Toro Micro-Irrigation Owner's Manual

Count on it

www.toro-ag.it

Count on it.

Toro Micro-Irrigation Owner's Manual



This document is based on
"Toro Micro-Irrigation Owner's Manual" by Inge Bisconer
Toro Micro-Irrigation
El Cajon, CA

www.toro-ag.it

Table of Contents

Congratulations!

You have installed the most advanced method of irrigation known, a quality drip irrigation system from Toro. The drip system you've installed is an excellent investment. In fact, it can be the essential factor that integrates your crop, soil, nutrients and water for optimal results. This manual will help you take full advantage of the precise, efficient, and practical benefits of a drip irrigation system, so it will deliver the most value. Properly operated and maintained, a drip system will pay for itself quickly and last for many years.

Long-Term Benefits

Intelligent irrigation is the precise, efficient and practical method of delivering water to crops that allows growers to maximize profitability and minimize the use of resources. With drip, many growers have successfully increased crop yield and/or quality to **increase income**, while at the same time **reduced the costs** of water, fertilizer, energy, labor, weed control, chemical applications, equipment usage and insurance.

This increase in income and reduction of costs often offsets the irrigation equipment investment quickly, thus allowing growers to enjoy **higher profitability** with the investment in drip irrigation. Field accessibility is often improved, too, along with the ability to farm odd-shaped fields. In most cases, the environmental problems associated with irrigation water runoff, deep percolation, evaporation or wind drift are substantially reduced or eliminated, and wildlife may be enhanced since habitat is not routinely flooded. Whatever the motivation, drip irrigation offers numerous benefits and warrants a commitment to proper operation and maintenance.

Learn how drip is different to ease the learning curve.

Drip Is Different

Drip is different from sprinkler and gravity irrigation, and should be managed differently to maximize its benefits and avoid problems. For instance, drip irrigation is typically used to ***maintain*** moisture, whereas sprinkler and gravity irrigation may be used to ***replace*** depleted moisture. The chart on the facing page summarizes the main differences.

Note that both English and Metric units are shown in charts, graphs, equations and examples. Where possible, the metric unit equations and examples have been shaded to ease differentiation.

Comparing Drip, Sprinkler and Gravity Irrigation Systems

System Attribute	Drip	Sprinkler	Gravity
• **Emission device flow rate**	**GPH (l/h)**	**GPM (l/min)**	**N/A**
• Operating pressure	4–60 psi (0.3–4 Bar)	30–90 psi (2–6 Bar)	Low
• **Duration of irrigation**	**Secs, Mins, or Hrs**	**Minutes**	**Hours, Days**
• Frequency of irrigation	Daily	Weekly	Monthly
• **Level of filtration required**	**120–200 mesh**	**20–80 mesh**	**None**
• Wetting patterns	0.5–4 feet (0.15–1.2 meters)	5–100 feet (1.5–30 meters)	Broadcast
• **System application rates**	**Excellent (low–med)**	**Moderate (medium)**	**Poor (high)**
• Typical system uniformity	Excellent	Moderate	Poor
• **Ability to avoid wetting non-targeted areas**	**Excellent**	**Poor**	**Poor**
• Ability to avoid weed germination and irrigation	Excellent	Poor	Poor
• **Ability to avoid runoff, deep percolation, and wind drift**	**Excellent**	**Moderate**	**Poor**
• Ability to avoid foliage wetting and increased humidity associated with diseases	Excellent	Poor	Poor
• **Ability to automate the delivery of water and nutrients**	**Excellent**	**Poor**	**Poor**
• Ability to spoon feed nutrients via fertigation	Excellent	Poor	Poor
• **Ability to reduce irrigation and weed control labor costs**	**Excellent**	**Excellent – Moderate**	**Poor**
• Ability to reduce energy costs	Moderate	Poor	Moderate
• **Ability to allow field access during irrigation**	**Excellent**	**Poor**	**Poor**
• Ability to avoid insurance costs	Excellent	Poor	Excellent

1

DRIP IRRIGATION SYSTEM OVERVIEW

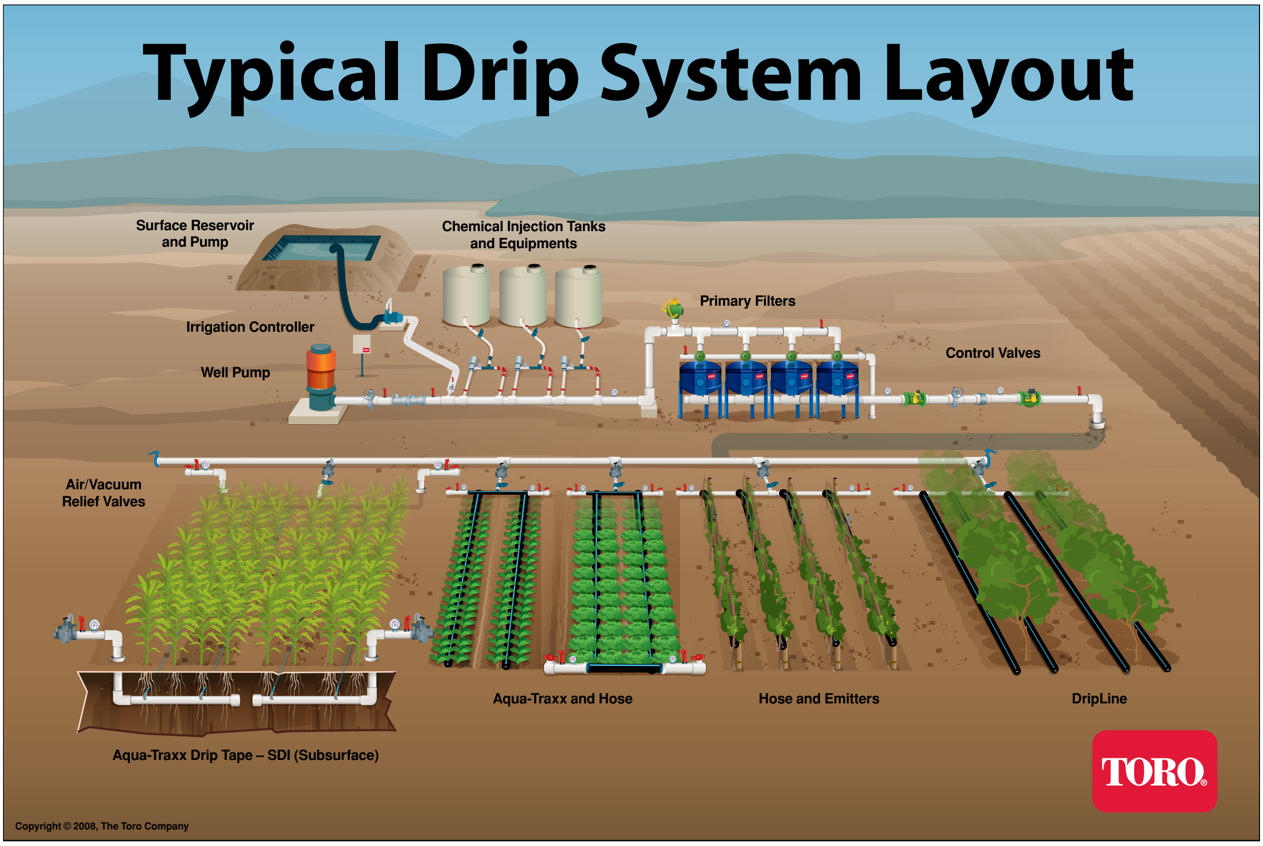
1.1 System Design

Designing a drip irrigation system can be complex. Toro Irrigation's companion document, The Micro-Irrigation Design Manual, covers all aspects of design (including plant/soil/water relationships, water treatment, hydraulic theory and pumps) as well as some information regarding installation, operation and maintenance. Below is a summary of important issues that should have been considered during the design and selection process.

It's best to review these issues with the design engineer before and after system design, installation and purchase to ensure that the system operates properly and performs to your expectations.

Review your system with the designer, both before and after your purchase.

Drip Irrigation System Design Stage Checklist ☑	
☑ **System Life**	Expected system life will influence the type and quality of system components. Systems may last well over 10 or even 20 years if high quality and well maintained.
☑ **System Uniformity**	Expected irrigation uniformity will also influence the type and quality of system components. Drip systems routinely operate at over 90% uniformity if high-quality components are chosen and well maintained.
☑ **Water Analysis**	Find out what's in the water before the system is designed and built. Water quality will dictate filtration, emission device selection and chemigation, and may change seasonally or with heavy pumping.
☑ **Soil Analysis**	Find out the soil type such that an emission device with the right flow rate, spacing and application rate may be chosen, and so that any soil physical or chemical problems may be addressed at the design stage.
☑ **Crop Information**	The designer should know the cost and quantity of water and fertilizer that will be needed to grow the crop(s), as well as the cultural practices and planting dimensions.
☑ **Pump Test**	If a pump is already present, get a pump performance curve to make sure it runs efficiently at the desired flow and pressure.
☑ **Site Information**	The designer should have access to topographic, weather, water, fuel, and other infrastructure information.
☑ **Labor**	Cost and availability of labor is an important element of equipment selection and decisions regarding automation.
☑ **Expansion**	Small adjustments in the current design will ease future system expansions, if any.
☑ **Maintenance**	The designer should make provisions for the safe and effective injection of all chemicals that will be used including fertilizers, acid and chlorine. In addition, the designer should ensure the system may be properly flushed.
☑ **Automation**	If system automation is desired initially, or even later, it should be known at the time of design.
☑ **Monitoring**	Basic flow and pressure monitoring equipment should always be specified. If additional soil, weather or plant monitoring equipment will be used, integration with the irrigation control equipment should be considered.



1.2 Important Tips for System Components

Drip irrigation systems are unique because much of the system is buried. As the Typical Drip System Layout illustration shows, the water sources, pumps, filters, chemical injection equipment and controls are clearly visible, while little of the "field" portion of the system is seen. This is true for field crop sub-surface drip irrigation (SDI), short-term vegetable crop, longer-term vegetable crop, vineyard and orchard irrigation. Here's what you need to know about the principal components, along with a brief description of each component's role in the system. Your system probably has many of these components.

Water Source

Water quality influences many aspects of irrigation including filtration, wetting patterns, fertilizer compatibility and plant growth. Although clean, potable water supplied by a water district is occasionally used to irrigate crops, irrigation water is more likely to come from a surface river, stream, lake or canal, or from the groundwater by drilling a well. Depending on the water quality, a reservoir or a screen, disc and/or sand media filtration system must be used to remove sand, algae and other contaminants that could clog the drip irrigation system. If certain minerals are present, or if the pH isn't right, chemical treatment may be required as well. Even if you didn't obtain a Water Quality Analysis prior to installing the system, it's never too late. Obtaining one will provide immediate help with important drip irrigation management decisions. ***See Chapter 4 for more about water testing and analysis.***

> Know what's in your water and how conditions may change during the course of the season.

It takes 250,000 liters of water to equal 25 mm/ha of water, so pumping efficiency is essential for energy savings.

Pump

Make sure your pump is adequate and efficient for the flow and pressure conditions. Unless water is pressurized at the source, a pump will be needed to push water through the pipes and emission devices. Vertical turbine pumps are typically used on wells, and centrifugal pumps are used for surface water supplies. Obtain a performance curve for your pump and have changes made if it isn't right — the energy savings alone will easily pay for any upgrades you might have to make, which will also improve system operation and, ultimately, crop production.

Backflow Prevention

Prevent irrigation water and/or chemicals from accidentally contaminating the water supply with a backflow prevention device. The many different backflow prevention system types may include flow sensors and interlocking electrical connections that shut down both the irrigation and chemigation pump should a failure in either system occur. This prevents chemicals from entering the water source as well as from entering the irrigation system when it is not operating properly.

Backflow prevention is important, recommended and in some areas required by law.

Filtration System

Good filtration is essential for proper system operation and long-term performance. Filters are commonly used to remove sand, silt, precipitated minerals and organic matter so that irrigation water will not clog the emission devices. Water quality and emission device specifications will determine the filtration type, level and quantity, but most drip systems require from 120–200 mesh filtration. Irrigation filters will NOT remove salt, dissolved solids or other toxic elements, nor will they adjust the water pH. Even if potable water is used, a basic screen filter is still required to remove sand and minerals. For good filtration, filters must be backflushed when they become dirty.

Backflushing the filters is crucial to system performance.

Chemigation System

If you use a chemigation system, make sure the injected chemical will not clog or otherwise damage the irrigation system. Prior to chemigation, a simple "jar test" should be conducted and/or a compatibility chart consulted. Chemical injectors deliver nutrients to the plants with the water and also apply system maintenance chemicals such as acid, chlorine or other line cleaners. Some systems use a separate pump, and others use a venturi-type device that uses a pressure differential in the circuit to create suction pressure in tubes connected to the chemical tanks. ***See Chapter 4 for jar test instructions.***

Flow Meters and Pressure Gauges

Make sure your system has a flow meter and pressure gauges that work! Although simple and relatively inexpensive, these gauges are often overlooked or not maintained. These monitoring devices are essential to proper system operation. System flow rate helps detect leaks or clogging, and must be known to determine the application rate for irrigation scheduling purposes. System pressure also helps detect leaks or clogging, and is essential for managing filters, chemical injectors and the system operating window.

Control Valves

Control valves must be properly "set" to achieve proper system flow and pressure. Sometimes simple ball or butterfly valves are used, but often the system uses sophisticated flow and pressure regulating valves. Larger valves control flow from the pump to the filters and then to the field, and sometimes a valve will reduce field flow to enhance filter backflush. Zone valves control which blocks receive water, and flush valves at the ends of all system pipelines allow the system to be purged of impurities. Although valves are typically operated by hand, many are now automated.

> Negative suction pressure can cause serious clogging problems.

Air/Vacuum Relief (AVR) Valves

AVR valves help prevent negative suction pressure, which can cause serious clogging problems — especially if laterals are buried or in constant contact with settled soil. AVR valves are commonly installed at high points and at the end of irrigation pipelines — including supply lines, mainlines, submains and control risers — to let air escape when pipelines are filling, to allow air to enter when pipelines are draining, to remove air pockets at system high points caused by entrained or dissolved air, and to prevent negative suction pressure in laterals after system shutdown. In most cases, clogging from vacuum suction may be prevented by properly installing vacuum relief valves on the lateral inlet, high point and outlet submains, or by installing flush valves at the end of each lateral for vacuum relief.

Automation Equipment

Automation equipment consisting of controllers, valves and/or sensors can help maximize drip irrigation system benefits. Many systems incorporate a controller that communicates with valves and sensors via wires or via wireless devices. The user typically programs the controller to turn valves on and off at desired times. Since most controllers allow sensor input as well, systems may also be automated according to weather, soil or system conditions. Note that systems capable of automation may also be operated manually.

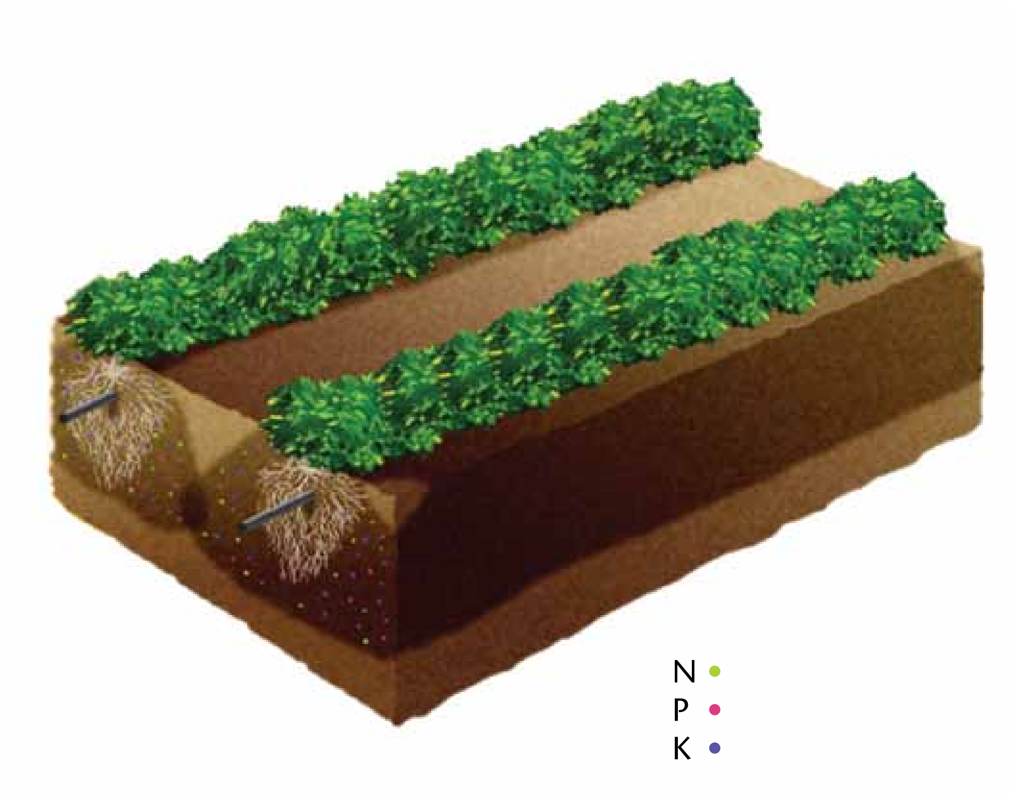
Pipelines and Fittings

It's important that all pipelines and fittings are properly sized to withstand maximum operating pressures and convey water without excessive pressure loss or gain. Pipelines carry water from the pump to the filters, valves and emission devices. PVC pipe may be used throughout the system or combined with steel at the pump station, flexible PVC or polyethylene (PE) layflat for submains, and polyethylene hose or drip tape for laterals. Be sure to consider the expansion and contraction that occurs under normal outdoor operating conditions, and make sure pipelines are properly secured, thrustblocked and connected to one another with welds, glue or friction fittings. PVC pipe and fittings should be cleaned, deburred and primed before gluing. Because much of the pipeline is buried and difficult to access and repair, especially after crop growth, making sure fittings are secure at installation can save significant repair issues later.

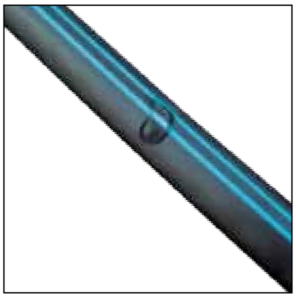
> Prevent potential crop damage from a system shutdown by pressure-testing pipelines early.

Emission Devices

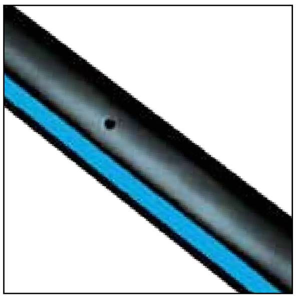
Emission devices must be selected and installed with the utmost care because problems are difficult to solve — solving problems is difficult since there are literally hundreds or thousands of emission devices in a typical system. Emission devices deliver water and nutrients directly to the plant root zone as shown in the illustration below. Drip tape and dripline will have built-in emission devices, and polyethylene hose will have emitters, jets or micro-sprinklers attached. Quality is essential, since a typical drip system includes hundreds or even thousands of emission devices. Each device should be durable, resistant to clogging, and emit the same amount of water even under variable pressures. In addition to quality, the flow rate and spacing of the emission device is important in determining the wetting pattern as well as the likelihood of having runoff or deep percolation problems. The illustration below (Mikkelsen, 2009) shows how a well managed drip system provides water and nutrients to the crop rootzone without runoff or deep percolation. Emission devices of poor quality may require more maintenance, not provide optimum irrigation efficiency, and need replacement far earlier than a quality device. Simply put, this is no area to try to cut costs — quality is essential. At a minimum, emission devices should have a low manufacturing coefficient of variation (CV), the irrigation system should have a high design Emission Uniformity (EU), and all components should have a good warranty, backed by a company that can be trusted.

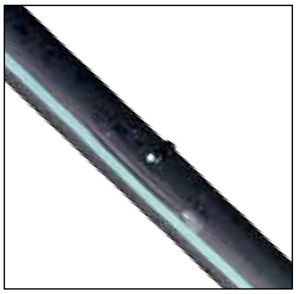


Main Toro Components


Aqua-Traxx PBX


Aqua-Traxx PC


BlueLine PC and Classic


Neptune


Lay Flat


Fittings


Online Emitters


Micro Sprinklers


Injectors


Toro and Irritrol (pictured) Valves


Controllers

2

STARTING UP YOUR SYSTEM

Starting Up Your System

Properly designed, installed, operated and maintained drip irrigation systems may last indefinitely. However, drip systems are vulnerable to over-pressurization and clogging, both of which can drastically reduce the system's life and performance. The following step-by-step guide shows how the system should be initially pressurized and tuned, and how it should be routinely operated and monitored for optimal performance. ***Note: It is assumed that the system has been completely installed and pipelines have been partially backfilled, but that lateral lines have NOT been connected to the submains yet.***

2.1 Flush, Pressurize, Test and Adjust the System

a. Open all control and flush valves.

b. Close all submain control valves.

c. Turn on the pump and slowly fill and flush the mainlines, allowing air to exit the system through the air-relief valves. If necessary, divert the flush water from the flush valves.

d. Once the mainlines have been thoroughly flushed, close the mainline flush valves and bring the mainline up to test pressure.

e. Maintain test pressure for 24 hours. If leaks develop in the mainline, immediately shut off the system, repair leaks, flush the mainline again, and repeat the pressure test.

f. After the mainline has been flushed and passes the pressure test, flush the submains until clean by opening the submain control and flush valves. Again, divert the submain flush water if necessary.

g. After the submains are thoroughly flushed, adjust the submain block control valves so that downstream pressure will not exceed the maximum pressure rating of the lateral lines that will be connected after the flush valves are closed. Thin-walled tape products may have a maximum pressure rating of 0.7 Bar, while thick-walled polyethylene hose or dripline products typically withstand 3.5 Bar or more.

h. While the submains are flushing, make sure the filters are working properly, and that they have been thoroughly backflushed.

   If a backflush controller is used, set the pressure differential point at which the filter will automatically backflush. Depending on the filter make and model, inlet and outlet pressures should differ about 0.1 - 0.2 Bar when the filters are clean, and about 0.7 Bar when the filters are dirty and should be backflushed. If a controller is not being used, these gauges must be monitored often so that manual backflush is performed before the filters become fouled. Variables in gauge readings and elevation differences should be taken into account. **Remember that 1 meter of elevation equals 0.1 Bar.**

   The valve controlling the volume of flush water exiting the sand media filter drain line during backflush must be carefully set. The valve must maintain enough backpressure on the filters during backflush to prevent sand from exiting the filter tanks. At the same time, the valve must allow enough volume to exit the filters so that the sand bed is adequately lifted and cleansed. The valve is set properly when minute quantities of sand begin to appear in the flush water.

i. After the submain block valves and filter valves have been properly set, close the submain flush valves and pressurize the submain to test pressure for a period of time. If there are leaks, shut the system off, make repairs, and repeat the pressure test.

Pressure testing is essential!

Automating the backflush function is highly recommended.

2.2 Connect Lateral Lines to Submains

a. After the submains have been successfully flushed and pressure tested, open the submain flush valves and the ends of all lateral lines for flushing after connection. If the lateral lines are plumbed into a flushing submain, open the flushing submain flush valves.

b. Connect the lateral lines to the submain, and flush the lateral lines until clean. If necessary, close the submain flush valves to achieve adequate flushing volume on the laterals.

c. After the lateral lines have been flushed clean, close all submain and lateral flush valves and allow the system to stabilize at operating pressure.

d. Re-adjust all submain block valves as necessary to conform to design pressure specifications, taking care to not exceed the maximum pressure rating of the lateral lines.

> Don't over-pressurize or clog emission devices.

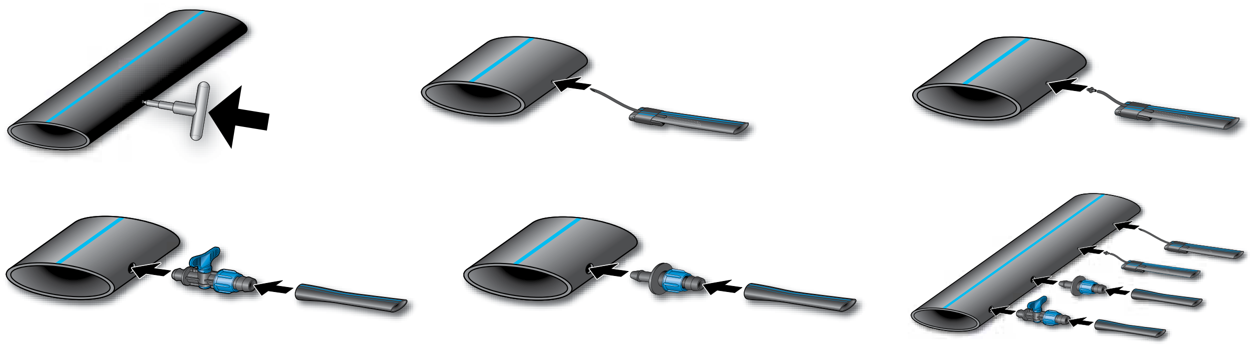
It's extremely important that the laterals are connected properly to the submains to prevent leaks, kinking or clogging. Holes must be drilled correctly with care taken to remove shavings and burrs. Also note the variety of lateral end connections that are available to help facilitate flushing, whether automatically or manually. Although end-of-line flush valves or flushing submains are more costly, they greatly enhance the irrigator's ability to easily flush laterals manually as opposed to closing each lateral with a figure 8, a threaded cap, a valve or, in the case of tape, tying a knot.

The following pictures show actual field applications.

The following illustrations show how tape, hose or dripline laterals may be connected to polyethylene oval hose, flexible PVC layflat, or rigid PVC supply or flushing submains. The initial cost of some options are more expensive than others, but in exchange enhanced performance, durability and longevity are delivered. Since some operations such as lateral flushing may occur frequently, the cost of operational labor must be factored into the connection type decision as well.

