required. If frequent flushing is required, then automatic flush valves should be used.

Uniformity. To obtain maximum benefits from drip irrigation, the system must maintain a high degree of uniformity throughout the season. That is, approximately the same amount of water and fertilizer must be applied to all parts of the system. High uniformity is obtained by proper system design and installation. Uniformity of fertilizer application will be no higher than the uniformity of water application. Uniformity of the system can decrease through the season if there are problems or failures in the components of the system such as pressure regulators or if drippers become clogged.

Drip irrigation systems should be checked periodically for water flow uniformity (Smajstrla et al., 1990). Uniformity of application is tested by measuring the flow from various emitters in the field and calculating an efficiency value. Information on system design and field-testing for uniformity is described elsewhere (Smajstrla et al., 1990). A simple field procedure was described by Smajstrla et al., (1992), and is especially recommended for systems used for fertilizer application. Application uniformities of 90% or better should be sought for systems through which fertilizer is applied.

Soil Bedding and Application of the Drip Irrigation Tubing

Most plastic mulched vegetables in Florida are produced on raised soil beds. Drip irrigation is easily incorporated into the raised bed cultural system. Most mulch application and bedding equipment can be adapted easily to apply drip irrigation tubing in the bed at the same time that the bed is formed and covered with polyethylene mulch. When drip irrigation is used, bed sizes on sandy soils, both height and width, can be reduced compared to the bed sizes and heights used for subirrigation. Reducing the bed height can be appropriate with drip irrigation because water tables are not managed as high as with subirrigation, and therefore there is less tendency for flooding problems. Because of the limited lateral wetting with drip irrigation, bed widths can be narrowed, resulting in less dry soil under the mulch compared to where drip irrigation is used on wide beds (Figure 4) and (Figure 5). Research with several crops showed that there were no differences in yield, for nearly all of the crops tested, for bed widths ranging from 16 inches to 32 inches (Maynard and Clark, 1989). For some crops, such as tomatoes, bed sizes can be reduced to 24-inch wide tops to accommodate the operation of the drip irrigation system. Narrower beds require less plastic mulch (if bed spacing remains the same) and reduced power required to form the beds.

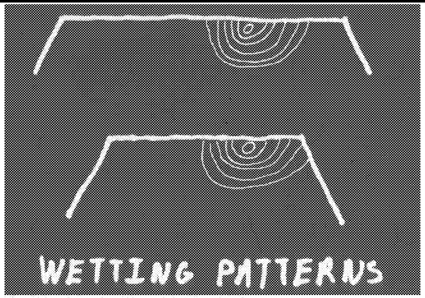

Figure 4. Narrow beds can be wetted more effeciently than wide beds.

Figure 4

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Figure 5. Typical wetting pattern of drip tube with 12-inch emitter spacing on sandy soil in a 24-inch wide bed

Figure 5

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Lateral placement. Drip irrigation laterals can be placed on the surface of the bed, in a shallow groove, or buried at a shallow depth beneath the soil in the bed. The main benefits from burying the tubing would apply mostly to the thin-walled disposable tubing. Burying the tubing places the laterals in a position less accessible to rodents, crickets, and ants. Another advantage of burying the tube is that it prevents the tubing, especially the thin-walled disposable tubing, from "fish-tailing" or moving on the surface of the bed.

Some manufacturers recommend that drip irrigation tubing be buried from 1 to 2 inches deep in the bed. However, burying makes the tubing less accessible for repair operations, should they be needed. It also makes it more difficult to replace a piece of tubing that has become seriously clogged. If the "fish-tailing" is the only anticipated problem, then the tubing can be placed in a shallow depression formed in the surface of the bed (Figure 6). Tubes should not be buried deep in typical Florida sandy soils because the upward movement of water will be severely limited. Do not bury tubes greater than 1 to 2 inches deep.

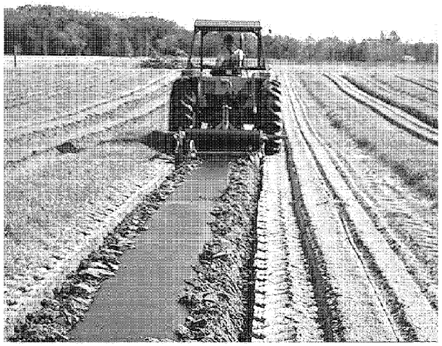

Figure 6. Depressions in surface of beds for placement of drip tubes.

Figure 6

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In most situations, the tubing is placed in the center, or just off center of the bed with a single lateral per bed. For single-row crops such as tomatoes or melons, the tubing can be placed 3 to 4 inches off center and the crop planted down the center of the bed. In twin-row cropping systems, such as strawberries or peppers, the tubing can be laid down the center of the bed with the two crop rows placed 4 to 6 inches from the tubing.

It is important to consider the soil-wetting pattern of the tube in relation to placement of the crop. In most situations, on sandy soils in Florida, the wetting pattern from the emitter rarely exceeds 9 or 10 inches in any one lateral direction. This means that a wetted band on the bed will rarely exceed 20 inches in width. This wetting pattern would be considerably less, perhaps 12 to 14 inches, on very sandy soils, and could be slightly higher, 30 inches or more, on soils that contain a significant amount of clay or silt.

Narrow wetting patterns in sandy soils may mean that only a portion of the bed is wetted, especially when the tube is placed to one side of bed center. When fertilizer is broadcast in the bed, this restricted wetting pattern will result in drying out of the fertilizer in the dry part of the bed. An alternative practice would be to place the tube in the center of the bed regardless of whether single-row or double-row crops are grown. In this system, single-row crops can be planted in modified double-row fashion by staggering the placement of plants on either side of the tube. With this planting pattern and tube placement, plants have better access to nutrients in a more uniformly wetted bed.

Most drip irrigation manufacturers recommend that the drip irrigation lateral tubes be positioned in the bed with the emitter facing upward. This positioning of the emitters normally reduces the potential for clogging the emitters with particulate matter.

The Effective Wetted Root Zone

Efficiency of irrigation with drip irrigation is only obtained if the water and fertilizer delivered by the system are confined to the plant root zone (Persaud et al., 1976; Persaud et al., 1977; Graetz et al., 1978; Sweeney et al., 1987). In Florida, water quality is normally good so that leaching of salts is not required. Under these conditions a drip irrigation system should be managed to prevent water and fertilizers from moving below the root system of the crop. Research has shown that for tomatoes, more than 80% of the roots are normally contained in the upper 12 inches of soil in a subirrigated field. When drip irrigation is used, root development will not be limited by a high water table, and the root zone might extend deeper than 12 inches. In other areas of Florida where soils do not have a hardpan, roots might also extend deeper. Growers will need to determine the root zone for their particular soil and crop. This knowledge will be critical to efficient management of water and nutrients. For most Florida vegetable crops, the root zone depth to be managed will range from 12 to 24 inches.

It is important to maintain optimum soil moisture in the root zone so that the crop can efficiently obtain water and nutrients. If part of the root zone dries out, then it is difficult to re-wet, because of the limited capillary movement of water in sandy soils. Therefore, any nutrients in the dry area will not be available to the crop.

Drip irrigation installations on Spodosols (poorly drained soils with a natural hard pan), may require a second irrigation system to establish soil moisture for bedding, fumigation, seed germination or crop establishment. Either sprinkler or subirrigation can be used for these purposes. For most crops, irrigation can be taken over by the drip system after seed germination or transplant establishment. The water table can be lowered and allowed to fluctuate naturally with drip irrigation. Lowering the water table provides more water storage capacity in the field to accommodate excess water from heavy rainstorms. Water table should be monitored (Figure 7a) and (Figure 7b) and kept at the proper depth, usually more than 36 inches below the surface of the bed, while the drip system is being used.

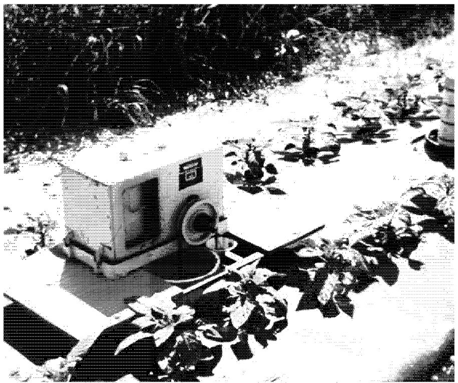

Figure 7a. Device for monitoring and recording water table level in field with hardpan.

