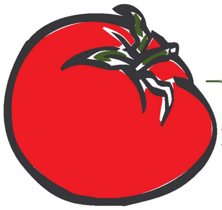

NETAFIM USA

AGRONOMIC SERIES

PROCESSING TOMATOES

NETAFIM™

THE TOMATO VINE

Netafim USA Agronomic Series for Growing Processing Tomatoes with Drip Irrigation

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Meet the Author

Lauren Thompson

Lauren Thompson is an Agricultural Consultant based in the state of New South Wales (NSW), Australia. She received her Bachelor of Science degree from U.C. Davis in 1980, with a major in Agricultural Science and Management. After working for several years as an on-farm agronomist, both in California and Australia, she accepted a position with the Australian Processing Tomato Research Council. There, her main role was to increase technology awareness and adoption by processing tomato growers. She also had a strong involvement with the R&D funded by the industry. In 1996, Lauren received a prestigious national award for her achievements in this position. Her efforts contributed to the widespread adoption of drip irrigation which was one of the main factors that led to significant productivity improvements in the Australian processing tomato industry. Lauren's most recent job was as an agronomist with Netafim Australia. In 2000, she worked with Netafim USA to assist with efforts in the processing tomato industry in California. In the coming 2003 growing season, Lauren will be making significant contributions to Netafim USA's continuing efforts.

Soil Moisture Management for High Solids and High Yields in Processing Tomatoes

Using Subsurface Drip Irrigation

With the use of subsurface drip irrigation (SDI), processing tomato growers benefit from higher yields as well as savings on water, energy and labor. However, the inverse relationship between yields and soluble solids, a key quality attribute, is well documented. The higher the yield, the lower the soluble solids. Drip irrigation will only be adopted by growers and accepted by processors if the yields and soluble solids can be manipulated to achieve the combination that is right for both parties. Genetics plays a big part in determining the range of soluble solids that can be expected out of each variety. Careful irrigation and nutrition management will give growers the best chance of achieving average or better solids for each variety along with high yields.

Drip irrigation's ability to supply water to the crop frequently, and in a highly controlled manner, makes it possible to establish and maintain ideal conditions for each stage of development. The volume of soil that is wetted by the drip system can be manipulated in terms of size and moisture content, right up to the day the water is cut off for harvest. This is the key to attaining high yields and solids.

Research and farmer experience in many countries have led to the following guidelines for managing moisture during the four growth stages of a drip irrigated processing tomato crop:

STAGE 1: Seed Germination and Plant Establishment

Where equipment and labor are available, and it makes agronomic and economic sense, sprinkler irrigation can be used to establish the crop. Overhead irrigation allows a relatively small amount of water to be applied so that a desired depth of wetting is achieved. Sprinklers can be used for 2-3 irrigations before the drip system is used, and about 6 inches of water will be applied for germination and establishment of a direct-seeded crop.

Watering up can also be carried out with the subsurface drip system. The requirement that the system be used for this purpose is a very important factor in determining the depth of installation of the dripperlines.

Pre-irrigation (or adequate rainfall), good seedbed preparation, precise planting techniques (including rolling after seeding to achieve a firm seedbed), and proper system design are critical to SDI's ability to achieve a uniform, wetted strip that reaches and adequately wets the seeds or seedlings. Water might not break the surface in all places, but it is essential to ensure adequate wetting at the depth of seeding or transplanting to achieve the desired stand. Sometimes a technique called "pulse irrigation" will have to be used to achieve adequate watering up. The total amount of water applied with this initial irrigation will vary depending on conditions.

Once the field has been watered up with SDI, additional water should only be applied if the seedbed dries out. Frequent checking during this critical stage is essential. If more water is required, it should be applied carefully. Waterlogging must be prevented to reduce the risk of damping-off.

STAGE 2: Vegetative Growth

Once the stand is established, it is important to encourage the crop to develop a strong, extensive root system. This will make the plants more stable and make it possible for a deficit irrigation regime to be carried out during the fruit ripening period. If water is applied too frequently during the vegetative growth stage, the plants will be encouraged to develop their roots where water and nutrients are readily available, resulting in a small, restricted root system. Part of the “art” of drip irrigated tomato production involves letting the young plants search for moisture, but not to the point that they experience water stress.

STAGE 3: Flowering and Fruit Setting

From the time a processing tomato crop starts flowering, its water and nutrient requirements start increasing at a rapid rate. The peak water requirement is reached at the time of full bloom, and this peak is maintained up to the time that the oldest fruits begin changing color (“first color” stage). In the early part of Stage 3, the wetted pattern should be increased to its maximum size (e.g. 4 feet deep, but not any deeper, and horizontally out as far as the edges of the bed at the widest point), and the soil moisture should be brought back to field capacity at all depths. To encourage maximum fruit setting, stress should be avoided during the flowering and fruit setting stage, and this is where drip irrigation is particularly useful. By replacing the crop’s water use daily or every second day, the soil moisture can be kept close to field capacity. The estimated daily crop water use can be calculated from reference evapotranspiration (ETo) figures (available from the CIMIS network or other sources) multiplied by the estimated crop coefficient. At the start of flowering, the crop coefficient will be about 0.4, and it rises steadily to a peak of 1.2 at full bloom. With the use of soil moisture monitoring devices, the crop coefficient can be adjusted up or down, giving a very accurate means of determining how much water to apply each day.

Caution is advised during the very early part of the flowering stage. Many processing tomato varieties are very vigorous, and SDI can further enhance the vigor if watering and fertilizing are not done carefully at this time. The crop should not experience stress once flowering commences, but at the same time, too much of a vegetative growth spurt is not desirable. Depending on soil type and weather, the commencement of a frequent irrigation and fertigation regime can be delayed until about 2 weeks after the first flowers open. Another guideline is to wait until the fruit that has set on the first flowers reaches the size of a small pea before commencing the intense irrigation and fertigation regime. This will be discussed further in the next newsletter, with an article on managing nutrients.

Direct-Seeded Furrow Irrigated Crop	Water Application	Direct-Seeded Irrigated with SDI
10 Inches	**Pre-Irrigation of Field**	10 Inches
6 Inches	**Two to Three Sprinkler Irrigations** *(for germination and establishment)*	6 Inches
26 Inches	**Alternate Row Furrow Irrigations** *(at 7 - 14 day intervals)*	–
–	**Drip Irrigation** *(initially once or twice a week, then daily during peak water demand, followed by a deficit irrigation regime during ripening)*	9 to 14 Inches
42 Inches	**TOTAL WATER APPLIED**	**25 to 30 Inches**

STAGE 4: Fruit Ripening

Once the crown set starts ripening, it signals a time to change the approach to irrigation management in order to achieve high soluble solids. The aim is to create and maintain a moderate level of stress by reducing moisture levels in the soil in a determined but controlled manner. A reliable form of soil moisture monitoring is required to ensure the deficit irrigation regime is carried out correctly. Further information on deficit irrigation of processing tomatoes will be presented in a future newsletter.

In a recent University of California Cooperative Extension (UCCE) publication, “2002 Sample Costs to Produce Processing Tomatoes, San Joaquin Valley-South (Fresno County),”the authors presented representative water use amounts for direct-seeded, furrow-irrigated crops grown in that area. Their figures appear on the left side of the table. A representative scenario for drip irrigated processing tomatoes is presented on the right side.

SUMMARY:

In summary, SDI is the ideal tool for manipulating a processing tomato crop’s growth and development to achieve the desired balance between yields and soluble solids while saving on water, energy and labor. Keeping the crop free of moisture stress during the flowering and fruit setting stage ensures maximum fruit numbers are attained. Drip irrigation is the only method that gives total control, enabling these stress-free moisture conditions to be maintained. This level of control also makes it possible to create and maintain a moderate level of water stress during the ripening phase so that desirable levels of soluble solids can be achieved along with the high yields.

Nutrient Management with Subsurface Drip Irrigation in Processing Tomatoes

for High Solids and High Yields

Subsurface drip irrigation (SDI) is an excellent tool for supplying nutrients directly to the root systems of crops like processing tomatoes. Nitrogen (N) is the main element supplied with the water, and SDI enables it to be added in line with the crop's changing demands during the growing season. Other nutrients that can be fed through the irrigation system include phosphorus (P), potassium (K) and calcium (Ca).

Nutrient management begins with an analysis of soil test results and a reasonable estimate of expected yield. N and P are often the only nutrients that need to be added to obtain maximum yields, although soils in some areas of California may be low in K or zinc.

In a recent University of California Cooperative Extension (UCCE) publication, "2002 Sample Costs to Produce Processing Tomatoes, San Joaquin Valley-South (Fresno County)," the authors assumed an average yield of 40 tons per acre and based their costs on the use of 10-34-0 as a preplant fertilizer at 180 pounds (15 gallons) of material per acre, and UN-32 as the sidedress fertilizer at 44 gallons (or 478 lbs.) of material per acre. This is considered representative of fertilizer use for direct-seeded, furrow-irrigated crops in the area. The amount of N applied in this case is 171 lb/ac. In addition, they've assumed the use of a "popup" fertilizer and an anti-crustant material in their costings. Other UCCE publications indicate that under normal conditions, maximum yield can be obtained with approximately 140-180 lb/ac of N.

The main differences between what is stated above and what occurs with SDI are the expected yield and the fact that the UN-32 will be injected into the drip system for delivery to the root system with the water, a practice known as "fertigation". The basis for determination of the amount and type of preplant fertilizer, and whether to use a "popup" fertilizer and an anti-crustant, remains unchanged.

Another important difference with SDI is that water is moving "from the inside out," whereas with furrow irrigation, water moves in the opposite direction, carrying sidedressed nitrogen into the bed. This has implications for placement of any banded fertilizer. In Australia for example, growers often place two 8-inch deep bands of diammonium phosphate (DAP) or monoammonium phosphate (MAP) as close to the center of the bed as possible (straddling the dripperline). With this placement, the band is continually in a moist zone and the P and N are pushed towards the edges of the beds with the applied water. Fertilizer bands located near the edges of the beds, which is an appropriate placement for furrow irrigation, would not be effective for a drip-irrigated crop.

Drip irrigation also results in a smaller volume of soil being explored by the root system. With higher expected yields, the amount of nutrients extracted from the reduced volume of soil needs to be taken into consideration in the fertilizer management program. For example, it is estimated that a 30 ton per acre tomato crop takes up the following amounts of nutrients in the fruit.