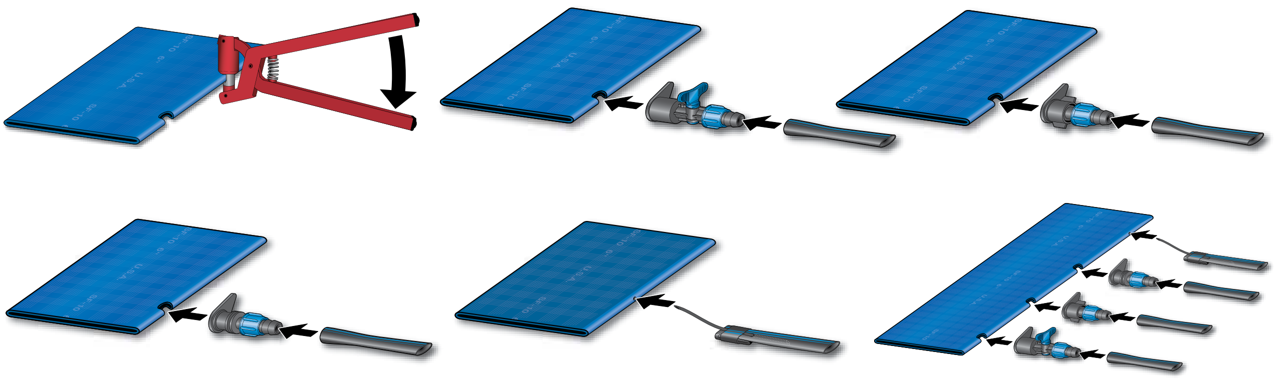
Flexible Polyethylene Hose

The six illustrations below show how the PE hose is punched and then connected to tape laterals via spaghetti tubing or barbed connectors of various sizes. Note that the bottom left illustration shows fitting with a valve option that facilitates control of individual laterals from the polyethylene hose submain.



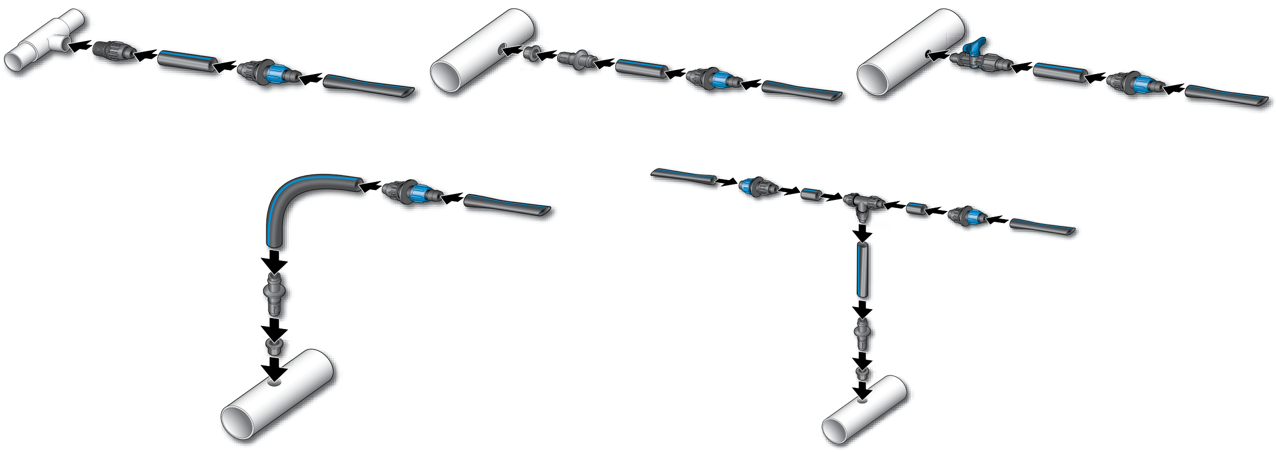
Flexible PVC Layflat

This submain material is very popular because it collapses easily for portability. A more secure tear-drop shaped fitting may be used to connect the layflat to the tape laterals as shown in the first four illustrations below. In addition, as with oval hose, spaghetti tubing may be inserted into a hole as well.



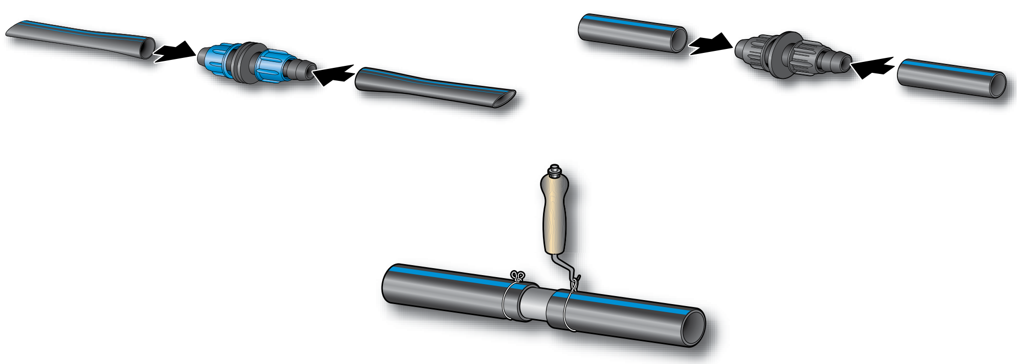
Rigid PVC or PE Pipe

Rigid PVC or PE pipe are typically used to connect laterals in permanent crops and in subsurface drip irrigation systems. Since the pipeline is usually buried, it is important that the fittings are reliably secure and that transition tubing does not bend or crimp to obstruct water flow.



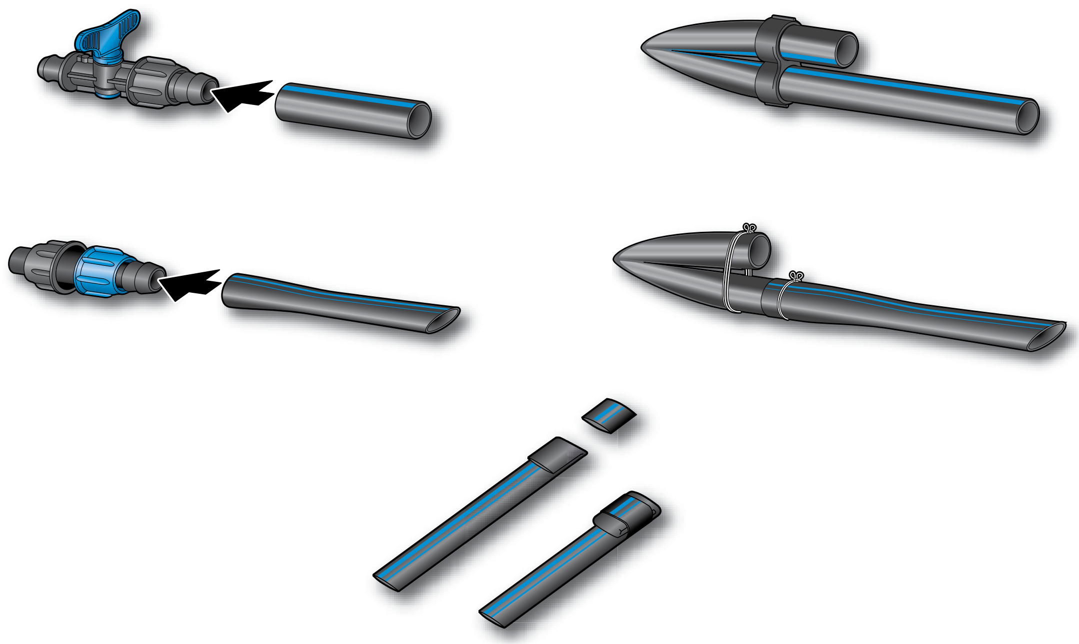
Lateral Couplings

The following illustrations show how tape and hose/dripline are coupled in the field with dripline fittings and couplings.



Lateral Ends

Hose, dripline and tape lateral ends may be closed with a variety of fittings including valve fitting, with a figure-8 fitting (for hose only), with a wiretie fitted to rigid hose, or with a "napkin ring" (tape only).



2.3 Test System Operation and Backfill Trenches

System connections, flushing, pressure testing and pressure setting have now been completed. Once you've determined that all underground components, including pipes, fittings, control wires and tubing, are working properly, backfill the trenches. Care must be taken during backfilling to prevent collapse or other damage to the pipe, particularly with large, thin wall pipe. Note that open trenches can pose a danger and should be protected prior to backfilling. In some cases, backfilling prior to pressure checking may be warranted.

2.4 Establish Baseline Readings

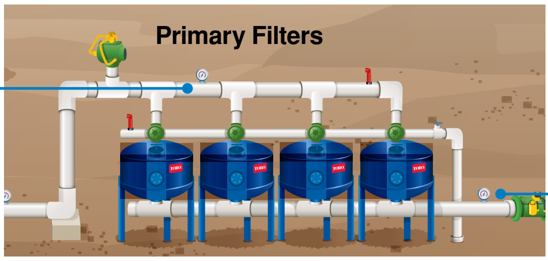
Because significant portions of drip systems are buried and can't be easily viewed, pressure gauges and flow meters are key to diagnosing problems and checking operating status. After the system has been connected, flushed and pressure-tested with control valves properly set — and it's been verified that all underground components are working properly — take the following baseline readings:

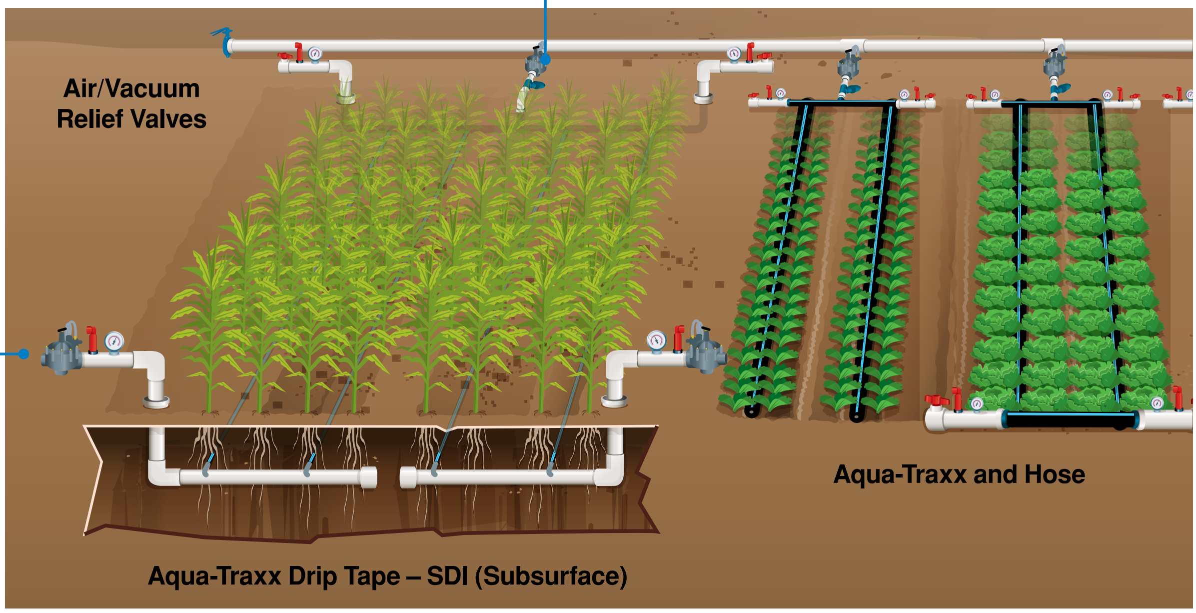
Compare baseline readings with design specs.

- **Record readings from all pressure and flow gauges,** including before and after pumps, filters, main and submain control valves, tape inlets and tape outlets.
- **Examine the condition of filter flush water** to verify that the backflush valve has been properly set.
- **Examine block tape flush water** by capturing water in a jar to make sure a clogging hazard doesn't exist.

These readings should be used to verify that the system conforms to design specifications, and should serve as operational benchmarks in the future. The flow meter reading should also be used to determine and/or verify the application rate for future irrigation scheduling calculations (discussed in Section 3.2).

The following pictures show where some of the readings should be taken.





To assist in data collection, the following template may be used:

SDI Baseline Readings Data Collection Sheet

		System Flow Rate	Pump Pressure	Filter Inlet Pressure	Filter Outlet Pressure	Mainline Control Valve Outlet Pressure	Appearance of Filter Outlet Flush Water	Block Valve #______ Block Valve Inlet Pressure	Block Valve Outlet Pressure	Tape Inlet Pressure	Tape Outlet Pressure	Appearance of Tape Flush Water
Example: Target value of reading supplied by design engineer:		400 GPM (100 m^3/hr)	40 psi (3.0 Bar)	38 psi (2.9 Bar)	30–37 psi (2.0 - 2.5 Bar)	28 psi (1.9 Bar)	No sand, clear after backflush	18–23 psi (1.2 - 1.5 Bar)	15 psi (1.0 Bar)	12–14 psi (0.8 - 0.9 Bar)	4 psi (0.3 Bar)	Clear
Immediately after purchase:												
Actual Readings	Week 1											
	Week 2											
	Week 3											
	Week 4											
	Week 5											
	Week 6											
	Week 7											
	Week 8											
	Week 9											
	Week 10											
	Week 11											
	Week 12											
	Week 13											

SDI Block Valve Baseline Readings

		Block Valve #______ Block Valve Inlet Pressure	Block Valve Tape Outlet Pressure	Inlet Pressure	Tape Outlet Pressure	Appearance of Tape Flush Water
Example: Target value of reading supplied by design engineer:		18–23 psi (1.2 - 1.5 Bar)	15 psi (1.0 Bar)	12–14 psi (0.8 - 0.9 Bar)	4 psi (0.3 Bar)	Clear
Immediately after purchase:						
Actual Readings	Week 1					
	Week 2					
	Week 3					
	Week 4					
	Week 5					
	Week 6					
	Week 7					
	Week 8					
	Week 9					
	Week 10					
	Week 11					
	Week 12					
	Week 13					

When to Take Readings

As a general rule, baseline readings and subsequent monitoring should occur after the system pressure and flow have stabilized. The system should be filled slowly so that air has plenty of time to escape through the air-relief valves and to prevent water hammer on the filters, valves and critical pipe fittings. A manually operated butterfly valve, generally pre-set or automated to facilitate a slow fill, is often placed downstream of the pump prior to the filters to help regulate fill-up flow.

How to Determine Stabilization Time

The following calculations will help you determine how long the system must operate before pressure and flow have stabilized, so the operator knows when readings may be taken. For example, if the system consumes 20 cubic meters of water, and the system flow rate is 100 m3/hr, then stabilization will occur after about 12 minutes of operation.

Equation:

1. **Calculate the total volume of area within the drip tapes and conveyance pipes in cubic meters. Use the following formula:**

   Pipeline Volume (cubic meters) = 3.14 x $\mathbf{D}^2$ /4 x **L**
   Note: D = Pipeline Internal Diameter (in meters) and L = Pipeline Length (in meters)

2. Divide the total volume in cubic meters (Step 1) by the cubic meters per hour flow (m3/hr). Then multiply this number by 60 to determine how many minutes it will take to fill the pipeline.

Example:

200 meters of pipe (L) with an internal diameter of **83.4 mm (D)** would have the following internal volume **in cubic meters** (remember to convert mm to meters):

Pipeline Volume (cubic meters) = 3.14 x (**83.4 mm** / 1,000 mm/meter)^2 / 4 x **200 meters**
3.14 x 0.00696 / 4 x 200 meters
3.14 x 0.00174 x 200 = **1.09 cubic meters of water**

If the system flow rate were 10 m3/h, then it would take (1.09 m3/ 10 m3/h) x 60 minutes = **6.5 minutes** to fill the pipeline.

3

BASIC SYSTEM OPERATION

Basic System Operation

Now that the system has been constructed and is operating properly, it's time to irrigate! To protect and maximize your investment, it's highly recommended that the system be monitored on a routine basis to ensure proper operation, and that irrigations are scheduled intelligently to avoid waste.

3.1 Monitor Key Operating Parameters

Once the irrigation season is under way, the system's pressures and flows should be monitored, the flush water assessed, and system integrity ensured on a routine basis.

Monitor for Differences in System Pressure and Flow

After the system has stabilized, the system's vital flow and pressure signs should be monitored and compared with the benchmark readings you recorded after initial system startup to make sure the system is operating as designed. Remember, flow and pressure are closely related, so differences from the benchmark readings may indicate:

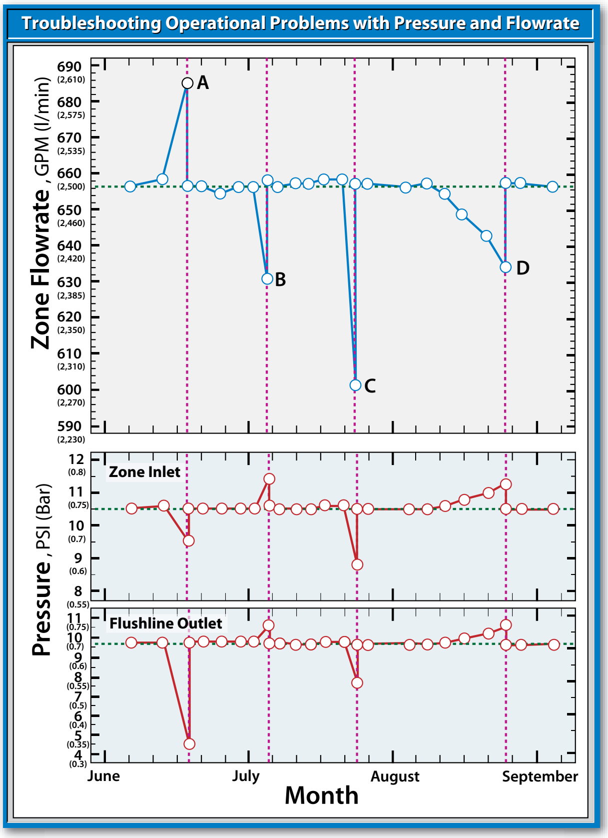
- Wrong control equipment settings or control equipment failure
- Clogging of the filters or emission devices from inorganic, organic or mineral precipitants
- Leaks from pipe or tape failure, loose fittings, rodent or insect damage

Use the System Troubleshooting Guide shown here to help isolate the problem.

System Troubleshooting Guide

PUMP Outlet Pressure:	High	Low	Low	High
System Flow Meter:	High	Low	High	Low
Possible Problem and Solution:	1. Pump valve is opened too wide. 2. Pump output should be decreased.	1. Pump valve should be opened wider. 2. Pump output should be increased.	1. There is a leak in the system. 2. A valve is opened in error.	1. Emission devices or filters are clogged. 2. A valve needs to be opened more. 3. Additional zone valves need to be opened. 4. Correct zone valves need to be opened.
FILTER Outlet Pressure:	High	Low	Low	High
System Flow Meter:	High	Low	High	Low
Possible Problem and Solution:	1. Pump valve is opened too wide. 2. Pump output should be decreased.	1. Filters are clogged and should be backflushed / cleaned. 2. Pump valve should be opened wider. 3. Pump output should be increased.	1. There is a leak in the system. 2. A valve is opened in error.	1. Emission devices are clogged. 2. A valve needs to be opened more. 3. Additional zone valves need to be opened. 4. Correct zone valves need to be opened.
BLOCK VALVE Outlet Pressure:	High	Low	Low	High
System Flow Meter:	High	Low	High	Low
Possible Problem and Solution:	1. Block valve is opened too wide. 2. Pump output should be decreased.	1. Block valve should be opened wider. 2. Pump output should be increased. 3. Filters are clogged and should be backflushed.	1. There is a leak in the system. 2. A valve is opened in error.	1. Emission devices are clogged. 2. A valve needs to be opened more.

In addition, these hypothetical examples show how pressure and flow rate measurement records may be used to discover and resolve operational problems (Lamm & Rogers, 2009).



Anomaly A: The irrigator observes an abrupt flowrate increase with a small pressure reduction at the Zone inlet and a large pressure reduction at the Flushline outlet. The irrigator checks and finds rodent damage and repairs the dripline.

Anomaly B: The irrigator observes an abrupt flowrate reduction with small pressure increases at both the Zone inlet and the Flushline outlet. The irrigator checks and finds an abrupt bacterial flare-up in the driplines. He immediately chlorinates and acidifies the system to remediate the problem.

Anomaly C: The irrigator observes an abrupt flowrate decrease from the last irrigation event with the pressure reductions at both the Zone inlet and Flushline outlet. A quick inspection reveals a large filtration system pressure drop indicating the need for cleaning. Normal flowrate and pressures resume after cleaning.

Anomaly D: The irrigator observes a gradual flowrate decrease during the last four irrigation events with pressure increases at both the Zone inlet and Flushline outlet. The irrigator checks and finds that the pipelines are slowly clogging. He immediately chemically treats the system to remediate the problem.

Monitor Lateral Flush Water Quality

As often as each irrigation, the ends of laterals should be opened and the contents emptied into a jar for visual inspection of water quality. When water quality begins to degrade, as shown by color, grit, organic or any solid materials in the flush water, then system maintenance should be performed. Since the ends of laterals in SDI systems are typically plumbed into a flushing submain as shown in the illustration at the bottom of page 20, the flushing submain valve must be opened and the flush water examined. If this is impractical to perform during each irrigation, another alternative is to install a Tee into the end of a tape lateral with the third leg capped at the surface for easy viewing of lateral flush water on a periodic basis.

The following pictures show how pressure, flow and flush water can be checked.

From left to right: Pressure gauge on mainline; flow meter; pressure gauge on tape; monitoring tape flush water.

Monitor for Mechanical Damage

Drip tape and polyethylene laterals are also susceptible to mechanical damage from a number of sources, including installation equipment, tillage equipment, insects, birds, rodents, excessive pressure or the lens effect of sunlight when magnified through water beneath clear plastic mulch. Tape injection equipment should be routinely inspected, and the drip system should be inspected for evidence of mechanical damage, indicated by puddles of water, squirting, loss of pressure or crop loss. When such damage occurs, pests must be controlled or managed — or equipment adjustments should be made — to avoid future problems. The following pictures illustrate the various types of mechanical damage that can occur. Note that sunlight damage from the lens effect is uncommon in SDI applications since the tubing is buried and is not subject to magnification of sunlight under clear mulch. However, SDI systems are especially susceptible to rodent damage since populations are no longer controlled with the previous irrigation or cultural practices.

Examples of Mechanical and Other Damage

Bird Damage

Equipment Damage

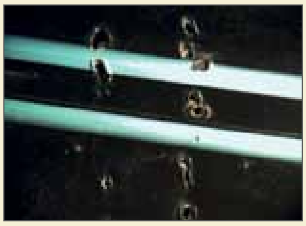
Equipment Damage

Excessive Pressure

Insect Damage

Insect Damage

Insect Damage

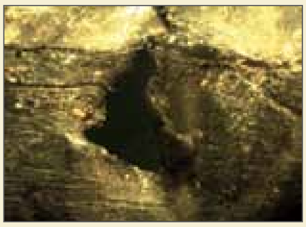


Lens Effect Damage

Rodent Damage

Rodent Damage

Rodent Damage

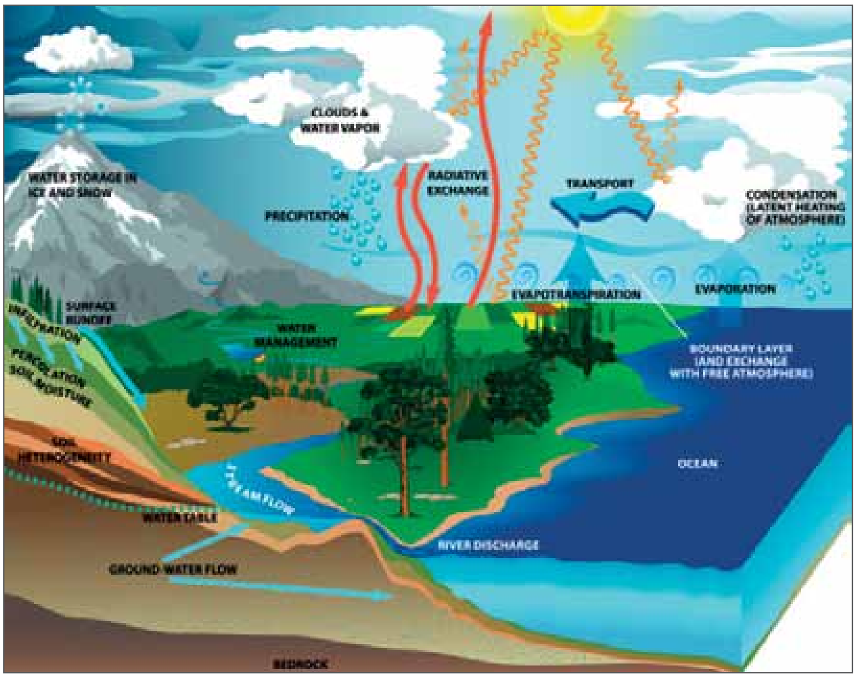


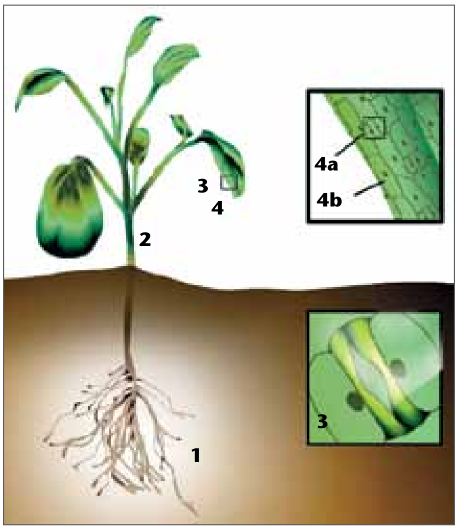
Rodent Damage

3.2 Irrigation Scheduling

Irrigation scheduling is the process of deciding when and for how long to run the irrigation system. It's a complex but important topic because it influences whether the crop gets the right amount of water and nutrients, whether valuable water is wasted to runoff or deep percolation, and whether salts are moved beyond the root zone.

The Hydrologic Cycle illustration (NASA, 2009) demonstrates how complex weather, soil, geography, geology and plant growth influence water movement and use. Irrigation scheduling uses both art and science to balance known facts such as soil type, system application rate and crop species with changing conditions such as weather, chemistry, stage of plant growth and farm cultural operations. On one end of the spectrum, the irrigator may make decisions by physically evaluating the moisture content in a sample of soil or visually monitoring the appearance and color of the crop. On the other hand, sophisticated instruments may be used to collect data on soil moisture, plant water stress, weather conditions and theoretical plant water use.