Figure 7a

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In drip irrigated fields, it is very important to have sufficient drainage to rapidly remove water from the field after heavy rainfall. Plant roots of drip irrigated crops may extend to depths of 15 to 20 inches or more. On Spodosols, these roots might be subjected to high concentrations of salts from solubilized fertilizer if the water table suddenly increased after a heavy rain storm. Field lateral ditches and drainage systems must be well-maintained throughout the production season to provide drainage in a drip irrigated field on these soils.

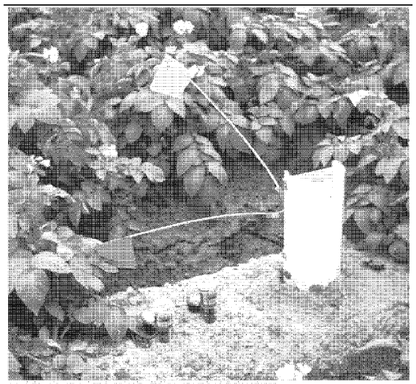

Figure 7b. Less expensive float monitors can be fashioned from PVC.

Figure 7b

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Preplant Fertilizer

Starter fertilizer. Current recommendations are only a fraction of the total seasonal fertilizer requirement, either liquid or dry, be applied in the bed as a starter fertilizer for drip irrigated crops. This starter fertilizer would contain all of the phosphorus (P) and micronutrients and up to 40% of the nitrogen (N) and potassium (K). On soils testing very low in P and K, the starter can be broadcast or banded in the bed. If only small amounts of P and micronutirents are required, then it is normally better to band these materials. Bands should be placed below the bed surface 2 to 4 inches and to the side of the plant row, but not between the drip tube and row. In most cropping situations, approximately 30-40 lb/acre of N and K would be sufficient in the starter fertilizer mixture. The amounts of P and micronutrients should be determined by a calibrated soil test. In situations where the soil test index for P is high to very high, then no P is required in the fertilizer.

Phosphorus and micronutrients. In general, P and micronutrients are not recommended for simultaneous application in drip irrigation systems in Florida. This is because of the possibility of precipitation of P and micronutrients or the P and calcium or magnesium in the well water. Research has shown that P can be successfully applied through drip irrigation systems with certain precautions (Rolston et al., 1981; Mikkelsen, 1989). However, if application of P is required during the season (such as during cold periods), it should be injected alone. Acidification of the irrigation water to pH 4.0 to 5.0 might be needed to keep the P in solution during application, especially when using the high pH water from the Floridan aquifer. Acidification can be achieved by using phosphoric, sulfuric, hydrochloric, or other acids to reduce the pH of the water. In summary, injection of P is possible and can be an efficient method of P application, however injection must be done with careful attention to water pH and is generally not recommended for Florida vegetables.

Caution: When acids must be diluted with water, always pour the acid into the container of water. Never pour water into acid because it will splatter when it contacts the acid.

Micronutrient injection can present problems similar to those experienced with P injection. The key is to avoid precipitation events. Potential problems with micronutrients are less severe compared to P because rates of application are normally much less with micronutrients than P. If micronutrients must be injected, then soluble forms, less subject to precipitation, such as chelates, should be used. Like P, micronutrients should be injected alone to avoid potential precipitation problems.

Although there are serious problems and considerations with injecting P and micronutrients, there are several potential benefits from proper injection where water chemistry is suitable. Phosphorus and most micronutrients are relatively immobile in the soil so that generally only one or two applications are needed in a growing season. Also, in most Florida vegetable soils, only small amounts are needed. Research has shown that plant recovery of these nutrients can be increased when they are applied through the drip system (Rolston et al., 1981; Mikkelsen, 1989). This is probably due to resulting "band-like" application in the drip-irrigated zone where the nutrients are not widely mixed with the soil where fixation can occur. Although only a portion of the root zone would be exposed to the nutrients, research shows that not all of the root system needs to absorb the nutrient to benefit the plant.

There have been some serious clogging problems in Florida from improperly managed P and micronutrient injections. This is why injecting P and micronutrients is not often practiced. If injections are required, proper procedures should be followed.

Zero in-bed (preplant fertilizer). In some production systems where soils are relatively high in organic matter, micronutrients, P, and K, it is possible to grow successful crops with no in-bed fertilizer (i.e. all fertilizer (nitrogen) applied through the drip-irrigation system). This is particularly attractive for areas in the state where growers experience soluble salt problems in the soils. Reducing the amount of dry fertilizer applied in the bed could potentially reduce soluble salt injury to young seedlings or transplants. The use of soluble N and P starter solutions with the transplants might still be advantageous but these amounts of N and P are very small.

Slow-release. For some crops such as strawberries, tomatoes, and peppers, benefit can be achieved from using slow-release fertilizers in the in-bed starter fertilizer mixture to provide an early season N supply. Slow-release fertilizers are less subject to leaching during the early part of the season when the beds are wetted with subirrigation. Also, slow-release fertilizers have a lower salt index so they are less likely to damage young seedlings and transplants early in the season (Everett, 1977). Supplying 30-40 lb/acre of N from slow-release fertilizer, although more expensive, might be beneficial for these crops. It is important to select a slow-release fertilizer with a nutrient-release pattern appropriate for supplying N to the young crop. This practice is more important for fall crops when frequent rain reduces the need for irrigation, yet fertilizer is still required by the young crop.

Preplant fertilizer. Since preplant fertilizer is applied in small amounts, the most efficient application method is to band the fertilizer near the plant row. The fertilizer can be banded in the bed as dry or liquid material as the bed is formed and pressed. Incorporation of fertilizer by mixing it throughout the bed is acceptable if it will not be exposed to leaching or drying out.

Any fertilizer placed in the bed before planting should be placed so that it will be least likely to leach, either from rain coming through the holes in the plastic or from water applied with the drip irrigation tubing. This means that fertilizer applied in bands should be applied to the area of the bed outside of the tubing placement. The band should not be placed on the surface between the tubing and the row because irrigation water from the tubing would have a tendency to move the fertilizer salts toward the plant where soluble salt injury could occur.

Fertilizer bands should not be placed on the surface of the bed because they may dry out as the surface of the bed dries when the water table is lowered. Banded fertilizer should be placed 2 to 4 inches deep in the bed where it will remain in contact with moist soil, dissolve, and be available to the plants. In-bed fertilizer materials can use many fertilizer sources. Materials such as triple-superphosphate, ammonium nitrate, potassium chloride, and potassium nitrate have worked well as starter fertilizers.

After preplant fertilization, the remaining 60 to 80% of the N and K is applied in increments through the cropping season via the drip irrigation system. In some cases, growers apply some of this N and K in bands ("hot-mix") on the surface of the bed. These growers feel they need a certain amount of fertilizer in the bands for rainy periods when they do not need to irrigate with the drip irrigation system. In most situations, hot-bands are not needed, and most often the fertilizer material in the hot-bands is not fully utilized by the crop (Figure 8)

. This is because, in many cases, the hot-bands dry out after the water table is lowered, especially in the shoulder area. A significant amount of the N and K fertilizer in these hot-bands is then not available to the crop. If drip irrigation is being used for the injection of fertilizer materials, it is best to use the system to its fullest extent. This means injecting 60 to 80% of the N and K through the system.

Injected Fertilizer

Rates. On typical Florida sandy soils, in most situations injected fertilizers will consist only of N and K. The amount of N to use is determined by the crop nutrient requirement for N for that particular crop. This amount of N is recommended for each crop for each season. Specific recommendations for each crop are presented in SP 177 (Hochmuth and Hanlon, 1995) and in this publication for drip-irrigated crops. Recommendations are under continual revision as more research results become available.

Figure 8. Banded N and K fertilizer not required in a drip fertigation program. Lateral movement of water in sandy soil not sufficient to wet the band of fertilizer on left side of bed.