Nutrient Removal *30 t/ac crop*

Nitrogen	100 lb/ac
Phosphorus	10 lb/ac
Potassium	180 lb/ac

Source: Knott's Handbook for Vegetable Growers, Third Edition

Yields from drip-irrigated tomato crops are generally in the range of 45 to 60 tons per acre, so nutrient removal levels could be expected to be 1.5 to 2 times higher than the above amounts. If the soil is marginal in its available potassium content, this level of extraction from a reduced volume of soil cannot be ignored. Annual soil testing and in-season leaf and petiole testing is recommended to insure N, P and K levels are not limiting at any point during the growth of the crop.

Nitrogen Additions According to Expected Yields

The total amount of N that needs to be made available to the crop (from the soil, starter and popup fertilizers, other banded materials, and from fertilizers applied through the irrigation system) can be estimated based on expected yield. Approximately 4 to 5 lb/acre of N is required per expected ton per acre of tomatoes.

Expected Yield	N Requirement
40 t/ac	160 - 200 lbs./ac
50 t/ac	200 - 250 lbs./ac
60 t/ac	240 - 300 lbs./ac

First Bloom

Before first bloom, the crop should have access to about 40% of this requirement. Some of this 40% will come from the preplant material and any deep fertilizer bands, and the amount the soil is expected to supply can be determined from soil analysis of NO3-N after the initial watering up. The remainder should be supplied via the drip system. Note that in a recent study conducted by UCCE personnel, pre-sidedress soil nitrate testing (PSNT) was used, and results indicated that residual soil N can make a very significant contribution to the crop’s requirements.

First Fruit

It is advisable to wait until the first fruits (set on the first open flowers) are the size of a small pea before starting to apply any further N. Applying more N before this can cause too much of an early vegetative growth spurt, leading to long internodes and a lanky bush. This is also a critical time for monitoring soil moisture and withholding irrigation until it is required.

“Pea Size” Stage

When the fruit reaches this “pea size” stage, N is applied at a rate of 2 lb/ac per day for 7 days. This can be applied daily if convenient or in two or three equal amounts during this first week of intense fertigation.

Second Week of Fertigation

From the second week of intense fertigation onwards, the rate to be applied is 3-4 lb/ac per day, depending on the total amount to be applied based on expected yield. The goal is to have all of the N applied before the first color stage.

The following table gives an example of the use of these guidelines for a 55 t/ac expected yield.

55 TONS PER ACRE EXPECTED YIELD*	**Range of Nitrogen Amounts**	**Middle of Range**
Total Nitrogen Requirement *(4 - 5 lb/ac per expected ton) =*	**220 - 275 lb/ac**	**248 lb/ac**
40% to be Available to the Plant by First Bloom =	**88 - 110 lb/ac**	**99 lb/ac**
Subtract Amount Soil Will Supply *(determined by soil testing)*	**-32 lb/ac**	**-32 lb/ac**
Subtract Amount Applied with Preplant Fertilizer	**-18 lb/ac**	**-18 lb/ac**
Amount of N to be Supplied Via Fertigation by First Bloom =	**38 - 60 lb/ac**	**49 lb/ac**
60% to be Applied from Pea Size Stage to First Color =	**132 - 165 lb/ac**	**149 lb/ac**
Amount of N to Apply in 1st Week After Pea Size Fruit *(@ 2 lb/ac/day)*	**-14 lb/ac**	**-14 lb/ac**
Amount of N to Apply for Next 4 - 6 Weeks *(@ 3 - 4 lb/ac/day) =*	**118 - 151 lb/ac**	**135 lb/ac**

*Assumptions - Soil testing indicated 32 lb/ac N available from soil. The preplant fertilizer contained 18 lb/ac N. Figures used in this table are presented only for the purpose of demonstrating the guidelines and are not to be taken as a recommendation. Users of the guidelines must determine their own expected yield, available soil nitrogen and preplant fertilizer requirement.

Fine Tuning

Petiole sap nitrate levels should be monitored on a weekly basis to fine-tune the nitrogen fertigation schedule. Every 2 to 3 weeks, N, P and K levels in dried petioles should be determined. Guidelines for sample collection, determination and interpretation of sap nitrate levels can be obtained from reliable sources. Interpretation guidelines for N, P and K levels in dried petioles are explained in “Integrated Pest Management for Tomatoes, Fourth Edition”, University of California (Publication 3274).

If additional P is required, it is likely to be around the time of full bloom. P can be supplied through the drip system with acidifying fertilizer materials, including “drip grade” phosphoric acid and N-P-K blends specifically manufactured for injection into drip systems. If K is determined to be deficient, fertigation with potassium nitrate or other soluble sources of K can bring the levels in the plant back into the sufficient range. Before any fertilizer material is injected into a drip system, it is important to consider its compatibility with the water source and with other materials that are being injected. Clean water should be run for a sufficient period in between the injection of materials that have the possibility of reacting to form precipitates that can cause blockages in the emitters. Information on compatibility can be obtained from publications, your PCA or CCA, and other reliable sources. A “jar test” can also be informative. This involves adding small amounts of the fertilizer materials to a jar of irrigation water and watching for any signs of “milkiness” or the formation of precipitates during the next 24 hours. Appearance of these signs indicates that there is a chance of emitter plugging.

Summary

In summary, to obtain high yields and high soluble solids in processing tomatoes, the irrigation must be managed carefully, and at the same time, nutrients must not be limiting. The nitrogen fertigation schedule should be based on expected yield and the results of a pre-sidedress soil nitrate test. We recommend that the fertigation program be implemented in line with recognizable crop stages and fine-tuned with sap analysis and dried tissue testing. With subsurface drip irrigation, you have the ultimate tool for precisely matching the crop’s nutrient needs so that production goals can be achieved.

Netafim's Thinwall Dripperlines - Your Solution for Growing Processing Tomatoes

Netafim's Typhoon Thinwall Dripperline is the ideal irrigation tool for manipulating a processing tomato crop's growth and development to achieve the desired balance with yields and soluble solids while saving on water and energy. For irrigating large-sized fields with rows up to a 1/2 mile, it is available in a variety of large hose sizes - allowing you to save more by reducing material and labor costs. Netafim's Typhoon Thinwall Dripperline can also be ordered in specific dripper spacings, flow rates and wall thicknesses to meet the unique requirements of your soil and crop combinations.

Unique Product Features and Benefits

- Drippers are welded into a wall of seamless tubing. This prevents damage to the drippers during installation and distortion of the dripper's flow even as the tubing stretches and expands - delivering a uniform application of water to the crop.
- The tubing's seamless design also protects it from bursting under high water pressures required for proper flushing.
- Each dripper is equipped with Turbonet Technology - the industry's widest flow path. Turbonet Technology improves the dripperline's irrigation performance by maximizing flow path velocity, allowing particles to pass easily through the dripper - virtually eliminating plugging.

Recommended Products for Processing Tomatoes

Thinwall Dripperline With Flap

For runs up to 1/4 mile

- Typhoon 875
- Typhoon 990

For runs up to 1/2 mile

- Typhoon 1 3/8"

Application: Subsurface
Crop: Processing Tomatoes
Wall Thickness: 10 or 13 mil
GPH: .16 @ 14" spacing

Deficit Irrigation for Managing Soluble Solids in Processing Tomatoes Grown with Subsurface Drip Irrigation

In the first issue of "The Tomato Vine" (April 2003), guidelines for managing soil moisture with subsurface drip irrigation (SDI) were given for processing tomato growth stages up to the point of fruit ripening. Once the first fruits begin showing color, it signals a time to change the approach to irrigation management in order to achieve desirable soluble solids along with high yields. A deficit irrigation schedule is implemented at this point, which involves reducing the moisture levels within the wetted pattern in a controlled manner and maintaining a moderate level of crop water stress. The increase in soluble solids is accompanied by a proportional decrease in yield. Getting the balance right will be the aim of all users of SDI. The goal is to achieve soluble solids that are high enough to satisfy processors without sacrificing too much yield.

Deficit Irrigation

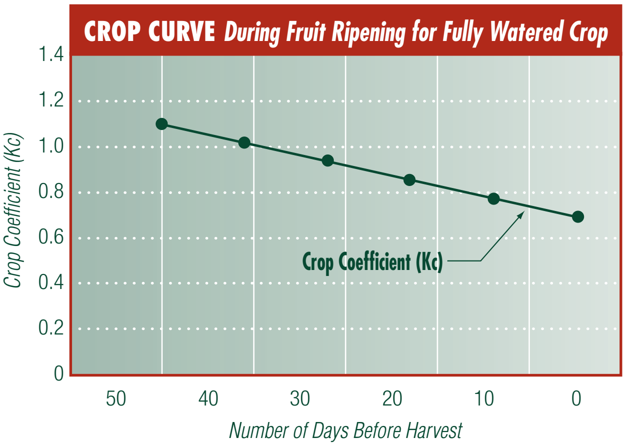
Deficit irrigation is the application of less water than crop evapotranspiration (ETc) during fruit ripening. ETc is determined by multiplying reference evapotranspiration (ETo) by the crop coefficient (Kc) that pertains to the particular growth stage of the processing tomato crop.

ETc = ETo x Kc

Daily Evapotranspiration

Daily reference evapotranspiration (ETo), which is calculated from weather station data, can be obtained for all tomato production areas through the California Irrigation Management Information System (CIMIS). Crop coefficients for processing tomatoes have been developed by researchers and are available in several publications, allowing for the calculation of daily crop evapotranspiration (ETc).

Recent research along the west side of the San Joaquin Valley has led to guidelines for using measurements of canopy cover to determine the crop coefficient up to the time of full coverage. At 100% canopy coverage, which generally occurs at about the time the crop reaches full bloom, the crop coefficient is about 1.15. If the crop has been vine-trained or vine-trimmed, some dry soil area will be exposed, and the crop coefficient will be reduced accordingly, e.g. the peak Kc will be about 1.0 - 1.05.



At the beginning of ripening, the Kc for processing tomatoes is still near the peak, but by the time of harvest it has decreased to

0.6 - 0.7 for a fully watered crop, i.e. a crop being supplied with ETc plus a small additional amount to account for system inefficiencies. For the 40 - 45 days from the start of fruit ripening until harvest, we assume the crop coefficient decreases in a straight line, as illustrated in the figure on page 9. (Note that a deficit-irrigated crop adjusts to the moderate water stress by decreasing its water use and therefore has a different crop curve during ripening.)