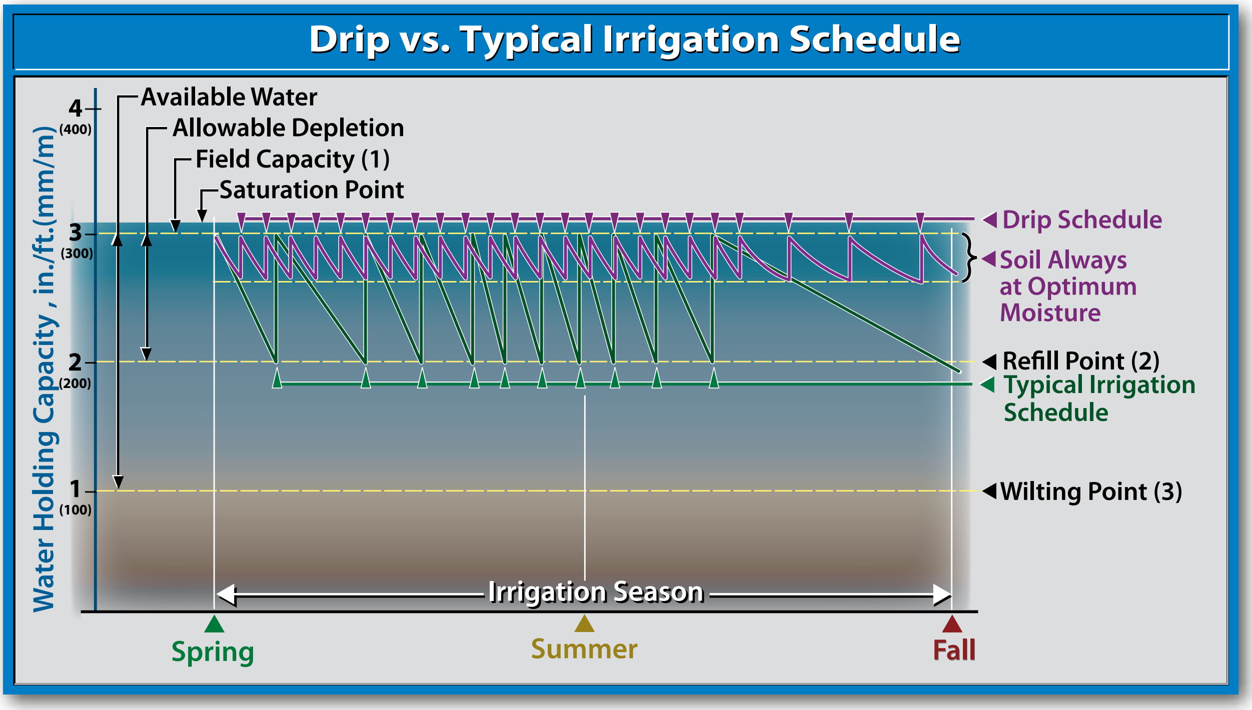
This figure, Transpiration (Techalive, 2009), shows the process by which plants use water as it's taken in through the roots, moves up the stem and then transpirates to the atmosphere. Researchers have generated data on this process for many crops, and it's available for growers to use. Software may also be used to interpret this information and generate scheduling recommendations for advanced applications or automated operation.

TRANSPIRATION

1. Water is taken in through the root hairs.
2. Water moves up the stem through the xylem vessels, which conduct water and minerals to the leaves.
3. Guard cells open, creating a pore through which water vapor can escape.
4. Water vapor escapes through open stoma (singular = stomata), mainly on the undersides of leaves. (4a. Stomata, 4b. Plant Cell)

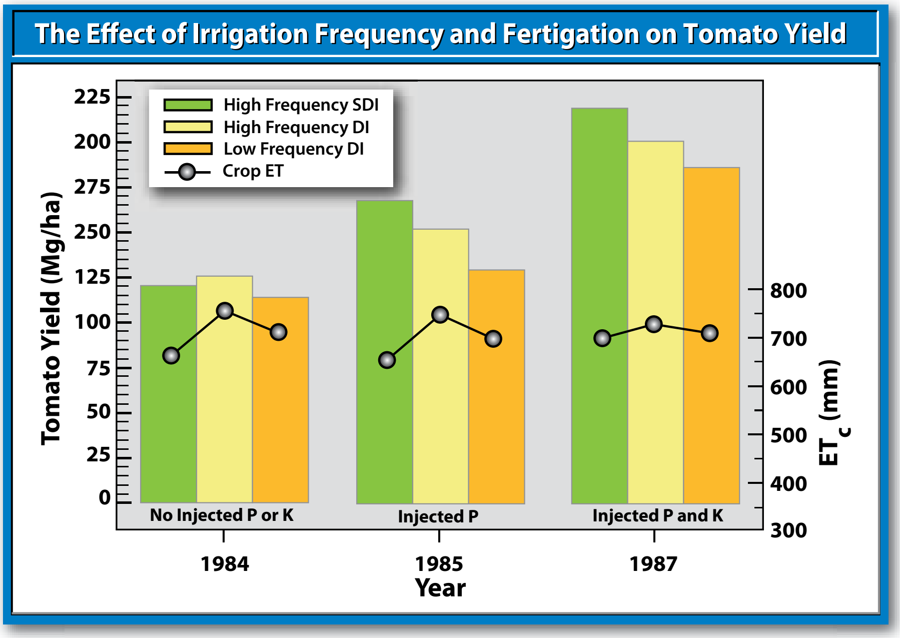
Proper scheduling maximizes profits and minimizes problems.

The figure below, Irrigation Schedule Based on Soil Moisture Status (adapted from USBR, 2000, pg. 87) shows two different irrigation scheduling strategies. The first strategy (in purple) employs the use of a drip irrigation system to refill the soil profile frequently, keeping the soil at optimum moisture. The second strategy (in green) refills the profile infrequently, thus allowing approximately 50% of the available soil moisture to become depleted before refilling the profile. This schedule is typical of sprinkler irrigation systems as well as some gravity systems, and may not provide optimum moisture to the crop. Note that the definition of "optimum moisture" may change according to crop, stage of growth, quality parameters and other variables, and may include some level of drying down, or deficit irrigation, with any type of irrigation system.



(1) Full soil reservoir
(2) Often 50% of available soil capacity
(3) Empty soil reservoir

In addition to high frequency irrigation, high frequency fertigation in trials with phosphorus and potassium also has proven higher yield results as shown in the adjacent graph (Lamm, 2007 after Phene et al.,1990).



Tomato yield and crop ET as affected by irrigation system type and fertigation of macronutrients phosphorus (P) and potassium (K) on a clay loam soil. Data from Phene et al. (1990).

In short, the irrigation manager must decide when and how long to irrigate to achieve the best results for any given crop and its unique conditions. In this manual, we will discuss the Water Balance Method and then explore additional factors affecting scheduling before creating a typical irrigation schedule based on theoretical conditions.

A. Using the Water Balance Method

The Water Balance Method assumes that the crop root zone is a water reservoir, similar to a bank account. As the crop uses water through the process of evapotranspiration (ET), water is withdrawn from the account. This water can then be replaced by rainfall or irrigation deposits. A running balance keeps track of the theoretical water level in the water reservoir, and actual field monitoring verifies the theoretical balance before final irrigation decisions are made.

How to Calculate Run Time and Schedule

At a minimum, you need to know two things to successfully calculate theoretical run time and schedule irrigations using the Water Balance Method: 1) crop water use (to determine daily water withdrawal), and 2) irrigation system net application rate (to determine how much water is applied per hour of irrigation). Both are used to calculate theoretical run time. Reference ET, Crop Coefficient and Crop Coverage Decimal data are readily available from local government and university sources, and we encourage you to use these resources for help.

The irrigation system net application rate should be supplied by the irrigation dealer at the time of purchase, but irrigation system manufacturers, consultants and extension agents can help as well. The following formulas will help calculate Theoretical Run Time, Crop Water Use and Net Application Rate.

EQUATION 1 – THEORETICAL RUN TIME:

Run Time (mins.) = Crop Water Use (mm) / System Net Application Rate (mm/h) x 60

Example

If crop water use is 8 mm/day, and the net application rate of the irrigation system is 2 mm/h, how long should the system operate per day to replace crop water use?

Equation 1 — Theoretical Run Time Per Day

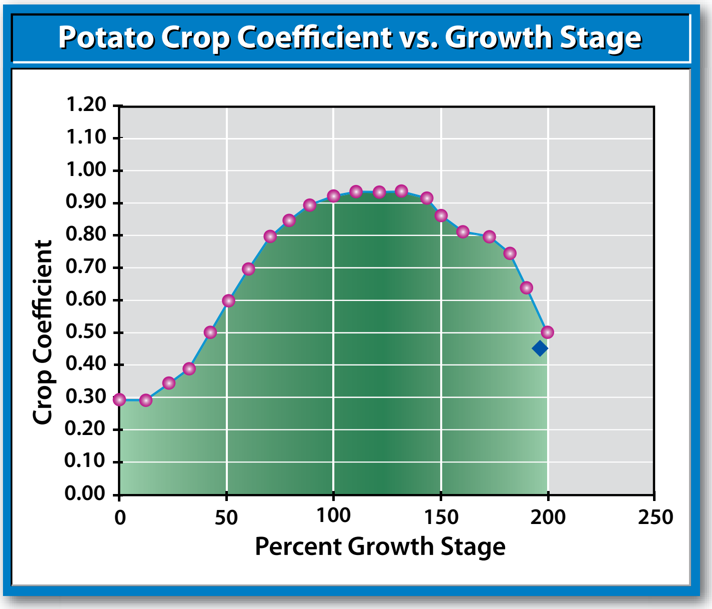
Crop Water Use	÷	Net Application Rate	x	60	=	Run Time Per Day
Example: 8mm/day	÷	2mm/hour	x	60	=	240 minutes/day

Since the system's net application rate typically doesn't change, only crop water use data must be collected on a frequent basis to calculate theoretical run time. However, plant and soil field conditions must also be monitored to verify that the calculated schedule will deliver desired results or for learning how theoretical values must be adjusted.

The following provides more detailed information regarding the development of crop water use and net application rate information.

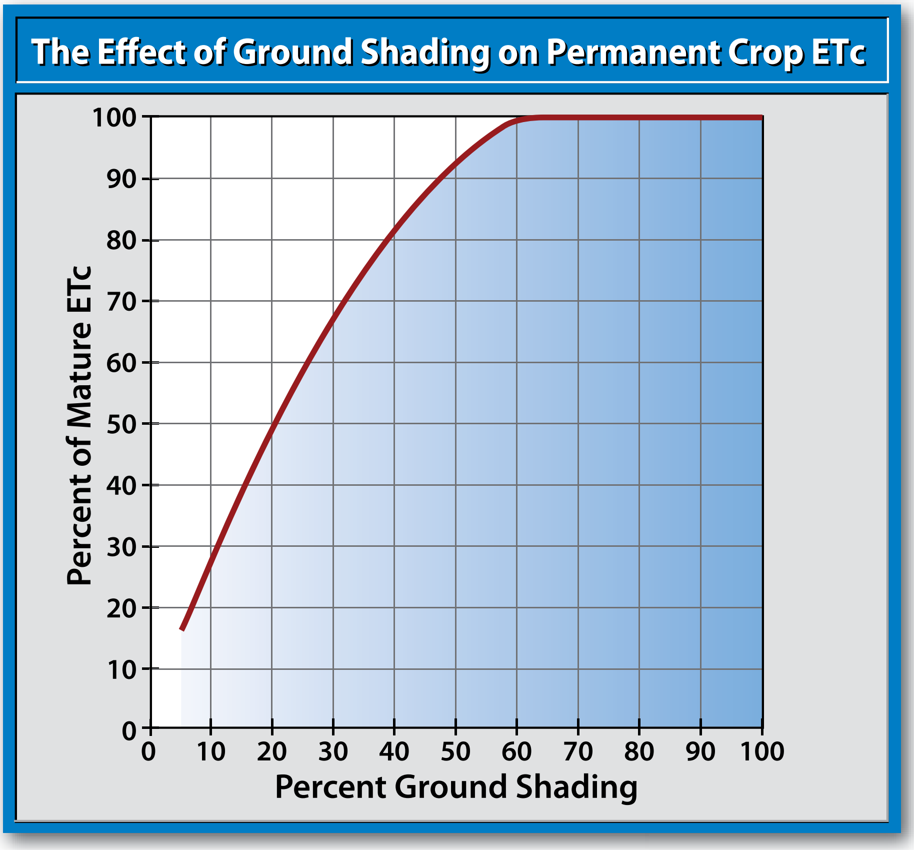
Determining Crop Water Use

Crop water use is typically expressed in millimeters of water per day as ETc (evapotranspiration of the crop). It's typically calculated by multiplying the reference evapotranspiration (ETo) rate, which is generated from daily local weather station data, by the crop coefficient (Kc), which is unique to the crop and the geography where it is grown. The purpose of the Kc is to adjust generic weather information to reflect the specific crop being grown. Weather and crop coefficient data may be obtained from local government or university sources, or may be generated on the farm with proper equipment and research procedures.



The adjacent illustration, Potato Crop Coefficient vs. Growth Stage (AgriMet, 2009) shows how the crop coefficient changes according to Percent Growth Stage (0 = emergence, 100 = row closure, 200 = dead vines). Note how ETo and Kc values both change during the season.

Theoretical crop water use should also be reduced if the crop doesn't cover 100% of the soil surface. For instance, University of California researchers recommend that if a tree crop provides more than 62% shading, then established crop coefficients should be used. However, if less than 62% of the soil surface is shaded with the tree canopy, then a 2:1 ratio should be used to generate a correction factor. For example, if an immature canopy only shaded 20% of the soil surface, then estimated water use of the immature orchard would be 2 x 20 = 40% as much water as a mature orchard. Thus, a multiplier of .4 should be used. The graph below illustrates how percent of mature ETc varies with percent ground shading (Snyder, UC Leaflet 21259).



EQUATION 2 – CROP WATER USE, MM PER DAY:

Crop Water Use, ETc (mm) = ETo x Kc x Crop Coverage Factor

Example

The ETo in mid June in central California is 9 mm/day. The crop is almonds, which has a Kc of .95 during this time of year. The orchard canopy covers 80% of the total orchard surface area. What is the crop water use (ETc) per day?

Equation 2 — Crop Water Use (mm/day)

ETo	x	Kc	x	Crop Coverage	=	Crop Water Use, ETc
Example:						
9mm/day	x	0.95	x	1.00	=	8.55mm/day

In some areas, ETc (crop ET) information is made available based on modeling average cropping situations, thus eliminating the need to track ETo and Kc information. The charts on the following pages show such ETc rates for drip-irrigated crops in Central California (Burt, 2007). Note that precipitation and reference ETo data are also supplied on the top two lines, whereas the rest of the data is "pre-estimated" crop ET.

EQUATION 3 – CROP WATER USE, GALLONS PER PLANT:

In some cases, you may wish to convert crop water use data from millimeters to liters per plant. In this case, the following formula should be used:

Crop Water Use (liters/plant) = Crop Water Use, mm/Day x Row Spacing, meters x Plant Spacing, meters.

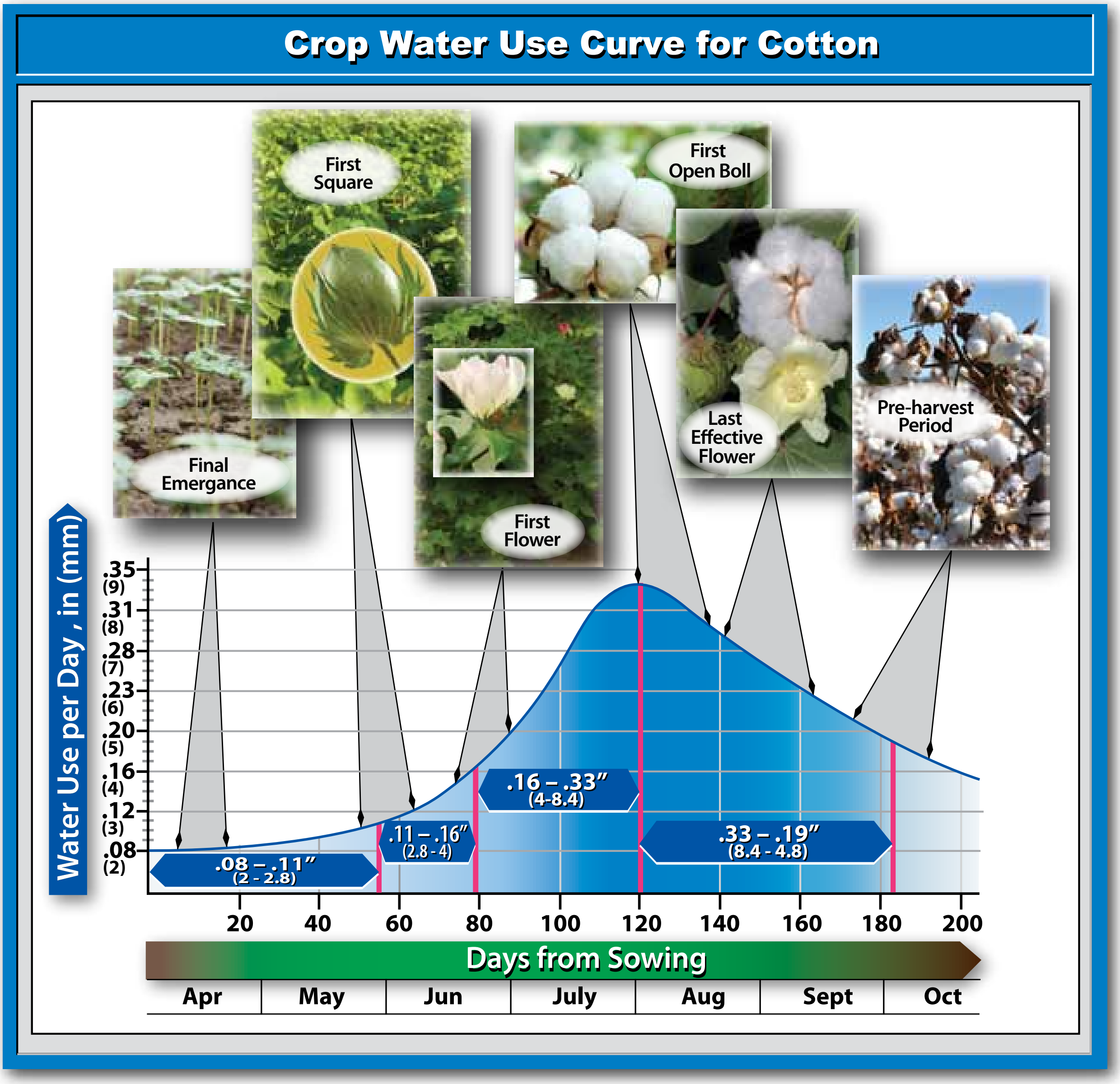
Example

The almond orchard mentioned above was planted on a 6 m x 6 m spacing. How many liters of water are used per tree per day?

Equation 3 — Crop Water Use (liters/plant)

Crop Water Use	x	Row Spacing	x	Plant Spacing	=	Liters/Plant
Example:						
8.55mm/day	x	6 meters	x	6 meters	=	307.8 liters

As you'd expect, crop water use changes with weather and stage of crop growth. The figure below shows a theoretical crop water use curve for cotton, in inches and millimeteres per day, in graphic form throughout the year.



EQUATIONS 4a AND 4b: IRRIGATION SYSTEM APPLICATION RATE

The drip system application rate, dependent on emission device flow rates and the spacing at which they're placed, is defined as the volume of water applied to a surface area, and is usually stated in inches or millimeters per hour. Equations 4a and 4b calculate application rates for tape with tape lateral spacing units in mm or meters respectively, while Equation 5 calculates application rates for on-line emitter, dripline, microjet, microspray and microsprinkler systems. Once the application rate is known, it must be derated by the drip system emission uniformity using Equation 6 to calculate a "net" application rate.

EQUATION 4A – DRIP TAPE APPLICATION RATE, MILLIMETERS PER HOUR

(Lateral spacing in **centimeters**)

Application Rate (mm/h) = Q-100 x 60/ Tape Lateral Spacing, **centimeters**

Where: Q100 = Aqua-Traxx tape flow rate in l/min 100 meters
Lateral Spacing = Spacing between tape lines, centimeters

Example

Drip tape is being used to grow peppers. The flow is 4.5 l/min/100 m, and the laterals are spaced 110 centimeters apart. What is the application rate?

Equation 4a — Drip Tape Application Rate, mm/h (lateral spacing in centimeters)

Q-100 Drip Tape	x	60	÷	Lateral Spacing (centimeters)	=	Application Rate (mm/h)
Example: 4.5 l/min/100 m	x	60	÷	110 centimeters	=	2.45 mm/h

EQUATION 4B – DRIP TAPE APPLICATION RATE, MILLIMETERS PER HOUR

(Lateral spacing in **meters**)

Application Rate (mm/h) = Q-100 x 0.6 / Tape Lateral Spacing, **meters**

Where: Q-100 = Aqua-Traxx tape flow rate in l/min /100 meters
Lateral Spacing = Spacing between tape lines, meters

Example

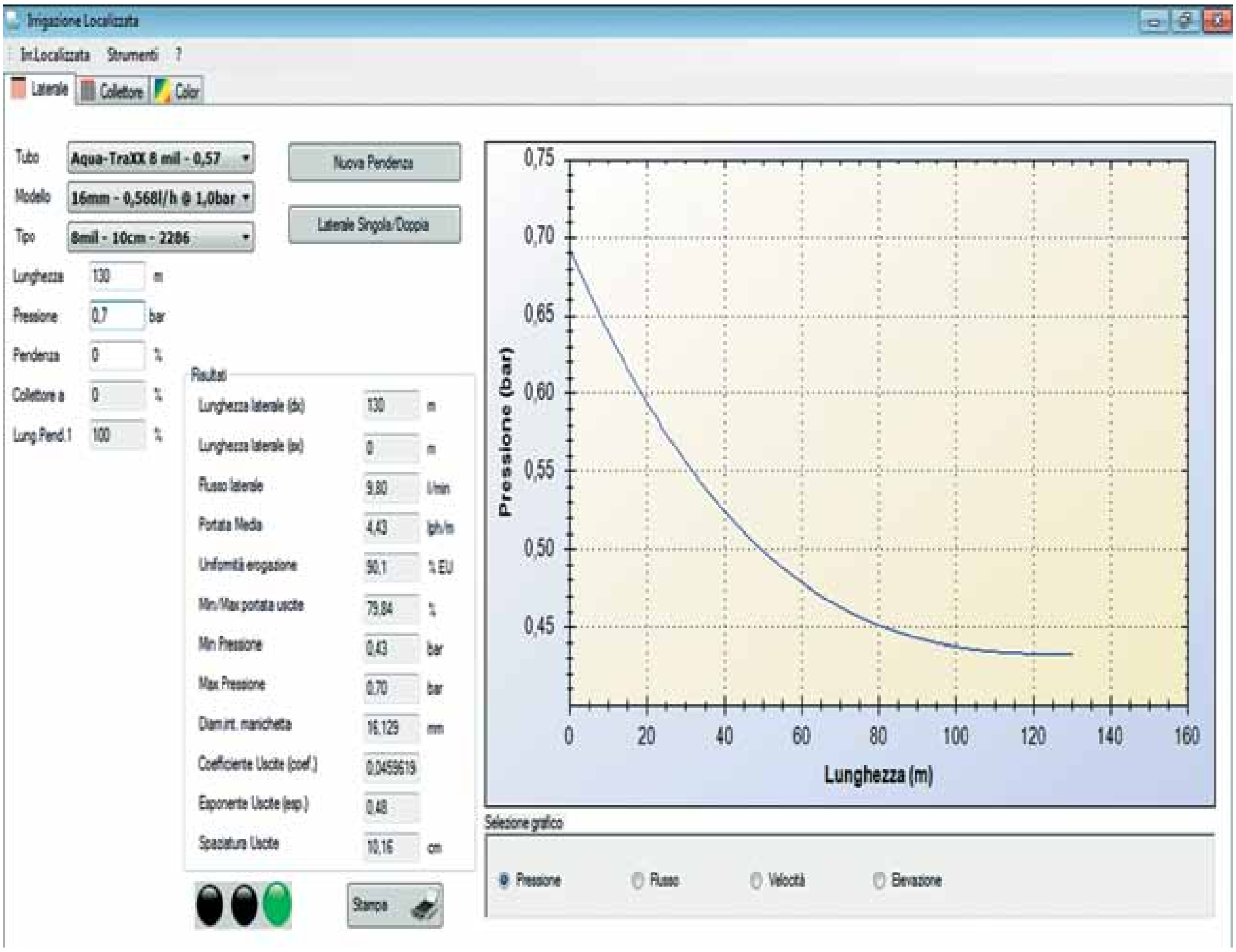
Drip tape is being used to grow peppers. The flow is 4.5 l/min/100 m, and the laterals are spaced 1.1 meters apart. What is the application rate?

Equation 4b — Drip Tape Application Rate, mm/h (lateral spacing in meters)

Q-100 Drip Tape	x	0.6	÷	Lateral Spacing (meters)	=	Application Rate (mm/h)
Example: 4.5 l/min/100 m	x	0.6	÷	1.1 meters	=	2.45 mm/h

Online Calculator Available

Note that users of Aqua-Traxx, Neptune and Blue Line may calculate application rates and run times using Toro's online Irrloc and Aquaflow available at toro-ag.it and toro.com respectively.
Once the Aqua-Traxx model is chosen and the system pressure, lateral spacing and emission uniformity are entered, the calculator will present the system application rate.



