Using Plastic Mulches and Drip Irrigation for Vegetable Production

Revised 1/01 -- Author Reviewed 1/01 HIL-33

Douglas C. Sanders
Extension Horticultural Specialist
Department of Horticultural Science
College of Agriculture & Life Sciences
North Carolina State University

Muskmelons, tomatoes, peppers, cucumbers, squash, eggplant, watermelons and okra are vegetable crops that have shown significant increases in earliness, yield, and fruit quality when grown on plastic mulch. Some less valuable crops such as sweet corn, snap beans, southern peas and pumpkins have shown similar responses. Some of the advantages and disadvantages of using plastic mulches are outlined below. (For additional information, see Bulletin AG-489, *Plasticulture for Commercial Vegetables.*)

Advantages

1. **Increased soil temperature:** At a 2 inch depth; 4 to 5 ^{0}F under black mulch or 8 to 10 ^{0}F under clear mulch.
2. **Reduced soil compaction:** Soil under plastic mulch remains loose, friable and well-aerated. Roots have access to adequate oxygen and microbial activity is excellent.
3. **Reduced fertilizer leaching:** Water runs off the impervious mulch resulting in maximum utilization of the fertilizer.
4. **Reduced drowning of crops:** Water is shed from the row area and excess water runs off the field thus reducing drowning and other excess soil water stresses.
5. **Reduced evaporation:** Soil water does not escape from under plastic mulch. Plant growth on mulch is often at least twice that on bare soil. The resulting larger plants will require more water, so mulching is NOT a substitute for irrigation.
6. **Cleaner product:** A mulched crop is cleaner and less subject to rots due to elimination of soil splashing on the plants or fruits. **Note:** Beds should be firm and tapered away from the row center. Plastic should be tight to promote run-off. **There should be no puddles on the mulched beds!**
7. **Root pruning eliminated:** Cultivation is not necessary except for the area between the mulched strips. Therefore, roots are not pruned.
8. **Reduced weed problems:** Black plastic mulch provides good weed control in the row. Clear plastic will require use of a herbicide or fumigation. Often, weeds between mulch strips can be controlled by a herbicide.
9. **Earlier crops:** Black plastic mulch can result in 2 to 14 days earlier harvest while clear plastic can result in a 21-day earlier harvest.

10. **Increased growth:** Plastic mulch is practically impervious to carbon dioxide (CO_2), a gas that is of prime importance in photosynthesis. Very high levels of CO_2 build up under the plastic, because the film does not allow it to escape. It has to come through the holes made in the plastic for the plants and a "chimney effect" is created, resulting in localized concentrations of abundant CO_2 for the actively growing leaves.

Disadvantages

1. **Costly to remove:** Plastic mulch and drip irrigation tube must be removed from the field annually. Black plastic does not break down and should never be disked into the soil. Clear plastic does break down with time but leaves a messy field. Photo and bio-degradable plastics hold promise.
2. **Greater initial costs:** Plastic mulch and drip irrigation will increase cost of production. These costs should be offset by increased income due to earlier harvests, better quality fruit and higher yields.
3. **Increased management:** Plastic mulch and drip irrigation must be carefully monitored (daily) to be successful.
4. **Increased soil erosion:** Soil erosion in-creases in middles between plastic strips.
5. **Increased crop/weed competition:** Weeds can grow out of the holes in close proximity with crops.

Preparation of the Soil - The first step is to take two soil samples in early fall. Have one sample assayed for mineral content and one for nematodes. If the soil test suggests applying lime, apply enough in the fall to reach pH 6.0 to 6.5 using dolomitic lime if magnesium is low. If there is a nematode problem, fumigate the soil at the time the plastic mulch is being laid. By using a multipurpose fumigant (e.g., Methyl Bromide, Terr- O-Gas 67, Vapam), you can get good control of weeds, nematodes and soil-borne diseases. The soil should be free of debris and in good physical condition prior to preparing the beds for fumigation.

Fertilization - Using the soil test report as a guide, apply fertilizer during bed preparation. Consult Horticultural Information Leaflets for specific crop recommendations. Amounts to be sidedressed need to be included in the total fertilizer requirements. **Caution:** Using fertilizers with ammoniacal N in fumigated soils can result in ammonium toxicity to the crop. Normally, at least 50% of the nitrogen (N) should be in the nitrate (NO_3) form.

When using drip irrigation with plastic mulch, one half of the N and K and all of the P should be incorporated at bedding. The remaining N and K should be applied through the drip tube using soluble fertilizers (e.g. calcium nitrate, sodium nitrate, 20-20-20, 15-0-14, or potassium nitrate). Overhead irrigation and fertigation can be used by perforating the plastic. The entire amount of fertilizer may be incorporated in the bed but utilization by plants might be less efficient than with fertigation.

Bedding the Soil - Bedding machines available to growers include Kennco Mfg. Inc. and Riddick Equip. Co. single and multiple row models. With some bedding machines, the soil is lifted and then bedded in one operation (Superbedders). With others, the soil is first lifted in one operation with hilling disks or double disk hillers on a tool bar and then compressed to a uniform height and density using a bed press pan. **Note**: Be sure that enough soil is pulled up so that the bed has good sharp corners. Bedded rows should be spaced on 5- or 6-ft centers depending on the equipment. A bed with a 30 inch top should slope from the center to the edge with a drop of 1.25 inches, allowing excess rainfall to run off the mulch.