Deficit Irrigation Guidelines

Research conducted by University of California Cooperative Extension (UCCE) personnel indicates that in the case of soils with relatively high water holding capacities (e.g. silt loams, clay loams and clays), which are commonly used for production of processing tomatoes, the irrigation cutback should begin at the start of ripening, approximately 40 - 45 days before harvest. If the crop is grown on deep loamy soils or under conditions of high water tables (non-saline), the irrigation cutback may need to be started earlier or be more severe. Deficit irrigation guidelines presented in this article should not be attempted on light soils or in saline conditions. Investigations are currently underway to develop guidelines for these situations.

Once deficit irrigation commences, instead of supplying the crop with 100% of daily crop water use (ETc), only 30% to 70% of daily reference evapotranspiration (ETo) is supplied through the drip system. Initially, this will cause the moisture in the top two feet of soil to be depleted, resulting in moderate crop water stress. The crop will also start drawing on the deep moisture in the third and fourth foot. Irrigation should still occur frequently during this period, but the soil in the top two feet should not be brought back to field capacity.

The deficit irrigation schedule can be continued until 4 to 7 days before harvest (under most conditions), at which point the water is completely cut off for harvest. Research has shown that where shallow, non-saline water tables are present, an earlier cutoff might be necessary.

From the time of cutoff until harvest, the crop must have access to sufficient moisture to maintain vine cover. At the time of harvest, moisture will be strongly depleted at all depths. Guidelines for managing moisture if processors get behind are presented in a separate article titled "Using Subsurface Drip Irrigation to Field Store Processing Tomatoes when Harvest is Delayed."

A comparison between a full irrigation schedule starting 45 days before harvest with cutoff 10 days before harvest (dbh), and a deficit irrigation schedule starting 45 days before harvest with cutoff 5 dbh, is presented in the table on page 11.

A comparison between full irrigation and deficit irrigation starting 45 days before harvest is presented in the table.

			FULL IRRIGATION	DEFICIT IRRIGATION
Dates	ETo (Historical Data for Five Points, CA)	Average Kc During the Period (from the graph)	Amount to be Applied with a Full Irrigation Schedule (100% of ETc) with Cutoff 10 Days Before Harvest (dbh)	Amount to be Applied with a Deficit Irrigation Schedule (50%* of ETo) with Cutoff 5 Days Before Harvest (dbh)
August 6 - 15 *45 Days Before Harvest (dbh) to 36 dbh*	.28 inches/day	1.06	10 days x .28 in./day x 1.06 = 3.0"	10 days x .28 in./day x 50% = 1.4"
August 16 - 30 *35 dbh to 21 dbh*	.25 inches/day	0.94	15 days x .25 in./day x 0.94 = 3.5"	15 days x .25 in./day x 50% = 1.9"
August 31 - September 9 *20 dbh to 11 dbh*	.23 inches/day	0.84	10 days x .23 in./day x 0.84 = 1.9"	10 days x .23 in./day x 50% = 1.2"
September 10 - September 14 *10 dbh to 6 dbh*	.23 inches/day	0.77	0"	5 days x .23 in./day x 50% = 0.6"
Total Water Applied During Fruit Ripening Period →			8.4"	5.1"

**The actual percentage may vary from 30% to 70%. Adjustments should be made according to soil moisture determinations during the deficit period.*

Soil Moisture Monitoring

The above guidelines only provide a starting point for carrying out deficit irrigation. A reliable, accurate method of soil moisture monitoring is essential for fine-tuning the deficit irrigation schedule. Using the water budget method (or "ET scheduling") on its own can lead to mistakes. For example, if a grower has made a small but continual over-estimation of the crop coefficient from mid-bloom to full bloom, there will be a buildup of deep moisture. The effort to create moderate stress conditions early in the ripening phase could be thwarted if there is a large amount of stored soil moisture available to the crop. By the time the stress conditions are achieved, a significant proportion of the fruit will have already ripened under non-stress conditions.

A tomato crop's moisture requirements can sometimes be partially supplied by groundwater, and where this is likely, it is essential to understand the contribution being made by the water table during implementation of the deficit irrigation schedule. In practice, this can only be achieved with soil moisture monitoring.

The method of soil moisture monitoring can be simple, e.g. collection of 1-foot samples (down to 3 or 4 feet) using a soil probe, and moisture determination by the "feel method." The other end of the spectrum involves continuous logging of volumetric soil moisture content at specific depths with soil moisture sensors, such as Netafim USA's Gro-Point™. The trends of the continuous graphs can be very useful in determining whether the irrigation applications are resulting in an increase or decrease in soil moisture. Soil moisture should be monitored at 3 depths if possible, namely at 1 ft., 2 ft. and 3 ft. This group of sensors at a single site is referred to as a soil moisture monitoring station. There should be a minimum of two stations per irrigation block, located in representative spots. If the block has more than one variety or variable soils, more stations will be required.

Testing the Soluble Solids of Newly Ripened Fruit to Fine-Tune Deficit Irrigation

Research conducted by UCCE personnel in 2003 has shown that once a fruit reaches the stage of having significant external orange color, its soluble solids is no longer influenced by soil moisture availability. However, the water content of green fruit is strongly influenced by soil moisture availability. Their results have shown the importance of imposing the moderate stress conditions while most fruit are still green, leading to a new approach for fine-tuning the deficit irrigation schedule. This initially involves testing the soluble solids of a representative sample of newly ripened fruit at the first color stage (i.e. when the crown set begins to ripen) to get an idea of how severe the deficit irrigation schedule needs to be. The size of the gap between this initial soluble solids result and the desired final field average will help determine how much water to apply. The deficit irrigation schedule can involve adding as little as 30% to as much as 70% of ETo, and can be adjusted up or down during the ripening period.

Once the initial amount (e.g. 50% of ETo) is decided, the crop's response can be monitored with weekly testing of the soluble solids of a composite sample of 20 to 30 newly ripened fruit (indicated by external orange color over most of the tomato with a bit of green blush still showing). It is important to obtain a sample that represents all areas of the field. In most situations, this will involve collecting fruit at evenly spaced points along a diagonal line from one corner of the field to the other. Different varieties should be sampled separately. The weekly soluble solids results, along with soil moisture monitoring, can be used as the basis for fine-tuning the deficit irrigation schedule on a field-by-field basis.

Further details on this new approach can be found in an article produced by Dr. Tim Hartz and other UCCE personnel involved in conducting the research: "Managing Soluble Solids of Processing Tomatoes with Drip Irrigation", page 2, ***Vegetable Notes - Special Edition #5: Tomatoes - Processing & Fresh Market, March 2004,*** edited by Michelle Le Strange. (This is available from the UCCE Vegetable Research & Information Center website: ***http://vric.ucdavis.edu/selectnewcrop.tomato.htm*** in the "Other" category of publications that can be downloaded.)

SUMMARY:

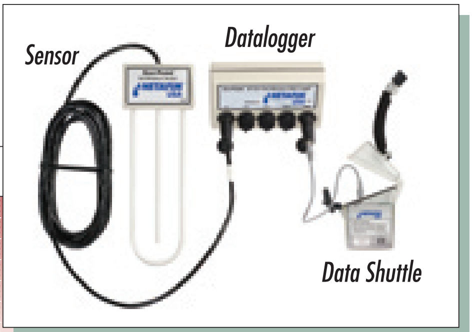
Processing tomatoes grown with SDI must be managed carefully to ensure processors are supplied with tomatoes that have desirable levels of soluble solids. Deficit irrigation can be used during the ripening period to improve solids. However, to ensure the crop is not water stressed too strongly, which would lead to an unacceptable loss of yield, growers must be guided by a reliable and accurate method of soil moisture monitoring. The dripperlines should also be monitored to ensure the deficit irrigation schedule is not encouraging root intrusion. Prevention of root intrusion will be covered in a separate article.

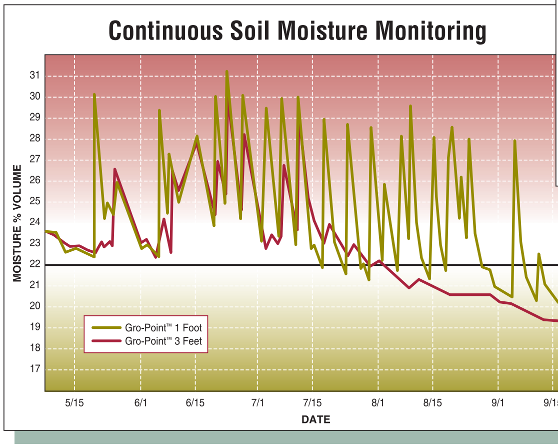
“When should I irrigate and how much water should I apply?”

Netafim USA’s Gro-Point™ Soil Moisture System provides continuous, real-time soil moisture data - the critical information needed to help you make better irrigation decisions. It provides answers to the questions of when to irrigate and how much water to apply.

Gro-Point’s™ easy-to-use, maintenance-free soil moisture sensors are installed into the soil, supplying immediate and accurate logging of volumetric soil moisture content at specific depths. These measurements allow you to respond with changes in irrigation schedules and cycles, preventing unwanted situations such as high water stress and potential yield loss. With soil moisture monitoring, yields are increased while water usage is optimized and excessive leaching is reduced.

Netafim USA’s Gro-Point™ Soil Moisture System Answers Your Questions




Continuous Soil Moisture Monitoring

Continuous Logging

The Gro-Point™ Soil Moisture System provides continuous feedback (similar to a video), rather than a snap shot of current conditions. This continuous logging capability, combined with graphing software, gives users a powerful means of determining whether the irrigation applications are resulting in an increase or decrease in soil moisture. Use of this management tool at recommended depths:

- Allows precision control of irrigation
- Provides building blocks for crop management
- Assures repeatable results year after year

Netafim USA’s Gro-Point™ Soil Moisture System - your answer to maximizing yields, quality and profits.

Managing the Potential for Root Intrusion with Subsurface Drip Irrigation

When Deficit Irrigating

When processing tomato crops are grown using well-designed subsurface drip irrigation (SDI) systems, and they are watered frequently and provided with sufficient water to meet daily crop water use (ETc), plus a small additional amount to cover system inefficiencies and any leaching requirements, root intrusion is generally not a problem. However, the system must be maintained properly so that the dripper flow rates are not reduced by organic matter or mineral particles. Also, early in the crop's life, a desirable wetted volume and root system must be established as described in our first newsletter (April 2003), and the size of the wetted pattern should be maintained until the start of crop ripening. In situations where deficit irrigation is used during crop ripening to increase soluble solids, it is important to be aware of the potential for root intrusion and to adopt a preventative approach.