EQUATION 5 – MICRO-IRRIGATION DEVICE APPLICATION RATE, MILLIMETERS PER HOUR

Application Rate (mm/h) =
Emission Device Flow Rate, l/h / (Row Spacing, meters x Device Spacing, meters)

Where: Emission Device Flow Rate = Flow rate of each emitter or jet or microsprinkler, stated in l/h per device
Row Spacing = Spacing between lateral lines of hose or dripline, meters
Device Spacing = Spacing between emission devices along the lateral, meters

Example

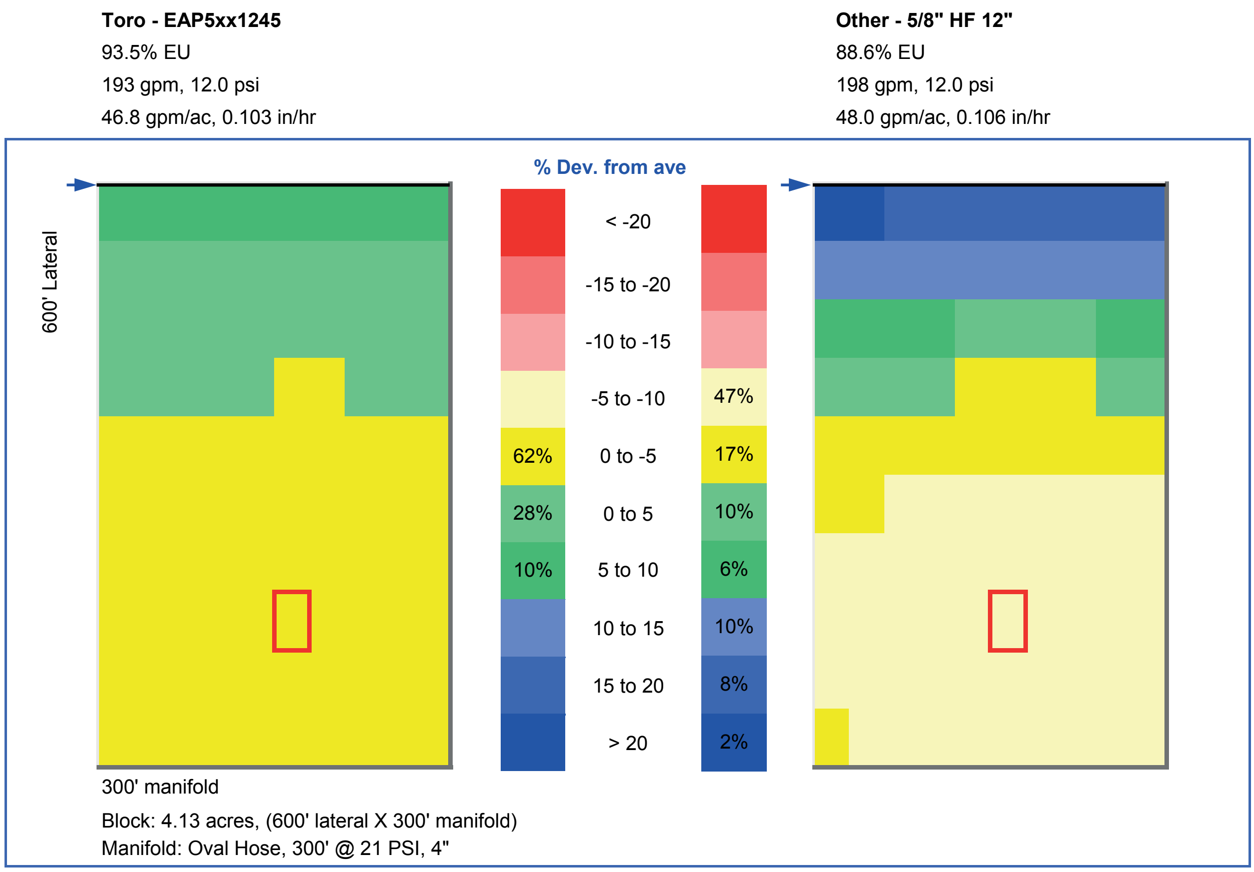
Dripline is being used to grow almond trees. The emitter flow rate is 2 l/h and emitters are pre-inserted every 1.2 meters. The dripline rows are spaced 3 meters apart. What is the application rate?

Equation 5 — Micro-irrigation Device Application Rate (mm/hr)

Emission Device Flow (l/h)	/	Row Spacing (meters)	x	Device Spacing (meters)	=	Application Rate (mm/h)
Example: 2 l/h	/	(3 meters	x	1.2 meters)	=	.56 mm/h

Irrigation System "Net" Application Rate

Now that the application rate is known, it must be de-rated by the irrigation system's uniformity to calculate net application rate. The system uniformity tells how evenly water is applied throughout the field and indicates how much over-irrigation must occur to ensure the driest part of the field receives enough water, i.e., how much over-irrigation will be required to compensate for imperfect uniformity. The system designer provides the theoretical uniformity, however, the actual uniformity of an exiting system may be determined by taking flow measurements from a number of field emission devices, and then dividing the average measurement of the "low quarter measurements" (lowest 25% of the readings) by the overall average. Various terms are used by irrigation engineers to describe system uniformity, including distribution uniformity (DU) and emission uniformity (EU). The illustration below was created using Toro's Color-Traxx design software: the system design's flow variation is mapped by color throughout the field. Note that a design with an EU of 93.5% has less color variation, or flow variation, than a design with a lower, less desirable EU of 88.6%.



One of the main advantages of drip irrigation is the opportunity to obtain high system uniformity. In general, drip irrigation systems often achieve over 90% uniformity with proper design, installation and maintenance. This is in contrast to typical uniformities of 40-60% for gravity systems and 50-75% for sprinkler systems.

To determine the "net" application rate, simply multiply the application rate by the emission uniformity, expressed as a decimal, as shown in EQUATION 6 as follows.

EQUATION 6 – NET APPLICATION RATE (ALL TYPES OF SYSTEMS)

Net Application Rate (millimeters/h) = Application Rate x Emission Uniformity

Example

The theoretical system application rate is 3 mm, and the emission uniformity was measured in the field to be 90%. What is the net application rate?

Equation 6 — Net Application Rate - All System Types

	Application Rate (mm/h)	x	Emission Uniformity	=	Net Application Rate
Example:	3 mm/h	x	0.90	=	2.7 mm/h

High system uniformity reduces operating hours.

To help translate the importance of emission uniformity, the following illustrates how many hours are required to apply a minimum of 25 mm of water to all parts of an irrigated field assuming various emission uniformities and assuming an application rate of 2.29 mm per hour:

The Effect of System Uniformity on Hours to Apply 1.0 Inch or 25.4 mm

Application Rate (inches/h, millimeters/h)	Emission Uniformity	Net Application Rate (inches/h, millimeters/h)	Hours to Apply 1.0 inch or 25.4 mm
0.09, 2.29	0.95	0.086, 2.176	11.7
0.09, 2.29	0.90	0.081, 2.06	12.3
0.09, 2.29	0.80	0.072, 1.832	13.9
0.09, 2.29	0.70	0.063, 1.603	15.9
0.09, 2.29	0.60	0.054, 1.374	18.5
0.09, 2.29	0.50	0.045, 1.145	22.2

Thus, if the desired application rate is a minimum of 25.4 mm of water to all parts of the field, then the system must be run 12.3 hours if the system uniformity were 90%, whereas the system must be run for 13.9 hours if the system uniformity were 80%. Clearly, high system uniformities utilize time and resources more efficiently. In addition, high system uniformity often prevents runoff, deep percolation, fertilizer waste and over-irrigation to parts of the field and the resulting crop damage.

SUMMARY

Once the crop water use and the net application rate are known using Equations 2 through 6, then a theoretical run time may be easily calculated using Equation 1.

Equation Summary

Equation 1 — Theoretical Run Time Per Day

Crop Water Use	÷	Net Application Rate	x	60	=	Run Time Per Day
Example: 8mm/day	÷	2mm/hour	x	60	=	240 minutes/day

Equation 2 — Crop Water Use (mm/day)

ETo	x	Kc	x	Crop Coverage	=	Crop Water Use, ETc
Example: 9mm/day	x	0.95	x	1.00	=	8.55mm/day

Equation 3 — Crop Water Use (liters/plant)

Crop Water Use	x	Row Spacing	x	Plant Spacing	=	Liters/Plant
Example: 8.55mm/day	x	6 meters	x	6 meters	=	307.8 liters

Equation 4a — Drip Tape Application Rate, mm/h (lateral spacing in centimeters)

Q-100 Drip Tape	x	60	÷	Lateral Spacing (centimeters)	=	Application Rate (mm/h)
Example: 4.5 l/min/100 m	x	60	÷	110 centimeters	=	2.45 mm/h

Equation 4b — Drip Tape Application Rate, mm/h (lateral spacing in meters)

Q-100 Drip Tape	x	0.6	÷	Lateral Spacing (meters)	=	Application Rate (mm/h)
Example: 4.5 l/min/100 m	x	0.6	÷	1.1 meters	=	2.45 mm/h

Equation 5 — Micro-irrigation Device Application Rate (mm/hr)

Emission Device Flow (l/h)	/	Row Spacing (meters)	x	Device Spacing (meters)	=	Application Rate (mm/h)
Example: 2 l/h	/	(3 meters	x	1.2 meters)	=	.56 mm/h

Equation 6 — Net Application Rate - All System Types

Application Rate (mm/h)	x	Emission Uniformity	=	Net Application Rate
Example: 3 mm/h	x	0.90	=	2.7 mm/h

B. Additional Considerations Affecting the Irrigation Schedule

Once theoretical run time is calculated, the irrigation manager must then adjust theory with real-world field conditions to decide how often to run the system to replenish each day's withdrawals. This decision will depend on the Management Allowable Depletion (MAD) as well as other agronomic, cultural and weather related factors. The following Agricultural Irrigation Scheduling Table is an example of a full season schedule for tomatoes in central California based on average data from the Waterright scheduling tool (CIT, 2009).

Use online scheduling tools to start, then fine-tune.

These and other types of spreadsheet tools allow the user to input data on a daily or weekly basis regarding actual crop ET, application information, soil moisture data and/or crop data. The worksheet on the next page may be used on a daily basis to keep track of available water in the soil profile along with soil moisture readings.

Agricultural Irrigation Scheduling

Field Data Summery

CIMIS Station: Madera #145 City of Madera in Madera County

Field Number	1	Irrigation Efficiency	90%
Description	East	Gross Application Rate (mm/hr)	1.07
Crop	Tomato	Scheduling Basis	Max Allowed Depletion
Crop Season	4/1 – 8/1	Management Allowed Depletion	10%
Stop Irrigation	7/29	Allowed Depletion at Max. Rootzone (mm)	10.7
Soil Type	Clay Loams	Runtime at Maximum Rootzone (hh:mm)	11:01
Maximum Rootzone (m)	.61		
Irrigation System	Drip Tape		

Seasonal Irrigation Schedule

For Week Ending	Average Year ETo (mm/day)	Average Year Rain (mm/wk)	This Year ETo (mm/day)	This Year Rain (mm/wk)	Kc	Averages for Week ETc (mm/day)	Averages for Week Rootzone (m)	Averages for Week Runtime (HH:MM)	Change This Year vs. Average Year (%)	Total ETc to Date (mm)
04/8/2009	3.0	7.9	N/A	N/A	0.3	0.8	0.30	6:17	N/A	6.1
04/15/2009	3.0	2.8	N/A	N/A	0.3	1.0	0.30	6:45	N/A	12.7
04/22/2009	3.3	6.1	N/A	N/A	0.3	1.0	0.30	7:14	N/A	19.6
04/29/2009	3.8	2.3	N/A	N/A	0.32	1.3	0.34	8:28	N/A	27.9
05/6/2009	4.1	4.3	N/A	N/A	0.38	1.5	0.42	11:09	N/A	38.6
05/13/2009	4.6	1.3	N/A	N/A	0.51	2.3	0.51	17:10	N/A	55.1
05/20/2009	5.3	1.8	N/A	N/A	0.70	3.8	0.60	26:45:00	N/A	81.0
05/27/2009	5.8	3.6	N/A	N/A	0.8	5.1	0.61	36:50:00	N/A	116.8
03/6/2009	6.4	0.5	N/A	N/A	1.03	6.6	0.61	46:50:00	N/A	162.3
10/6/2009	6.9	1.3	N/A	N/A	1.09	7.6	0.61	54:42:00	N/A	215.1
06/17/2009	7.4	0.0	N/A	N/A	1.1	8.1	0.61	58:39:00	N/A	272.0
06/24/2009	7.6	0.0	N/A	N/A	1.1	8.4	0.61	59:57:00	N/A	329.9
01/7/2009	7.4	0.0	N/A	N/A	1.1	8.1	0.61	59:04:00	N/A	387.1
08/7/2009	7.1	0.0	N/A	N/A	1.08	7.9	0.61	56:35:00	N/A	442.0
07/15/2009	7.1	0.0	N/A	N/A	1.02	7.1	0.61	51:51:00	N/A	492.3
07/22/2009	6.9	0.0	N/A	N/A	0.89	6.4	0.61	45:00:00	N/A	535.7
07/29/2009	7.1	0.0	N/A	N/A	0.76	5.3	0.61	38:39:00	N/A	573.3

Total Runtime = 592:03 hh:mm = 637 Millimetres Gross Applied

Irrigation Scheduling "Replace What's Used" Template

Field west Zone 1 Acres 4 Hectares Soil Type sandy loam Applied Water/Meter 40mm

Day	Pump Pressure - kPa	Pump Flow - m³/hr	Application Rate - Inches mm/h*	Hours of Operation	Gross Water Applied - mm	Net Water Applied - mm**	Crop ET mm/day	"Banked Water"	Net Water Banked	Soil Moisture Status - Site 1	Soil Moisture Status - Site 2	Soil Moisture Status - Site 3	Soil Moisture Status - Site 4
1	350	90	2.25	6	13.5	12.2	5.1	7.1	7.1				
2	350	90	2.25	0	0.0	0.0	6.4	-6.4	0.7				
3	350	90	2.25	6	13.5	12.2	7.6	4.5	5.3				
4	350	90	2.25	4	9.0	8.1	7.6	0.5	5.7				
5	350	90	2.25	0	0.0	0.0	6.4	-6.4	-0.6				
6	350	90	2.25	6	13.5	12.2	7.6	4.5	3.9				
7	350	90	2.25	6	13.5	12.2	8.9	3.3	7.2				
8	350	90	2.25	4	9.0	8.1	10.2	-2.1	5.1				
9	350	90	2.25	6	13.5	12.2	10.2	2.0	7.1				
10	350	90	2.25	6	13.5	12.2	8.9	3.3	10.4				
11	350	90	2.25	0	0.0	0.0	7.6	-7.6	2.7				
12	350	90	2.25	6	13.5	12.2	7.6	4.5	7.3				
13	350	90	2.25	0	0.0	0.0	7.6	-7.6	-0.3				
14	350	90	2.25	6	13.5	12.2	5.1	7.1	6.7				

* Millimetres per hour = Pump Flow, m3/h x 1000/ (hectares x 10,000)
** Net Water Applied = Gross water Applied (mm) x 0.9 application efficiency.

In both of these examples note that soil texture, available water and soil moisture conditions must be known. Instruments are available to help determine these values, but simple field analysis is possible as well using readily available resources from government and academic sources. The following will discuss how Soil Texture, MAD, wetting patterns and the desire to avoid puddling influence the irrigation schedule beyond what the Water Balance Equations predict.

Soil Texture

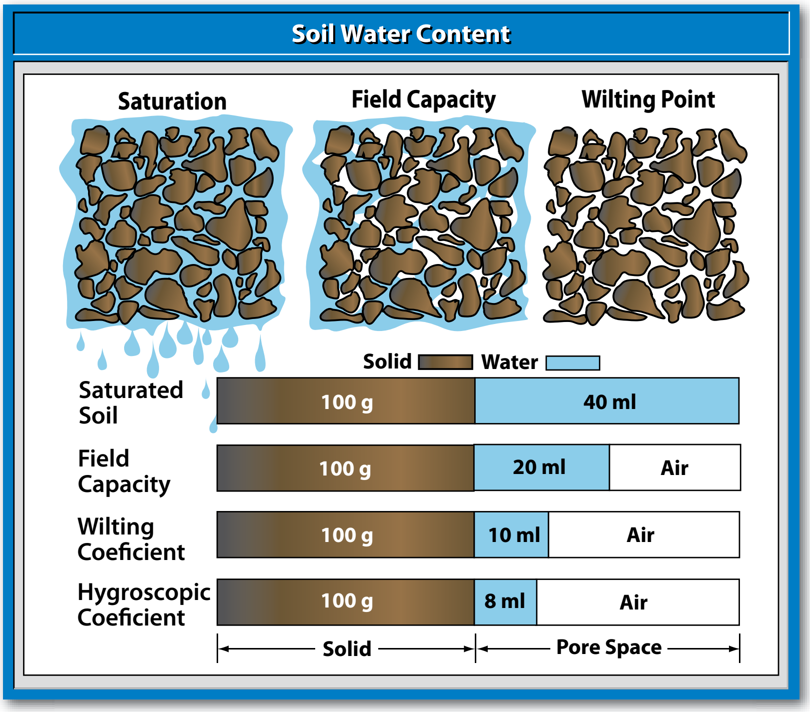
Soil texture affects irrigation scheduling in two important ways. First, it determines how quickly the soil accepts water, and it should be known prior to design since it influences emission device flow rate and spacing. An application rate, or precipitation rate as it's sometimes called, should have been chosen that does not exceed the soil's ability to accept the water. Otherwise, runoff or puddling will occur. The adjacent Maximum Precipitation Rates table (USDA, 1997) shows that on heavier soils, runoff will occur with an application rate as low as 3 to 4 mm per hour. One of the advantages of drip irrigation systems is that application rates are often far below the maximum values shown in this chart, and pose less risk to create runoff than sprinkler systems, especially on bare, sloped ground.

Maximum Precipitation Rates *

Slope	0–5%		5–8%		8–12%		12%+	
Soil Coverage	Covered	Bare	Covered	Bare	Covered	Bare	Covered	Bare
Soil Composition								
Coarse sandy	50	50	50	38	38	25	25	13
Coarse sandy soils over compact subsoil	45	38	30	25	25	19	19	10
Uniform light sandy loam	45	25	30	20	25	15	19	10
Light sandy loams over compact subsoil	30	19	25	13	19	10	13	8
Uniform silt loams	25	13	20	10	15	8	10	5
Silt loams over compact soil	15	8	13	6	10	4	8	3
Heavy clay or clay loam	5	4	4	3	3	2	3	1.5

** The maximum PR values, listed in mm/hr, are suggested by the United States Department of Agriculture. The values are average and may vary with respect to actual soil and ground cover conditions.*

Second, soil texture determines how much water the root zone water reservoir holds per meter and how much of that water is available to the plant. The adjacent Soil Water Content illustration shows three levels of soil moisture: saturation, field capacity and wilting point. Much of the water in a saturated field will be lost to gravity and cannot be used for plant growth. After about 24 hours, the soil will achieve "field capacity" where water is available for plant use. At the wilting point, water is still present in the soil, but is held so tightly by the soil particles that it's unavailable for plant use. The difference between field capacity and wilting point is considered water that is "available" to the plant. This is the soil moisture that growers manage to optimize crop production.



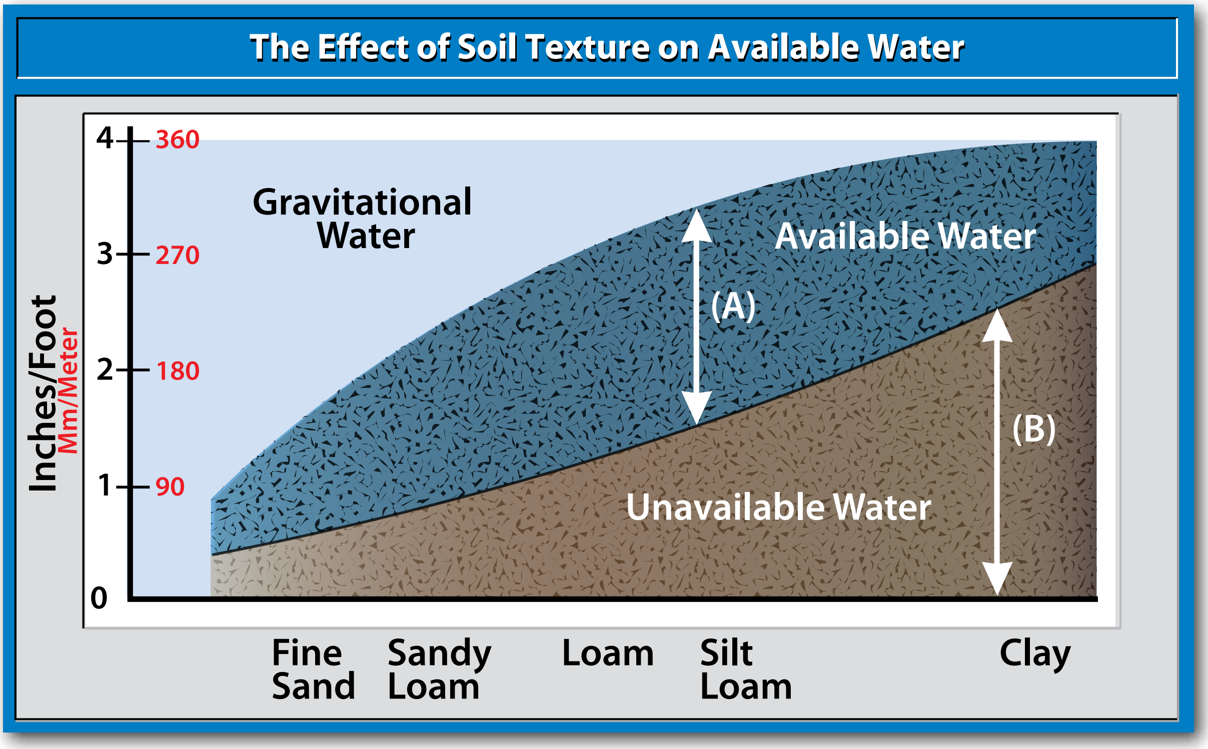
The adjacent Available Soil Moisture chart (Plaster, 2003) shows the range of moisture, in millimeters, that is potentially available to plant roots for different soil textures. Note that a sandy soil only has about 40-90 mm of available water per meter of depth whereas a loam or silt loam has as much as 170-230 mm of available water per meter of depth.

Available Soil Moisture *

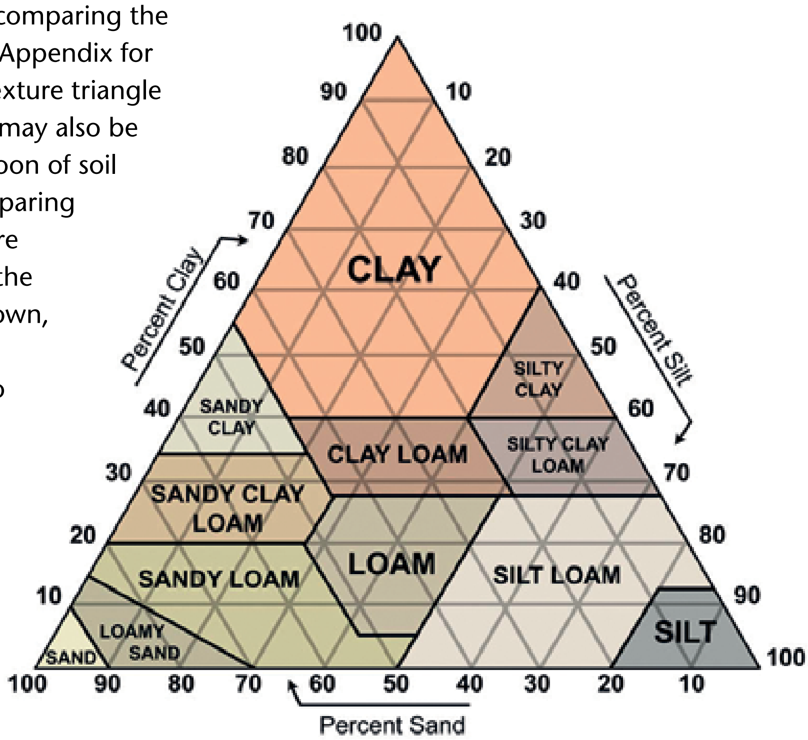
Soil Texture	mm/cm	mm/meter
Coarse sand and gravel	0.2 — 0.6	20 — 60
Sand	0.4 — 0.9	40 — 90
Loamy sand	0.6 — 1.2	60 — 120
Sandy loam	1.1 — 1.5	110 — 150
Fine sandy loam	1.4 — 1.8	140 — 180
Loam and silt loam	1.7 — 2.3	170 — 230
Clay loam	1.4 — 2.1	140 — 210
Silty clay loam	1.4 — 2.1	140 — 210
Silty clay and clay	1.3 — 1.8	130 — 180

** metricated version of original chart (Plaster, 2003)*

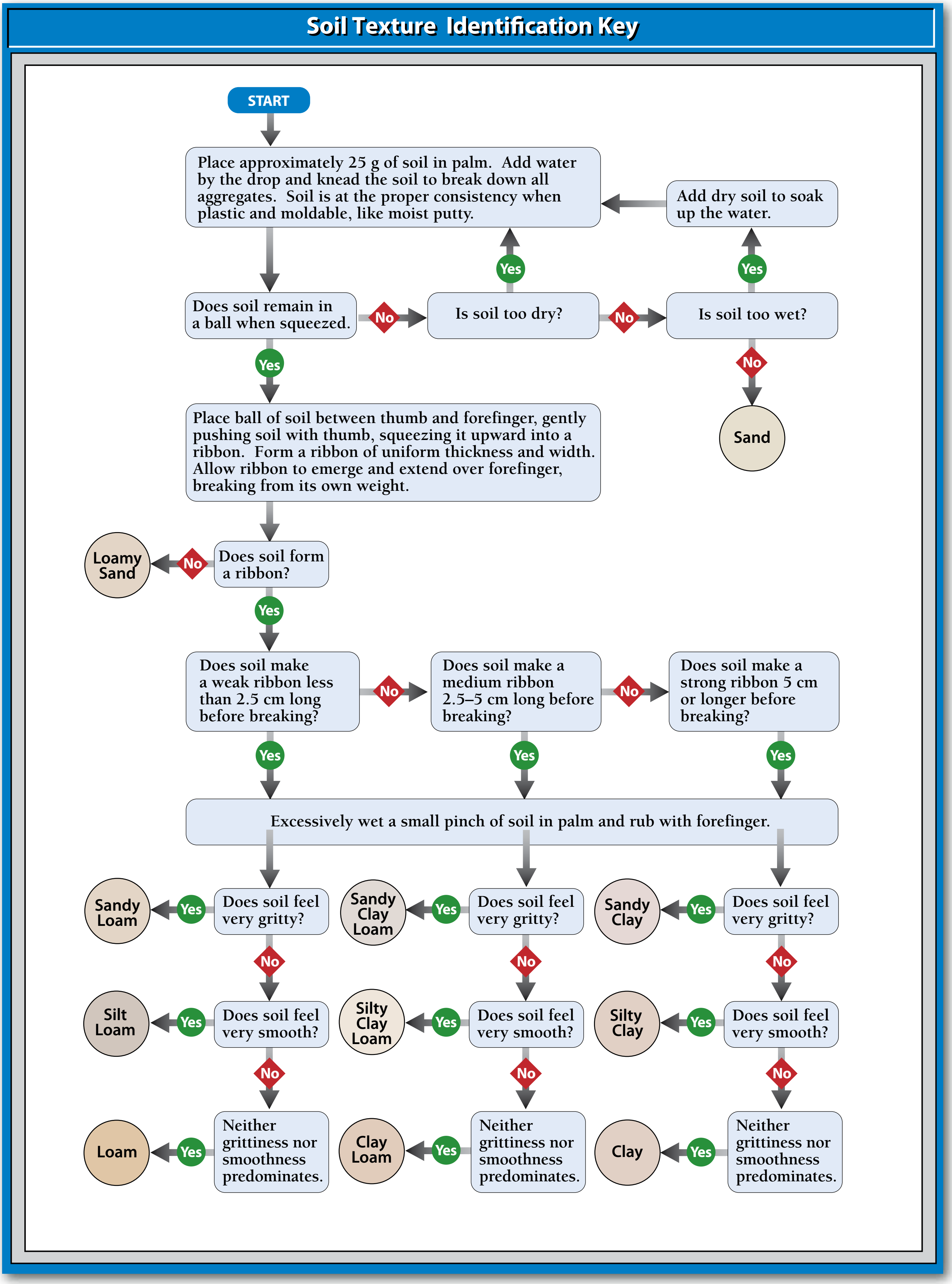
This is further illustrated in the illustration below, "The Effect of Soil Texture on Available Water" (Plaster, 2003). Soils that have limited available water must be managed very carefully because if crop water use cannot be replaced on a daily basis, if crops are shallow rooted, and/or if crop water usage is high, available water could become depleted and plants could wilt, possibly permanently. Irrigators must manage the available water in the root zone so that optimal crop production is achieved.