(Figure 8)

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The K amount to be injected is based on the soil test predicted amount of K required for the crop minus the amount that is applied in the bed preplant. For example, if the soil tested medium in K, perhaps only 100 lb of K_2O fertilizer would be required for the season. If 20% of this K_2O (i.e. 20 lb) were applied in the bed as starter fertilizer, then 80 lb would be injected through the season.

Sources. There are several sources of N and K that can be used for drip irrigation injection (Locascio et al., 1978; Locascio and Fiskell, 1979; Locascio et al., 1981a; Locascio et al., 1982; Fiskell and Locascio, 1983; Locascio et al., 1984; Locascio and Martin, 1985). All sources must be highly water soluble to be effective for drip irrigation injection. Nitrogen sources including ammonium nitrate, calcium nitrate, various nitrogen solutions, and potassium nitrate can be used to supply the N. Potassium sources include potassium nitrate, potassium sulfate, or potassium chloride. Chlorides from potassium chloride should not be a problem where soil-test recommended amounts of K are not exceeded.

The ratio of N to K is not important for vegetables. As long as the soil test predicted amounts of N and K are added, then the crop nutrient requirements will be satisfied. If some sort of ratio theory such as 2 K to 1 N ratio is practiced, then overfertilization with K is likely. For example, if 175 lb of N is required by a tomato crop, then 350 lb of K_2O would be applied by using this 2:1 K:N ratio theory. Recent research with tomatoes and peppers has shown that equal crop yields and equal crop quality are achieved with various ratios of K to N ranging from 1 N to 3 K through 3 N to 1 K. It should be noted that as the ratios change, so do the rates. Therefore it is impossible to separate a rate effect from a ratio effect. Furthermore, in situations where the soil tests medium or above in K, specific ratio of K to N fertilizer would have little impact once that fertilizer is mixed with the soil which already contains large amounts of K.

A portion, approximately 25 to 50% of the N, should be applied in the nitrate form, especially for crops planted in cool soil conditions. For crops planted in warm seasons, the bulk of the N (75%) can be supplied from the ammoniacal form. Plants can absorb and utilize appreciable quantities of ammoniacal N. In addition, under warm soil conditions, the ammoniacal form of N is rapidly converted by nitrification to the nitrate form. The ammoniacal form of fertilizer is less expensive than nitrate forms and, in most situations, would be suitable for supplying at least part of the N to the crop. If recommended levels of N are applied, then the ammoniacal form should have no effect on the availability of other nutrients, such as K and calcium, to the plant.

Some growers become concerned about relative salt indices of fertilizer materials. This concern is generally not that important if soil-test-predicted and crop nutrient requirement amounts of N and K are applied to the crop. In situations where soluble salt injury has been a problem and where well water with high soluble salt content is used, it is even more important to refrain from overfertilization.

Commercial liquid fertilizer materials for injection into drip irrigation systems are often mixtures of N and K. These typically range from solutions that have an analysis of 6-0-6 up to an analysis of 10-0-10. These mixed solutions should be formulated with several factors in mind, including crop nutrient requirement, the soil-test-predicted amount of fertilizers to be applied, and the pumping capacity of the injection system.

Concentrated materials are easier to inject because shorter injection cycles are required to inject the same amount of nutrient as compared to a more dilute fertilizer solution. In cropping situations where the soils test very low in K (so that the total crop nutrient requirement of K is supplied from fertilizer), fertilizer materials such as 7-0-7, 8-0-8, or 10-0-10 are satisfactory for most vegetable crops. Growers should purchase as high an analysis of liquid fertilizer as possible to avoid purchasing large amounts of water. In some situations, particularly those where the soil already contains large amounts of K, it might be possible to inject single-nutrient solutions such as 19% or 28% N solution. These N solutions are usually mixtures of ammonium nitrate and urea in various proportions.

Weather conditions have a great effect on the solubility of fertilizer solutions. Higher concentrations of N and K can be maintained in solution under warm weather conditions compared to cooler temperatures. For example, fertilizer solutions used in the early fall or late spring might be as high as 10 or 12% N and K. However, in the winter under cooler temperatures, lower concentrations will be required to avoid precipitation or "salting-out" of fertilizer elements. 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 during winter conditions so that the solution does not sit in a field tank too long.

Some growers may want to investigate the possibility of formulating their own liquid nutrient solutions. This approach might be especially feasible for growers with extensive acreage of drip-irrigated vegetables or for small growers who use only very small quantities of solution. For large acreages, the formulation of fertilizers on site might be less expensive compared to purchasing premixed solutions with the associated transportation costs.

Growers wishing to investigate the possibility of formulating their own fertilizers should thoroughly investigate the techniques. This investigation should include the cost of the installation to mix and possibly heat the fertilizer solutions. Purchasing nutrient materials such as potassium nitrate, ammonium nitrate, or potassium chloride in bulk and formulating nutrient solutions on site from these might be a good approach. When formulating nutrient solutions, one should take into consideration the associated problems with maintaining nutrients in solution under various conditions as well as ensuring that the solutions are made according to desired specifications. Mixing one's own fertilizer would have the additional benefit of providing same-day mixing and utilization, avoiding the need for long-term storage of nutrient solutions with the associated potential for salting-out.

It is most convenient to think of rates of injection in terms of pounds of a particular nutrient per acre per day or week. For example, the recommended rate of N injection for a particular crop might be to start out early in the season with 1 lb N/acre/day then increase to 1.5 lb N/acre/day and finally inject 2 lb N/acre/day when the crop is at its peak growth rate. Pounds/acre/day are calculated based on the number of linear bed feet (LBF) of crop in an acre (43,560 square feet). For example, for tomatoes, the typical bed spacing is 6 feet between centers or 7,260 LBF of crop in an acre. Therefore, for a rate of 1 lb N/acre/day, a grower would inject 1 lb N/7, 260 LBF/day. Typical bed spacings for vegetables are presented in Table 5. The calculations below demonstrate how to calculate the number of gallons of an 8-0-5 solution to supply 1 lb N/acre/day. Amounts of various materials needed to supply one lb of various nutrients are presented in Table 1. More information on calculating rates of nutrients, in terms of LBF was presented by Hanlon and Hochmuth (1989).

Number of gallons of 8-0-5 needed to supply 1 lbof N per acre per day:

1 gallon 8-0-5 weighs 10.5 lb, therefore each gallon contains 0.84 lb actual N (10.5 x .08). Specific weights of liquid fertilizers are obtained from the fertilizer dealer.

If 1 gallon contains .84 lb N, then 1.2 gallons contain 1.0 lb N (1 ÷ by 0.84). The grower will need to inject 1.2 gallons of 8-0-5 for each acre (7,260 LBF).

Frequencies. Nutrients can be injected into the system at various frequencies. Basically the frequency to inject, whether once a day or once every two days or even once a week, depends on system design constraints, on soil type, and on grower preference. Research has shown that the frequency, even up to once per week, is not as important as achieving a correct rate of application of nutrients to the crop during a specified period of time (Locascio and Smajstrla, 1989). With computer control of drip irrigation systems, some growers find it easy to inject more frequently such as once every day.

Injecting fertilizer more frequently, such as once per day, would reduce the chances that nutrients are leached from the beds during a heavy rainstorm or excessive irrigation compared to injecting larger amounts on a less frequent basis. If the chances for leaching losses are extremely low, then injection once per week would be satisfactory. In any event, it is extremely important that the nutrients applied in any irrigation event are not subject to leaching either during that same irrigation event or by subsequent irrigation events. This is why knowledge of the crop root zone is important for optimum fertilizer management. It is very important to monitor the application of water and to realize that fertilizer application is linked to water application (Locascio et al., 1989).

When injecting fertilizer in non-continuous (bulk) fashion, such as once per day or once per week, it is important to bring the drip irrigation system up to operating pressure before injecting. After the system has been fully pressurized, the fertilizer can be injected. Following the completion of injection, the drip irrigation system should be operated long enough to ensure flushing of the nutrients out of the tubes and into the soil. If complete flushing cannot be achieved without excessive water applications, this flushing period might be the next irrigation cycle of the day. It is very important to design the drip irrigation system so that fertilizer injection can be achieved in a reasonable amount of time without running the risk of overwatering the crop to get the fertilizer applied. This means that injection pumps, pipe sizes, and injection rates must be properly sized to be able to apply the nutrients in the desired amount of time so that the system can still be flushed without applying excess water during the injection and flushing cycles.