Preventing Root Intrusion

Netafim USA's thinwall dripperlines have design features that reduce the likelihood of root intrusion, however, under certain circumstances it can still occur. The main causes of root intrusion and the corresponding ways of preventing it appear in Table 1.

Prevention is the preferred approach, although minor cases of root intrusion can be "cured" if caught early enough. The way to catch it early is with frequent monitoring of pressure gauges and flow meters. Stable flow rates over time, at set operating pressures, indicate a properly functioning SDI system. Any noticeable reduction in flow should be investigated and acted upon quickly.

Table 1: *The Main Causes of Root Intrusion and Corresponding Prevention Measures*

Causes of Root Intrusion	Prevention of Root Intrusion
Insufficient water available to the crop.	Avoid water stress, particularly during times of vigorous vegetative growth when the root system is also growing vigorously.
Poor maintenance leading to reduced water application in zones where emitter plugging occurs.	Flush the system periodically, in line with prevailing water quality conditions, and use chlorine and/or acid treatments as required.*
Emitter plugging due to injection of incompatible materials or failure to acidify water before injecting certain fertilizer materials.	Always consult publications and specialists, including your PCA or CCA, before injecting materials that may react with each other or with substances present in your water source.*
Weed growth, particularly weeds belonging to the *Gramineae* family (grasses, cereals).	Control weeds, with particular attention to the elimination of grass weeds.
Fertilizers not flushed from the dripperlines.	Use proper fertigation practices, including flushing fertilizers from dripperlines by running water that contains no fertilizers at the end of each irrigation cycle.*
Not adhering to a good system design.	Do not exceed run lengths of dripperlines as specified in the system design, and do not alter the filtration type or capacity. Consult your dealer before making these types of changes so the design can be altered.
Watering infrequently when deficit irrigating.	Water frequently, even when supplying less than daily crop water use (ETc), to try to maintain saturated conditions in the soil surrounding each emitter.

*A list of publications containing information on these subjects can be found at the end of this article.

Generally root intrusion is not the first problem. If full flow is not restored after a thorough flushing and maintenance treatment, and if root intrusion is suspected, the next step is to examine the root system in the vicinity of the emitters by carefully excavating the soil to expose the dripperline. When root intrusion is just starting to occur, it might not be detected if the soil and roots are pulled away from the dripperline too aggressively. It is important to carry out the investigation in the area that is receiving the least amount of water due to flow variation in the system. With many designs, this will be about 70% of the way down the irrigation run, however it pays to check with the designer to ensure that this is the case with your particular installation.

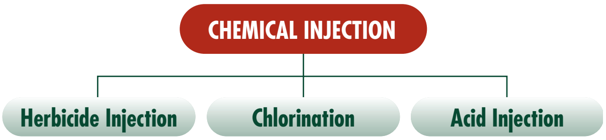
If root intrusion has occurred, specific treatment guidelines (involving the injection of high doses of chlorine and/or acid) should be obtained from publications, your irrigation dealer or a Netafim USA representative. All necessary precautions and regulations should be observed, and the problem should be treated as soon as it is detected. The expected increase in flow may only be noticeable a day or two after the treatment. If the response is not satisfactory, one or two additional treatment cycles may be required.

Deficit Irrigation

The use of deficit irrigation to improve soluble solids was discussed in our third newsletter (June 2003). Deficit irrigation involves adding less water than crop evapotranspiration (ETc) in order to subject the crop to sustained, moderate water stress during the fruit ripening period. Soon after deficit irrigation commences, the moisture in much of the top two feet of soil will be depleted to the point of moderate water stress. A moisture gradient will exist in the soil. The closer the soil is to the emitter, the higher its available moisture content will be. Since plant roots tend to grow in the soil areas with the highest water content, deficit irrigating may encourage more root activity near the emitters, increasing the risk of root intrusion. However, tomato roots will not grow into saturated soil. As noted in Table 1, frequent irrigation during the deficit period can help prevent root intrusion by helping to maintain a saturated soil condition around the emitters.

Additional Preventative Measures

There are reports of the successful use of chemical injection (“chemigation”) to prevent root intrusion in subsurface drip irrigation systems, however the “evidence” of success is mostly anecdotal and very little research has been conducted on this topic. Netafim will be keeping abreast of any new developments in this area that will enable us to provide specific guidelines for our customers.



Chemigation can be broken down into three main categories: herbicide injection, chlorination, and acid injection.

For root intrusion prevention, it would be ideal to be able to carefully inject an herbicide at a rate that would kill root tips in close proximity to the emitters without killing the plants themselves. Unfortunately, there is currently no registration in California for application of an herbicide via chemigation in processing tomato crops for the purpose of preventing root intrusion.

Growers of various crops have used periodic injections of acid or chlorine products to prevent root intrusion. The treatments “burn off” any feeder roots that are growing in close proximity to the emitters, and the soil environment immediately adjacent to the emitters is temporarily modified to discourage root growth.

Prevention practices reported in the publications listed at the end of this article, and things to be aware of regarding the practices, are presented in Table 2.

Table 2: *Chemical Injection Practices Used By Growers with Various Crops to Prevent Root Intrusion.*

Practices for Root Intrusion Prevention	Important Considerations
Weekly acid injections that lower the pH of the irrigation water to 2 - 3 for a short period (e.g. 30 minutes). Acids that can be used include phosphoric, hydrochloric, nitric and sulfuric.	May damage some irrigation system components and may drastically alter the pH in soils with low buffering capacity (i.e. soils with little or no free lime). A low soil pH can cause aluminum toxicity and micro-nutrient deficiencies.
Use of N-pHURIC® (a combination of urea and sulfuric acid, which is safer to handle than straight acid) on a weekly basis to lower the pH as above.	Same as above. In addition, processing tomatoes do not need the nitrogen supplied by N-pHURIC® during the crop ripening period.
Continuous injection of phosphoric acid at 15 ppm of P.	The higher grades of phosphoric acid that must be used in the production of edible crops are expensive. The additional P may not be needed by the crop during the ripening period. The soil pH might be altered significantly and some system components could be damaged.
Weekly injections of chlorine resulting in 7-10 ppm "free" or "residual" chlorine concentrations for a short time (e.g. 30-60 minutes) at the end of an irrigation. Alkaline water should be acidified to a pH of 6.5 to maximize effectiveness of the chlorine treatment.* **A thorough flushing of the system prior to the injection will enhance the effectiveness of the chlorination treatment and reduce the amount of material needed.**	Crops vary in their sensitivity to chlorine. Care should be taken to ensure heavily chlorinated water is not moved too far into the root zone. Some system components may be damaged by high concentrations of chlorine (e.g. pressure compensating emitters should not be exposed to concentrations exceeding 10 ppm). Application of ammonium or urea fertilizers during chlorination should be avoided. Contact between free chlorine and these fertilizers results in the formation of chloramine (which is known as "combined chlorine"), reducing the effectiveness of the chlorination treatment.

*When chlorine is injected into the water, hypochlorous acid (HOCl) is produced. Some of this acid becomes ionized and there is an equilibrium between the hypochlorous acid (HOCl) and hypochlorite ions (OC1^{-}). The relative percentage of the two components, which together make up the "free" or "residual" chlorine, varies with pH. Lowering the pH pushes the reaction from the hypochlorite side to the hypochlorous acid side. Hypochlorous acid is 40 to 80 times more powerful as a biocide than hypochlorite. Note that the procedure of acidifying the water requires two separate injection points. ***Never*** mix acid and liquid chlorine in the same tank, as this will result in the formation of chlorine gas, which is highly toxic.

Chlorination

In the case of chlorine injection, liquid sodium hypochlorite (NaOCl) is the easiest material to handle and is the form most often used for treatment of drip irrigation systems. Chlorine gas ($Cl2$) can be injected, but it is more dangerous to handle and it requires more expensive injection equipment. It is not advisable to use powdered calcium hypochlorite, which is commonly used in swimming pools. When mixed with water, the calcium can form precipitates, especially at higher pH levels.

When chlorine is injected into a drip system, the aim is to achieve the stated concentration at the end of the furthest lateral from the injection point. Chlorine concentration decreases as time and distance from the injection point increases. To achieve 7-10 ppm at the end of the furthest lateral, a concentration of 20 to 50 ppm might be required at the system head (downstream of the filters). These relatively high levels of free chlorine (also referred to as "residual" chlorine) cannot be measured by some swimming pool test kits. Test kits or strips that measure the higher concentrations of free chlorine used in micro-irrigation systems might be available from irrigation dealers or suppliers of swimming pool products and chemicals. Other sources are listed at the end of this article.

CAUTION: *With both acid and chlorine, there are many precautions that must be taken to ensure the safety of personnel, irrigation system components and the crop. Follow the manufacturer's directions at all times. Contact your dealer, PCA, CCA or farm advisor to assist with determining the amount and type of material to be injected and the injection time required to achieve the target concentration of residual chlorine or the desired pH at the end of the furthest lateral from the injection point. Obtain detailed step-by-step procedures from publications or other reliable sources before carrying out acid injection or chlorination. Publications containing further information are listed at the end of this article.*

Timing of Chlorine Injections

Use of Netafim USA's thinwall dripperlines in a well-designed SDI system, implementation of an appropriate system maintenance schedule and frequent irrigation during the deficit period may be sufficient to prevent root intrusion. Growers who wish to use chemical injection as an additional preventative measure should keep in mind that the soil in the top two feet of the profile dries out fairly quickly once the deficit irrigation schedule commences. The appropriate timing for the first treatment would be prior to or within the first few days of the start of the deficit period. Depending on the severity of the deficit irrigation schedule and the vigor of the crop, periodic acid or chlorine treatments may need to be repeated every 4 to 10 days. The final watering before irrigation cutoff should include a thorough flushing of the system, followed by any final acid or chlorine treatment. Further maintenance procedures can be carried out after harvest.

PLEASE NOTE: The use of chemicals mentioned in this article must be in accordance with local, state and/or federal health and safety regulations related to chemical injection. A licensed PCA should be consulted for a recommendation before any regulated materials are used for preventative or corrective action against root intrusion. Where product and company names are mentioned in this article, no endorsement is implied. Also, no criticism of companies, products and brands not mentioned is intended.

Additional Sources of Information

The following publications contain information on root intrusion, system maintenance, and injection of acid and chlorine.