Soil texture may be determined by comparing the results of a Sedimentation Test (see Appendix for procedure) with the adjacent Soil Texture triangle (www.soilsensor.com). Soil texture may also be determined by evaluating a tablespoon of soil with the palm of the hand and comparing it with information in the Soil Texture Identification Key (Thien, 1979) on the following page. Once texture is known, potential available water may be estimated using the table above. To determine actual moisture status of a known texture, the Feel Method may be used as illustrated in the table on the following pages titled, "Soil Moisture, Feel and Appearance Description" (USDA, 1998). Pictures of a Fine Sand and Loamy fine Sand are included to illustrate.



Soil Texture Identification Key



Management Allowable Depletion (MAD)

MAD is a term that describes how much of the available water is allowed to deplete before it's replaced with irrigation. This is largely an agronomic decision because water availability is often used to manipulate crop growth and quality. In some cases, a full reservoir is desired and water is replaced as it is depleted as discussed in the Water Balance Method. In other cases, some level of plant water stress may be desired and maintained via the irrigation schedule. In any case, the Water Balance Method may be used to manage the soil water reservoir. The scheduler must simply determine whether the reservoir is to be kept full or depleted to some level.

Sometimes MAD is dictated by system or cultural logistics. It may be inconvenient or impossible to fill the soil reservoir on every block each day, or cultural activities may prohibit irrigation. However, using drip often eliminates these issues, because:

- Drip application rates are low, so more acres may be irrigated at once.
- Drip systems typically apply water to the crop root zone and/or beds only and leave furrows and drive roads dry, allowing irrigation to occur — even when field operations (including harvest) are taking place.
- Since nutrients are often applied through the drip system, tractor applications can be minimized or even eliminated.

In summary, agronomic reasons rather than logistics usually dictate the drip schedule.

Soil Moisture, Feel and Appearance Descriptions

Available Water *	Sand	Sandy Loam	Loam/Silt Loam	Clay Loam/Clay
Above field capacity	Free water appears when soil is bounced in hand.	Free water is released with kneading.	Free water can be squeezed out.	Puddles–free water forms on surface.
100% (field capacity)	Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand. (**1 in/ft, 83 mm/m**) §	Appears very dark. Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand. (**1.5 in/ft, 125 mm/m**)	Appears very dark. Upon queezing, no free water appears on soil, but wet outline of ball is left on hand. Will form about a 1" (25 mm) ribbon. (**2.0 in/ft, 167 mm/m**)	Appears very dark. Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand. Will form about a 2" (50 mm) ribbon. (**2.5 in/ft, 208 mm/m**)
75–100%	Tends to stick together slightly, sometimes forms a weak ball with pressure. (**0.8–1.0 in/ft, 67-83 mm/m**)	Quite dark. Forms weak ball, breaks easily. Will not stick. (**1.2 –1.5 in/ft, 100 - 125 mm/m**)	Dark color. Forms a very pliable ball. Sticks readily if high in clay. (**1.5 – 2.0 in/ft, 125 - 167 mm/m**)	Dark color. Easily ribbons out between fingers–has slick feeling. (**1.9–2.5 in/ft, 158 - 208 mm/m**)
50–75%	Appears to be dry, will not form a ball with pressure. (**0.5–0.8 in/ft, 42 - 67 mm/m**)	Fairly dark. Tends to form a ball with pressure, but seldom holds together. (**0.8–1.2 in/ft, 67 - 100 mm/m**)	Fairly dark. Forms a somewhat plastic ball. Will sometimes stick slightly with pressure. (**1.0–1.5 in/ft, 83 - 125 mm/m**)	Fairly dark. Forms a ball, ribbons out between thumb and forefinger. (**1.2–1.9 in/ft, 100 - 158 mm/m**)
25–50%	Appears to be dry, will not form a ball with pressure. (**0.2–0.5 in/ft, 17-42 mm/m**)	Light colored. Appears to be dry, will not form a ball. (**0.4–0.8 in/ft, 33 - 67 mm/m**)	Light colored, somewhat crumbly–holds together with pressure.(**0.5–1.0in/ft, 42 - 83 mm/m**)	Slightly dark, somewhat pliable. Will form a ball under pressure. (**0.6–1.2 in/ft, 50 - 100 mm/m**)
0–25%	Dry, loose, single-grained – flows through fingers. (**0–0.2 in/ft, 0-17 mm/m**)	Very slight color. Dry, loose–flows through fingers. (**0–0.4 in/ft, 0 - 33 mm/m**)	Slight color. Powdery, dry, sometimes slightly crusted– easily broken down to a powdery condition. (**0–0.5 in/ft, 0 - 42 mm/m**)	Slight color. Hard, baked, cracked–sometimes with loose crumbs on surface. (**0–0.6 in/ft, 0 - 50 mm/m**)

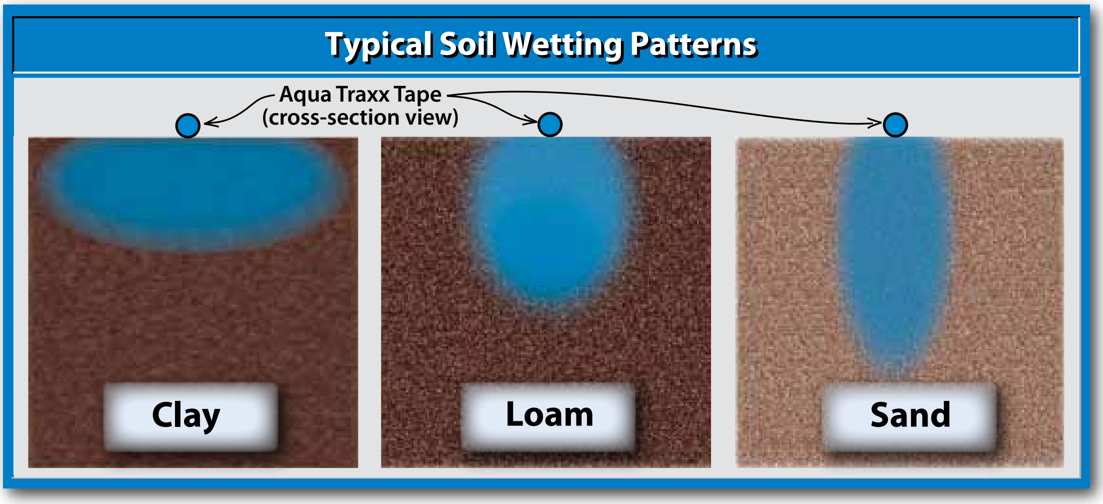
** Available water is the difference between field capacity and permanent wilting point.*
§ Bold-face numbers in parentheses represent available water contents expressed as inches of water per foot, or mm of water per meter, of soil depth.

Appearance of sandy clay loam, loam and silt loam soils at various soil moisture conditions (left to right): 25-50%; 50-75%; 75-100%

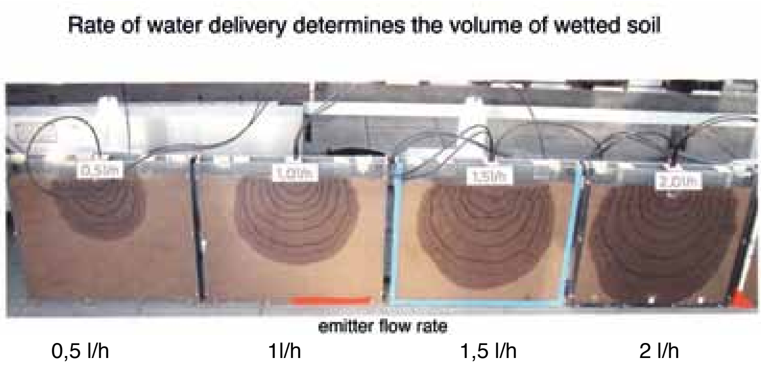
Desired Wetting Pattern

Water movement in the soil is dictated by capillary action prior to saturation as shown in the adjacent photo where water is "wicking" up the bed against the force of gravity. Wetting patterns are primarily dictated by soil texture, but may also be influenced by soil tilth, structure, compaction and chemistry, emitter flow rate and spacing, lateral spacing and depth of burial, system pressure and irrigation schedule. In general, water from an emitter will exhibit more lateral, horizontal movement in heavier clay soils, and more vertical, downward movement in lighter sandy soils. The following pictures and figures illustrate the relative shapes of wetting patterns that might be created under an emitter in various soil types, flow rates and operating conditions:

> Probe the soil to ensure water isn't traveling beyond the root zone.

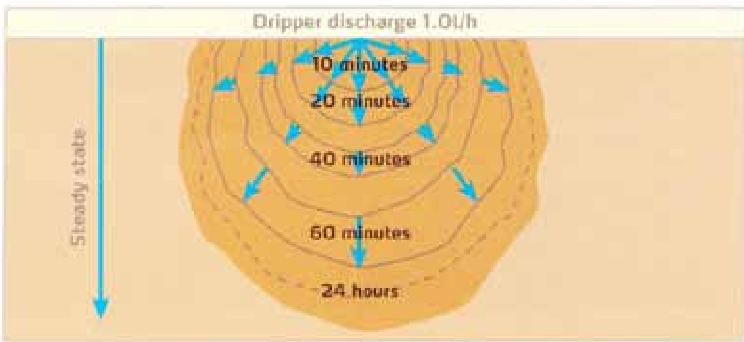


Note that emitter flow rate will also determine wetting pattern as illustrated in the adjacent laboratory photos, where emitter flow rate varied while the soil and operating duration were consistent (Mikkelsen, 2009).



The adjacent diagram illustrates how water typically moves laterally and downward during the first 24 hours of discharge from a 1.0 l/h emitter (Mikkelsen, 2009).

Typical wetted soil volume following a one-hour irrigation



Monitoring Wetting Patterns

Just as irrigation managers monitor soil moisture, wetting patterns should also be monitored to ensure desired results. The wetted surface diameter should be observed, and then the subsurface wetting pattern "mapped" by systematic probing and evaluation of the soil moisture. If excessive moisture is evident beyond the root zone or planted bed, then the schedule should be adjusted accordingly. The adjacent picture shows the startup wetting pattern on the left, and the wetting pattern after 12 hours of operation on the right. Note how a uniform corridor of moisture was created across the entire planting bed.

Pulse Irrigation

Pulse irrigation, the practice of applying water in short durations with intervals in between, is sometimes used to encourage lateral water movement. Despite various research and anecdotal experiences, there's little conclusive evidence that pulse irrigation significantly improves wetting patterns. Nevertheless, pulse irrigation should remain an option if horizontal water movement is a challenge. Instead of applying the desired amount of water in a single irrigation event, two events of shorter duration could be scheduled with an interval in between. For instance, instead of running the system once for four continuous hours, run it for two hours, turn the system off for an hour, and then run it again for two hours. Careful monitoring and observation will help you determine whether this tactic is effective in your specific conditions.

Achieve good wetting patterns using closely spaced emitters and pulsing techniques.

Closely Spaced Emitters

The use of closely spaced emitters is rapidly gaining in popularity due to the ability to achieve superior wetting patterns more quickly than with wider spaced emitters. The photos below (Klauzer, 2009) compare the wetting patterns of emitters spaced at 30 and 20 cm, and the subsequent "wetted corridor of moisture" achieved down and across the bed after 30 hours of irrigation with 20 cm spacing. Such rapid "blackening of the beds" is highly desirable by many growers, especially when setting transplants or germinating seeds.

Toro Aqua-Traxx drip tape 30 cm emitter spacing, 3.09 l/min/100 m on left 20 cm emitter spacing 3.09 l/min/100 m on right.

Aqua-Traxx 20 cm emitter spacing, 3.09 l/min/100 m after 30 hours of irrigation.

Avoiding Puddling and Runoff

Irrigation schedules may also be adjusted to avoid runoff or puddling due to heavy soil conditions and/or chemical problems, both of which result in low infiltration rates. As mentioned earlier, the choice of low application rates will help reduce runoff in low infiltration rate soils such as clays and clay loams. Pulse irrigating in frequent, short durations may also help avoid runoff and puddling.

In the case of saline and/or sodic soil conditions where soil and/or water chemistry is the culprit, leaching in the presence of gypsum will often exchange detrimental sodium with beneficial calcium to condition the soil (see Chapter 4 "Fertigation and Chemigation" for more information). If lime is present in the soil, the application of acid may accomplish the same benefit. The addition of organic matter may also prove beneficial. Ultimately, the detrimental salts must be leached out of the root zone.

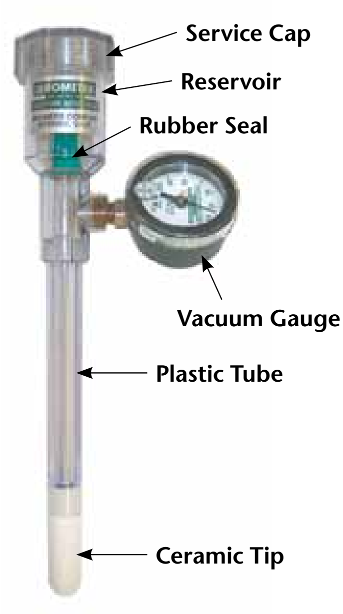
In some cases, conditioning the water may prove beneficial. Some growers have reported success in applying gypsum through the drip irrigation system, but extreme caution should be practiced since clogging may occur. Other commercial water conditioners are marketed with varied results. Consult with an expert before spending time, money and energy on this activity.

C. Monitoring Equipment

There are a number of ways to predict crop water use and measure soil moisture content and plant water stress. While historical, actual and predictive crop water use data is typically available from local farm advisors or universities, soil moisture and plant water stress must be measured on the farm.

Soil moisture may be accurately estimated using a variety of methods. First, soil moisture may be measured by an experienced hand using the "feel method"mentioned earlier. Second, soil moisture may be measured via porous body devices such as granular matrix sensors (GMS) and tensiometers as shown respectively in the illustrations adjacent top and on the next page (courtesy of The Irrometer Company). Note the data logger output to the right.

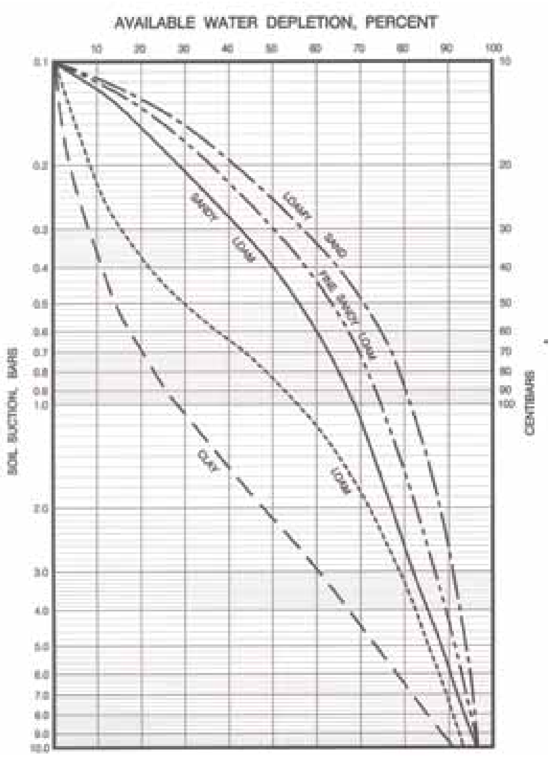
Tensiometers measure the vacuum, in centibars, that plant roots exert on the soil in contact with the device, while GMS devices measure the electrical resistance, in centibars, of the GMS sensor that is in contact with the soil. In both cases, the higher the centibar readings, the drier the soil. In addition, both sensors may be read manually in the field, or can transmit data automatically to a data logger (example shown on previous page). However, tensiometers must be routinely serviced to replace the water that is lost to suction as the soil becomes drier.



Tensiometer Components

Results must be interpreted to assist in irrigation scheduling decisions. For example, a given tensiometer reading can translate into widely different soil moisture content depending on the soil texture. The graph below shows Available Water Depletion, Percent vs. Centibar Reading (Van der Gulik, 1999). Note that a reading of 50 centibars translates into a 70% available water depletion in a loamy sand, but less than 15% soil moisture depletion in a clay. Thus, in lighter soils that have less total water holding capacity, growers may wish to maintain lower tensiometer readings than they would for heavier soils. It is clear that a thorough knowledge of the field's soil texture must be known to interpret the data in a useful manner.

Third, soil moisture may be measured via other technologies including time domain reflectometry (TDR), frequency domain reflectometry (FDR), and neutron probes. The choice of technology depends on a number of factors including the size of the farm, variability of soils, availability of labor, desired accuracy, ability to automate, cost, and available local support. Since results must be interpreted, training on their use and interpretation are often the most important considerations.



Plant water stress may be measured in a number of ways as well. Visual observation of the crop will readily reveal such indicators as leaf rolling, color changes, wilting, or fruit abscission to the trained eye. However, these indicators are subjective and qualitative. Pressure bombs and infrared thermometers are technologies that provide a quantitative measurement of plant water stress. Whatever the method, plant water stress measurements are typically used in conjunction with atmospheric (crop water use) and soil moisture measurements to predict and decide when to irrigate and for how long. For best results, local technology experts should be consulted to calibrate atmospheric, soil and plant data, and to interpret results. Ideally, irrigation scheduling should use both technical data and localized knowledge.

D. Run-Time Calculators

The following irrigation run-time calculators for permanent and row crops may be used to integrate application rate, available water in root zone, crop water requirements and recommended run-time.

Permanent Crop Example

Checkbook Style Irrigation Run Time Calculator for EMITTERS/MICROS - Metric Units

Complete steps 1–6 below to determine irrigation system run time per day.

		Emitter/Micro flow, Lph	Emitter Spacing, meters	Lateral Spacing meters	Application Uniformity, decimal	Net application rate, mm per hour
Step 1:	To determine system Net Application Rate, enter four bolded values to the right. As an example, dripline laterals with 2 Lph emitters spaced every 1.2 meters are spaced 3 meters apart. The application uniformity is 90%. The resulting net application rate is .50 mm/hr.	**2**	**1.2**	**3**	**0.9**	0.500
Step 2:	Enter Available Water in crop rootzone **for Day 1 only**. This is dependent on soil texture and rootzone depth. In the example below, the soil is a loam with 83 mm of available water per meter when at field capacity. The root zone is 1.5 meters deep, so there is a total of 125 mm of available water to manage. It is assumed the rootzone is at field capacity on Day 1.					
Step 3:	Enter crop water use for each day. As an example, 14 days have already been filled out below: 2.5 mm per day the first week, 5 mm per day the second week.					
Step 4:	Enter amount of water to be applied in blue column. The amount may be the same as daily crop water use, or a deficit may be allowed to build up if a Management Allowable Depletion, MAD, has been set. In the example below, the MAD has been set at 5 mm, so irrigations have been scheduled when Available Water approached 120 mm.					
Step 5:	Enter how much rain fall has occurred, if any.					
Step 6:	Read irrigation run time in hours or minutes per day. Irrigation Run Time = Amount to be applied/application rate.					

Summary:	**Step 1: Calculate net application rate above.**	**Step 2: Enter Available Water, in mm, in Crop Root Zone for Day 1 only!**	**Step 3: Enter Crop Water Use, in mm, for each day,**	**Step 4: Enter the amount of water, in mm, to be applied**	**Step 5: Enter how much rainfall has occurred, if any.**	**Step 6: Read irrigation run time in hours or minutes per day.**	
	Day	Available Water in crop rootzone at beginning of day, mm	Daily Crop Water Use, mm	Amount of water to be applied, mm	Nett Rainfall, mm	Irrigation run time, **hours** per day	Irrigation run time, **minutes** per day
	1	125	2.5		0.0	0.00	0
	2	122.5	2.5	5	0.0	10.00	600
	3	125	2.5		0.0	0.00	0
	4	122.5	2.5		0.0	0.00	0
	5	120	2.5	7.5	0.0	15.00	900
	6	125	2.5		0.0	0.00	0
	7	122.5	2.5		0.0	0.00	0
	8	120	5	10	0.0	20.00	1200
	9	125	5		0.0	0.00	0
	10	120	5	10	0.0	20.00	1200
	11	125	5		0.0	0.00	0
	12	120	5	10	0.0	20.00	1200
	13	125	5		0.0	0.00	0
	14	120	5	10	0.0	20.00	1200
	15	125					

Analysis of example: The first week, crop water use was 2.5 mm per day, and irrigations were scheduled on day 2 and day 5 to replace depleted water. On day 8, crop water use doubled to 5 mm per day for the rest of the week, so irrigations were scheduled to apply 10 mm every other day to replace depleted water.

Row Crop Example

Checkbook Style Irrigation Run Time Calculator for TAPE - Metric Units

Complete steps 1–6 below to determine irrigation system run time per day.

Step 1:	To determine system Net Application Rate, enter the three **bolded** values to the right. As an example, tape with a Q-100 of 4.5 Lpm / 100 m is laid on 1.1 meter centers (1.1 meter lateral spacing). The application uniformity is 90%. The resulting net application rate is 2.2 mm/hr.	Tape Q-100 (Lpm/100 meters)	Lateral Spacing meters	Application Uniformity, decimal	Net application rate, mm per hour
		4.5	**1.1**	**0.9**	2.20
Step 2:	Enter Available Water in crop rootzone **for Day 1 only**. This is dependent on soil texture and rootzone depth. In the example below, the soil is sandy with .42 mm of available water per cm when at field capacity. The root zone is 30 cm deep, so there are 13 mm of available water to manage.				
Step 3:	Enter crop water use for each day. As an example, 14 days have already been filled out below: 1.5 mm per day the first week, 2 mm per day the second week.				
Step 4:	Enter the amount of water to be applied in the blue column. The amount may be the same as daily crop water use, or a deficit may be allowed to build up if a Management Allowable Depletion, MAD, has been set. In the example below, the MAD has been set at 1.3 mm, so depleted water is replaced on a daily basis.				
Step 5:	Enter how much rain fall has occurred, if any.				
Step 6:	Read irrigation run time in hours or minutes per day. Irrigation Run Time = Amount to be applied/application rate.				

Summary:	**Step 1: Calculate nett application rate above.**	**Step 2: Enter Available Water, in mm, in Crop Root Zone for Day 1 only!**	**Step 3: Enter Crop Water Use, mm, for each day,**	**Step 4: Enter the amount of water, in mm, to be applied**	**Step 5: Enter how much rainfall has occurred, if any.**	**Step 6: Read irrigation run time in hours or minutes per day.**	
	Day	Available Water in crop rootzone at beginning of day, mm	Daily Crop Water Use, mm	Amount of water to be applied, mm	Nett Rainfall, mm	Irrigation run time, **hours** per day	Irrigation run time, **minutes** per day
	1	**12.60**	1.50	1.50	0.0	0.68	41
	2	12.60	1.50	1.50	0.0	0.68	41
	3	12.60	1.50	1.50	0.0	0.68	41
	4	12.60	1.50	1.50	0.0	0.68	41
	5	12.60	1.50	1.50	0.0	0.68	41
	6	12.60	1.50	1.50	0.0	0.68	41
	7	12.60	1.50	1.50	0.0	0.68	41
	8	12.60	2.00	2.00	0.0	0.91	55
	9	12.60	2.00	2.00	0.0	0.91	55
	10	12.60	2.00	2.00	0.0	0.91	55
	11	12.60	2.00	2.00	0.0	0.91	55
	12	12.60	2.00	2.00	0.0	0.91	55
	13	12.60	2.00	2.00	0.0	0.91	55
	14	12.60	2.00	2.00	0.0	0.91	55
	15	12.60					

Analysis: The first week, crop water use was 1.5 mm per day, thus an irrigation was scheduled every day for 41 minutes to replace what was depleted each day. The second week, irrigation duration was increased to 55 minutes per day since crop water use increased. Management may opt to run every other day for twice as long, or every third day for three times as long, but in no case should the interval be so long that all available water is consumed.

4

FERTIGATION AND CHEMIGATION

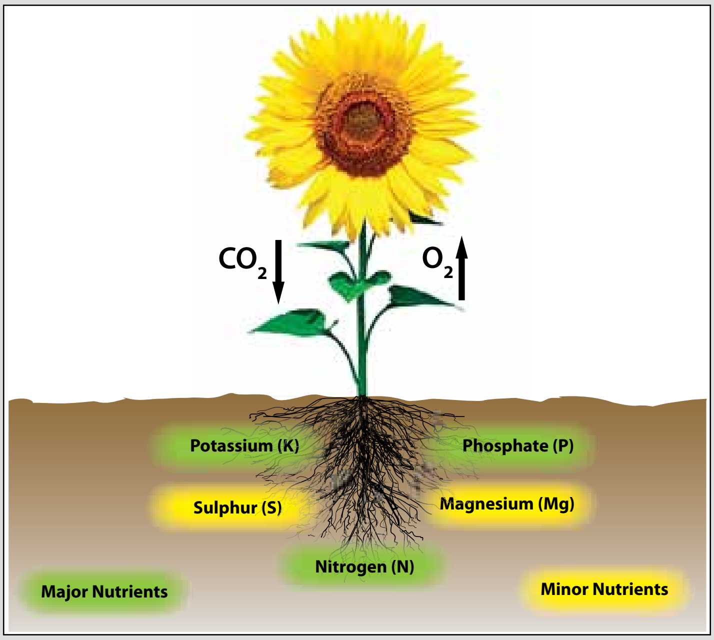
Fertigation And Chemigation

4.1 Plant/Soil/Water Relationships

There are many reasons for applying chemicals using the drip irrigation system. Here are a few examples:

- **System maintenance chemicals** may be applied to treat or prevent clogging from both organic and inorganic sources.
- **Soil and water amendments** may be applied to correct physical or chemical imbalances that impede water infiltration into the soil or threaten plant health.
- **Nutrients** may be easily and precisely spoon-fed directly to the soil and plant roots without wetting the foliage.
- **Other agronomic chemicals** may be applied to kill pests or enhance growth.

Major and Minor Soil Nutrients



Seventeen Nutrients Required by Plants

Major nutrients from water and CO_2	C H O	Carbon Hydrogen Oxygen
Primary Macronutrients	N P K	Nitrogen Phosphorus Potassium
Secondary Macronutrients	Ca Mg S	Calcium Magnesium Sulfur
Micronutrients	Fe Cu Mn Mo B Cl Ni Zn	Iron Copper Manganese Molybdenum Boron Chlorine Nickel Zinc

In short, the chemigation system must be designed to safely apply the right chemicals in the right quantities at the right time.