Fall vs. Spring - Laying the plastic mulch and drip tube plus fumigating in the fall has several advantages:

1. Wet weather conditions are prevalent in the spring and can result in delays in laying the plastic and in transplanting.
2. Better soil fumigation is possible in the fall because the soil is not apt to be too wet or too cold.
3. Nematode populations should be the highest in the fall and maximum eradication is possible at that time.
4. Fall applied mulch often makes it possible to transplant 10 to 14 days earlier in the spring.

* Consult theNCCVR (*North Carolina Commercial Vegetable Recommendations*, AG-586) or your county extension agent for the most recent recommendations on pesticides.

Fumigating and Laying the Plastic Mulch and Drip Tube - The amount of fumigant actually applied per acre will depend on row width and will be a percentage of the broadcast rate (Consult theNCCVR, *North Carolina Commercial Vegetable Recommendations*, AG-586). Air temperature should be at least 50F and the soil should be well worked, free of undecomposed plant debris and have adequate moisture for seed germination. If both the air and soil are warm most fumigants should escape through the plastic mulch within 12 to 14 days.

The plastic mulch is generally 4 or 5 ft wide, 1.25 to 1.50 mil thick, **embossed** (diamond shaped design on film which helps hold mulch tight against the soil) or **slick**, and comes in 2,400 ft rolls.

For single row crops such as tomatoes, cucumbers, muskmelons, honeydews, watermelons and pumpkins the drip tube should be placed 4 to 5 inches from the center of the bed and 1 to 2 inches deep with the emitters facing upward. There are 1,000 to 7,500 ft of drip tube on a roll depending on the brand. For double row crops like summer squash, okra, eggplant, peppers, beans, peas, lettuce and sweet corn, the drip tube should be placed directly on the center of the bed and buried 2 to 3 inches deep. For 5-ft row centers there are 8,712 linear ft of row per acre, so a grower would require about 3.5 rolls of plastic mulch per acre. For 6-ft centers, 3 rolls of plastic mulch will be required per acre. **Note:** Take time to adjust the machine so that the press wheels hold the plastic firmly against the bed and the disks place soil halfway up the side of the bed but not on top of the bed. Also, anchor the plastic and drip tube when starting applications, covering it with soil and standing on the drip tube.

PEST MANAGEMENT

Weed Control - For information on weed control under clear plastic mulch and in the row middles between black plastic mulch consult *Horticultural Information Leaflet No. 33-D*, the

NCCVR (North Carolina Commercial Vegetable Recommendations, AG-586) , or your county Extension center. Only approved herbicides can be used between rows of plastic, because this is not a fallow area.

Insect and Disease Control - Good insect and disease control is essential. Consult the current NCCVR (*North Carolina Commercial Vegetable Recommendations*, AG-586) or your county Extension center for recommendations.

Transplanting - For extra earliness in peppers and tomatoes, large containers (cell sizes 3 to 4 inches) should be used. For the other vegetable crops use 1 to 2 inch cell sizes. Consult Bulletin AG-337, *N.C. Commercial Transplants* for details on transplant production. Transplants can be set by hand or machine (e.g. Kennco plant-setter, waterwheel or pot transplanters). When transplanting by hand, several tools can be used to make holes in the plastic such as a long handled bulb setter or a sturdy can or cylinder welded onto the end of a handle. The hole should be 2 to 4 inches wide and deep enough for the plants to be transplanted. A hand tobacco plant setter works well once the holes are made in the plastic mulch. With both hand setting and machine setting, the use of a "starter solution", a soluble fertilizer high in phosphorous (P) will often get the plants off to a good start. Examples are 12-52-12, 10-20-10, or 12-48-8.

Irrigation - Drip irrigation is recommended for use with plastic mulches although other types can be used successfully. The frequency of irrigation will depend on soil type and stage of crop growth. Irrometers at the 6 inch and 12 inch depth in the mulched bed are recommended as an aid in determining irrigation needs. Frequent probing with a soil tube near the plant row will also help to keep a check on soil moisture. Normally the area around the drip tube is very soft to the touch and the side of the row away from the tube should be only slightly soft. For more detailed information on trickle/drip irrigation consult a *Horticultural Information Leaflet Nos. 33-A* and *33-B, The Irrigation Handbook*, Dept. of Biological and Agricultural Engineering, *Trickle Irrigation in the Eastern United States* prepared by Northeast Regional Agricultural Engineering Service, Cornell University, Ithaca, NY 14853, an irrigation specialist, or your county extension center office. **DO NOT USE PLASTIC MULCH WITHOUT IRRIGATION**.

Double Cropping the Plastic Mulch - Once the first crop has been harvested it is recommended that a second crop be grown on the mulch. This "intensive cropping" results in two acres of production from each acre of actual land. The second crop can be fertilized (1) through the drip line using soluble fertilizers and a fertilizer injector, (2) through overhead fertigation, or (3) by placing fertilizer in holes in the plastic between plants. Consult Horticultural Information Leaflet No. 33-C for additional information on injecting fertilizers through the drip line.