Drip Irrigation for Row Crops
Hanson, B. R., L. J. Schwankl, S. R. Grattan and T. L. Prichard, 1997, University of California, Division of Agriculture and Natural Resources, Publication 3376, Dept. of Land, Air and Water Resources, U.C. Davis

Drip and Micro Irrigation for Trees, Vines and Row Crops - Design and Management (with special sections on SDI)
Burt, C. M. and S. W. Styles, 1999, Irrigation Training and Research Center (ITRC), California Polytechnic State University, San Luis Obispo

Fertigation
Burt, C. M., K. O'Connor and T. Ruehr, 1998, Irrigation Training and Research Center (ITRC), California Polytechnic State University, San Luis Obispo

Subsurface Drip Irrigation - Theory, Practices and Application
Jorgensen, G. S. and K. N. Norum, 1993, CATI Pub. No. 92 1001, Fresno, CA, California State University

Sources of Products for Measuring pH and Free Chlorine

The pH levels and free chlorine concentrations used in micro-irrigation systems are out of the range of measurement of many test kits and strips used for testing swimming pools. Suitable products might be available from irrigation dealers and suppliers of pool and spa products. The following list of companies has been compiled from the results of an internet search for sources of suitable kits, strips and devices, including specific ion probes.

Spectrum Technologies, Inc., Plainfield, IL
www.specmeters.com, (800) 248-8873

Hach Company, Loveland, CO
www.hach.com, (800) 227-4224

Hanna Instruments, Inc., Woonsocket, RI
www.hannainst.com, (877) 694-2662

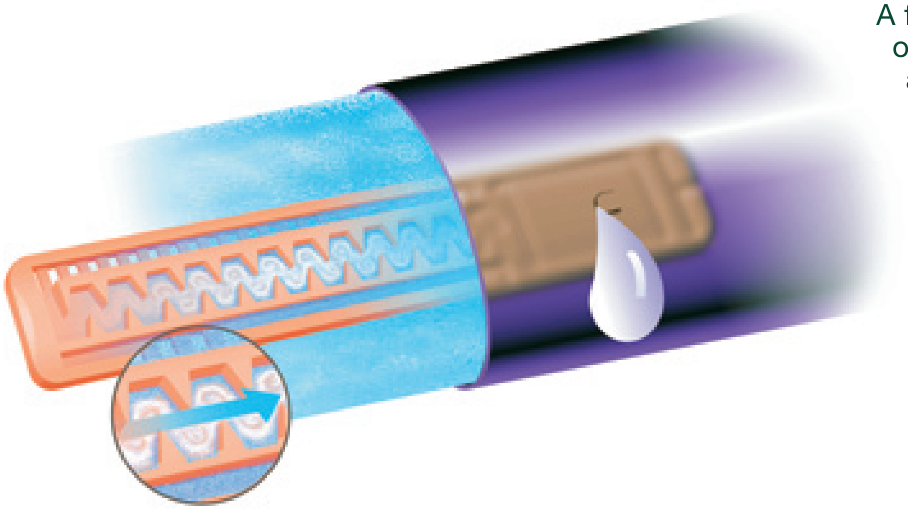
Palintest USA, Erlanger, KY
www.palintestusa.com, (800) 835-9629

Netafim USA's Thinwall Dripperline's Superior Technology Provides Added Protection Against Root Intrusion

When you plan to deficit irrigate during crop ripening to increase soluble solids, it is essential to have a drip irrigation system that will help protect against root intrusion. Netafim USA's Thinwall Dripperlines are designed with features that provide the extra layer of protection you need.

Superior extrusion technology results in a seamless construction, with the drippers welded to the inside wall. With a smooth outside surface, no path is provided for roots to follow, reducing the likelihood of root intrusion.

Additional protection is provided by advanced flap technology on Netafim USA's thinwall dripperlines. A flap over each dripper outlet systematically opens and closes during start-up and shut-down, providing uninterrupted flow while open and protection against soil ingestion and root intrusion when closed.



Selecting Dripper Spacings and Flow Rates
to Maximize the Benefits of Subsurface Drip Irrigation

When the decision has been made to use subsurface drip irrigation (SDI) for production of processing tomatoes, growers have the opportunity to consider various options for dripper spacings and flow rates before finalizing the design. If you were to look for a single recommendation from Netafim USA, it would be the use of a low flow (0.16 gallon per hour) dripper at a spacing of 14 inches. However, a preferable approach to making this decision involves a consideration of the soil types present in the field, whether the system is to be used for germination and establishment, whether salinity problems exist, and other factors such as the requirements of the rotation crops.

A "Standard" System

The nominal flow rate for Netafim's low flow dripper in our main 7/8" diameter product (Typhoon 875) is 0.16 gallons per hour (GPH) at 10 psi. Use of this product with a 14-inch spacing results in a particular dripperline flow rate (in terms of gallons per minute per 100 feet), and from this information, an application rate can be determined for a typical 5-foot bed spacing as listed in the chart below:

Flow Rate per Dripper at 10 psi, in GPH	Dripper Spacing	Flow Rate in GPH & GPM per 100' of Dripperline	Application Rate, in inches of water per hour, to a field with a 5' bed spacing
0.16	14"	13.7 GPH = 0.228 GPM	0.044 in/hr

In most field situations that are suitable for processing tomatoes, and at typical dripperline depths (10-12"), this spacing-flow combination enables the system to be used for germination of direct-seeded crops and establishment of transplanted crops. For the balance of the season, it is important for this spacing-flow combination to also be able to create an adequate subsurface wetted pattern without creating surface moisture.

Soil Type Considerations

Water movement is greatly influenced by soil type. For processing tomatoes and the likely rotation crops that will be grown, it is desirable for the spacing-flow combination to create a wetted pattern characterized by overlapping of the individual wetted patterns from each dripper. In Australia, we refer to this as a "wetted sausage." Of course, it is virtually impossible to achieve a uniform, cylindrical wetted pattern in the soil.

Figure 1 illustrates the need for narrower emitter spacings on lighter soil types, and the ability to use wider spacings in heavier soils in which greater lateral movement can be expected.

Using Other Methods for Germination and Establishment

When it is possible to use sprinklers (or furrow irrigation) for germination and establishment, the need for significant overlapping of wetted patterns is much less critical. Once the root system is established to the point that the wetted pattern from the drip system will intercept it, the subsequent root growth will occur in the areas where water and nutrients are supplied. Since dripperline run lengths must be shortened when dripper spacings are narrower, growers must weigh the cost-benefit of sprinklers irrigating the crop versus the economics of longer run lengths. In general, longer run lengths result in lower overall system costs.

There are distinct agronomic benefits associated with using sprinklers for germination and establishment due to the ability to wet the entire top of the bed. The application will also be fairly uniform and water will only be applied to the desired depth. Sprinklers allow roots to grow throughout the most desirable soil zone, i.e. the area having the most organic matter, nutrients and oxygen. Getting this entire area wet also helps to consolidate the topsoil, aiding lateral movement of water when the drip system begins to be used.

Higher Flow Rates

Higher dripper flow rates also necessitate shorter run lengths, but in some instances, a more desirable wetted pattern or the ability to use the drip system for germination and establishment can only be achieved with higher flow rates. Because soils vary in structure as well as texture, the surest way of determining the best spacing-flow combination as well as the most suitable depth for dripperlines, is to conduct a trial. Netafim can manufacture dripperlines with any specified spacing using drippers with the following nominal flow rates: 0.16, 0.2, 0.4 and 0.53 gallons per hour.

Trial Installations

Each grower should establish a trial installation of dripperlines in all major soil types in the field. This can be done simply and quickly. A small pump and filter can be used to feed several dripperlines with varying flow-spacing combinations, buried at different depths. In determining which combination suits each major soil type in the field, growers will need to consider whether they want to use the system for germination and establishment, and how important it is to be able to maintain a dry soil surface. With processing tomatoes, a dry surface is critical and is one of the major benefits of adopting drip irrigation. The agronomic requirements of other crops in the planned rotation should also be taken into consideration. For example, successful production of a shallow-rooted crop like onions will require a different spacing-flow-depth combination than cotton.

Saline Situations

Drip irrigation can be used in saline conditions to successfully grow crops that could not otherwise be grown in these fields. However, these situations require constant attention to irrigation management to insure wetted pattern dimensions are maintained and the moisture levels are kept high enough to prevent crops from suffering significant salt stress (also referred to as “osmotic stress”). There will also be a requirement for leaching salts from these soils, and it is important that wetted patterns so that leaching can be accomplished along the entire continuous wetted strip. Higher flow rates should be considered in saline situations to enable significant overlapping, more control over leaching and greater ability to get water to the root zone quickly if there is a breakdown or a heat wave.

Netafim Provides All the Right Choices in Thinwall Dripperlines

For maximizing crop quality and yields and minimizing water, energy, fertilizer and labor costs, growers across America are choosing the proven performance of Netafim Thinwall Dripperlines. From medium sized fields to large fields - Netafim Streamline and Typhoon dripperlines are available in a wide range of all the right choices to meet each season's growing demands.

Streamline Dripperline

The perfect choice for row crop growers planting short to medium sized runs up to 1/4 mile during individual seasons. Available with variable dripper spacings, allowing growers to tailor make systems based on application rates and wetting patterns and four wall thicknesses that can weather various environmental conditions. For surface or subsurface installation in virtually any soil type.

Typhoon Dripperline

The ideal growing choice for growers irrigating large-sized fields with dirty water conditions and rows up to 1/2 mile long. Available in a variety of large hose sizes, giving growers the freedom to design longer runs - reducing material and labor costs. For both surface or subsurface installations - season after season.

Streamline 630 4 Mil

For medium-sized fields, short seasonal crops with short runs. Light to medium textured soils, minimum rocks, clods or under plastic mulch. Thinwall dripperline must be buried at least one inch under clear plastic.

Flows (GPH) at 10 psi: .16, .22, .38

Spacings: 8”, 12”, 16”

Streamline 630 6 Mil

For medium-sized fields, short seasonal crops with short runs. Double cropping, minimum tilled, heavy textured soils, where rocks and previous crop residue is a factor.