The illustration above (Improving Plant Life, 2009) shows how plant leaves and roots work together to obtain the 17 nutrients required by plants as shown in the adjacent chart (Adapter from Plaster, 2003). A drip irrigation system can be very effective in applying many of these nutrients directly.

Testing for Nutrients

Drip irrigation applies water and nutrients to the soil for plant uptake by the roots. Both scientific facts and local knowledge of the plant/soil/water environment are necessary to determine nutrient status.

- Before your irrigation system is designed, **soil and water analyses** are necessary to ensure that the system application rate matches the soil's ability to accept water — and to discover and correct any chemical imbalances or toxicities that threaten infiltration or plant health.
- As water, fertilizer and other chemicals are applied during the growing season, it's important to monitor and correct **physical or chemical imbalances** that may develop as well.
- Advances in field monitoring equipment allow frequent **soil and plant analyses** to monitor crop growth and nutrient status.

By managing all three parameters (soil, water and plants) correctly, you can maximize profitability and minimize the risk of applying water and chemicals incorrectly. The following chart (Burt, 1995) summarizes the timing, determinations, observations and procedures of various plant/soil/water tests. Additional details about water, soil and plant tests follow.

Category of Nutrient Test

	Soil	Soil Solution	Plant Tissue	Plant Sap	Irrigation Water
Typical Timing	Preplant, and if deficiency symptoms arise.	Weekly	Several times during growing season.	Several times during growing season.	Once or twice during growing season.
What is determined	Total fertilizer need for the season.	Availability of nutrients at that moment.	Are levels of specific nutrients sufficient for that growth stage?	Are levels of specific nutrients sufficient for that growth stage?	Nutrient contribution by water; potential toxic elements such as boron and chloride.
Special Observations	Potential for problems in fertility or infiltration. Examine nutrient ratios in the soil.	Release rates of various fertilizers.	Nutrient ratios in the plant itself (DRIS).	Nutrient ratios in the plant itself (DRIS).	Permeability hazards.
Typical Procedure	Laboratory	Field	Laboratory	Field	Laboratory or Field

A. Water Analysis and Interpretation (Boswell, 2000)

The preliminary study for a micro irrigation system requires a careful analysis of the source water. A micro irrigation system requires good quality water free of all but the finest suspended solids. **Neglecting to analyze the quality of source water and provide adequate treatment is one of the most common reasons for the failure of micro irrigation systems to function properly.**

Taking a Water Sample

A representative water sample must be taken. If the source is a well, the sample should be collected after the pump has run for about half an hour. For a tap on a domestic supply line, the supply should be run for several minutes before taking the sample. When collecting samples from a surface water source such as a ditch, river or reservoir, the samples should be taken away from the shore, near the center and below the water surface. Where surface water sources are subject to seasonal variations in quality, these sources should be sampled and analyzed when the water quality is at its worst.

Test water early for clogging, toxicity, salinity and infiltration hazards.

Half-gallon (two liter) glass or plastic containers are ideal for sample collection. They should be thoroughly cleaned and rinsed with the sample water to avoid contamination of the water sample. Two samples should be collected. The first sample should be used for all tests except iron, and no additives are required. The second sample is used for the iron analysis, and after collecting the water, ten drops of HCl should be added. HCl is commonly available in the form of muriatic acid.

Sample bottles should be filled completely to the top (with all air removed), carefully labeled, tightly sealed, and kept in a cool place (do not freeze!). Samples should be sent immediately to a water-testing laboratory.

Typical Constituents of a Water Analysis

Suspended Solids – Suspended solids in the water supply include soil particles ranging in size from coarse sands to fine clays, living organisms including algae and bacteria, and a wide variety of miscellaneous waterborne matter. Suspended solids loads can vary considerably from day to day and season to season, particularly when the water source is a river, lake or reservoir. Since suspended solids above a certain size must be filtered out of the water before it enters the system, it's a good idea to obtain a reliable estimate of the total quantity of material to be removed.

pH – The pH of source waters used for irrigation is normally within a range of 6.5 to 8.0, and seldom presents a problem in and of itself. However, since pH plays a major role in a variety of chemical reactions in the water and in the soil, it must be considered. The pH of the source water may determine whether or not various dissolved solids present in the water, such as iron or calcium carbonate, will precipitate out to cause emitter clogging. The water pH may help or hinder the action of chlorine used for control of biological growth, may affect soil pH, and may cause fertilizers to precipitate out of solution and cause clogging problems.

Total Dissolved Solids (TDS) – TDS is usually reported as ppm and describes the total salt content of the water. TDS can be determined by evaporating all the water from a water sample of known weight and then weighing the salt remaining. More often it's estimated by measuring the Ecw in ds/m and multiplying by 640. This estimates TDS in ppm. To calculate kilograms of TDS applied per meter of irrigation water over a hectare, multiply ppm TDS by 9.989. In this example, water with 736 ppm TDS is adding 7,352 kg of salt per hectare with every meter of water applied.

Bicarbonate – Bicarbonate (HCO_3) is common in natural waters. Sodium and potassium bicarbonates can exist as solid salts, such as baking soda (sodium bicarbonate). Calcium and magnesium bicarbonates exist only in solution. As the moisture in the soil is reduced by transpiration or by evaporation, calcium bicarbonate decomposes, carbon dioxide (CO_2) escapes into the air, and water (H_2O) is formed, leaving insoluble lime ($CaCO_3$) behind.

$Ca(HCO_3)_2$ upon drying = $CaCO_3 + CO_2 + H_2O$

continued on next page

A similar reaction takes place with magnesium bicarbonate. Large amounts of bicarbonate ions in irrigation water will, as the soil approaches dryness, precipitate calcium, which effectively removes it from the clay. This leaves sodium in its place. In this way a calcium dominant soil can become a sodium dominant (sodic) soil by the use of a high-bicarbonate irrigation water.

Carbonate – Carbonate (CO_3) is found in some waters. Since calcium and magnesium carbonates are relatively insoluble, high carbonate waters mean that the cations associated with them are likely to be sodium with possibly a small amount of potassium. Upon drying in the soil, the carbonate ion will remove calcium and magnesium from the clay in a process similar to that of bicarbonate, and an alkali (sodic) soil will develop.

Manganese – Manganese (Mn) occurs in groundwater less commonly than iron and generally in smaller amounts. Like iron, manganese in solution may precipitate out as a result of chemical or biological activity, forming a sediment that will clog emitters and other system components. The color of the deposits ranges from dark brown, if there is a mixture of iron, to black if the manganese oxide is pure. Caution should be exercised when chlorination is practiced with waters containing manganese because there's a time delay between chlorination and the development of a precipitate.

Iron – Iron (Fe) may be present in a soluble (ferrous) form, and may create emitter clogging problems at concentrations as low as 0.1 ppm. Dissolved iron may precipitate out of the water due to changes in temperature or pressure, in response to a rise in pH, or through the action of bacteria. The result is an ocher sludge or slime mass capable of incapacitating the entire irrigation system (See Chapter 15).

Sulfides – If the irrigation water contains more than 0.1 ppm of total sulfides, sulfur bacteria may grow within the irrigation system, forming masses of slime that may clog filters and emitters.

Bacterial Populations – Populations of less than 10,000/ml are considered of little hazard, while over 10,000/ml likely require treatment.

Oil – Oil will rapidly block both sand media and screen filters and may clog emitters or orifices. Oil may also result in chemical degradation of plastic pipes, tubing, or other components.

Sodium – Sodium (Na) salts are all very soluble and found in most natural waters. A soil with a large amount of sodium associated with the clay fraction has poor physical properties for plant growth. When wet it runs together, becomes sticky and is nearly impervious to water. When it dries, hard clods form, making it difficult to till. Continued use of waters with a high proportion of sodium may bring about severe changes in an otherwise good soil. Sodium is also evaluated using the Sodium Adsorption Ratio (SAR).

Chloride – Chloride (Cl) is found in all natural waters and is toxic to some plants in high concentrations. All common chlorides are soluble and contribute to the total salt content (salinity) of soils. The chloride content must be determined to properly evaluate irrigation waters.

Boron – Boron (B) occurs in water in one or another anion form. A small amount of boron is essential for plant growth, but a concentration slightly above the optimum is toxic to plants. Some plants are more sensitive to boron excess than others.

Salinity (EC and TDS) – Plant roots take up water from the soil primarily as a result of osmotic pressure, which exists because plant cells contain a higher concentration of dissolved salts than is present in the soil water. This difference in salt concentration forces water to move from the area of lower to higher salt concentration, through the semi permeable cell walls of the plant, in a process called osmosis.

When saline water is applied to soils it raises the salt content of the soil water, lowering the osmotic pressure across the permeable root membrane and reducing water absorption by the plant roots. During the period between irrigations, as pure water is removed from the soil, the salt concentration in the soil water increases to further lower osmotic pressure.

continued on next page

Salinity may be expressed as electrical conductivity (EC) in mmho/cm or as total dissolved solids (TDS) in ppm, with 1.0 mmho/cm approximately equaling 640 ppm. Under traditional irrigation methods, irrigation water having an EC value of 0.75 or more (TDS = 480 ppm) may present a potential salinity problem for salt sensitive crops (e.g. strawberries), while certain salt tolerant crops (e.g. cotton) may flourish using water many times as saline.

A properly designed and operated micro irrigation system can significantly reduce salinity problems because the system maintains a high soil moisture content, and also because water moving outward from emitting sources will move salts to the outer edges of the root zone in a process called micro leaching.

However, this is not to suggest that salinity can be ignored in the design and operation of micro irrigation systems. On the contrary, because of the absence of deep percolation under micro irrigation, there will be virtually no vertical leaching of salts unless the engineer incorporates this capability into the design of the system.

Sodium Adsorption Ratio (SAR) – The SAR, which compares the concentration of sodium ions with the concentration of calcium and magnesium ions, is helpful in assessing the degree to which detrimental sodium will replace beneficial calcium on soil clay particles. In recent years, another calculation called "adjusted SAR" (adj. R_{Na}) has been developed to include the role bicarbonates play in stripping the soil of beneficial calcium. It's now believed that an inter-relationship exists between adj. R_{Na} and EC_w to properly estimate permeability hazard.

Calcium – Calcium (Ca) is found to some extent in all natural waters. A soil predominantly saturated with beneficial calcium is friable and easily worked, usually permits water to penetrate easily, and does not puddle or run together when wet. For this reason calcium, in the form of gypsum, is often applied to tight soils to improve their physical properties. Generally, irrigation water high in dissolved calcium is desirable.

Magnesium – Magnesium (Mg) is usually found in measurable amounts and behaves much like calcium in the soil. Often laboratories will not separate calcium and magnesium, but will report them simply as Ca + Mg in me/L.

Potassium – Potassium (K) is usually found in only small amounts in natural waters. It behaves much like sodium in the soil. In water analysis, it's generally included with the sodium rather than reported separately.

Sulfate – Sulfate (SO_4) is abundant in nature. Sodium, magnesium and potassium sulfates are readily soluble. Calcium sulfate (gypsum) has a limited solubility. Sulfate has no characteristic action on the soil except to contribute to the total salt content. The presence of soluble calcium will limit sulfate solubility.

Nitrate – Nitrate (NO_3) is not commonly found in large amounts in natural waters. While beneficial as a plant nutrient, nitrate may have undesirable effects on crop maturation or ripening. High nitrate levels in water may indicate contamination from excessive use of fertilizers or from sewage. Nitrates have no effect on the physical properties of soil except to contribute slightly to its salinity.

Use the following chart as a summary and guideline for water analysis parameters and possible interpretations:

Water Analysis and Interpretation

Constituent	Why It's of Interest	Hazard Level			Source
		Low	Medium	High	
Suspended Solids	Physical Clogging	<50 ppm	50-100 ppm	>100 ppm	1
pH	Chemical Clogging	<7.0	7.0 – 8.0	>8.0	1
Salt	Chemical Clogging	<500 ppm	500–2,000 ppm	>2,000 ppm	1
Bicarbonate	Chemical Clogging	—	100 ppm	—	1
Manganese	Chemical Clogging	<0.1 ppm	0.1–1.5 ppm	>1.5 ppm	1
Total Iron	Chemical Clogging	<0.2 ppm	0.2–1.5 ppm	>1.5 ppm	1
Hydrogen Sulfide	Chemical Clogging	<0.2 ppm	0.2–2.0 ppm	>2.0 ppm	1
Bacterial Populations/ml	Biological Clogging	<10,000/ml	10,000–50,000/ml	>50,000/ml	1
Oil	Physical Clogging		Unknown		1
Sodium, adj. R_{Na} value:	Toxicity to Plant Growth	<3.0	3.0 - 9.0	>9.0	2
Chloride, me/l	Toxicity to Plant Growth	< 4.0	4.0 - 10	>10.0	2
Chloride, mg/l or ppm	Toxicity to Plant Growth	< 142	142 - 355	>355	2
Boron, mg/l or ppm	Toxicity to Plant Growth	< 0.5	0.5 - 2.0	2.0–10.0	2
EC_{w7}, dS/m	Salinity (inhibits roots from absorbing water)	<0.75	0.75 - 3.0	>3.0	2
EC_{w7}, TDS		480	1,920	1,920	2
Sodium, adj. R_{Na} value of:	Infiltration Problems (water fails to penetrate into soil)				
0–3	...together with EC_w =	>0.7	0.7 - 0.2	<0.2	3
3–6	...together with EC_w =	>1.2	1.2 -0.3	<0.3	3
6–12	...together with EC_w =	>1.9	1.9 - 0.5	<0.5	3
12–20	...together with EC_w =	>2.9	2.9 - 1.3	<1.3	3
20–40	...together with EC_w =	>5.0	5.0 - 2.9	<2.9	3

Sources:
1. Bucks and Nakayama, 1980
2. Ayers, 1977
3. Westcott & Ayers, 1984

B. Soil Analysis and Interpretation

Drip irrigation technology lets farmers spoon-feed nutrients and soil amendments much more frequently than with conventional practices. In addition to traditional pre-plant laboratory analyses that indicate total fertilizer requirements for the crop, field "quick tests" report current nutrient status of the soil solution (water held in the soil). With this data, fertilizer and soil amendment applications may be adjusted frequently to optimize crop production and profitability.

It should be noted that soil tests and soil solution tests are different as are their interpretations. The following guidelines will help ensure success:

- **Use a reputable lab and/or reputable field quick-tests.**
- **Be careful to interpret results using the correct units.** Various laboratories express results in different units and forms that influence the interpretation.
- **Consult with laboratory personnel regarding exact sampling procedures** for soil tests and/or manufacturer recommendations for field soil solution testing. The results will only be as good as the sampling technique.

Soil tests should be interpreted differently than soil solution tests.

- **Keep in mind that the results of soil solution tests are typically interpreted differently than soil tests** and are highly dependent upon the crop, soil type and percentage of the soil wetted by the irrigation method. For this reason, soil solution tests are typically used to detect ***sufficiency*** levels of nutrients, and are often used in conjunction with plant tissue analyses. Some consider soil solution testing more suited for monitoring nutritional trends rather than determining absolute sufficiency levels.
- **Many believe that the nutrient *balance* within a soil must be considered** in addition to total nutrient quantity in soil (Burt, 1995).

The following provides general rules for interpreting soil test results (Burt, 1995 after Tisdale et al., 1985):

General Rules for Interpreting Soil Test Results

Soil Nutrient	Rule
NO3-N (Nitrate-Nitrogen)	**Deficient if NO3-N < 10 ppm. Generally sufficient if NO3-N > 20 ppm.**
Ca (Calcium)	**Ca (mEq) should occupy 65 –75% of CEC.* If Ca/Mg < 2/1, then Ca deficiency may occur.**
Mg (Magnesium)	**Mg (mEq) should occupy 10 –15% of CEC.* If Ca/Mg > 20/1, then Mg deficiency may occur.**
K (Potassium)	**K (mEq) should occupy 2.5 –7.0% of CEC.*** **Cation Exchange Capacity*

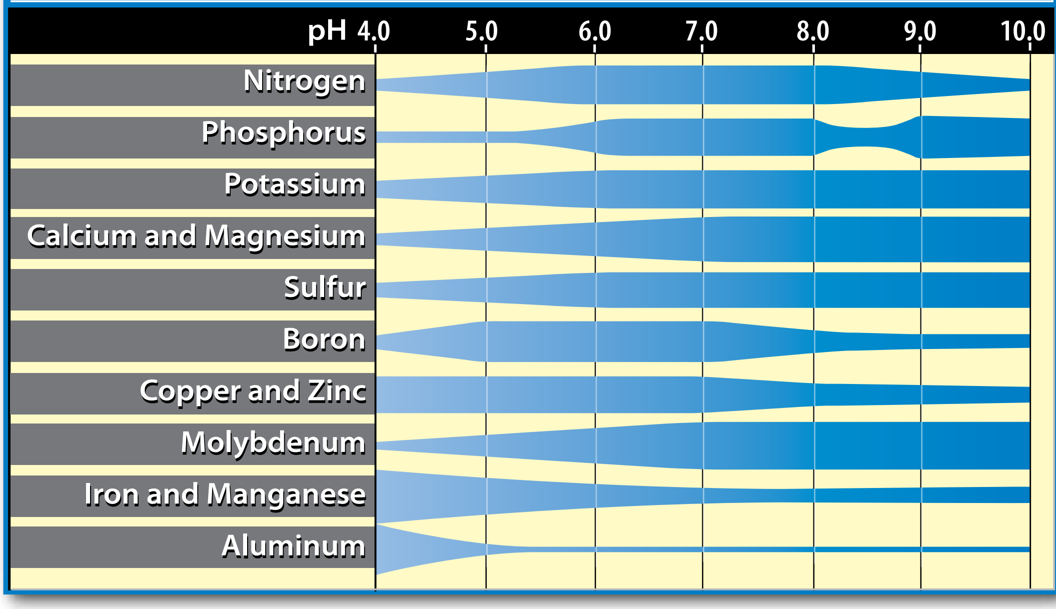
The following provides general interpretations of nutrients in the soil solution (Burt, 1995 after Hartz et al., 1994; Tisdale et al., 1985).

General Interpretations of Nutrients in the Soil Solution

Soil Nutrient	Sufficiency Level	Notes
NO_3-N (Nitrate-Nitrogen)	**> 50–75 ppm**	**Generally considered sufficient during early half of the season.**
K (Potassium)	**20 – 60 ppm is generally adequate**	**Suggested solution balance: K (ppm) = 0.10 x Ca (ppm)**
Ca (Calcium)	**Unclear**	**Suggested solution balance: Ca (ppm) = 10 x K (ppm)**
Mg (Magnesium)	**24 ppm**	

In addition to nutrients, soil pH must be monitored because nutrient availability, solubility of toxic ions and microbial activity are all influenced by pH. The pH of acidic soils may be raised with the addition of free lime. This chart illustrates how toxic elements such as aluminum become more soluble, and available, at lower pH, and how neutral pH favors beneficial nutrient availability and microbial activity. The thicker the width of the bar, the more available the nutrient is. (Truog, 1943).

Effect of Soil pH on Nutrient Availability



It should be noted that maintenance chemicals and common fertilizers often lower the pH of the water, and in turn can also lower the pH of the soil.

In addition to pH, the soil's salt and sodium levels must be monitored to prevent injury to plants and the collapse of soils. The following are characteristics of salted soils (Plaster, 2003):

Characteristics of Salted Soils

Salted Soil Class	Conductivity (mmhos/cm)	Exchangeable Sodium (%)	Sodium Absorption Ratio	Soil pH	Soil Structure
Saline	>4.0	<15	<13	<8.5	Normal
Sodic	<4.0	>15	>13	>8.5	Poor
Saline-sodic	>4.0	>15	>13	<8.5	Normal

The amount of free lime (calcium carbonate) present will dictate treatment materials and methods. The following provides a guideline to treatment of saline, sodic (alkaline) and saline/sodic conditions (adapted from Plaster, 2003, pgs 191-192). As always, preventive maintenance and monitoring are best to avoid toxicity and/or water infiltration problems. More information on managing salinity may be found in Chapter 5.

Treatment Guidelines for Saline, Sodic, and Saline/Sodic Soils

	ECe (dS/m)	ESP (%)	pH	Physical Properties	Amendments
Saline	>4.0	<15	<8.5	Good	Leaching with high quality water; good drainage necessary.
Sodic (Alkali)	<4.0	>15	>8.5	Poor – also called black alkali.	Gypsum and/or acid; organic matter to improve leaching.
Saline/Solic	>4.0	>15	<8.5	Fair to poor – water penetration inhibited.	Leaching in the presence of gypsum; acid in the presence of limestone; good drainage necessary.

C. Plant Analysis and Interpretation

Plant tissue analyses reveal what the plant actually needs, whereas soil analyses reveal what's actually available, or deficient, in the soil. Although tissue analysis is common in irrigated agriculture, the ability to spoon-feed a crop with a drip irrigation system has prompted a trend towards more frequent tissue testing so that mid-season fertigation adjustments may be made for the current crop. Fresh plant tissue and sap testing can be done by labs or in the field by farmers themselves. This allows for frequent, inexpensive testing.

There are many techniques and interpretations for tissue testing. Regardless of the technique, it's important to consider the stage of growth, the part of the plant and the correct sampling time when collecting tissue samples. For proper interpretation, the tissue sampled must be the same as the tissue used as the standard for comparison in making the nutrient recommendation. Types of approaches include the critical level approach, the sufficiency range approach, the nutrient ratio/product approach, and the diagnosis and recommendation integrated system (DRIS) approach. Fresh plant sap testing has also gained popularity, due to the speed and simplicity of this test compared to traditional tissue testing. Plant tissue interpretation techniques can potentially be applied to plant sap measurements as well.

Summary of Plant/Soil/Water Relationships

Old practices may no longer apply with drip irrigation.

Drip irrigation systems have empowered growers to fine-tune and spoon-feed their crops as never before. For this reason, new types of soil/water/plant tests are being performed more frequently, and in many cases, **old guidelines are being rewritten to take into account drip's higher yield potential**. In order to maximize drip system benefits, it's important to seek out current information for local crops and conditions, and to be open to changing previous practices that may no longer apply to the drip irrigation growing environment.

4.2 General Chemical Injection Guidelines

Acid, chlorine, pesticides and other chemicals may be applied to keep the irrigation system clean and to protect system components from damage. In addition, chemicals are routinely applied for agronomic purposes. It's important to chemigate properly in order to avoid clogging the irrigation system, jeopardizing components, polluting the water source and/or the surrounding environment, or jeopardizing the safety of humans who have access to the irrigation systems. Chemigation can be complicated and dangerous and should be performed with extreme caution and care. This discussion is not meant to be comprehensive and is only meant to provide some general guidelines. Further information regarding chemical injection rates, formulas, safety and compliance information are readily available from local dealer, manufacturer, university or consultant sources. It is highly encouraged that these or other sources be consulted regarding this important topic. The label should always be read and followed carefully.

Guidelines for Applying Chemicals

Here are general guidelines to keep in mind when applying chemicals (Boswell, 2000):

1. The chemicals must be **reasonably soluble**.
2. If two or more chemicals are mixed to prepare a stock solution for injection into the irrigation system, **a "jar test" should be performed** (see below) to ensure the chemicals do not react with each other to form a precipitate.
3. The chemicals must be **compatible with the irrigation water.** Factors such as salinity and pH may affect solubility of injected chemicals. Chlorine and various dissolved solids may react with injected chemicals after injection into the irrigation water.
4. When dissolved in water, the chemicals must not form scum or sediments that will enter the irrigation system to create problems. Chemicals should be **reasonably free of impurities that could cause clogging.**
5. The chemicals used **must not attack, corrode, or otherwise impair materials or components** used in the micro irrigation system. Some chemicals can be particularly damaging; for example, chlorine can damage brass components used in gauges, meters, or pump impellers, and some pesticides will attack PVC and other plastics.
6. The chemical injection point should be located **upstream** of the system filter so that any impurities or precipitates resulting from chemical injection are removed.
7. **CAUTION: ALWAYS ADD ACID TO WATER. NEVER ADD WATER TO ACID.**
8. **CAUTION: NEVER MIX OR STORE ACID AND CHLORINE TOGETHER.**

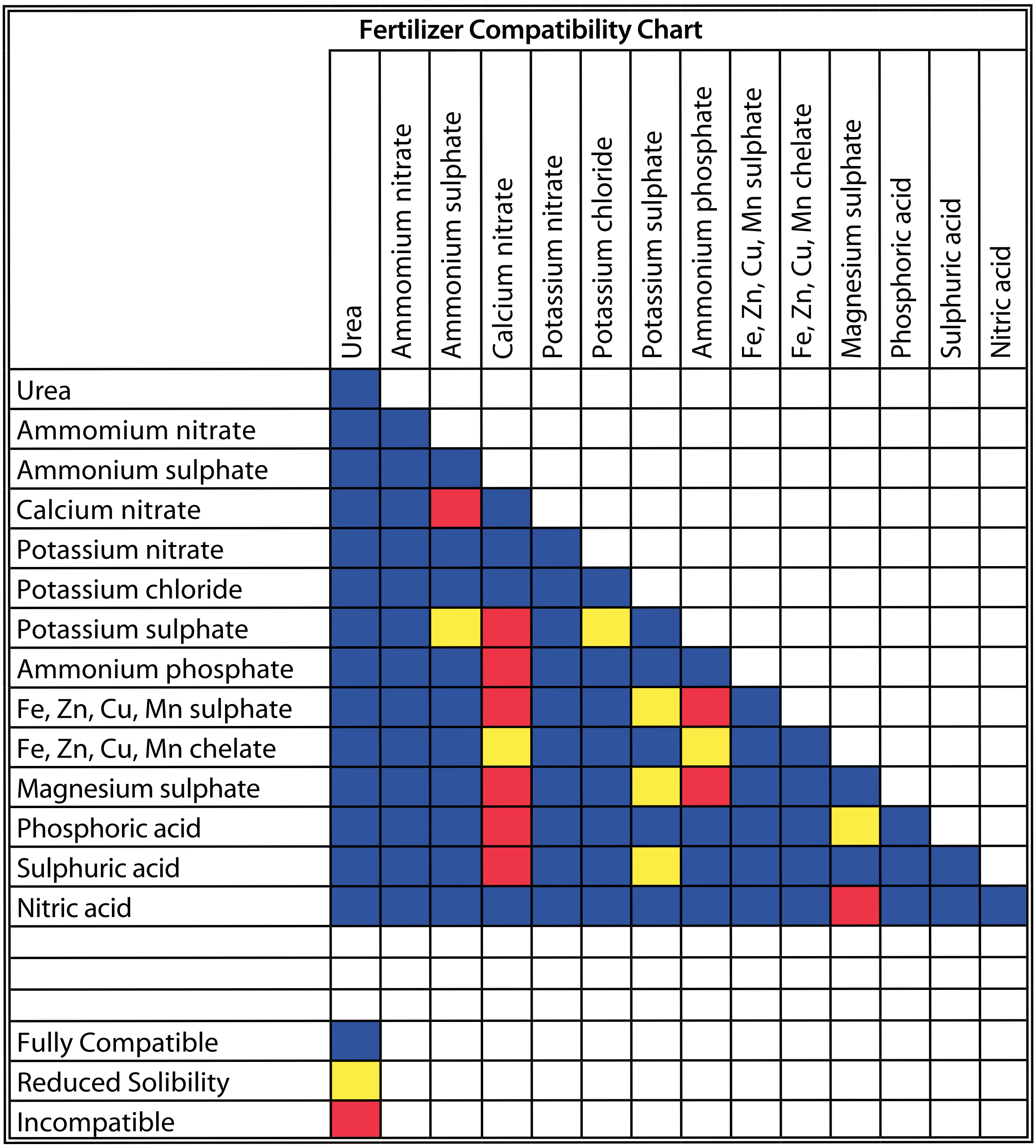
Conduct a Compatibility Test ("Jar Test")

A simple compatibility test, sometimes called "the jar test", should always be carried out before any chemical, including fertilizer, is injected into the system. Take a clean jar and fill it with water from the irrigation system water supply. Add a small amount of the chemical to be injected so that the concentration is slightly higher than anticipated for injection, then shake well. Allow the jar to sit undisturbed for 24 hours and then examine it for cloudiness, sediments on the bottom, or scum on the surface of the water. If any reaction occurs, injection of this chemical is not recommended.