In many situations in Florida, more than one irrigation will be needed during the day to supply adequate water to a particular crop. This will be needed most 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 irrigation events during the day.

In some systems, fertilizer is injected continuously (concentration injection) so that all irrigation water applied contains nutrients. This system is acceptable as long as no irrigation cycle is excessive causing nutrients to be leached below the root zone.

Another method to apply fertilizer would be to inject the nutrients during the latter part of each of the irrigation cycles, keeping in mind that enough time must be left after the fertilizer injection to flush the system. An alternate method, where more than one irrigation cycle is used daily, would be to inject fertilizer in only one of the irrigations. It would be important, then, to take care in the subsequent irrigations so that nutrients applied in the first are not leached by successive irrigations.

The duration of injections should be long enough to allow uniform injection of nutrients. For example, it would not be acceptable to inject nutrients so rapidly that a large amount of nutrients is injected into the system in only a (few minutes). It would be more appropriate to spread the nutrient injection over a 15 or 20 minute period followed by a 15 or 20 minute flushing period. Research on sandy soils in Florida shows that 45 minutes (young tomato crop) up to 1.5 hours (mature crop) would be sufficient to apply the amount of water required by the crop during any one irrigation cycle (Smajstrla, 1985b; Clark et al., 1990a). Irrigation cycles longer than 1.5 hours on a mature crop run the risk of leaching nutrients and moving water below the root zone. If more water is needed, then multiple cycles should be used rather than one cycle of length longer than 1.5 hours. It should be apparent from the above discussions that water application and fertilizer application are closely linked.

Fertilizer Injection Calculations

Fertilizer mixtures and injections. Fertilizers may be applied as a precisely managed level of injected concentration or as a bulk mass of fertilizer with possibly varying concentration levels. Concentration injection requires a precise injection system and is more difficult than bulk injection. The injection system must be specifically calibrated for the irrigation system it is to be operated on and under the operating conditions that will exist when fertilizer solutions are to be injected. Variations in operating pressure, system flow rate, and at times even temperature can influence the calibration of the system. Bulk injection simply involves the injection of a desired volume or amount of fertilizer into the system. This is easier to do because the injection rate does not need to be precisely controlled.Concentrations are generally expressed in parts per million (ppm), which is not a convenient term for mixing purposes. Fertilizers may be supplied in dry form or liquid form. The following equation or can be used to determine the amount of fertilizer mixture required to achieve a particular ppm level of a certain fertilizer element:lb of fertilizer mixture to add to 100 gallons of water = (100 * desired ppm) ÷ ((% conc. X) * 1205).

For example, a 200 ppm concentration level of N as a fertilizer solution using a 20-20-20 dry fertilizer mixture will require:(100 * 200 ppm) ÷ (20 % * 1205) = 0.83 lb of fertilizer mixture per 100 gallons of water.

When fertilizers are supplied in liquid form, it is more convenient to measure volumes rather than masses or weights. This requires knowledge of the specific density or specific weight (Sx) of the liquid mixture in pounds of solution per gallon of liquid. The specific weight should be provided by the manufacturer or fertilizer supplier and can be used to simply convert from required lb to required gallons. For example a liquid fertilizer provided as a 8-0-4 solution has 8% N by weight. However, the amount of N is not known unless the specific weight of the fertilizer solution is known, such as 10 lb per gallon. As was previously mentioned, this value varies among fertilizer mixtures and should be on the fertilizer label, or may be obtained from the supplier.

Concentration injection rates. Concentration injection rates work with the flowing water in irrigation systems and a requirement to maintain a desired concentration of a fertilizer element in that system. This requires injecting a fertilizer supply mixture at the proper rate to maintain the desired concentration level. If the specific weight of the fertilizer solution is close to 10 lb/gal, the following equation or can be used to estimate the injection rate necessary to maintain the desired concentration of a fertilizer element X.

$Qi = (0.005)(ppm)(Qw)/(\%X)$;

where Qi = Injection rate in gallons per hour (gph);

Qw = Water supply flow rate (gpm);

ppmX = Desired ppm level of fertilizer, element X; and

%X = Percentage of fertilizer element X in the stock solution.

As an example, consider a N injection cycle where the irrigation system flow rate is 550 gpm, a 4% N solution is used, and a 100 ppm N concentration is intended.

Qw = 550 gpm; ppm = 100; %X = 4; and

$Qi = (0.005)(100)(550)/4 = 68.8$ gph, the necessary injection rate of the N fertilizer source.

Injection volumes. To determine the required injection volume for bulk applications, the amount of the desired fertilizer element and the percent concentration of the fertilizer element in the mixture must be known. Assuming a fertilizer solution weight of 10 lb/gal, the following equation or may be used to determine the required liquid fertilizer volume.

V = 10 * (Amount of required fertilizer element lb) (% concentration of fertilizer element in the solution); where V = Required mixture volume (gal).

For example, a grower wishes to apply 1.5 lb of N per 1000 feet of plant row **each week** in one injection cycle; 20 acres are to be irrigated per set; and the system has 7200 feet of plant row and drip tube per acre. What size feeder tank is necessary for injecting a 4-0-4 fertilizer solution which has a specific weight of 10.0 lb per gallon?

The weekly production requirement of total N is: (20 acres)(7200 ft/acre)(1.5 lb of N/1000 feet) =216 lb of N per week. The injection volume per application is: V = 10* 216 lb, divided by 4 % = 540 gallons of fertilizer solution.

Therefore, the feeder tank must be able to contain at least 540 gallons to provide the needed volume for each weekly fertilizer application.

Sometimes fertilizers are injected on a periodic basis to maintain a certain injected concentration of that fertilizer element during that period. In this case, the required injection volume of stock solution depends on the length of the injection period and the injection rate. The required stock solution volume can be determined as follows:

$V = (Qi) * (Ti)$,

where V = Required mixture injection volume (gal),

Qi = Injector flow rate (gpm), and

Ti = Injection period (minutes).

For example, a drip irrigation system manager desires to inject 200 ppm of N into his irrigation system for a period of 1 hour. The irrigation system delivers water at a rate of 550 gpm, the N stock solution contains 4% N by weight. From a previous example, the required injector flow rate was 68.8 gph. Therefore, the required injection volume is:

V = (68.8 gph) (1 hour);

= 68.8 gallons of stock solution.

Therefore, only a small feeder tank is required for each application

Injection periods and calibration. The length of the injection cycle is important from an irrigation management viewpoint. With respect to the injection period, several criteria may need to be addressed, such as the frequency of fertilizer application (daily, semi--weekly, weekly, etc.) and the maximum time allocated per irrigation zone. For example, for daily fertilizer applications the number of irrigation zones multiplied by the injection period per zone cannot exceed 24 hours. Furthermore, if the injection period exceeds the maximum irrigation period, resulting in over-irrigation and nutrient leaching, then split fertilizer applications are necessary.

The injection volume was discussed in the previous section. Although the injection rate may be provided by the supplier of the injection system, calibration is required. Calibration should be performed on the irrigation system which is to be used with the injection system. Also, because irrigation system operating pressures and flow characteristics may influence injection rates, calibration should be performed while the irrigation system is operating.

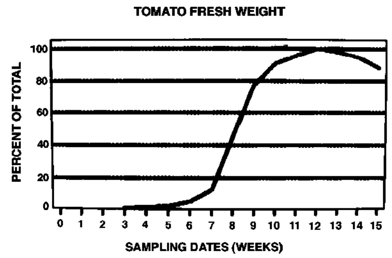
A simple calibration procedure involves physical measurement of the injected volume during the injection period. This procedure can be performed by either measuring the time to inject a known volume of liquid, or by measuring the volume of liquid injected during a pre-set specified injection period. In each method, a container is filled with a known volume of the fertilizer to be injected. For calibration, water or colored water may be substituted for the fertilizer solution but results may not be completely accurate with some injectors if the viscosity of the fertilizer solution is very different from that of water.