Flows (GPH) at 10 psi: .16, .22, .38

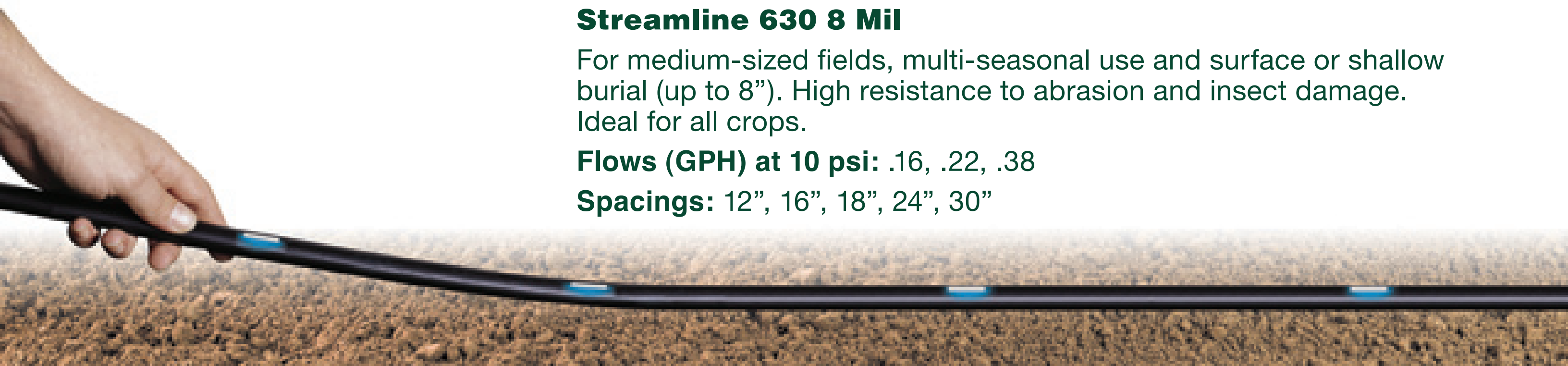
Spacings: 8”, 12”, 16”, 18”, 24”

Streamline 630 8 Mil

For medium-sized fields, multi-seasonal use and surface or shallow burial (up to 8”). High resistance to abrasion and insect damage. Ideal for all crops.

Flows (GPH) at 10 psi: .16, .22, .38

Spacings: 12”, 16”, 18”, 24”, 30”



Streamline 875 8 Mil

For long runs up to 1/4 mile. Seasonal or multi-seasonal use, surface or shallow (up to 8”) burial.

Flows (GPH) at 10 psi: .16, .22, .38

Spacings: 8”, 12”, 16”, 18”

Typhoon 875 10 Mil

For long runs up to 1,300 feet. Multi-seasonal use, surface or shallow (up to 10”) burial, retrieval or reuse applications.

Flows (GPH) at 10 psi: .18, .24, .36, .58

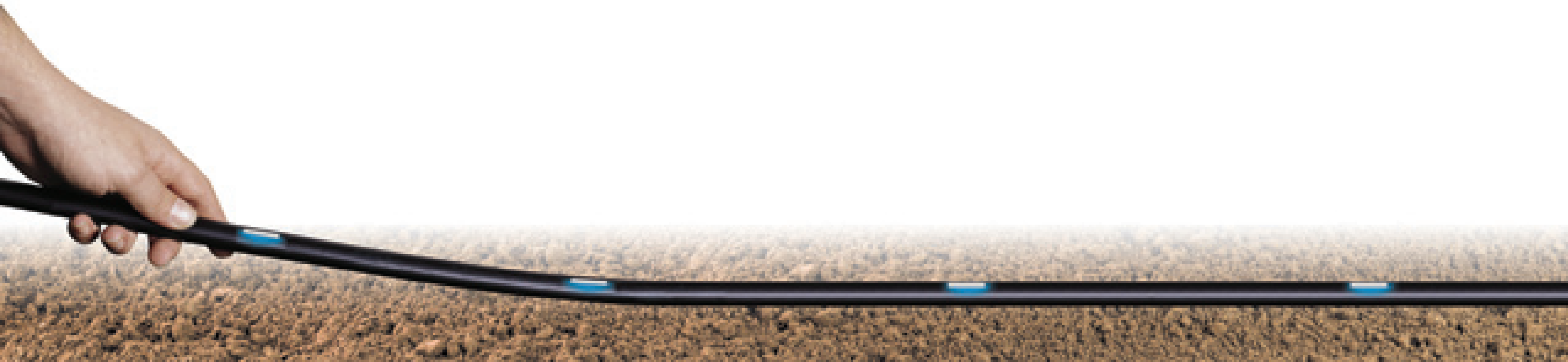
Spacings: 12”, 16”, 18”, 24”, 30”

Typhoon 990 13 Mil

For long runs up to 2,000 feet - long runs save on labor, submains and fittings - increases usable field growing area. Multi-year use, subsurface, for all soil types including heavy rocky soils.

Flows (GPH) at 10 psi: .18, .24, .36, .58

Spacings: 12”, 18”, 24”, 30”



Using Subsurface Drip Irrigation to Field Store Processing Tomatoes

When Harvest is Delayed

One of the key decisions in the production of processing tomatoes is when to completely stop irrigating a crop in anticipation of harvest. Many growers who use furrow and/or sprinkler irrigation understand the extent of their root zone, the available moisture in their particular soil types, and the influence of factors such as water tables. They make sound irrigation cutoff decisions by knowing how much water to make available to a ripening tomato crop under normal weather conditions in their area. However, weather doesn't always behave normally, as we saw in 2003, and growers cannot always be certain of the harvest date, as processors' schedules are continually being modified.

Deficit irrigation

When subsurface drip irrigation (SDI) is used to grow processing tomatoes, the factors involved in irrigation cutoff decisions are the same, but the dimensions of the wetted zone are generally much smaller. Deficit irrigation will commonly be used during the ripening period, followed by irrigation cutoff 4 to 20 days before harvest, depending on conditions. Where shallow, non-saline water tables are present, a 20 day cutoff might be suitable. In lighter soil types, it may be necessary to continue applying small amounts of water to within four days of harvest.

If there is likely to be a significant delay in harvest, it can be risky to choose a cutoff date based on an estimate of the moisture within the restricted wetted zone that remains after deficit irrigation has been carried out. Fortunately, recent trial work conducted by Tim Hartz, Extension Vegetable Crops Specialist, UC Davis, has confirmed that the quality improvements achieved with deficit irrigation can be maintained and the risk of losing vine cover can be lowered if small amounts of water continue to be applied until 4 to 7 days before harvest. If the processor is unable to take the crop at the scheduled harvest time, these small additions can be continued as a means of maintaining vine cover. However, it should be understood that varieties differ in their field holding characteristics, and although SDI is the only method of irrigation capable of being used in this manner, the ripening process cannot be halted.

Since the mid-1990s, research has been conducted into the field holding capabilities of various varieties, and since 1999, varieties having the desirable characteristic known as “extended field storage” (EFS) have become more prominent in plantings in most tomato-producing counties.

Field Storage Research

Don May, who recently retired from his longtime position as Farm Advisor for Fresno County, started examining the field holding capabilities of varieties in 1995. By the end of the 1999 growing season, his work had shown that under specific conditions, certain varieties could be “field stored” with minimal yield or quality losses for 2 to 4 weeks.

One of Don’s objectives was to determine whether this characteristic could be used to avoid flowering and fruit setting during the hottest part of the growing season. Normal practice is to plant crops a certain number of days before scheduled harvest. In the case of September harvest in Fresno County, following this practice means the crop will be setting most of its fruit in June and July. Processing tomato varieties with “heat setting” capabilities and consistent commercial acceptability have not yet been developed. Don had observed that lower yields were resulting from poor fruit setting during the high temperature periods, leading to a significant loss of income for growers who were contracted to deliver fruit in September.

A reasonable approach was to examine whether varieties known to be capable of field storing for 4 weeks could be planted 1 to 4 weeks earlier than the normal practice so that flowering could be finished before the detrimental temperatures started occurring. The tomatoes could then be field stored until the time of scheduled harvest.

Planning for High Temperatures

Don’s work showed that in the area of the state where high temperatures disrupt fruit setting, direct seeding selected EFS varieties no later than April 21st will give higher yields than if they are planted in late April or May for a September harvest. The results also showed that by planting EFS varieties as early as March 15th, yields can also be higher for late August harvests in Fresno County and the other tomato-producing counties in the southern San Joaquin Valley.

This work also demonstrated the benefit of using varieties with EFS in all growing districts, for situations when unusual weather events or processor delays necessitate field storing a tomato crop.

Jesus Valencia, who replaced Don as the Farm Advisor for Fresno County, was continuing this research, and in 2003 he examined the field holding capabilities of several varieties grown with SDI.

Don May’s work was done with furrow irrigation on the deep soils present at the U.C. West Side Research and Extension Center near Five Points, and on grower properties. He emphasized in his reports the importance of having a strong root system and using appropriate irrigation cutoff timings for each particular situation. At the West Side Research and Extension Center, they found that the best result was achieved when irrigation was cut off 30 days or more before the crop was 90% ripe.

Varieties That Will Field Store

When Don reported his results following the 1999 season, he stated that after five years of research, with over 150 varieties being tested, only six showed good potential for field storage.

By 2000, Don had identified three Heinz varieties with EFS:

- Heinz 9665
- Heinz 9492
- Heinz 9995

These appeared to be capable of being field stored for up to one month under specific conditions.

Don also described the field holding capabilities of two multi-purpose varieties that have been amongst the top 10 varieties in California (in terms of number of loads delivered) for several years. Under the conditions, in his trials, the following appeared to be capable of maintaining reasonable yields for two to three weeks beyond normal harvest:

- Halley 3155, the number one variety for many years, from Orsetti Seed Co.
- Hypeel 303, a Seminis variety, also known as Peto 303

Don's work also clearly demonstrated what experienced industry members already know -- most varieties have limited field holding capacity. As processing tomato crops reach a stage of 85% ripe fruit, the rate at which the remaining green fruit is ripening becomes roughly equivalent to the rate at which the oldest fruit is becoming overripe. By the time these varieties appear to have 100% red fruit, 10% or more of the fruit is likely to have been lost due to the oldest fruit becoming overripe. As harvest continues to be delayed, the rate of loss accelerates.

The difference with EFS varieties is the ability of the older fruit to "hold" for a significantly longer period (compared to standard varieties) rather than rotting or disintegrating while harvest of the crop is delayed. Thus, the crop is actually "building yield" as it continues to ripen beyond the 85% red fruit stage. The most profitable harvest date for an EFS variety is likely to be beyond the 90% ripe stage (in situations in which rainfall is unlikely).