Always conduct a jar test before applying chemicals.

These pictures show the results of a 24-hour test. An alternative fertilizer was chosen rather than this one.

If more than one chemical is injected at the same time, compatibility charts such as the one below (Van der Gulik, 1999, p. 241) may be consulted beforehand to help predict compatibility problems.



Follow Best Practices

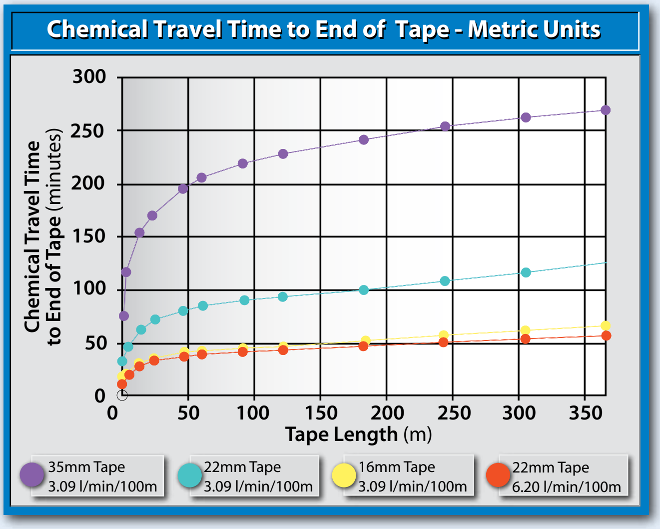
In addition, it's important to follow best management practices outlined by the chemical manufacturer to ensure the chemical provides the value intended, isn't wasted and/or doesn't cause unintended harm. Follow recommendations regarding when the chemical should be applied, for how long, and whether a clean water flush should occur after injection. **Some chemicals are best applied at the beginning of the irrigation event, others towards the end.** For example, highly mobile nitrogen fertilizers should be injected towards the end of the irrigation cycle rather than the beginning to prevent leaching.

Scheduling Considerations

Ideally, the chemical injected is evenly distributed throughout the field. The following graph, "Chemical Travel Time to End of Tape" (Burt, 2007), illustrates how long it takes a chemical to travel from the beginning to the end of various tape laterals, assuming the tape is already full of water (see Establish Baseline Readings for fill time calculation). For example, it can take anywhere from 40 minutes to over 4 hours for chemicals at the head of the tape line to reach the end depending on tape diameter, flow rate and length of run. This must be considered when scheduling chemigation events because the duration of operation must exceed the chemical travel time in order for all emitters to receive chemical.

> Chemical travel time must be considered.

To avoid chemical travel time issues, start the system in "flush mode" and then inject chemical at the desired concentration until chemical begins to exit the flush line. Then close the flush valves and resume normal operating conditions. This accelerates chemical travel time to the end of the field, and helps to balance the application to all parts of the field. If the chemical is chlorine for the purpose of shock treating algae and other contaminants, shut off the irrigation system after the flush valves are closed. In this way, concentrated chlorine will be delivered faster and more evenly throughout the field and can treat the algae in the pipeline (Burt, 2007, p. 233).



The following guidelines may be used as a rule of thumb (Schwankl, 2001):

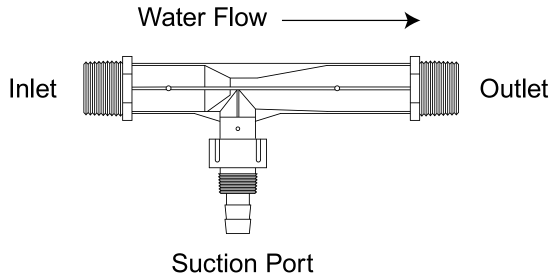
- **Trees and vines** – injections should last at least 1 hour, and at least 1 hour (longer is better) of clean water irrigation should follow it.
- **Row crop drip** – injections should be at least 2 hours in length, and there should be at least 2 hours (longer is better) of clean water irrigation following injection.

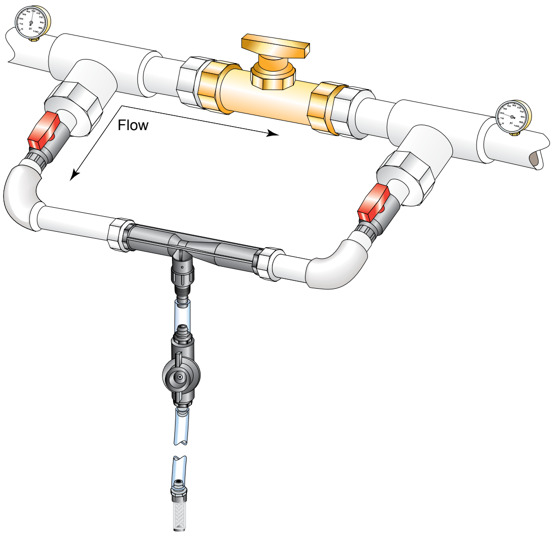
4.3 Chemical Injection Equipment

Chemicals may be injected into pressurized drip systems via a variety of methods including positive displacement pumps, differential pressure tanks, and venturi-type suction devices. Venturi devices such as those shown here are popular because of their simplicity and low cost, and because they don't require a power source. They use differential pressure in the irrigation system to create a low pressure zone, or vacuum, in the injector throat. This vacuum efficiently draws chemicals into the pressurized water line, eliminating the need for a separate chemical injection pump. Venturi devices may be installed directly into the mainline, or they may be connected in series with a small centrifugal pump in a parallel circuit.

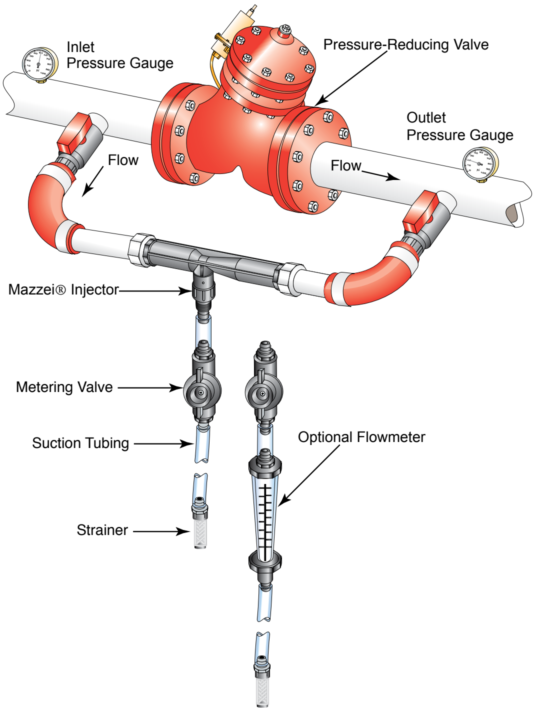
A venturi injector may also be connected in parallel with a valve or filter to take advantage of the pressure differential across these system components. Due to their simplicity, venturi injection systems are highly reliable, and are available in a wide variety of sizes to fit most applications. Portable injector units, driven by gasoline-powered pumps, are convenient for normal use and also for a variety of special applications.

Three typical configurations are shown in the following illustrations (courtesy of Mazzei® Injector Company).

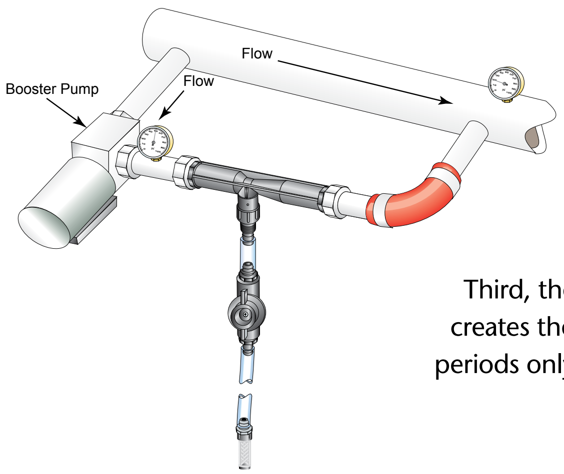




First, the injector may be plumbed in parallel with a simple, manually operated valve on the mainline circuit as shown to the left. Restricting flow on the mainline valve will create a pressure differential between the venture inlet and outlet, thereby creating suction pressure to the chemical line.



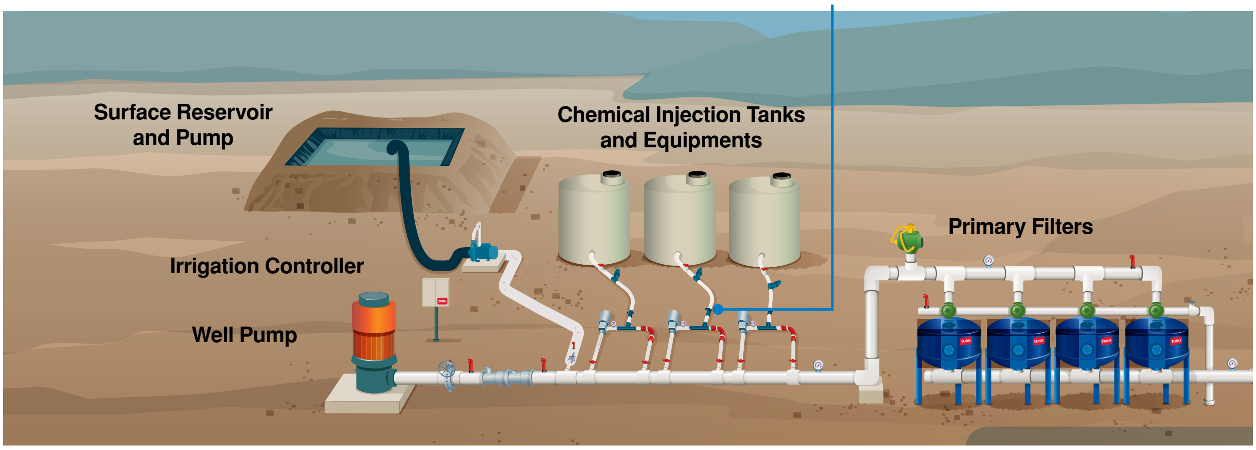
Second, the injector may be plumbed in parallel with a pressure reducing valve as shown to the right, which automatically creates a pressure differential and suction pressure.



Third, they may be plumbed with a small booster pump that creates the needed pressure differential during chemical injection periods only, as shown to the right.

The illustration below shows the boosted venturi configuration in use on three separate chemical tanks. Typically, one tank would be used for fertilizer, one for chlorine and another for acid such that pH may be lowered while injecting chlorine from a separate tank, thus improving the chlorine efficacy. Additional tanks and injectors may be desired if more than one type of fertilizer or chemical other than acid and chlorine will be injected.

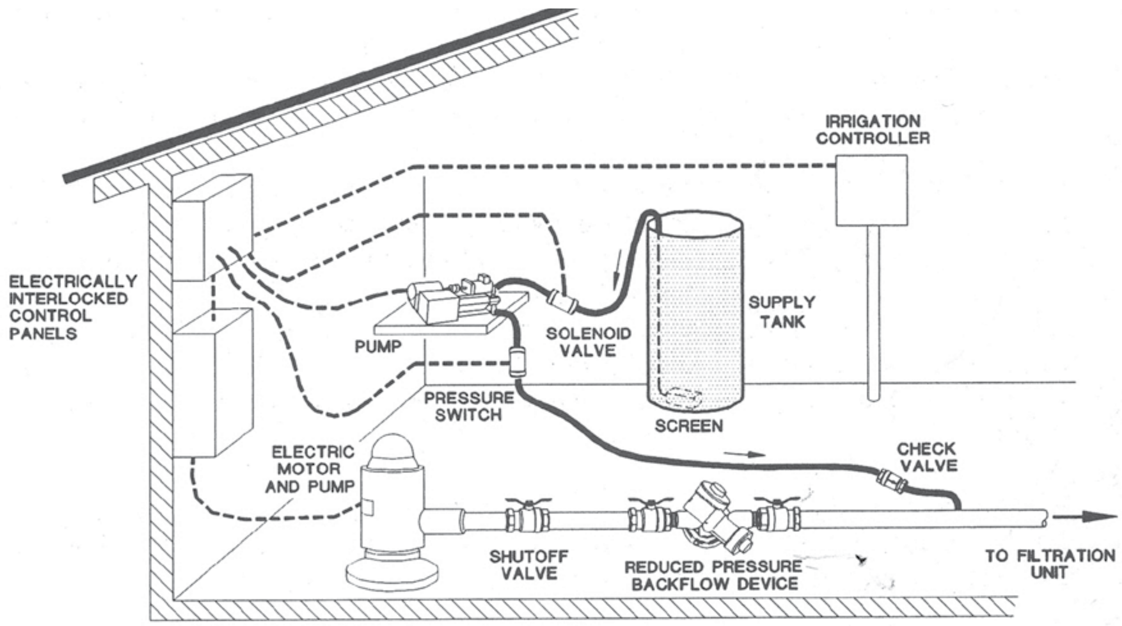
Boosted Venturi configuration



The choice of configuration depends on desired injection rate, standard system operating flow and pressure, and energy costs, and is best decided at the time of system design to maximize energy efficiency. It is best to consult with fertilizer and chemical suppliers in advance so that desired injection rates may be supplied to the irrigation designer.

Safety Considerations

Regardless of the injection system type, proper safety equipment must be employed to prevent chemicals from contaminating the water source or the surrounding environment, and to prevent chemicals from being injected without water being pumped. The figure below (Van der Gulik, 1999) shows the key safety features that should be employed in any chemigation system, including electrically interlocked control panels, check valves and approved backflow prevention devices.



This schematic illustrates the injection system safety features if the irrigation system includes an irrigation pump and injector pump.

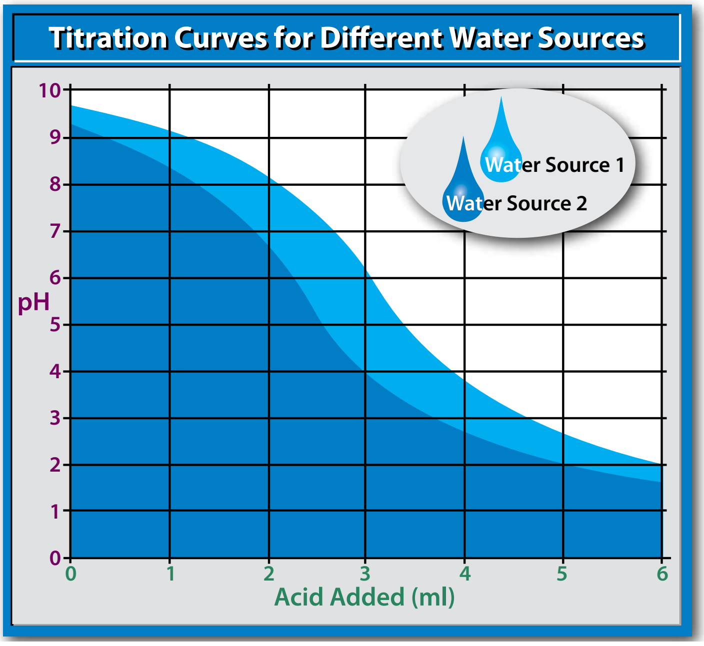
4.4 Chemical Injection Formulas

Consult with a professional to determine the proper rate of chemical injection to achieve desired results, and to comply with all safety requirements and precautions.

Acid

In order to calculate the amount of acid to add to irrigation water to achieve the desired pH, a titration curve is necessary. This can be developed in a lab, or in the field with 200 liter drum filled with the irrigation water. Slowly add the type of acid you wish to inject to the drum and stir the water to ensure complete mixing. Measure the pH of the water along with the amount of acid added, then repeat until the desired pH is obtained. Once this ratio is known, it can be applied to the volume of water that will be applied during the irrigation. The Titration Curve shown in Figure 4-4 is typical for two different water samples with two different pHs (Boswell, 1990).

> Chlorine and acid should always be injected from separate tanks and never mixed together.

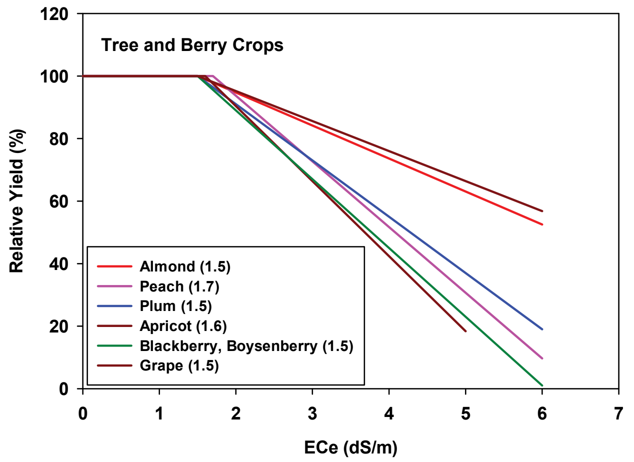


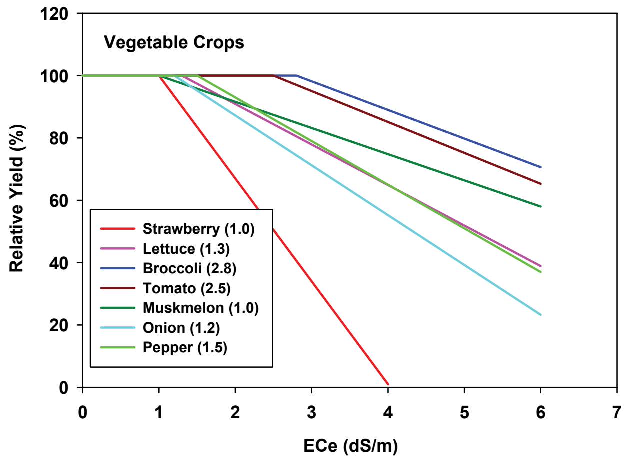
5

SALINITY MANAGEMENT

Salinity Management

Irrigation water often contains salts that are left in the soil after the water has been removed through the evapotranspiration process. Where rainfall is insufficient, supplemental irrigation may be required to leach salts from the root zone, since many crops are sensitive to relatively low levels of salts and may incur a yield drop. The following charts (Hanson, 2003) illustrate how yields may decline with relatively low salt levels:





In arid regions where saline irrigation water is used, a buildup of salts will frequently occur on the soil surface. Salts also concentrate below the soil surface at the perimeter of the soil volume wetted by each emitter.

Operate the drip system during rain to ensure that salts are leached beyond the root zone.

In the absence of rain, this buildup can be tolerated with occasional irrigations to perform leaching. However, if rain occurs before salts have been routinely leached away with irrigation, the rain may wash accumulated salts back into the root zone and threaten plant health. To avoid toxic salt levels in the root zone during a rain event, **run the irrigation system *while it is raining* until salts have been leached beyond the root zone.**

Emitter Spacing and Bed Shape Can Help

Salinity management is especially important during seed germination and emergence, and closely spaced emitters and bed shape can help. Use surface tape (or tape only a few centimeters below the soil's surface) with closely spaced emitters to leach salts downward. In more arid areas, widely spaced holes (i.e. one tape for every two rows, or hole spacing greater than 40 cm can cause salt buildup between the holes. Seeds later planted in those salty areas will not emerge. Decades of experience with flood irrigation have taught farmers to shape furrows so that salt-laden irrigation water evaporates at high points in the bed with the plants/seeds located at lower points (Burt, 2007).

Likewise, drip irrigated beds should be shaped with an indentation where salts will accumulate away from the seed line planted below the indentation. (Burt, pgs. 76-77). Salinity management is also important in established drip irrigated orchards and vineyards. Drip laterals typically wet less than 40% of the total soil surface. Over time, salts carried to this wetted strip through the irrigation water will safely leach away from the soil close to the emitter. However, salts will concentrate in the soil as distance from the emitter increases. For this reason, the standard "leaching requirement" equations and principles for maintenance leaching are not applicable for drip/micro irrigation. Instead, periodic "reclamation" leaching is needed to remove the salt from these outer zones of the soil.

Target Leaching Reduces Waste

For reclamation, either broadcast flood or sprinkler irrigation is typically used to leach these concentrated salts below the root zone, but it can be wasteful since only 20-40% of the surface area of the orchard or vineyard needs to be leached. If 100% of the soil area is wet to treat this 20-40% of the area, 2.5 to 5.0 times the necessary leaching water will be applied. Most of the water is ineffective because it is applied to zones that do not need leaching. Instead, ITRC researchers have suggested using a portable drip tape system to "target leach" the orchard or vineyard dripline zone. In 2005, Burt and Isbell showed that salts were effectively removed in a pistachio orchard using six lines of retrievable surface drip tape with emitters spaced closely 30 cm apart, to "target leach" the dripline zone (see photo below). Subsequent leaching experiments closely match the pistachio orchard results. Once leaching is complete, the drip tape can be retrieved and reused. In this way, closely spaced tape emitters perform leaching with less water (Burt, pgs. 82-83).

Low-flow drip tapes, spaced 0.3 meters apart, were used to apply the leaching water.

Improving Yield

Drip irrigation can also help dilute soil salinity to improve yields. Yields typically decrease once the soil salinity reaches a threshold value, and as the soil dries between traditional irrigations, salinity concentration becomes worse. Irrigating frequently with closely spaced emitters can help. Studies and experience show that if drip is managed so that the soil salinity remains dilute, yields can be higher than they would be with the same water quality using sprinklers or furrow irrigation. For some crops such as processing tomatoes, some research (Hanson and May, 2003) has observed that on very salty fields the crops have no damage even though the salinity levels would traditionally cause serious yield declines. (Burt, pg. 86).

6

FILTRATION

Filtration

6.1 Scope and capacity of the filtration

Irrigation water filtration is a physical process that can remove solids (both of an organic and inorganic nature) suspended in the water that are large enough to cause emitters' clogging. The filtration is not able to remove substances dissolved in the irrigation water such as iron, manganese, bicarbonate, sulphydric acid, etc. The removal and the processes to reduce clogging caused by these solutes relate to water treatment and are not covered in this section.

6.2 Filtering capacity

The filtering capacity is a filter's ability to remove particles that have a dimension greater than a certain value. A filter with a filtering capacity of 115 microns (0.115 mm) is able to stop particles that are larger than 115 microns. The filtering capacity is often expressed in mesh, which is a measurement that is derived from the textile industry and indicates the number of holes per surface unit; this comes from the fact that the first filters were composed of filtering elements that were made of fabric.

There are mesh/micron conversion tables that give approximate values because the passage for a fabric not only depends on the number of holes per surface unit, but also the thickness of the yarn used to make the fabric.

This is where the difference between total filtering surface and active filtering surface is derived.

For screen filters the total filtering surface is determined by the circumference of the filtering mass multiplied by its height. The active surface is a fraction of the total surface and is the overall surface of the free passage holes that are not blocked by the structure that holds the filtering fabric. This difference is very important, especially when selecting automatic screen filters.

The filtering capacity should be selected based on the flow properties of the emitters (size of the internal passages, level of flow turbulence).

6.3 Selection and sizing of filtration systems

For water with more than 300 ppm of suspended solids, a sedimentation tank must be installed upstream of the filtration system. Amounts less than this can be removed with filtering devices used in the agriculture industry.

The filters for microirrigation systems must be selected based on the nature of the substances to be filtered (organic or inorganic) as well as on their quantity and origin.

The sizing of the filtration systems is in line with the system's maximum flow rate and with the amount of suspended solids in the water, therefore physical analysis of the water should be performed to determine the amount.

This analysis should determine the content in parts per million of suspended solids (1 ppm = 1 mg/l) and should differentiate the percent organic from the percent inorganic.

In some cases a particle size analysis of the suspended solids should be performed. If the water is drawn from a well, physical and chemical analyses should be performed on it in order to identify and quantify the solutes that can be the source of clogging in the irrigation systems. If the water is taken from canals or open-air basins, the amount of suspended solids will vary during the irrigation season in relation to the weather, sunlight, amount of organic substances (algae and other microflora) as well as other environmental conditions. Regular sampling and testing can be repeated to monitor any changes.

For collection basins, appropriate substances selected to reduce the organic content can be used.

6.4 Types of filters

The filters used in the irrigation systems can be classified based on their filtration principle: hydrocyclones or sand separators, screen filters, disc filters and sand filters.

A. Hydrocyclone sand separators

Hydrocyclones sand separators are devices that use centrifugal force to separate coarse particles from water that have a specific weight greater than that of water (mainly sand). The separated particles fall into the tank below the hydrocyclone, where they can be removed either manually or automatically.
To be efficient, the speed of the water inside the hydrocyclones must be very high. Since there are no instruments available that can economically measure this speed, the head loss between the inlet and the outlet of the hydrocyclone (speed and head loss are directly proportional) is measured. A hydrocyclone must have a head loss of 0.6 - 1.0 bar between the inlet and outlet to be efficient. At lower head losses the efficiency will be minimal or none. The head loss is closely related to the flow rate, therefore hydrocyclones should not be used in systems with variable flow rates. A correctly sized hydrocyclone can separate 70-90% of the coarse and medium sand suspended in the water. Hydrocyclones must always have downstream screen, disc or sand filters.