Nutrition Injection Scheduling

Fertigation schedules. Research with crop response to selected injection schedules showed that yield was similar whether N and K were injected in equal weekly amounts or via the projected crop growth curve. In this research, irrigation was carefully monitored to minimize nutrient leaching. Equal injections sometimes might result in application of more nutrients than the crop can absorb, especially early in the crop growth cycle. However, even if more nutrients than the crop can absorb are applied in a single injection, leaching will not occur as long as excess water is not applied with the fertilizer or in a subsequent irrigation. Where leaching potential exists, then fertigation via the crop growth curve might provide for more efficient nutrient management.

Crop growth curve. Injecting fertilizer into a drip-irrigation system offers the benefits of nutrient application to the crop in precise amounts and at times in the crop growth cycle when fertilizer is most likely to be absorbed by the plant. The most efficient technique for scheduling nutrient applications to a crop would be to anticipate the crop nutrient demand during the season. Injection begins early in the crop cycle with small amounts of nutrients and then increasing the rate of application of the nutrients as the crop growth rate increases and the demand increases. Once the crop has reached maturity, (for example, tomatoes at first harvest) nutrient applications can level off and may even be slightly decreased toward the end of the growing season. This leveling off and reduction of nutrient application rate coincides with the times when the growth of the crop is slowing and nutrients already absorbed are being translocated from the vegetative part of the plant into the fruits.

Plant growth follows what is called a sigmoid curve (Figure 9). Dry matter accumulation starts slowly at first and proceeds at a relatively slow rate for two to three weeks following plant emergence. Then, the crop growth rate becomes rapid and dry matter accumulation is rapid for a period and then begins to level off. Some crops, such as broccoli, cauliflower, and lettuce, grow very rapidly, absorbing large amounts of nutrients. Dry matter accumulation is rapid until harvesting date. Since harvesting is usually once-over, there is no need to make a late-season reduction in injection rate. Plants are very efficient accumulators of nutrients under most cropping situations. There are rarely any benefits to be achieved by special small adjustments made in a nutrient injection program at special periods during the growth cycle. Plants often accumulate more nutrients than they need at any specific time. This extra accumulation is referred to as luxury consumption. Nutrients absorbed in luxuriant amounts are translocated from the leaves of the plant to the newly developing parts of the plant or to the fruits during the growth cycle. This translocation is most applicable to the mobile nutrients such as phosphorus, potassium, nitrogen, and magnesium. It does not apply as strongly for the non-mobile elements such as calcium, boron, and other micronutrients.



Marlowe et at., 1983, FSHS

Figure 9. Typical growth curve for tomatoes. Fertilizer schedules for fertigation follow growth and nutrient demand.

Figure 9

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For the mobile elements, the key is to supply them in reasonable amounts during the growth cycle so that they are available to the plant for absorption and subsequent transport to the newly developing plant parts and fruit. These nutrients do not necessarily need to be injected with every irrigation, because these nutrients can be absorbed when they are present in the soil for later transport within the plant. This does not mean, however, that there can be extra long periods between fertilizer applications. Micronutrients and major non-mobile nutrients such as calcium need to be in fairly continuous supply from the soil during the growth cycle. In well-developed fertilizer programs, these nutrients are made available continuously from the soil by following soil test recommendations. These nutrients are less likely to leach from the soil compared to N or K and thus, can remain in continuous supply from the soil during the growth cycle.

Often, growers ask if there is any specific nutrient that they should inject in increasing or decreasing amounts at some specific physiological stage of growth. For example, should a particular nutrient injection rate be increased exactly at early flowering or at early fruiting as opposed to one week before or after? From the above discussions, it should be apparent that the key to successful fertilization with drip irrigation is to ensure that the required nutrients are made available in timely fashion to the plant, either from the soil such as the case with P and micronutrients, or via drip irrigation as in the case of N and K. There is rarely a benefit of increasing or decreasing the rate of application of a particular nutrient at some specified physiological growth stage when that nutrient has already been well managed in a soil- and/or drip-applied fertilizer program. In these well-managed programs, the plants will not be deficient of any nutrient and should not be expected to respond to sudden changes in nutrient application rates.

Growers should understand the growth rate of the particular crop they are growing for the particular season (fall, spring, or winter). Scheduling application of nutrients should be a reflection of the growth rate of the crop for a particular season and to schedule the injections so the nutrients will be in the soil at the time the projected growth rate changes will be occurring. Research shows that there are probably very few adjustments that need to be made during the growth cycle for vegetables. Growers can begin the season with small amounts of nutrients and maintain the same injection rate for 2-4 weeks. When the change is made to a higher rate of injection, this rate can be maintained again for 2-4 weeks. For most vegetables, there will probably be at most four or five changes in the rate of injection of nutrients during the crop's cycle. For some of the fast-growing and short-season crops such as summer squash, there may be even fewer changes to be made in the injection rate during the season.

Accounting for preplant N and K. N and K are normally applied as preplant fertilizer at the rate of 20% to 40% of the total N and K crop nutrient needs. When these preplant applications are made, then the N and K injections can be delayed. This delay may be up to about two weeks after transplanting depending on the crop. When N and K are added to the soil before planting, 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 transplanting the crop or at seedling emergence. Delays in beginning the fertigation program will result in reduced yields.

Length of season. Another consideration in nutrient scheduling with drip irrigation has to do with the length of season for a particular crop. For example, tomato crops may be 14 to 15 weeks in length in the spring, but only 12 weeks in length in the fall due to the warm temperatures in early fall and the associated high growth rate. It follows that nutrient applications, especially early-season injections, should be slightly higher for any particular week in the fall compared to the spring. Plant growth rate is rather slow early in the season in spring crops because the crop is established under cool temperatures compared to the warm temperatures for crop establishment in the fall. However, the total amount of nutrients injected for fall crop should be similar (e.g. 175 lb of N/acre for tomatoes) compared to a spring crop.

Florida schedules. The recommended schedules for injecting N and K via the growth curve for vegetables in Florida appear in Table 5. These schedules are based on research and commercial grower experience (Hochmuth et al., 1989; Hochmuth, 1990a; Hochmuth, 1990b; Hochmuth, 1990c).

The injection schedules have been modified in two ways from their previous presentation in SS-VEC-45 "Fertilizer application and management for micro (drip) irrigated vegetables in Florida. " The first change involved the rates of application of N and K, which were revised to conform to the recommendations in Circular 1152 (Hochmuth and Hanlon, 1995a) and Circular 177 (Hochmuth and Hanlon (1995b). Secondly, the injection schedules were modified to reduce the number of changes in rates of application from one crop growing stage to another.

The method of injection via the growth curve was chosen for this publication presentation. N and K efficiency might be maximized with this injection scheduling since less nutrients might be risked to leaching during early-season applications. Research with tomato, however, showed that amounts of N and K could be divided into equal weekly injections as long as potential for leaching is low.

For some crop groups, such as melons, extrapolations of nutrient programs from one crop to another are possible. The schedules in Table 5 assume that the soil will supply none of the K crop nutrient requirement. Therefore, for tomatoes, the schedule is based on applying 175 lb of N and 225 lb of K_2O for the season. It is important to keep in mind that the actual K amount used in a grower situation will depend on the soil test index for K. In many situations some K will already be present in the soil, and the actual K amount that the grower needs to apply will be less than the amounts specified in Table 5.

The amount of nutrients for injection presented in Table 5 vary from some of the popular literature and pamphlets that appear in the trade literature from time to time. At least two differences are apparent. One difference has to do with the rates of application, in other words, the crop nutrient requirement for a particular vegetable crop, that appear in various literature. The amounts presented in Table 5 are amounts of nutrients shown to be required by mulched, drip-irrigated vegetables in Florida from research in Florida. These amounts have been shown in many test demonstrations on commercial sites to be adequate for optimum vegetable production. Where water management programs are efficiently operated and where environmental factors are optimum for vegetable production, these amounts of nutrients would be sufficient for optimum vegetable production and quality.

The second difference between Table 5 and some commercial literature has to do with the N and K ratio concept. As discussed earlier, ratio concepts often result in overfertilization, particularly of K. The overfertilization might cause more problems (e.g. high soluble salts and poor fruit quality) than it helps. Soil testing for K, and applications of K fertilizers to supplement that part of the crop nutrient requirement for K that can be supplied by the soil are the most efficient management practices to use for vegetable fertilization.