Never plant a field to the same crop twice in one year!

Suggested Spring-Fall Planting Sequences.

Spring	**Fall**	
Peppers	Summer squash, cucumbers or cole crops	
Tomatoes	Cucumbers, summer squash or cole crops	

Summer squash	Tomatoes or cole crops	
Eggplant	Summer squash	
Cucumbers	Tomatoes	
Muskmelons	Tomatoes	
Watermelons	Tomatoes	
Honeydews	Tomatoes	
Cole crops	Summer squash, pumpkins, muskmelons, tomatoes	
Cauliflower	Summer squash, pumpkins, muskmelons, tomatoes	
Snap beans	Summer squash, pumpkins, muskmelons, tomatoes	
Southern peas	Summer squash, pumpkins, muskmelons, tomatoes	
Lettuce	Summer squash, pumpkins, muskmelons, tomatoes	
Sweet Corn	Summer squash, tomatoes, or cucumbers	
Strawberries	Tomatoes, summer squash, cucumbers, pumpkins	

Glyphosate (Roundup and various other trade names) can be used to terminate the first crop. See *Horticulture Information Leaflet No. 33-D.* **Note:** Take care to avoid damaging the trickle/drip tube when planting the second crop.

Windbreaks - Strips of rye should be established to protect vegetable seedlings from prevailing winds. Each rye strip should be the width of a typical grain drill (8 to 10 ft) and far enough apart to plant 5 or 6 rows of vegetable seedlings. Well grown rye strips planted in the fall will promote earliness and provide protection for the young transplants. Spring topdressing in February will help assure a good thick rye stand.

When laying plastic in the spring, plant the entire field with rye but be sure to work up the crop area early enough in the spring to minimize crop debris interference with fumigating and plastic laying. Once wind protection is no longer required, mow the rye and use this area as a drive row for spraying and harvesting. Use this drive row for a boom sprayer that covers 2.5 or 3 rows on either side of the drive. An airblast sprayer can also be used.

Reflective Plastic Mulches - The reflective properties of aluminum faced plastic have been shown to interfere with the movement of aphids which spread the watermelon mosaic virus II. This virus causes the green streaking in the fall yellow squash. By using this mulch, a grower would be able to harvest marketable squash for a longer period of time in the fall. Painting the plastic with aluminum paint or white paint increases its reflectivity and cools late planted crops resulting in better fruit quality.

IRT Mulch - InfraRed Transmitting (IRT) mulch is a recent development. These plastics transmit the warming wavelengths of the sun, but not those that allow weeds to grow. These materials result in warmer soils than black plastic, but cooler soils than clear plastics. The IT mulches retard the growth of weeds including nutsedge. Crops grown on IT mulch will develop 7 to 10 days earlier than crops grown on black plastic.

Some Yield Increases - Plastic mulch systems can produce significant yield increases, if managed properly.

Examples of Yield Increases.

Crop	**Average yield per acre with plastic and drip**	**Increase over state average**
Eastern cantaloupe	6000 fruits	4X
Western cantaloupe	15000 fruits	5X
Cucumbers	1200 bu	5X
Pepper	1200 bu	4X
Squash	800 bu	4X
Tomato	2500 boxes	3X
Watermelon	3000 fruits	4X

Final Comments - In addition to the machines you can purchase for laying plastic mulch and drip tube and fumigating the soil, custom applicators are also available. With proper planning, good management, **attention to details** and dedication to all aspects of the cropping sequence, earlier and higher yields are possible using the "intensive" cultural methods described in this publication.

NC STATE UNIVERSITY
A&T STATE UNIVERSITY
COOPERATIVE EXTENSION
Helping People Put Knowledge to Work

Published by the North Carolina Cooperative Extension Service

---

Distributed in furtherance of the Acts of Congress of May 8 and June 30, 1914. Employment and program opportunities are offered to all people regardless of race, color, national origin, sex, age, or disability. North Carolina State University at Raleigh, North Carolina A&T State University, U.S. Department of Agriculture, and local governments cooperating.

Fertility Management of Drip-irrigated Vegetables

T.K. Hartz[1] and G.J. Hochmuth[2]

Additional index words. trickle irrigation, nutrients, fertigation

Summary. Drip irrigation provides an efficient method of fertilizer delivery virtually free of cultural constraints that characterize other production systems. Achieving maximum fertigation efficiency requires knowledge of crop nutrient requirements, soil nutrient supply, fertilizer injection technology, irrigation scheduling, and crop and soil monitoring techniques. If properly managed, fertigation through drip irrigation lines can reduce overall fertilizer application rates and minimize adverse environmental impact of vegetable production.

Drip irrigation allows precise timing and uniform distribution of fertilizer nutrients. Improved efficiency results from small, controlled fertilizer applications throughout the season, in contrast to large preplant or early-season sidedress applications. Fertilizer application through drip irrigation (fertigation) can reduce fertilizer usage and minimize groundwater pollution due to fertilizer leaching from rain or excessive irrigation. Significant technical skill and management are required to achieve optimum performance. The following discussion highlights the main elements of formulating and evaluating a fertigation plan.