Heinzseed Breeding Program

The Heinzseed breeding program has been the primary source of the addition of EFS varieties for the California and international processing tomato industry so far. It continues to be a big emphasis of Heinzseed to identify varieties that have good field holding characteristics. By introducing genetic material from their Ohio breeding program into their California breeding program, they have incorporated characteristics that are vital for successful processing tomato production in the Midwest (e.g. Ohio, Indiana, and Michigan), Canada and Australia. These traits include tolerance to mold and various foliage diseases, as well as fruit that can withstand mild pressure without bursting or cracking. Each year, trials are set up in Australia and Ontario, Canada to examine variety performance in dry and moist conditions to enable selection of varieties for advancement with EFS.

The EFS trait can be particularly beneficial later in the season when damp conditions are conducive to the development of mold. Heinz 9665 is an EFS variety that is often put in late plantings due to its excellent field holding capabilities. Also, when high yielding processing tomato crops are being grown with SDI, the vines are often somewhat larger, with healthier, denser foliage, potentially leading to less air circulation (compared to furrow- and sprinkler-irrigated crops). Due to their mold tolerance, EFS varieties can be expected to perform better in situations where air circulation is reduced. Non-tolerant varieties may require additional vine trimming, especially in high humidity conditions.

California’s Top Varieties

Heinz 9780 has recently become a prominent EFS variety, making it into California’s list of top 10 varieties in 2003. Several other recent releases from Heinz are also identified as having EFS capabilities in the 2003 catalogs issued by the two major California seed distributors:

- Sun 6119
- Seminis PS 296
- Seminis PS 849

Using SDI to Assist with Field Storage

With EFS varieties, as well as standard varieties that have a range of field holding capabilities, the SDI system allows growers to continue adding small amounts of water to maintain vine cover so that the fruit is protected from sunburn while harvest is delayed. This will maximize the amount of useable fruit that will be recovered from the field. No other method of irrigation is capable of doing this while maintaining all of the desirable field conditions for harvest.

Maintaining vine cover at this point in the crop’s life does not require much water. As a guide, small daily additions of about 50% of reference evapotranspiration (ETo) can be given until 4-7 days before the revised harvest date. Tim Hartz’ work has shown that this will not cause a reduction in soluble solids. To avoid creating conditions conducive to mold growth, it is important to insure these late irrigations do not lead to surface moisture. Also, a fairly dry profile should be maintained to limit compaction by harvest equipment. If growers are able to leave soil moisture monitoring instruments in place during this time, the data can assist with decision making.

Proper Post-Harvest Ground Preparation
for Subsurface Drip Irrigation Based Processing Tomato Production Systems

One of the main comments by processing tomato growers who have switched from furrow irrigation to subsurface drip irrigation (SDI) is, "There's a significant move away from power farming when you put in SDI." Much of the "power farming" used with furrow and sprinkler irrigation happens after harvest to prepare the field for the next crop. With SDI, the drip system is left in place for three or more seasons. Tillage operations that remove the previous crop and incorporate the residue into the soil, and that reduce compaction caused during harvest, must be carried out without damaging the dripperlines.

Proper post-harvest ground preparation with SDI essentially involves maintaining permanent beds for the life of the drip system and reconditioning them following harvest of tomato and rotation crops. Since the location of the buried tape is permanently fixed, the post-harvest operations must be performed with implements that do not cause shifting of the beds. This will insure that the lateral and vertical position of the dripperlines in relation to the beds remains the same season after season, a requirement that is greatly assisted by the use of GPS-based tractor guidance systems.

The approach commonly being used with SDI is essentially a reduced tillage system similar to the systems that have been investigated since 1995 in research projects led by Tim Hartz and Jeff Mitchell, University of California Cooperative Extension (UCCE) Vegetable Crops Specialists.

Reduced Tillage Research

Even when SDI is not being used, the adoption of reduced tillage is worthy of consideration according to the findings of a 2-year project funded by the California Tomato Research Institute (CTRI) in 1995 and 1996. This investigation was carried out by Tim Hartz and other University of California personnel on grower properties in Yolo County where furrow irrigation was being used. They compared conventional tillage to renovation of beds without deep tillage. Conventional tillage involved deep ripping (to a minimum of 24 inches) followed by disking, land planing, listing new beds and shaping the beds. The reduced tillage routine involved two or three passes with implements designed to provide shallow tillage of existing beds, followed by rolling and bed shaping. Tim noted that depending on the type, amount and condition of residues from the previous crop, a chopping/shredding operation may also be required.

After two years of work, it was estimated by the cooperating farmers that the reduced tillage routine was saving them $40 to $60 per acre (under 1996 cost structures). Research results indicated that the impact of reduced tillage on soil physical properties and plant growth and yield was minimal. Tim considered widespread grower testing to be warranted and noted that conversion to a reduced tillage routine would involve a degree of “trial and error,” particularly with regard to management of crop residues.

In one situation, Tim noted that there was a slightly higher level of compaction in the reduced tillage area compared to the conventional tillage area and considered it likely to be associated with harvest of the previous processing tomato crop. If significant compaction is caused during harvest, deep tillage may be required to reverse the damage.

With a well-managed SDI system, the profile should be very dry by the time of harvest, making it unlikely that harvest machinery will cause significant compaction. The exception would be in cases in which rain has wet the profile and harvest takes place before there has been sufficient drying.

Reduced tillage practices continued to be investigated as part of a CTRI-funded project titled, “Evaluation/Demonstration of Cover-Crop Mulches in Minimum Tillage Processing Tomato Production Systems,” which began in 1997. Jeff Mitchell, UCCE Vegetable Crops Specialist, based at the Kearney Agricultural Center in Parlier, was the project leader, and many others, including farmers, contributed to the research effort. In the 2001 CTRI Annual Project Report, Jeff described a comparison between conventional and minimum till operations used to prepare the ground for processing tomatoes following a wheat crop[1]. Conventional tillage involved flail chopping the wheat straw, disking in two directions, chiseling, re-disking, listing new beds and bed shaping. In the minimum till plots, the procedure involved flail chopping the wheat straw, followed by two passes with a minimum till bed reshaping implement.

Jeff also reported results from a related project that involved comparison of conservation and standard tillage tomato and cotton production systems, with and without winter cover crops. Plots were established in the fall of 1999 at the West Side Research and Extension Center in Five Points. The time required for all field operations was recorded for economic comparisons. Resource use, in terms of hours of labor and gallons of fuel per acre, was significantly lower in the conservation tillage plots. Processing tomato yields were similar in all four treatment combinations, i.e. standard tillage with and without cover crops, and conservation tillage with and without cover crops. In comparing pre-plant and plant operations for processing tomatoes in 2001 (following cotton) in the two different tillage treatments (without cover crops), it was estimated that operating costs were about $250/acre lower in the conservation tillage system than in the standard tillage system.

This project laid the foundations for further work to examine longer-term implications in terms of soil compaction, water use, soil carbon sequestration, pests and diseases, etc. The ongoing project, “Development and Extension of Conservation Tillage Production Practices for Processing Tomatoes,” is discussed in a separate article on Cover Crops in Netafim USA’s publication, “The Tomato Vine.”

Types of Implements

The implements used for reduced tillage bed reworking by Tim Hartz and Jeff Mitchell were the Hahn Perma-Bed Cultivator, the Hahn Bed Disk and the Wilcox ‘Performer’. The Hahn implements are manufactured in Stockton, CA and the Wilcox implement is manufactured by Wilcox Bros. Agri-Products, Inc. in Walnut Grove, California.

The Sundance System - Sundance Wide Bed Disk

Similar machinery has been specifically developed for use with SDI by Arizona Drip Systems, Inc. in Coolidge, AZ, and is part of what they refer to as “The Sundance System.” The full Sundance System includes a patented tape injector, a patented tape extractor and a patented “rootpuller,” which pulls the plants up by the roots or cuts the roots, leaving the bed intact.

The fourth implement, which is most relevant to this discussion, is known as the Sundance Wide Bed Disk. Details about this implement, which are available on the Arizona Drip Systems website (www.azdripsystems.com), are being provided for information purposes only. *(Please note that Netafim USA does not endorse or promote these products over those of other manufacturers.)*

Sundance Wide Bed Disk (patented):

- Disk, rip, and list all in the same pass
- Provides incorporation of crop debris
- Lends itself to the minimum-tillage strategy
- Maintains integrity of row, regardless of number of trips
- Provides coverage across wide beds (30” - 80”)
- Available in 1- through 8-row configurations
- Usually provides 3-point linkage mounted (Category II or III)

An Australian processing tomato grower has stated that one pass with this implement after harvest is sufficient to leave the ground in good condition. However, he has also added a flail chopper onto his harvester that the chops the vines as they come off the machine, which greatly assists with residue incorporation. Following harvest of other crops such as corn, two passes at different times are required for getting the beds ready for pre-plant operations associated with the next crop.

It has been reported that some growers have had problems with some of the standard minimum till equipment in heavy soils. Equipment suppliers have responded with heavier implements, while some growers have manufactured their own implements.

Most SDI systems in California are now installed in fields where the beds have been put up precisely with the use of GPS-guided tractors. This technology allows the saved GPS coordinates to be used for subsequent operations. If the guidance system can be used each season during the minimum tillage post-harvest operations, the proper bed position will be maintained in relation to the dripperlines.

If guidance systems cannot be used, the tillage equipment must be adjusted carefully and set up in such a way that components having a "pushing" action (e.g. disc blades) are mounted opposite each other so that both sides of the bed are being "pushed" in the same place at the same time. Other hints for maintaining proper tape alignment over several seasons can be found in "Drip and Microirrigation for Trees, Vines, and Row Crops," published by the Irrigation Training and Research Center (ITRC)[2].

Although use of these implements can lead to savings, they may not suit all farmers and all situations. Many Australian processing tomato growers using SDI continue to make several passes through the field with individual pieces of equipment such as rotary hoes, listers and bedshapers. In some cases the shoulders of the beds are ripped to reduce compaction. Since this leads to the bed being torn down a bit more, it is sometimes referred to as maintenance of semi-permanent beds with permanent furrows.

SUMMARY:

Jeff Mitchell, in a paper delivered at the 7th International Symposium on the Processing Tomato (in 2000 in Sacramento), stated that an average of 9 to 11 tillage-related passes were routinely performed in current processing tomato systems in California during the fall-spring period to prepare the soil for summer cropping. These operations were said to typically account for 18 to 24% of overall production costs, requiring considerable energy, equipment, and labor[3].