Situations Requiring Expanded or Compressed Injection Schedules

The schedules in Table 5 are for a typical season's duration and may need to be adjusted depending on specific cultural practices and growing season conditions. Some factors that might lead to expanding or compressing the injection schedule are described in this section.

Crop development rate can be increased by transplanting in contrast to direct seeding. For example, watermelons can produce earlier fruit by about 7 to 10 days from transplants compared to seeds. Transplanted crops will require slightly greater amounts of nutrients early in the season than seeded crops. Injection rates can be increased by 0.5 lb per acre per day for the first 4 to 6 weeks compared to a seeded crop. Since transplanted crops mature faster than seeded crops, the rates of injection can be reduced or discontinued earlier than for seeded crops. Although the scheduling may change slightly for seeded and transplanted crops, the total amount of nutrients injected by the end of the crops should be similar.

The crops and schedules detailed in this publication are for vegetables produced on polyethylene mulch. Mulch has a growth enhancing effect on crop development. Some growers desire to use drip irrigation without mulch. In these situations, the growth season might be increased by 7 to 10 days where the mulch is absent. Therefore, injection schedules can be expanded by reducing the amount injected in the early weeks.

For a given crop, growth in the fall is usually faster than spring growth. The difference can be one week for a crop such as squash or two weeks for tomato or pepper. Therefore, fall injection schedules would need to be compressed compared to spring schedules. Amounts of nutrients injected can be increased during the first few weeks by 0.5 lb per acre per day. Total seasonal fertilizer amounts for spring and fall crops should be similar.

The schedules in this publication are for situations where all N and K will be injected. It is usually best to place some nutrients in the bed before mulch application. The general rule-of-thumb is 20% of N and K as a starter. For most crops, this results in about 25 to 30 lb N per acre in the bed. Under these situations, the first injection can be delayed by one or two weeks.

The length of harvest period can have an effect on extending the injection schedule. In some of the southern winter-growing regions, the production season for pepper might encompass 4 to 6 months. In these situations, the injection schedule will be considerably longer than for a typical 3- to 4-week harvest season. Where the crop will be continued through the winter with approximately biweekly harvests, growers can inject 1 to 1.5 lb of N per acre per day as a maintenance program for these extra months. The exact amount of N and K should be determined by plant tissue analysis.

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 publication are for the standard cultivars presently recommended. In general, most cultivars currently being grown will do well under these injection schedules. For situations where a particular cultivar may mature significantly earlier or later than currently grown cultivars, an adjustment in the schedule might be needed.

Crop Establishment

Depending on the soil type and production experiences of the grower, some considerations will need to be taken into account when establishing a crop where drip irrigation will be used. In situations where drip irrigation will be used on a Spodosol, it might be advantageous to maintain adequate soil moisture with subirrigation for 1 week after seeding or transplanting the crop. Subirrigation may be needed to maintain soil moisture during soil bed preparation, fumigation, and mulching. It is probably a good idea, then, to maintain soil moisture during planting and for up to 1 week after planting. This might be needed most often with direct-seeded crops to ensure uniform germination. After crops have become established, the water table can be lowered with irrigation and fertilization being taken over by the drip-irrigation system.

In some cropping situations where water tables cannot be maintained, especially the rockland soil in Dade County, overhead-sprinkler irrigation might be needed for crop establishment. Following crop establishment, irrigation and fertilization can then be taken over by the drip-irrigation system.

Growers will need to pay particular attention to the wetting pattern of the drip irrigation. It is important to utilize as much of the wetted bed area as possible for a particular crop. Reducing the bed width helps maintain the effective root zone in a moist condition under the plastic mulch. In situations where crop establishment must be done without subirrigation for soil moisture maintenance, placement of seeds and plants in the moist soil near the drip tube becomes important to ensure uniform germination. For single-row crops such as melons, one option would be to place the drip tube in the middle of the bed and then place the plants in a pattern that alternates on both sides of the drip tube. This is an acceptable planting pattern compared to placing the drip tube off-center in the bed and then planting a single row of plants in the center of the bed. The alternating planting pattern utilizing both sides of the drip tube allows the drip tube to be placed in the middle of the bed and increases the potential for wetting the entire width of the bed. If the drip tube were placed off center, it might be impossible to wet all the way to the shoulder of the bed farthest from the drip tube. In any event, seeds or transplants must be placed within the wetted zone of soil in the bed.

Clogging Control

Drip tube orifices are easily clogged by three types of mechanisms. These three types of mechanisms are: particulate matter, such as limestone particles or sand from the well; biological material such as algae or organic matter from surface water, ponds, or lakes; and chemical precipitations such as might result from fertilizer precipitation in the nutrient solution. Another type of organic or biological clogging may also result from bacterial slime growth in the tube. All of these methods can easily occur in irrigation systems that are not monitored or maintained carefully during the season (Figure 10). Clogging control begins with a careful analysis of the water source for pH, carbonates, iron, and sulfur. It is important to determine what potential problems will lie ahead relevant to clogging. Once it is understood what possibilities exist for clogging, then measures can be taken to prevent clogging during the season. Clogging prevention centers around filtration and/or chemical treatment of the water. It is important to properly filter all liquid sources entering the irrigation system, including the water from the well, the fertilizer stock solution being injected, and the final nutrient solution being applied to the field. This filtration procedure will remove any particulate matter from the well or from the fertilizer stock solution, and any precipitates that may form at the point of injection.

Figure 10. Crop water stress due to clogging of drip tubing on single bed of squash.

Figure 10

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Chemical treatment of the water usually involves periodic chlorination to remove iron and prevent the growth of sulfur and/or iron bacterial slimes. Only labeled chlorination materials can be used for injection into an irrigation system. A small test kit that analyzes water for free chlorine will be needed. The procedure for chlorination and the amounts required depend on the severity of the problem. Details on the exact amounts and calculations for chlorine injection can be found (Ford, 1976; Ford, 1979; Pitts et al., 1990).

The basic approach is to inject chlorine at rates that will result in approximately 0.5 to 1 ppm of free chlorine at the end of the drip irrigation laterals in the field. Frequency of chlorine injection will depend largely on the extent of the problem and the frequency of system operation. If the water is such that it will support large amounts of bacterial growth, then frequency will have to be increased. Weekly chlorination may be required in many cropping situations.

Bacterial slimes account for most clogging problems in drip irrigation in Florida. There is however, another potential problem in some situations. This problem involves certain calcium carbonate scales that may build up around the emitters. These scale deposits can potentially clog the emitters. The most effective and least expensive means for ridding drip irrigation systems of scale precipitates would be acidification of the irrigation water. Acidification can be achieved by injecting acids in amounts sufficient to reduce the pH and neutralize most of the carbonates. Acidification should be done before serious clogging has occurred. A water analysis can help predict the level of scale problems to be encountered and calculate amounts of acid needed to keep carbonates solubilized.

With any water treatment system to prevent clogging, it is important to include a flushing sequence. This flushing sequence should immediately follow the water treatment so that materials can be flushed from the tubes and not present a physical clogging potential. More information on clogging control and filtration is available (Smajstrla et al., 1983a; Haman et al., 1988b; Pitts, et al., 1990).

Water Management in Relation to Fertilizer Injection

Water management and fertilizer management are linked. Changes in one of the programs will affect the efficiency of the other program. As mentioned earlier, amounts of water to be applied need to be carefully gauged with the fertilizer injection so that excess water is not applied that would result in leaching of fertilizer nutrients. Leaching potential is high for the mobile nutrients in the soil. These nutrients would include N and K.

Water management by drip irrigation depends on having a well-designed and well-managed drip-irrigation system (Clark et al., 1990b). Key points to remember include emitter spacing, bed size and shape, and the capability of monitoring soil moisture. All of these factors should be designed into the system so that water and fertilizer can be applied in an efficient and non-polluting manner.

Irrigation programs can be managed by using tensiometers that indirectly measure the water status of the soil and with a measure of evaporative demand to determine the plant requirements for water (Figure 11). Tensiometers indicate when to irrigate and if the scheduled irrigations are sufficient to recharge the root zone or excessive which results in leaching (Clark et al., l988). In most sandy soil situations in Florida, tensiometers placed 6 to 8 inches deep in the soil in the root zone should be maintained no wetter than -8 centibars and no drier than -15 to -20 centibars. When the tensiometers approach -15, an irrigation event should be scheduled.