[1]*Department of Vegetable Crops, University of California, Davis, CA 95616.*

[2]*Horticultural Sciences Department, University of Florida, Gainesville, FL 32611.*

The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement solely to indicate this fact.

Soil nutrient supply

Proper fertigation management begins with knowledge of the nutrient status of the soil. Most soils contain substantial quantities of available macronutrients and are frequently sufficiently supplied with micronutrients; using a standard drip fertigation program without soil testing will often lead to wasteful fertilizer application and, less frequently, result in a nutrient deficiency. Analytical procedures for soil analysis differ widely from location to location; it is important to use a laboratory using test procedures calibrated for the geographic area of interest.

Mineral (NO_3-N and NH_4-N) and organic forms of N are present in all soils. Analysis for mineral N often is confined to NO_3-N, because in most situations NH_4-N constitutes <20% of mineral N content. Estimating the rate at which soil organic N is mineralized is problematic, but N mineralization potential can be important; net N mineralization rates of 0.5 to 2.0 kg N/ha per d are common (Magdoff, 1991). Provided that the soil is drained adequately, mineralization potential generally increases with increasing organic N content; a low C/N ratio of recently incorporated plant residues and organic amendments also will favor more rapid mineralization.

Unlike NO_3-N, available soil P and K exist in chemical equilibrium with slowly available forms. The most appropriate soil test procedures vary depending on location and soil characteristics. In the southeastern United States, acidic sandy soils usually are assayed for P and K using the Mehlich I soil test (Hanlon et al., 1990). Neutral or alkaline mineral soils in the western United States are extracted more appropriately by the bicarbonate and ammonium acetate techniques for P and K, respectively (Reisenauer, 1983). Mineral soils in the western United States commonly contain sufficient K for maximum vegetable production and, where heavy fertilization has been used over years, sufficient P as well. Soil supply of K is generally more limited in the southeastern United States; however, P has accumulated to high levels in many soils used repeatedly for vegetable production.

Crop nutrient requirements

Vegetable crops differ widely in their macronutrient requirements and in the pattern of uptake over the growing season. In general, N, P, and K uptake follows the same course as the rate of crop biomass accumulation. Fruiting crops such as tomato, pepper, and melon require relatively little nutrition until flowering, when nutrient uptake accelerates, peaking during fruit set and early fruit bulking. As fruit mature, macronutrient requirement declines. Nonfruiting crops such as celery, lettuce, and cole crops have slow nutrient uptake through the first half of the season; the rate of nutrient acquisition accelerates until just before harvest. Fertilization recommendations, based on research conducted regionally or locally, vary considerable among areas of the United States; it is important to recognize these regional difference when formulating a fertigation program.

Nutrients applied through drip irrigation systems

Although most nutrients can be injected successfully into drip irrigation systems, the most-often applied nutrients are N and K. Crop requirements for N and K are large relative to other elements, and fertigation provides a system to supply the requirements of the crop in a scheduled fashion during the season. The leaching potential for N on most soils, and for K on sandy soils, makes split applications of these nutrients through a drip system attractive for improving fertilizer efficiency. In addition, there are few precipitation and clogging problems associated with N or K injection.

Phosphorus, Ca, Mg, and micronutrients can be injected successfully into drip irrigation systems if precautions are taken to mitigate against chemical precipitation. Analysis of irrigation water for Ca, Mg, Fe, pH, carbonate, and bicarbonate is important for predicting chemical precipitation problems; the risk of precipitation increases with increasing pH or increasing concentration of these materials. Acids may need to be injected with the fertilizer to maintain high nutrient solubility during fertilizer injection.

Nutrient sources

A variety of fertilizers can be injected into drip irrigation systems. Common N sources include urea–ammonium nitrate solutions, ammonium nitrate, calcium nitrate, and potassium nitrate. Potassium can be supplied from potassium chloride, potassium sulfate, potassium thiosulfate, or potassium nitrate. The choice of phosphorus products is more limited; phosphoric acid or ammonium phosphate solutions are used most commonly. Mono ammonium- or mono potassium phosphate are available, but are used infrequently.

The choice of fertilizer suitable for a specific application should be based on several factors: nutrient form, purity, solubility, and cost. The appropriate balance of NO_3-N to NH_4-N (or urea) depends on environmental conditions. In cool weather, 25% to 50% of applied N should be in the NO_3-N form (Hochmuth and Hanlon, 1995). In warm weather, nitrification occurs rapidly, allowing greater use of ammoniacal-N or urea fertilizers, which are significantly less expensive than nitrate fertilizers. All common N sources are available in clean, high-analysis, liquid solutions.

Solubility is an issue with potassium products, as are relative salt index and cost. Potassium chloride is inexpensive and reasonably soluble (solutions >10% K are available), but relatively high in salt index. However, the salt index issue is generally not critical if the application rate is limited to the crop requirement. Potassium sulfate is less soluble and more expensive than potassium chloride, but it has a lower salt index. Potassium thiosulfate and nitrate are highly soluble but also are more expensive. Potassium chloride is used commonly for drip injection in the western United States, whereas potassium nitrate is popular in the southeastern United States. Although a topic of some controversy, there is no definitive research that documents a need to maintain a certain N/K fertilizer ratio in vegetable production. As long as soil-test-predicted amounts of K are added, crop K requirements should be satisfied.