Reduced tillage processing tomato production systems are part of what growers adopt when they switch to the use of subsurface drip irrigation (SDI). The energy and cost savings with SDI are mainly due to the fact that the heavy tillage routines traditionally used with furrow and sprinkler irrigation are no longer carried out. The reduced tillage approach involves fewer passes, often with implements that perform several operations in one pass, leading to faster ground preparation and reduced tractor power usage.

Each year, when reworking the beds, it is advantageous to be able to use tractor guidance systems along with the GPS information that has been saved for each field when the beds were originally put up. Use of this technology, or other means of insuring the dripperlines remain in the middle of the beds, will assist with establishment of wetted patterns that promote good germination and establishment when the drip system is used for watering up. Maintaining precise positioning also helps insure that dripperlines will not be damaged when shovels or soil probes are used for collecting soil samples and checking soil moisture, when soil moisture monitoring instruments are being installed, and when sidedressing is used for close placement of certain fertilizer materials.

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Potential Use of Off-Season Cover Crops to Promote Soil Health in Processing Tomato Fields Irrigated with Subsurface Drip Irrigation

Conservation tillage (CT) practices have begun to receive more attention in California in recent years. When cover crops are used as part of the system, CT has the potential to reduce levels of respirable dust, improve water penetration in soils, increase water use efficiency, increase carbon sequestration, reduce tillage-induced soil carbon losses and compaction, and reduce operating costs, mainly through reductions in labor and energy inputs. In spite of these clear economic and environmental benefits, there has been minimal adoption of CT in California, primarily because of lack of successful examples of its use in irrigated farming systems in the Central Valley[1]*.*

Since 1997, Jeff Mitchell, University of California Cooperative Extension (UCCE) Vegetable Crops Specialist, based at the Kearney Agricultural Center in Parlier, has been the leader of several projects aimed at developing and communicating CT technology. Other people, including farmers, consultants, farm advisors and personnel from various departments at U.C. Davis, have provided vital input to these projects and remain actively involved as members of the project team.

Research Progress

A clear account of progress in the work on cover crops can be found in the California Tomato Research Institute's (CTRI's) Annual Project Reports[2]. In the early years (1997-1999), the main difficulties that members of the project team were trying to overcome were:

- Transplanting tomatoes into cover crop residues
- Controlling weeds when the tomato crop was growing, particularly in situations where the aim was to maintain rather than incorporate the surface residues from cover crops
- Handling cover crop residues during machine harvesting

As these practical issues were being sorted out, the benefits were beginning to be demonstrated, particularly the positive contribution of mulches to the annual water balance and the reductions in soil compaction as evidenced by lower penetrometer readings in the mulched plots. Earthworm populations were also higher under the mulches.

The cover crop mixtures were planted in October on pre-shaped, 60-inch tomato beds and killed with herbicides in late February to provide a surface mulch into which processing tomatoes could be machine transplanted. The cover crops were only planted on bed tops, not in the furrows.

By 1999 and 2000, the researchers were looking at five cover crop mixes in comparison to winter fallow with standard tillage practices. At that time, these species represented their best estimate of what would produce the quantity and quality of biomass needed to generate beneficial results. The cover crops were:

- Subclover

(which unfortunately had continual re-growth that competed with the tomato crop, resulting in reduced yields);

- A triticale/vetch mixture
- Merced rye/vetch
- Vetch/pea/faba bean
- Vetch/pea/faba bean/oats

Legume Cover Crops

In the 1999 trial established on the U.C. Davis campus, the vetch/pea/faba bean treatment had the highest tomato yield of the cover crop plots, which was comparable to the tomato yield on conventional till fallow plots.

An unusual cold spell in April 1999 led to significant damage to transplants that were grown over mulch. There was almost no damage where the transplants were grown in bare soil. A “strip till” approach was considered likely to be safer in situations in which there is a possibility of cold temperatures, and this method became incorporated into future experiments. It involves tilling a narrow strip down the center of the bed in a single operation carried out just prior to transplanting the tomatoes.

By 2000, the project team had demonstrated successful in-season cultivation techniques in high residue mulches, using an implement with L-shaped undercutter blades. A conservation tillage cultivator was also evaluated.

Facilitating farmer innovation in the development of conservation tillage practices was a major part of the project. At one of the on-farm demonstration sites, there were problems with re-growth of vetch, highlighting the importance of making sure cover crops are completely killed with herbicides prior to transplanting the tomatoes. In addition, the cover crops should not be allowed to set seed before being killed.

Trials conducted on farms in Yolo County for three years indicated that fall-planted, legume cover crops provided a yield increase in back-to-back tomato rotations. In October 2000, Gene Miyao, UCCE Farm Advisor for Yolo, Solano and Sacramento Counties, reported that the yield benefit did not appear to be based primarily on nitrogen contribution from the leguminous crop, but rather from some soil-related activity[3]. Another benefit measured by the researchers was a 40 to 70% reduction in winter rainfall runoff compared to the conventional fallow bed system.

Recent Findings

Results from more recent trials in Yolo County indicated that a high volume of vegetation may not be required[4]. In a 2002 trial, cover crops that were sprayed with herbicide in mid February provided similar yield benefits to full-growth vetch/pea cover crops that were 35 days older.

This work was repeated in 2003 in a field with subsurface drip irrigation (SDI) in Yolo County. An informal gathering of UC researchers viewed the trial site in June 2003. Gene Miyao confirmed that his previous year's results indicated that terminating the cover crop with glyphosate herbicide when it is about one foot high reduces the biomass without significantly reducing the yield boost. Early termination assists with tillage operations due to the reduced biomass, and it also stops continued water use by the crop. If the ground dries out too much due to water extraction by the growing cover crop, additional applied water may be needed to compensate for this depletion during stand establishment or soon thereafter. In years with high rainfall during the spring, the soil moisture depletion might be beneficial. Timing is always a critical factor in the production of processing tomatoes, and the earlier termination also provides some flexibility.

In fields with SDI, even though the furrows are not needed for irrigation, it is still recommended that cover crops be planted only on the tops of beds. It is too difficult to handle cover crop residues in the furrows. Although the cover crop only grows on the tops of beds, there is still a significant reduction in runoff of winter rainfall. The cover crop reduces the impact of rain, which leads to less surface sealing and therefore better infiltration.

Work with Mustard Species

Different species of cover crops began to be examined in the fall of 2002 by Gene Miyao and other members of the conservation tillage project team. At this same gathering of UC researchers (June 2003), Scott Sullivan of Ag-Seeds Unlimited and Gene discussed the use of "hot" mustard species as cover crops. One of the benefits of using these species is suppression of diseases such as Verticillium and Fusarium. A large amount of biomass is created, and as it breaks

down in moist soil, a compound is released that is similar to the active ingredient in Vapam(r), leading to disease suppression.

Growing mustards as a cover crop is more intensive than growing leguminous species, as the crop must be fertilized. However, as the cover crop breaks down, the added nutrients become available to the tomato crop. The cover crop may also be able to pick up any excess nitrogen applied to the previous tomato crop, preventing it from being leached and making it available to the next tomato crop.

The mustard crop creates a large amount of biomass that has to be flail chopped before being worked into the beds. The plants should not be allowed to go to seed before being chopped. Two planting windows are possible:

- Mid to late August - in this case the cover crop has to be irrigated up and it is about a 60-day crop.
- Late October - in this case, rain can be expected to germinate and sustain the crop.

A second trial had been established at this site using a mix of hot mustard species, and the grower cooperator, Jim Heidrick of E & J Farms in Woodland, stated that there were some difficulties with getting the mustard crop chopped and disked in. He also emphasized the importance of planting the cover crop only on the tops of beds. Each grower will have a different set of circumstances, but in Jim's case, he thought it might pay to not plant cover crops right up to the ends of the beds. Leaving the ends bare would make it easier to chop all of the cover crop using his existing rear-mounted flail mower, and he could work in the residue using his permanent bed minimum tillage implement (a Wilcox 'Performer') without any danger of damaging buried and above-ground drip system components.

The dripperline depth in Jim's field was 10 inches. In order to insure the dripperlines were not damaged, the cover crop residue was only incorporated to a depth of about 6 inches. This was considered by the researchers to be an adequate depth that would result in a beneficial response from a mustard or vetch/pea cover crop.

Australian processing tomato growers who have been using SDI for several years have started incorporating the use of cover crops into their production systems. One grower reported that he allowed a cover crop (mustard species) to get about 18" tall this spring before applying glyphosate to kill it. It seemed to be somewhat tolerant, and a second application of glyphosate was required to completely kill it. He strip-tilled down the center of the bed, and then made a second pass to incorporate Dual(r) and Treflan(r) prior to transplanting in early October. The terminated cover crop has not been disturbed on the shoulders of the bed. One role of the standing cover crop residue will be to protect the transplants from wind and hold soil in place to prevent sandblasting in very windy conditions.

SUMMARY:

New users of SDI may want to delay adopting a full CT system for a few years, due to the learning curve associated with an additional "layer" of new technology. However, growing winter cover crops as a source of green manure appears to be feasible and sufficiently beneficial to warrant consideration. It may pay to initially put in a trial, which would involve planting the cover crop on the tops of beds, killing it with herbicides, flail chopping it, and incorporating the residue with a permanent bed minimum tillage implement.

Growers interested in using cover crops are encouraged to contact members of the project team, including Farm Advisors and farmers who have had direct experience. Gene Miyao, in his "Tomato Info" newsletter dated October 25, 2000, has given guidelines on when and how to plant a cover crop of vetch and peas[3]. Information can also be obtained through the Irrigated Agriculture Conservation Tillage (IACT) Project.

The IACT Project is a new long-term research project being conducted on the same site as the former Sustainable Agriculture Farming Systems (SAFS) project. Some of the most important results from the 12-year SAFS project, which was conducted on large plots on the U.C. Davis campus, related to the use of cover-cropping in low-input and organic treatments. Positive long-term effects on soil biological, chemical and physical properties as a result of cover cropping resulted in greater accumulation of plant nutrients and carbon, greater biological activity, reduced root disease severity, less runoff of winter rainfall, etc. It is important to note that many of these results emerged slowly, over the entire duration of the long-term study. This project was completed in 2000. The IACT project will concentrate on research activities to refine CT systems and document the economic and environmental benefits. On-farm demonstrations will be integral to the continued advancement of the research, development and education efforts leading to adoption of conservation tillage in irrigated farming systems in California.

For further information, visit the University of California Conservation Tillage Workgroup's website, http://groups.ucanr.org/ucct/.

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