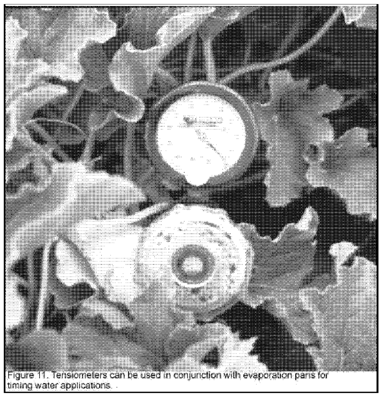

Figure 11. Tensiometers can be used in conjunction with evaporation pans for timing water applications.

Figure 11

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The exact amount of water to apply to a crop can be gauged by evapotranspiration. Evapotranspiraton may be estimated by measuring the amount of evaporation from a Class A Weather Bureau Evaporation Pan (Figure 12). Factors that affect evapotranspiration are discussed elsewhere (Clark et al., 1989.) Research shows that applications in the range of approximately 0.4 to 0.75 pan are needed for tomatoes during any particular day depending upon stage of crop growth (Locascio and Smajstrla, 1989; Dangler and Locascio, 1990a; Locascio et al., 1989; Clark et al., 1990b). For example, if the pan evaporation for a day was 0.3 inches of water, then the grower may need to apply approximately 0.12 inches of water per acre for young plants and up to 0.225 inches per acre for larger plants. This water is calculated based on a broadcast acre basis. For drip irrigation in a mulched bed situation where approximately half of the acre is covered with mulch, the effective water application rate under the mulch is approximately 1 pan. The above is a good general rule of thumb, however, more detailed information on this subject is available (Locascio et al., 1981b; Locascio et al., 1985; Rhoads, 1990; Smajstrla et al., 1988; Clark and Haman, 1988; Kovach, 1984; Clark et al., 1988b; Clark et al., 1989; Clark et al., 1990b). The keys are to tie water applications to a soil moisture measuring device such as a tensiometer and an application amount calculation based on evapotranspiration or pan evaporation, and to know the root zone.

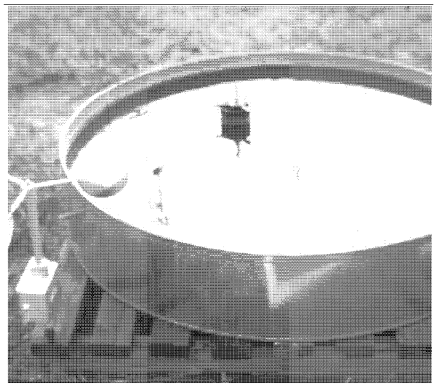

Figure 12. Class A Weather Bureau evaporation pan for estimating evapotranspiration.

Figure 12

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Double Cropping

Double cropping on polyethylene mulched beds is greatly facilitated in production systems that use drip irrigation. Where double-cropping will be practiced, soil moisture should be maintained by drip irrigation in between removal of the first crop and planting of the second crop. Small amounts of water applied on a regular basis will help maintain moisture.

Fertilizer management in double-cropping situations should be based on the individual fertilizer requirements of each crop. Extra fertilizer should not be placed in the bed for the first crop with the thought that leftover fertilizer will be available for the second crop. Each crop should be fertilized with its own program by drip irrigation. In most situations, P applied for the first crop will be sufficient for the second crop. If small amounts of P are required for the second crop, especially if the second crop is being established in cool weather conditions, then small amounts of P can be applied by injecting phosphoric acid through the drip system. Phosphoric acid should be injected alone and in amounts to adequately acidify the delivered solution and achieve the amounts of P needed. Excess phosphoric acid application should be avoided because it will result in extreme acidification of the soil around the drip tube.

Micronutrients applied for the first crop will probably be sufficient for the second crop. Like P, if certain deficiencies are anticipated, then these nutrients can be injected alone through the drip-irrigation system for the second crop.

Nitrogen and K should be injected as the crop nutrient requirement for each crop. If the crop nutrient requirements for the first crop for K and N were properly managed, then there should be little residual in the soil for the second crop (Clough et al., 1987). For most of the very sandy soils in Florida, the second crop should receive its own crop nutrient requirement amount of N and K. The exception would be where crop production is on soils testing very high in K and soils which have the capability for holding some K (e.g. clay or loamy sands).

Plant Tissue Analysis

Plant tissue analysis for mineral nutrients is a good tool to monitor the fertilizer program and to diagnose suspected nutrient deficiencies. Nutrient analyses help guide the fertilizer manager in the application of nutrients during a season, or may provide data to make adjustments in the upcoming season's fertilizer program. When conducting tissue nutrient analysis, it is important to collect representative samples. Representative samples are those that adequately represent the field with the suspected deficiency. Samples generally consist of most-recently-matured leaves. These are the leaves on the plant that have almost reached full size and have changed from the juvenile light-green color to the more-mature dark-green color. For example, the most-recently-matured tomato leaves would be approximately the 5th or 6th leaf back from the tip of the plant. Leaf includes the leaf blade plus the petiole (the leaf stem that attaches the leaf blade to the plant stem). Samples will need to be handled in accordance with the requirements of the specific laboratory that will do the analysis. Air-drying the samples to remove most of the moisture is sufficient prior to packaging and shipping to the lab. For situations where foliar nutrients or nutrient-containing pesticides have been applied to the plant, then leaf analyses for these elements would be questionable. For example, if copper has been applied as a bactericide, then requesting copper analysis on a leaf sample is questionable.

Tissue analysis provides the opportunity for the grower to observe the end result of the fertilizer management program. Growers should keep in mind the typical fluctuations of specific nutrients through the season. As mentioned before, plants have the capability for luxury nutrient consumption, especially early in the season. For example, nutrient analyses for tomato might be on the order of 4 to 5% for N or K early in the season. As the season progresses, the natural tendency for N and K concentrations in the leaves is to decrease. The key for fertilizer management is not to maintain the high levels that were present early in the season throughout the life of the crop. Maintaining 4 or 5% of N or K in a tomato crop throughout the season would result in excess fertilizer application but would not produce an increase in yield. Results on critical nutrient concentrations for vegetables are presented in the tissue analysis guide for vegetables (Hochmuth et al., 1991).

There are basically two types of tissue analysis methods available to growers. One method involves complete laboratory analysis of dried plant tissue. This is the technique offered by most commercial labs. The drawback to this technique is that it is relatively time consuming for growers with drip irrigation who desire to make changes or correct a suspected deficiency expediently. An alternative tissue analysis system for N and K would be the plant sap quick test kits. Several of these kits have been calibrated for tomatoes and other vegetables for Florida conditions (Hochmuth et al., 1988). There are at least two suitable colormetric kits and one ion-specific electrode kit for nitrate-N. There also is an ion -specific electrode for K. These sap tests and the calibration tables are presented in Table 6. Descriptions of sampling procedures, kit use, and precautions are presented elsewhere (Hochmuth et al., 1991; Hochmuth, 1994).

Summary

Drip irrigation is an excellent tool for increasing the efficiency of vegetable fertilization programs. It is a tool, but not an end to all means, for increasing fertilizer use efficiency. As a tool, it must be managed efficiently to achieve the potential benefits. The purpose of this publication has been to describe some of the keys that are important in efficiently managing a drip irrigation system for fertilizer applications to vegetable crops in Florida.

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Table 1.

Table 1. Amounts of various fertilizer materials required to supply 1 lb per acre of various nutrients.

Fertilizer Product	**Fertilizer Analysis**	**lb product for 1 lb nutrient per acre**			
	N - P_2O_5 - K_2O	N	P (P_2O_5)	K (K_2O)	Mg
Dry products					
Ammonium nitrate	33.5-0-0	3.0			
Potassium nitrate	13-0-44	7.7		2.3	
Potassium chloride	0-0-62			1.6	
Urea	45-0-0	2.2			
Magnesium sulfate	0-0-0-10 (Mg)				10.0
Liquids					
Phosphoric acid	54% P_2O_5 (13 lb/gal)		1.1 pint		

Table 2.