Liquid P fertilizers, except for food-grade phosphoric acid, may have impurities that complicate the already difficult task of eliminating chemical precipitation in the drip lines. However, with sufficient knowledge and attention to detail, fertilizer-grade phosphoric acid and ammonium phosphate solutions can be delivered successfully.

Fertigation scheduling

Efficient fertigation scheduling requires attention to three factors: crop- and site-specific nutrient requirements, timing nutrient delivery to meet crop needs, and controlling irrigation to minimize leaching of soluble nutrients below the effective root zone. Seasonal total N, P, and K requirements vary considerably by area and soil type (Hochmuth and Hanlon, 1995; Tyler and Lorenz, 1991). General recommendations should be adjusted based on soil test results to estimate seasonal application rates required for a particular field. In many situations a small percentage of N and K (20% to 30%) and most or all P is applied in a preplant broadcast or banded application. Preplant application of N (and K, if needed) is particularly important where initial soil levels are low (Locasio et al., 1982, 1985) or in conditions where early-season irrigation is not required.

Preplant application of P is common for several reasons. Soluble P sources (e.g., phosphoric acid) are more expensive than granular forms. The potential problem of chemical precipitation in the drip line is avoided. Also, the movement of drip-applied P away from the point of

Table 1. ***Injection schedules for mulched and drip-irrigated vegetables in Florida.***

Crop	Established method[w]	Typical bed spacing (m)	Total nutrients ($kg \cdot ha^{-1}$)[z] N	Total nutrients K	Crop development Stage	Crop development Weeks[y,x]	Injection rate ($kg \cdot ha^{-1} \cdot d^{-1}$) N	Injection rate K
Cantaloupe	TP	1.5	130	110	1	2	1.1	0.9
					2	3	1.7	1.4
					3	3	2.2	1.8
					4	2	1.7	1.4
					5	2	1.1	0.9
Cucumber	S	1.5	130	110	1	1	1.1	0.9
					2	2	1.7	1.4
					3	6	2.2	1.8
					4	1	1.7	1.4
Eggplant	TP	1.8	130	110	1	2	1.1	0.9
					2	2	1.7	1.4
					3	6	2.2	1.8
					4	3	1.7	1.4
Pepper	TP	1.8	180	150	1	2	1.1	0.9
					2	3	1.7	1.4
					3	7	2.2	1.8
					4	1	1.7	1.4
					5	1	1.1	0.9
Tomato	TP	1.8	180	150	1	2	1.1	0.9
					2	3	1.7	1.4
					3	7	2.2	1.8
					4	1	1.7	1.4
					5	1	1.1	0.9
Strawberry	TP	1.2	130	120	1	2	0.3	0.3
					2	Feb./Mar.	0.8	0.7
					3	All other	0.7	0.6
Summer squash	S	1.5	130	110	1	2	1.1	0.9
					2	2	1.7	1.4
					3	2	2.2	1.8
					4	5	1.7	1.4
					5	1	1.1	0.9
Watermelon	S	2.4	130	110	1	4	1.1	0.9
					2	2	1.7	1.4
					3	2	2.2	1.8
					4	3	1.7	1.4
					5	2	1.1	0.9

[z] *Includes any starter fertilizer: lb/acre = $kg \cdot ha^{-1}/1.12$; $K/0.83 = K_2O$.*
[y] *Where 20% of N and K have been applied as starter, N injection may be omitted for the first several weeks.*
[x] *For extended-season crops, N maintenance applications can proceed at 0.5 to 1.5 $kg \cdot ha^{-1}$ per d. 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 1 to 2 weeks*

injection is governed mainly by soil texture and pH. Movement of P is particularly limited in fine-textured, alkaline soils. During the critical crop establishment period, P banded near the developing seedlings may be used more efficiently. When making a preplant application of any nutrient it is important that the fertilizer be placed within the wetting zone of the drip system.

Once seasonal N, P, and K requirements have been estimated and preplant application (if any) has been made, the balance of the fertilizer can be delivered through the drip system in multiple applications over the growing season. From crop nutrient uptake characteristics, one can apportion fertigation to meet nutrient requirements by crop growth stage. To calculate fertilizer application on the basis of daily or weekly need, one must account for the relative rate of crop development, which depends on temperature. Total seasonal crop nutrient requirements are relatively independent of environmental conditions. For example, an early spring melon crop will need roughly as much total N as a midsummer or fall crop, even though the length of the growing seasons (planting to harvest) will differ significantly.

Ideally, a crop-specific fertigation template could be developed using growing degree day (GDD) information. In practice, this is not often done. Alternatively, historical information on crop phenology can be used to construct general fertigation schedules (Table 1); these schedules are based on research and commercial grower experience in Florida (Hochmuth, 1992). For some crop groups, such as cucurbits, extrapolation of the nutrient program for one crop to another crop is possible. These schedules assume the soil will be supplying little of the crop K requirement. It is important to keep in mind that the actual fertilizer requirement may be considerably less, depending on soil test K levels. Similarly, crops grown on soils with high N supply capacity (high organic matter, significant residual mineral N content, etc.) also may require substantially less N fertilizer. These schedules also can be compressed or expanded depending on the length of the growing season.