Table 2. Required amount of dry fertilizer mix (lb) to add to 100 gallons of water to make a liquid fertilizer solution of different concentrations (ppm) for different concentration levels of the fertilizer stock mix.

Desired Concentration Level (ppm)	**Concentration of fertilizer element in stock mix**						
	(percent)						
	4	6	8	10	15	20	25
	(lb of fertilizer mix to add to 100 gallons of water)						
50	1.0	0.7	0.5	0.4	0.3	0.2	0.2
100	2.1	1.4	1.0	0.8	0.6	0.4	0.3
150	3.1	2.1	1.6	1.2	0.8	0.6	0.5
200	4.1	2.8	2.1	1.7	1.1	0.8	0.7
250	5.2	3.5	2.6	2.1	1.4	1.0	0.8
300	6.2	4.1	3.1	2.5	1.7	1.2	1.0
350	7.3	4.8	3.6	2.9	1.9	1.5	1.2
400	8.3	5.5	4.1	3.3	2.2	1.7	1.3

Table 3.

Table 3. Required injection rate in gallons per hour (gph) of liquid fertilizer solution per 100 gpm of irrigation system flow rate for different concentration levels of the injected fertilizer element (ppm) and different concentration levels of the fertilizer element in the stock solution.

	Concentration of Fertilizer Element in Stock Mix						
Desired Concentration Level (ppm)	**(Percent)**						
	4	6	8	10	15	20	25
	GPH of injection per 100 GPM of water flow rate^z						
50	6.3	4.2	3.1	2.5	1.7	1.3	1.0
100	12.5	8.3	6.3	5.0	3.3	2.5	2.0
150	18.8	12.5	9.4	7.5	5.0	3.8	3.0
200	25.0	16.7	12.5	10.0	6.7	5.0	4.0
250	31.3	20.8	15.6	12.5	8.3	6.3	5.0
300	37.5	25.0	18.8	15.0	10.0	7.5	6.0
350	43.8	29.2	21.9	17.5	11.7	8.8	7.0
400	50.0	33.3	25.0	20.0	13.3	10.0	8.0

^{z}Assume specific weight = 10.0 lb/gal.

Table 4.

Table 4. Required volume of liquid fertilizer stock solution (gallons) to provide different amounts of a fertilizer element (lb) at different concentration levels of that fertilizer element in the stock solution.

	Concentration of Fertilizer Element in Stock Solution						
Desired Amount of Fertilizer (lb)	**(percent)**						
	4	6	8	10	15	20	25
	(Gallons of Liquid Fertilizer Required)^z						
50	125	83	63	50	33	25	20
100	250	167	125	100	67	50	40
200	500	333	250	200	133	100	80
300	750	500	375	300	200	150	120
400	1000	667	500	400	267	200	160
500	1250	833	625	500	333	250	200
750	1875	250	938	750	500	375	300
1000	2500	1667	1250	1000	667	500	400

^{z}Assumes specific weight = 10.0 lb/gal

Table 5.

Table 5. Fertilizer injection schedules for mulched and drip irrigated vegetables in Florida.

Crop	Estab. method^w	Typical bedspacing (ft)	Rows per bed	Total Nutr. (lb/acre)^z			Crop Development			Injection rate (lb/acre/day)	
				N	K$_2$O		Stage	Weeks^{yx}		N	K$_2$O
Broccoli	TP	6	2	175	150		1	1		2.0	1.75
							2	9		2.5	2.25
Cantaloupe	TP	5	1	150	150		1	2		1.0	1.0
(Muskmelon)							2	3		2.0	2.0
							3	3		2.5	2.5
							4	2		2.0	2.0
							5	2		1.0	1.0
Cauliflower	TP	6	2	175	150		1	1		2.0	1.75
							2	9		2.5	2.25
Collards	TP	6	2	150	150		1	3		1.5	1.5
							2	6		2.5	2.5
							3	2		1.5	1.5
Cucumbers	S	5	2	150	120		1	1		1.0	1.0
							2	2		2.0	1.5
							3	6		2.5	2.0
							4	1		2.0	1.5
Eggplant	TP	6	1	160	160		1	2		1.0	1.0

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							2	2		1.5	1.5
							3	6		2.5	2.5
							4	3		1.5	1.5
Lettuce	TP	6	2-4	150	150		1	1		2.0	2.0
							2	1		2.5	2.5
							3	6		3.0	3.0
Okra	S	6	2	150	150		1	2		1.0	1.0
							2	2		1.5	1.5
							3	8		2.0	2.0
							4	1		1.5	1.5
Onion	TP	5	2-4	150	150		1	2		1.0	1.0
							2	4		1.5	1.5
							3	4		2.0	2.0
							4	4		1.5	1.5
							5	1		1.0	1.0
							6	1		0.0	0.0
Pepper	TP	6	2	175	160		1	2		1.0	1.0
							2	2		1.5	1.0
							3	7		2.5	2.5

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							4	1		1.5	1.0
							5	1		1.0	1.0
Pumpkin	S	8	1	120	120		1	2		1.0	1.0
							2	2		1.5	1.5
							3	4		2.0	2.0
							4	2		1.5	1.5
							5	1		1.0	1.0
Tomato	TP	6	1	175	225		1	2		1.0	1.5
							2	2		1.5	2.0
							3	7		2.5	3.0
							4	1		1.5	2.0
							5	1		1.0	1.5
Strawberries	TP	4	2	150	150		1	First 2 weeks		0.3[u]	0.3
							2	Feb/Mar		0.75	0.75
							3	All other weeks		0.6	0.6
Summer squash	S	5	2	120	120		1	2		1.0	1.0
							2	5		2.0	2.0
							3	4		1.5	1.5
Watermelon	S	8	1	150	150		1	2		1.0	1.0

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							2	2		1.5	1.5
							3	4		2.5	2.5
							4	3		1.5	1.5
							5	2		1.0	1.0
Winter squash	S	8	1	120	120		1	3		1.0	1.0
							2	3		1.5	1.5
							3	2		2.0	2.0
							4	4		1.5	1.5
							5	1		0.0	0.0

[z] Includes any starter fertilizer.

[y] Where 20% of N and K_2O have been applied as starter, then first one or two week's injections can be omitted.

[x] For extended-season crops, N maintenance applications can proceed at 1.0 to 1.5 lb. per acre per day. Tissue testing should be used to fine-tune amounts.

[w] Establishment method, seed or transplant might affect the schedule. Transplanting shortens the growth cycle and the injection schedule by one to two weeks compared to seeding.

[u] Strawberry injection schedule assumes that 30 to 40 lb N and K each are applied preplant.

Table 6.

Table 6. Sufficiency ranges for nitrate N and K in fresh petiole sap of most recently matured leaves for several vegetable crops at various periods in the season.

		Fresh petiole sap concentration (ppm)	
Crop	**Crop developmental stage**	**NO$_3$-N**	**K**
Eggplant	First fruit (two-inches long)	1200-1600	4500-5000
	First harvest	1000-1200	4000-4500
	Mid harvest	800-1000	3500-4000
Pepper	First flower buds	1400-1600	3200-3500
	First open flowers	1400-1600	3000-3200
	Fruits half-grown	1200-1400	3000-3200
	First harvest	800-1000	2400-3000
	Second harvest	500-800	2000-2400
Potato	Plants eight-inches tall	1200-1400	4500-5000
	First open flowers	1000-1400	4500-5000
	50% flowers open	1000-1200	4000-4500
	100% flowers open	900-1200	3500-4000
	Tops falling over	600-900	2500-3000
Strawberry	November	800-900	3000-3500
	December	600-800	3000-3500
	January	600-800	2500-3000
	February	300-500	2000-2500
	March	200-500	1800-2500
	April	200-500	1500-2000
Tomato (field)	First buds	1000-1200	3500-4000
	First open flowers	600-800	3500-4000
	Fruits one-inch diameter	400-600	3000-3500
	Fruits two-inch diameter	400-600	3000-3500
	First harvest	300-400	2500-3000

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	Second harvest	200-400	2000-2500
Watermelon	Vines 6-inches in length	1200-1500	4000-5000
	Fruits 2-inches in length	1000-1200	4000-5000
	Fruits one-half mature	800-1000	3500-4000
	At first harvest	600-800	3000-3500