Application of N and K in excess of crop requirements can have significant adverse consequences in addition to the added fertilizer expense. Nitrate contamination of groundwater has become a serious environmental issue in some areas, and

Table 2. ***Sufficiency concentration ranges for plant leaf petiole fresh sap nitrate-nitrogen and potassium for Florida-grown vegetables.***

		Nutrient concn			
		Petiole sap ($mg \cdot L^{-1}$)		Whole-leaf dry wt ($g \cdot kg^{-1}$)	
Crop	Growth stage	Nitrate-N	K	N	K
Broccoli and collard	Six-leaf stage	800–1000	NA[z]	35–50	35–45
	Just before first harvest	500–800		30–45	15–40
	First harvest	300–500		30–40	15–40
Cucumber	First blossom	800–1000	NA	40–50	20–30
	Fruit 8 cm long	600–800		25–50	20–30
	First harvest	400–600		25–35	15–25
Eggplant	First fruit (5 cm long)	1200–1600	4500–5000	45–55	45–60
	First harvest	1000–1200	4000–4500	45–50	35–50
	Midharvest	800–1000	3500–4000	35–45	30–40
Muskmelon	First blossom	1000–1200	NA	45–50	50–60
	First fruit 5 cm long	800–1000		40–50	45–50
	First harvest	700–800		35–45	20–40
Pepper	First flower buds	1400–1600	3200–3500	45–50	50–60
	First open flowers	1400–1600	3000–3200	40–45	45–50
	Fruit half–grown	1200–1400	3000–3200	40–45	40–50
	First harvest	800–1000	2400–3000	35–40	35–45
	Second harvest	500–800	2000–2400	25–30	30–40
Potato	Plants 20 cm tall	1200–1400	4500–5000	30–60	35–60
	First open flowers	1000–1400	4500–5000	30–40	30–50
	50% Flowers open	1000–1200	4000–4500	30–40	30–40
	100% Flowers open	900–1200	3500–4000	25–40	25–40
	Tops falling over	600–900	2500–3000	20–30	15–30
Squash	First blossom	900–1000	NA	30–50	30–50
	First harvest	800–900		30–50	20–30
Tomato (field)	First buds	1000–1200	3500–4000	30–50	40–50
	First open flowers	600–800	3500–4000	35–40	35–40
	Fruit 2 cm in diameter	400–600	3000–3500	35–40	35–40
	Fruit 5 cm in diameter	400–600	3000–3500	30–40	30–40
	First harvest	300–400	2500–3000	25–35	25–35
	Second harvest	200–400	2000–2500	20–35	20–30
Tomato (greenhouse)	Transplant to second cluster	1000–1200	4500–5000	40–60	40–50
	Second cluster to fifth cluster	800–1000	4000–5000	40–50	35–40
	Harvest season (Dec.–June)	700–900	3500–4000	35–40	25–35
Watermelon	Vines 15 cm long	1200–1500	4000–5000	50–60	40–50
	First fruit 5 cm long	1000–1200	4000–5000	40–50	35–40
	Fruit one–half mature	800–1000	3500–4000	35–40	25–35
	At first harvest	600–800	3000–3500	30–40	20–30

[z]*Not available.*

excessive fertigation increases NO_3-N leaching loss (Pier and Doerge, 1995; Thompson and Doerge, 1995). Heavy N application, particularly when NH_4-N predominates, can induce blossom-end rot in crops like tomato and pepper and stimulate vegetative growth at the expense of fruit yield. Excessive K fertilization has been shown to reduce specific gravity of potato and size of strawberry fruit (Hochmuth et al, 1993; Albregts et al., 1996).

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

Fertigation frequency, in most situations, is not as important as achieving a correct rate of application of nutrients to the crop during a specified period (Cook and Sanders, 1991; Locascio and Smajstrla, 1989). Some growers find it easy to fertigate with each irrigation using automated controls, which places small amounts of nutrients at risk of leaching during any single leaching event. Since leaching is possible with drip irrigation, nutrients applied in any irrigation must not be subjected to excessive irrigation either during that application or in subsequent irrigations.

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

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

Water management is integrally linked to fertigation management. Water that moves below the active crop root zone can carry NO_3-N (and, in very sandy soils, K) in substantial quantities. One centimeter of leachate at 100 mg NO_3-N/L would contain 10 kg N/ha. Indeed, one of the major advantages of polyethylene bed mulch (frequently used in conjunction with drip irrigation) is the reduction of NO_3-N leaching with precipitation, but that advantage can be negated by excessive drip irrigation. Conversely, in some areas well water used for drip irrigation contains a significant concentration of NO_3-N; in regions such as the Salinas Valley, Calif., NO_3-N levels of 10 to 20 $mg \cdot L^{-1}$ are common. Irrigating a crop with a total of 30 cm of water at 15 mg NO_3-N/L would add about 45 kg N/ha.

Nutrient monitoring

The fertigation scheduling approach outlined above should, in most situations, supply adequate nutrition; however, monitoring soil and/or plant nutrient status is the essential safeguard to ensure maximum crop productivity. In conventional production, soil NO_3-N testing usually has been limited to preplant sampling; since drip irrigation provides the ability to add N at will, more extensive NO_3-N monitoring is justified. Traditional soil sampling and laboratory analysis offer the most complete, accurate information, but growers are not likely to go to the effort and expense of this technique on an ongoing basis through a cropping cycle.

There are several alternative techniques to aid on-farm N measurement. One approach is the use of soil solution access tubes, also called suction lysimeters. These devices are simply porous ceramic cups, similar to tensiometer cups, attached to hollow access tubes. The units are installed in the field with the ceramic tips in the active root zone. To collect a sample, a vacuum is applied which draws water from the surrounding soil into the tube. This soil water sample is collected and analyzed for NO_3-N content; most mineral N is usually in the nitrate form.

The use of suction lysimetry has serious limitations. There can be large spatial variability; one portion of a field may vary from another and, since NO_3-N moves with the wetting front, there can be stratification of NO_3-N within the bed. This problem can be minimized by using multiple lysimeters per field, but that also greatly increases the effort required, and the cost. Interpretation of results is also problematic. Extensive field data is lacking, but in general, a root zone soil solution NO_3-N concentration >75 $mg \cdot L^{-1}$ indicates that sufficient N is available to meet immediate plant needs. A lower NO_3-N concentration cannot be interpreted directly as N deficiency, given the difficulty of obtaining a sample representative of the whole root zone. Plant tissue analysis would be warranted to confirm crop N status.

Another simple technique for estimating soil nitrate concentration is the quick test procedure described by Hartz (1994). This test has the advantage of measuring NO_3-N in a composite soil sample representative of the root zone, compared to the site-specific measurement of a suction lysimeter. Soil and the NO_3-N extracting solution are measured volumetrically, eliminating the need to dry or weigh soil. The moisture content of soil will affect the test, but moisture content of drip-irrigated soils generally will fall in a relatively narrow range, so the impact will be minor in most cases. Adjusting the test based on soil texture (hence, water-holding capacity) will improve accuracy. In general, soil NO_3-N values above 20 $mg \cdot L^{-1}$ indicate sufficient available N to meet immediate plant needs.

Reliance on soil NO_3-N testing is most appropriate early in the crop cycle, when crop N uptake rate is low and the detection of substantial residual NO_3-N can lead to reduced additional N fertigation. By midseason, crop uptake rates increase and soil NO_3-N concentration correspondingly will change more rapidly. Also, once an extensive root system is developed, many crops can take up N in excess of crop needs (luxury consumption); low late-season soil NO_3-N does not necessarily reflect N deficiency. From midseason until harvest, plant tissue analysis should be the primary indicator of N status, although soil testing still may be used to identify fields where NO_3-N levels remain high enough to delay additional N application.

Conventional plant tissue analysis, in which tissue is dried, ground and analyzed chemically in a laboratory, is the most accurate way to determine crop nutrient status. Through decades of research, sufficiency guidelines have been developed for most important vegetable crops. These guidelines have been published for vegetables in Florida (Hochmuth et al., 1991) and California (Reisenauer, 1983). Although not specifically developed for drip irrigation, these standards are still generally applicable. Unfortunately, laboratory analysis of dry tissue is relatively costly, and the time lag between sampling and obtaining results can be significant. In recent years there has been increasing interest in on-farm tissue testing, particularly for monitoring drip-irrigated fields. On-farm monitoring usually involves the analysis of NO_3-N and K content of petiole sap; sap analysis for PO_4-P is uncommon. Measurement techniques include colorimetric methods, NO_3-N or K test strips (Hochmuth, 1994), or ion-specific electrode (Hartz et al., 1993; Vitosh and Silva, 1994). Although all methods can be used successfully, the ion-specific electrode is the most commonly used approach. Table 2 lists petiole sap NO_3-N and K sufficiency ranges developed under Florida conditions. These values are similar to those developed in California. The appropriate protocol for tissue collection, handling, and analysis is discussed by Hochmuth (1994).

Literature Cited

Albregts, E.E., G.J. Hochmuth, C.K. Chandler, J. Cornell, and J. Harrison. 1996. Potassium requirements of drip-irrigated strawberry. HortScience (In press.)

Clark, G.A., A.G. Smajstrla, D.Z. Harman, and F.S. Zazueta. 1990. Injection of chemicals into irrigation systems: Rates, volumes and injection periods. Fla. Coop. Ext. Bul. 250.

Cook, W.P. and D.C. Sanders. 1991. Nitrogen application frequency for drip irrigated tomatoes. HortScience 26:250–252.

Hanlon, E.A., G. Kidder, and B.L. McNeal. 1990. Soil, container media, and water testing. Fla. Coop. Ext. Circ. 817.

Hartz, T.K. 1994. A quick test procedure for soil nitrate-nitrogen. Commun. Soil Sci. Plant Anal. 25:511–515.

Hartz, T.K., R.F. Smith, M. LeStrange, and K.F. Schulbach. 1993. On-farm monitoring of soil and crop nitrogen status by nitrate-selective electrode. Commun. Soil Sci. Plant Anal. 24:2607–2615.

Hochmuth, G.J. 1994. Sufficiency ranges for nitrate-nitrogen and potassium for vegetable petiole sap quick tests. Hort Technology 4:218–222.

Hochmuth, G.J. 1992. Fertilizer management for drip-irrigated vegetables in Florida. Hort Technology 2:27–32.

Hochmuth, G.J. and G.C. Clark. 1991. Fertilizer application and management for micro (or drip) irrigated vegetables in Florida. Fla. Coop. Ext. Spec. Ser. SS–VEC–45.

Hochmuth, G.J. and E.A. Hanlon. 1995. Commercial vegetable crop nutrient requirements. Fla. Coop. Ext. Circ. SP–170.

Hochmuth, G.J., D. Maynard, C. Vavrina, and E. Hanlon. 1991. Plant tissue analysis and interpretation for vegetable crops in Florida. Univ. Fla. Coop. Ext. Spec. Ser. SS–VEC–042.

Hochmuth, G.J., E. Hanlon, G. Kidder, S. Hensel, W. Tilton, J. Dilbeck, and D. Schrader. 1993. Fertilization demonstrations for the tri-county potato production area of northeast Florida. Proc. Fla. State Hort. Soc. 106:190–198.

Locascio, S.J. and A.G. Smajstrla. 1989. Drip-irrigated tomato as affected by water quantity and N and K timing. Proc. Fla. State Hort. Soc. 102:307–309.

Locascio, S.J., S.M. Olson, F.M. Rhoads, C.D. Stanley, and A.A. Csizinszky. 1985. Water and fertilizer timing for trickle-irrigated tomatoes. Proc. Fla. State Hort. Soc. 98:237–239.

Locascio, S.J., J.M. Myers, and J.G.A. Fiskell. 1982. Nitrogen application timing and source for drip irrigated tomatoes, p. 323–328. In: A. Scaife (ed.). Proc. 9th Intl. Plant Nutr. Colloq., Warwick Univ., England.

Magdoff, F. 1991. Understanding the Madgoff pre-sidedressing nitrate test for corn. J. Proc. Agr. 4:297–305.

Pier, J.W. and T.A. Doerge. 1995. Concurrent evaluation of agronomic, economic, and environmental aspects of trickle-irrigated watermelon production. J. Environ. Qual. 24:79–86.

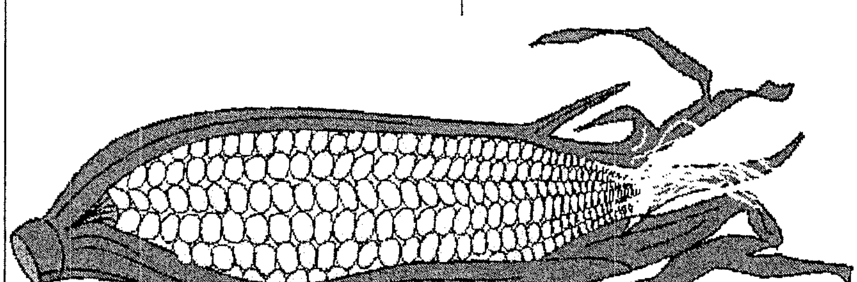
Reisenauer, H.M. (ed.) 1983. Soil and plant tissue testing in California. Univ. Calif. Bul. 1879.

Smajstrla, A.G., D.S. Harrison, and G.A. Clark. 1985. Trickle irrigation scheduling I: Durations of water applications. Fla. Coop. Ext. Bul. 204.

Thompson, T.L. and T.A. Doerge. 1995. Nitrogen and water rates for subsurface trickle-irrigated romaine lettuce. Hort Science 30:1233–1237.

Tyler, K.B. and O.A. Lorenz. 1991. Fertilizer guide for California vegetable crops. Univ. Calif., Davis, Dept. Veg. Crops Special Publ.

Vitosh, M.L. and G.H. Silva. 1994. A rapid petiole sap nitrate-nitrogen test for potatoes. Commun. Soil Sci. Plant Anal. 25:183190.



Rowcover and High Tunnel Growing Systems in the United States

Otho S. Wells[1]

Additional index words. crop protection, intensive production, season extension, spunbonded, plastics

Summary. Rowcovers and high tunnels are two intensive production systems used by commercial growers to extend the season and to improve yields of vegetables and strawberries. There are many types of rowcovers. These materials are summarized with descriptive information, primary use, and cost. The basics of high tunnel construction are presented to facilitate setting up a high-tunnel system.

Most horticultural crops respond favorably to protection from environmental extremes, particularly in northern Unites States. Protective growing may include several cultural systems; however, this paper considers only two types of protective growing systems: rowcovers and high tunnels. There are many reports of the benefits of these systems nationally (Hochmuth, et al., 1993; Lamont, et al.; Matthews-Gehringer 1988; Purser, 1993; Soltani, et al., 1995; Wells and Loy, 1985; Wells and Loy, 1993) and internationally (Jensen and Malter, 1994; Wittwer and Castilla, 1995). Also, there are reports of expanded uses of rowcovers and high tunnels (Hancock and Simpson, 1995; Wells, 1995; Williams, 1994). The purpose of this paper is not to reiterate the benefits, rather to provide an overview of the types and uses of rowcovers and pictorial details on the construction and layout of high tunnels.

[1]Professor of plant biology, University of New Hampshire, Durham, NH 03824.

The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement solely to indicate this fact.