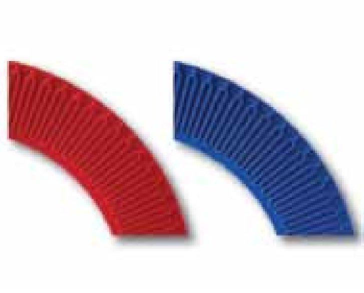
B. Screen filters

Screen filters are composed of a metal or plastic case that houses a filtering mass (cartridge) made of a screen (stainless steel or polyester) held by a metal or plastic support structure.
The filtering capacity is determined by the mesh size. Ideally, screen filters must be selected so that the head loss at the maximum flow rate is 0.2 bar but not greater than 0.3 bar with clean water. The amount of suspended solids in the water must be considered when determining the filter's size. The greater the active filtering surface of the filter, the longer the time interval between one cleaning operation and the next. The screen filters must be cleaned when the pressure differential between the inlet and outlet reaches 0.5 - 0.6 bar.
If this value is exceeded, the filtering screen will be subject to lacerations or deformation, allowing particles to pass through. These particles will then block the emitters; any organic substance will be broken up and forced to go through the filtering mass, which would then accumulate in the emitters creating a high risk of blockage. Timely cleaning of the filters is therefore essential for keeping the irrigation systems operating properly. The cleaning can be done manually by removing the filtering mass and cleaning it with a brush or a power washer. The filtering screen can also be cleaned automatically through the use of devices that are activated after a set time and/or when a set pressure differential is reached. A minimum operating pressure, which is indicated by the filter manufacturer, must be guaranteed during the automatic cleaning operations.

Screen filters are ideal for removing inorganic particles (well water) and for water with lower suspended solid values. They are used as field back-up filters in long main pipes and downstream from sand filters.

C. Disc filters

Disc filters are composed of a metal or plastic case that houses a filtering mass made up of a series of discs with knurled surfaces, stacked tightly around a support structure. The knurling on the surface of the discs determines the filtering capacity. With respect to screen filters, there is a lower risk of breakage of the filtering mass with disc filters.
Ideally, they must be selected so that the head loss at the system's maximum flow rate is 0.2 bar but not



greater than 0.3 bar with clean water. The amount of suspended solids in the water must then be considered when determining the filter's size. The greater the active filtering surface of the filter, the longer the time interval between one cleaning operation and the next. The disc filters must be cleaned when the pressure differential between the inlet and outlet reaches 0.5 - 0.6 bar. If this value is exceeded, the particles could become lodged between the discs and be difficult to remove during the washing operations and can sometimes even deform the structure of the discs. Any organic substance will be broken up and forced through the filter, which would then accumulate in the emitters causing a high risk of clogging. Timely cleaning of the disc filters is therefore essential for keeping the irrigation systems operating properly. Cleaning is done by removing the filtering masses, loosening the discs and then using a brush or power washer. If the discs are encrusted with precipitate or organic substance that cannot be mechanically removed, they can be washed by immersing them in acidic (if bicarbonate precipitates are present) or oxidizing substances (if organic substances are present).

Automatic filters can also be used. In this case the discs are automatically cleaned by means of special mechanisms that use devices which are activated after a set time and/or when a set pressure differential is reached. During automatic cleaning, the pack of discs are opened and they are then sprayed with water jets (coming from the support structure) which cause them to rotate quickly and expel the sediment while washing the surface of the discs at the same time.

A minimum operating pressure, which is indicated by the filter manufacturer, must be guaranteed during the automatic cleaning operations.

Disc filters are suitable for removing inorganic particles and limited amounts of organic substances. Their sizing depends on the amount of suspended solids in the water.

D. Sand filters

Sand filters are composed of containers generally made of metal that hold the sand in "slotted lateral assembly" or "mushroom" shaped diffusers that allow the filtered water to pass but not the sand.

The water flows over the sand bed and is purified of suspended organic and inorganic substances by both physical and electrostatic action.

In order for the filtration process to be effective, the sand must have a high roughness (crushed quartz sand), with dimensions that guarantee the predetermined filtering capacity (size of 0.7-1.2 mm is excellent for drip systems). The amount of sand should be such that it does not completely fill the filter, as there must be an empty space above the sand bed to allow the sand to rise during the cleaning process. Each manufacturer indicates the amount of sand to use for each filter model.

The water must pass through the sand bed at a slow speed. This speed is measured as: cubic metres per hour (m3/h) for each square metre of sand bed; the speed must be related to the amount of suspended solids in the water. The greater the suspended contaminants in the water the slower the speed must be to effectively remove the suspended solids. Water having between 100 and 200 ppm of suspended solids generally requires a filtration speed less than or equal to 40 m3/h for each square metre of sand bed.

Example:
Let's consider a water source that naturally has 150 ppm of suspended solids that are mostly organic and a system flow rate of 80 m3/h. Since a filtering surface that is less than or equal to 40 m3/h per square metre of sand is required, a filtration system with a sand filter bed of 2.0 m2 should be selected.

Ideally, the size of the sand filters must be chosen so that the head loss is not greater than 0.2 bar and with a limit of 0.3 bar with clean water. They must also be cleaned when the pressure differential between the inlet and outlet reaches 0.5 - 0.6 bar.
The sand filtration systems must have at least two elements in order to correctly perform the operations to clean the sand, which is done by reversing the flow (backwashing).

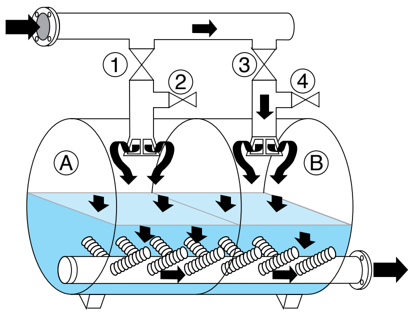
This process can be activated manually by opening the appropriate valves. The second element is cleaned using filtered water from the first element and vice versa. The cleaning of the sand can be automatically activated through the use of 3-way solenoid valves that are connected to a timer and are equipped with a differential safety pressure gauge.
The backwashing is scheduled to take place at set intervals based on the amount of contaminants in the water; if the pressure differential is above the set limit of 0.5 - 0.6 bar, the differential pressure gauge will automatically start the backwash by closing the contact and sending a pulse to the controller. If the backwash is not done at the frequency and in the manner described above, preferential pathways will be created in the sand bed which will severely damage the structure, with a subsequent loss in filtering capacity.
The duration of the backwash will vary based on the sand bed, the particle size of the sand, the pressure differential at the time of the backwash and the nature of the contaminants. The time will vary from approximately 1 to 5 minutes.
The backwash must be done at a speed that will lift and liquefy the sand bed, removing the trapped impurities. For sand with a particle size of 0.7 - 1.2 mm this value corresponds to 40-45 m3/h per square metre of sand.
The backwashing speed must not be too high, as this could cause the sand to be expelled from the filter and discharged. To prevent this from occurring, regulating gate valves should be installed on the drain; in order to monitor the process, put a section of transparent tubing on the drain pipe manifold in order to visually check for the presence of sand.
This transparent tube also allows you to check whether the times set for the backwashing of the sand are effective for removing all the particles held in the sand. When the wash cycle is finished, the head loss at the normal flow rate through the filtration system must be the same as that recorded for a new filter. If this is not the case, the wash process was not effective.

Screen filters (or disc filters) must be installed downstream of the sand filters and act as back-up filters. If the elements that hold the sand in the filter accidentally break, these screen filters will prevent the sand from flowing into the system and obstruct the emitters.
Sand filtration systems are suitable for most irrigation waters and are indispensable for water that has a high concentration of organic substances, such as earthen canals, open-air basins and surface waters in general.

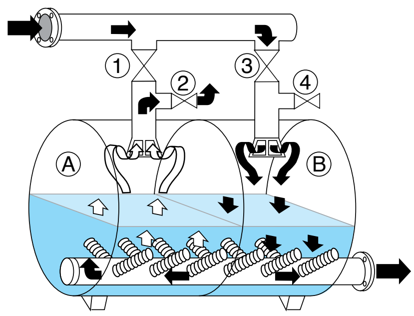
Double chamber sand filter operation

Operation	Position 1	Position 2	Position 3	Position 4
Filtering	❍	●	❍	●
Backwash A	●	❍	❍	●
Backwash B	❍	●	●	❍

Filter operation ➤



Backwash operation ➤



7

SYSTEM MAINTENANCE

System Maintenance

For optimal performance, drip systems require routine system maintenance. Even though recent innovations in drip tape design have made clog-resistant drip tapes readily available, the nature of agricultural water sources, fertilizer injection practices, natural limitations of filtration equipment and the general agricultural growing environment make maintenance a priority. Obviously, a clogged drip system could spell disaster for the current crop and jeopardize a significant investment. As mentioned earlier, taking baseline readings and monitoring flow, pressure and the condition of flush water regularly will provide guidance when maintenance should be scheduled.

Drip Irrigation System Maintenance Tips for the Growing Season

What to Check	Frequency	Compared to What	What to Look For	Possible Causes
Pump flow rate and pressures for each zone	Weekly	Design or benchmark flow rate and pressures	• High flow and/or low pressure • Low flow and/or high pressure	• Leaks in pipelines • Leaks in laterals • Opened flush valves; Opened ends of laterals • Closed zone valves; Pipeline obstruction • Tape clogging • Pump malfunctions; Well problems
Pressure difference across filter	Every irrigation	Manufacturer's specifications	• Exceeds or is close to maximum allowable	• Filter becomming clogged • Obstruction in filter
Operating pressures at ends of laterals	Monthly, unless other checks indicate possible clogging	Benchmark pressures	• Pressure greater than expected • Pressure lower than expected	• Possible clogging; Obstruction in tape • Broken lateral; Leaks in lateral; Low system pressure
Water at lateral ends & flush valves	Bi-weekly	Water source	• Particles in water • Other debris	• Broken pipeline • Hole in filter screen; Tear in filter mesh • Paticles smaller than screen; Filter problem • Chemical/fertilizer precipitation • Algae growth; Bacterial growth
Overall pump station	Weekly	Manufacturer's specifications	• Leaks, breaks, engine reservoir levels, tank levels	• Poor maintenance • Old equipment
Injection pump settings	Weekly	Calibrated setting at start up	• Proper setting for length of injection time	
Overall system	Weekly	System at start up	• Discoloration at outlets or ends of laterals • Leaks in tape • Wilting crop	• Indicates possible build up of minerals, fertilizer, algae, and/or bacterial slime. • Pest or mechanical damage • Tape off of fittings • Tape blowout from high pressure • Crop may also be affected by pathogens • Tape clogged, obstructed, or broken.

Maintenance Checklist

The table on the preceding page (Simonne et al., 2008, pg. 18) provides a checklist of what to inspect and when. Note that in addition to flow, pressure and condition of flush water, the overall condition of the pump station and distribution system should be routinely inspected and/or calibrated including control equipment, engines, motors, reservoirs, injectors, pipelines, valves, fittings, flow meters and pressure gauges. Broken or dysfunctional equipment should be replaced or repaired immediately with the same or similar equipment that will perform the same function according to system design criteria.

Aside from making equipment adjustments or repairs, the majority of system maintenance activities usually fall into three major categories: applying chemicals, flushing the system and controlling pests.

7.1 Apply Chemicals

Acid and/or chlorine are commonly injected into drip systems — each from its own separate tank using a separate injector for safety reasons — to treat the water and prevent clogging from organic growth, mineral precipitation and/or root intrusion. The following Table 5 (Rogers, 2003) summarizes the various problems and treatment options for chemical and biological growth problems in conventional systems. Note that all but one treatment option (aeration and settling) involves the use of chlorine or acid, and that mineral concentrations as low as .1 ppm can lead to clogging. Also note the importance of pH control, and that treatment options include intermittent or continuous injection strategies.

Water Treatments to Prevent Clogging in Drip Irrigation Systems

Problem	Treatment Options
• **Carbonate precipitation (white precipitate)** HCO3 greater than 2.0 meq/l – pH greater than 7.5	1. Continuous injection: maintain pH between 5 and 7. 2. Periodic injection: maintain pH at under 4 for 30 to 60 minutes daily.
• **Iron precipitation (reddish precipitate)** Iron concentrations greater than 0.1 ppm	1. Aeration and settling to oxidize iron. (Best treatment for high concentrations of 10 ppm or more). 2. Chlorine precipitation – injecting chlorine to precipitate iron: a. Use an injection rate of 1 ppm of chlorine per 0.7 ppm of iron. b. Inject in front of the filter so the precipitate is filtered out. 3. Reduce pH to 4 or less for 30 to 60 minutes daily.
• **Manganese precipitation (black precipitation)** Manganese concentrations greater than 0.1 ppm10	1. Inject 1 ppm of chlorine per 1.3 ppm of manganese in front of the filter.
• **Iron bacteria (reddish slime)** Iron concentrations greater than 0.1 ppm	1. Inject chlorine at a rate of 1 ppm free chlorine continuously, or 10 to 20 ppm for 30 to 60 minutes daily.
• **Sulfur bacteria (white cottony slime)** Sulfide concentrations greater than 0.1 ppm	1. Inject chlorine continuously at a rate of 1 ppm per 4 to 8 ppm of hydrogen sulfide – ***or*** – 2. Inject chlorine intermittently at 1 ppm free chlorine for 30 to 60 minutes daily.
• **Bacterial slime and algae**	1. Inject chlorine at a rate of 0.5 to 1 ppm continuously, or 20 ppm for 20 minutes at the end of each irrigation cycle.
• **Iron sulfide (black sand-like material)** Iron and sulfide concentrations greater than 0.1 ppm	1. Dissolve iron by injecting acid continuously to lower pH to between 5 and 7.

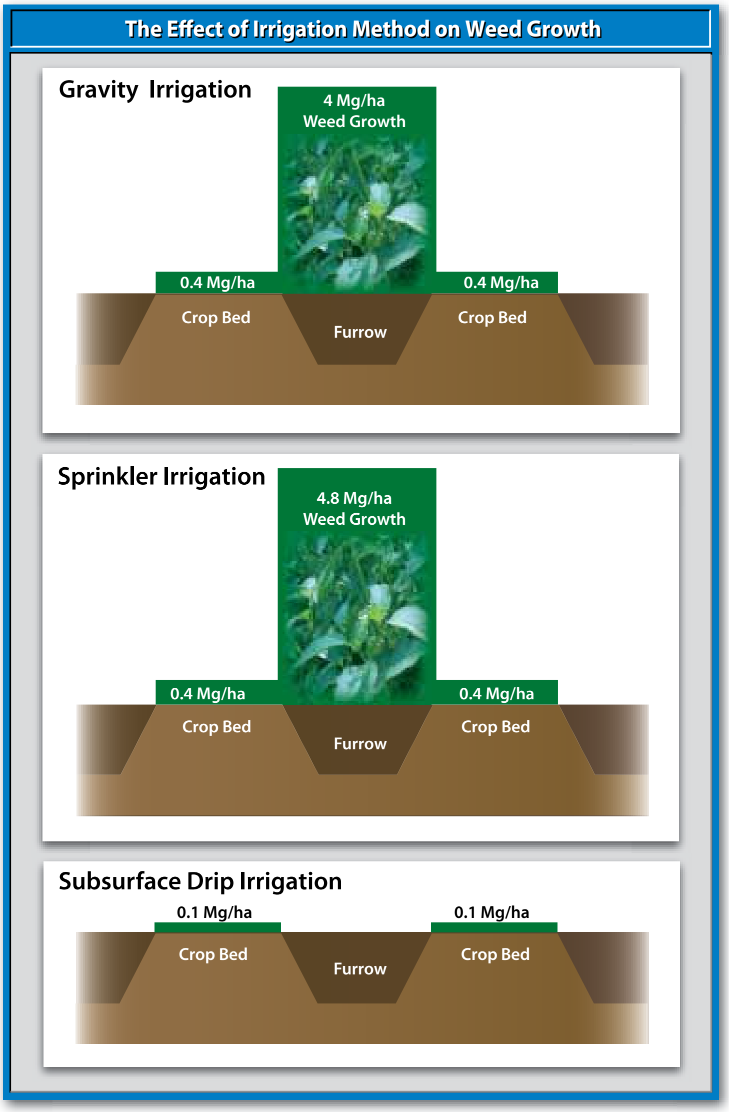
In addition to chemical and biological problems, acid and chlorine are often used to remedy root intrusion problems. Many growers report that root intrusion may be prevented if irrigations are frequent — and if deficit irrigation and seamed tapes are avoided. If roots have entered the flowpath, growers have achieved success by:

Use seamless Aqua-Traxx drip tape to avoid root intrusion.

- Applying acid or acidic fertilizers once a week to reduce the pH to 2.0 while the crop is still being grown. If acidic fertilizers are used, soil pH should be monitored carefully to avoid detrimental effects to the soil chemistry.
- Superchlorinating to 400 ppm and at a pH of 6.0 – 6.5 for long enough to fill the tubes with water, after the crop has been removed. (Burt 2007, pg. 272).
- Using various other pesticides and fumigants. Consult with local experts to ensure safe, effective and legal chemical application.

Organic Farming

In addition to conventional farmers, organic farmers use drip irrigation since spoon-feeding water and fertilizer directly to the root zone often reduces weed growth, disease and pest problems — all of which are difficult or expensive to control without chemicals. Research has shown, as illustrated here, that furrow and sprinkler irrigated fields experience severe weed growth without herbicides, while drip fields experienced little (Lamm, 2007 after Grattan et al). Although this benefit is significant for all drip-irrigated fields, it's especially important where chemical control is not allowed.



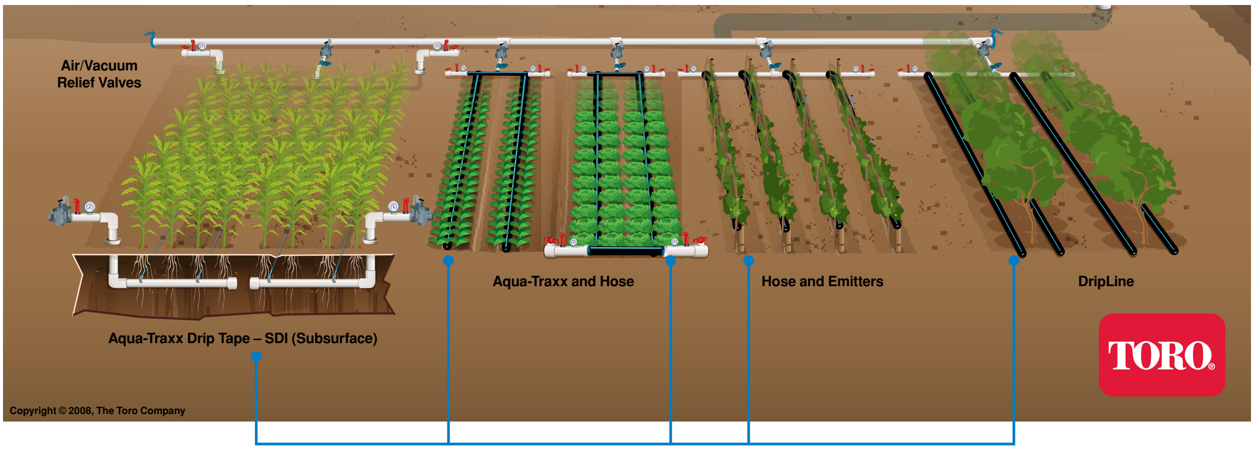
Since many of the materials routinely applied for system maintenance in conventional fields aren't allowed in organic fields, alternative materials must be used. Likewise, since many of the alternative materials used in organic fields are prone to clog a drip irrigation system, it's wise to install secondary filtration at each zone in case materials precipitate out of solution between the pump station filter outlet and the inlet to the zone (see Typical Drip System Layout illustration on page 8).

> Weed growth is drastically reduced in subsurface drip irrigation fields.

7.2 Flush the System

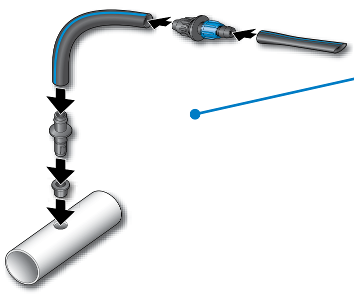
System flushing is often overlooked or given lower priority in surface drip systems. However, in SDI systems, system flushing must be given high priority since frequent tape replacement is impractical and tape is expected to last up to 20 years or longer. But even for short term tape use, flushing is important to maintain system uniformity. Thus, whether surface drip or SDI, it's imperative that the system not only be designed for high application uniformity, but for flushing as well to rid the system of settled debris in the pipelines and emitters. The Typical Drip System Layout diagram shows the various flushing options including a flushing submain for SDI systems, semi-permanent PE pipe flushing submains, end-of-the-line flush valves and simple end-of-the-line fittings. Chapter 2 shows detailed information on how these connections are made.

> Flush the system routinely with adequate pressure and flow.

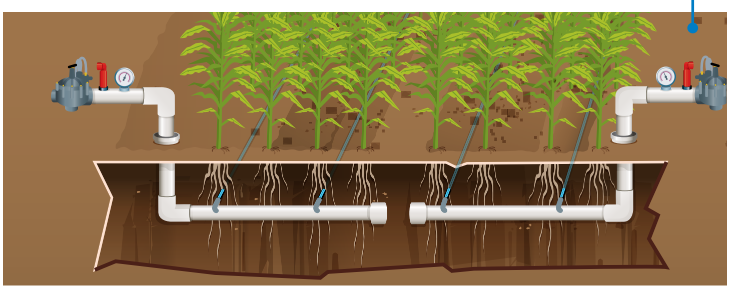


Various end-of-the-line configurations are available for both surface and subsurface drip irrigation systems.

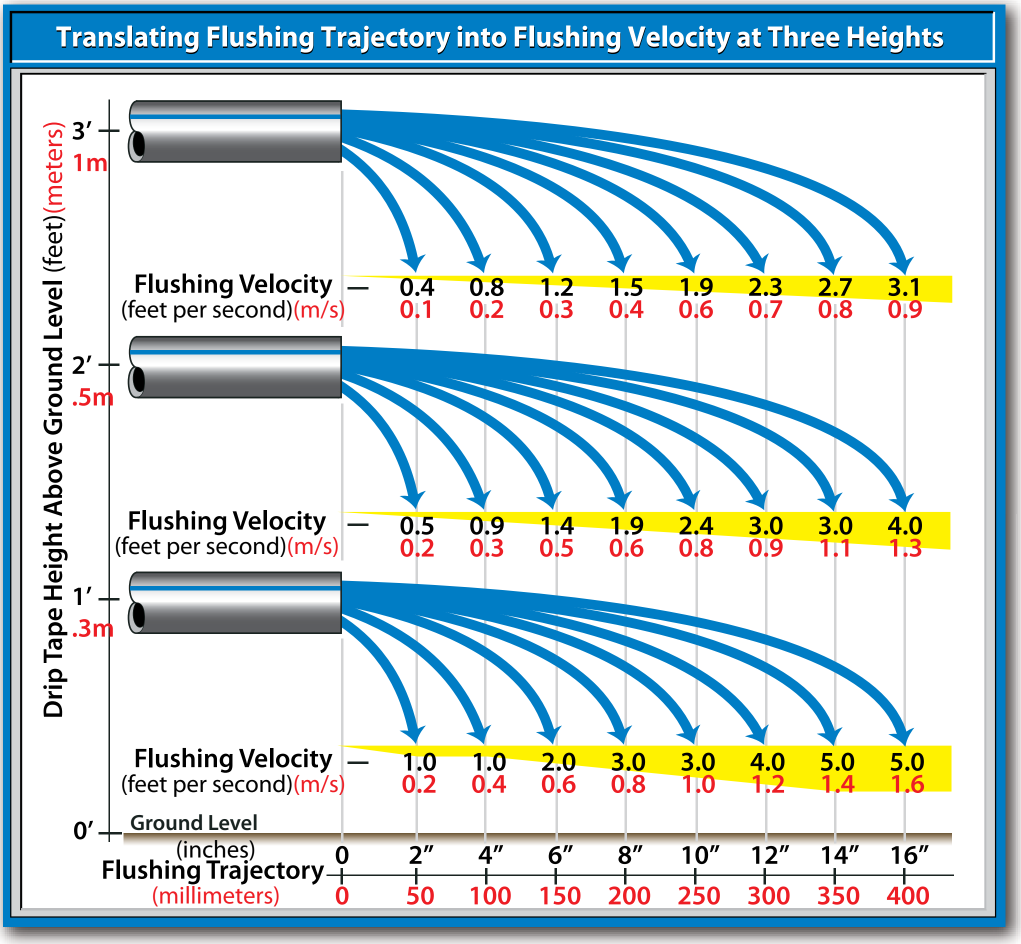
In most cases, tape length of run and pipeline sizes will be dictated by flushing velocity requirements rather than a targeted emission uniformity, and pumps will be sized according to flushing flow requirements.



Flushing pressure requirements are influenced by elevation changes and friction losses in the flushing submain assembly.



The adjacent photos show a hybrid SDI system where the ends of the buried tape lines have been brought to the surface. In this case, each line is opened manually and flushed until the water runs clear.



The previous illustration, "Translating Flushing Trajectory into Flushing Velocity at Three Heights," may be used by field personnel to determine whether adequate flushing velocities are being achieved during manual flushing. This is determined by measuring the distance of water flushing trajectory from the end of the hose, and then comparing that distance with flushing velocity on the chart. For instance, if a tape lateral is held one foot (0.3 meters) above ground level, and the flushing trajectory is eight inches (200 mm), then the flushing velocity is about 0.8 m/s, which in most cases should be adequate.

Flushing should occur as often as needed to keep lines clean and will depend on seasonal water quality, temperature and the effectiveness of the system filter. Mainlines, submains and laterals should be flushed sequentially until flush water runs clear for at least two minutes. Flush water should be disposed of properly to avoid deteriorating the system's inlet water quality and/or the quality of the environment surrounding the site. And since inlet pressures and system flows are significantly higher during flushing events, they must be supported with proper pumps, pipelines, dripline or drip tapes to perform flushing properly.

7.3 Control Pests

Because drip tape is susceptible to mechanical damage by mammals, rodents and insects, pests must be controlled or managed. A wide range of treatment options are available, including chemigation. **Before chemigation is performed, ensure that the product is labeled for the application and that all safety requirements and best management practices requirements are met.**

> Make monitoring for pests part of your routine so that control measures can be implemented before damage is done.

Animal damage to SDI systems can be a significant problem, especially in areas bordering on undeveloped land. Burrowing animals — such as gophers, rats, mice, voles, and ground squirrels — can cause damage to surface or buried polyethylene laterals. Rather than searching for water, these rodents are often gnawing on hard materials to wear down their continuously growing teeth (Lamm, 2007). Other animals, including crows and coyotes, have been known to damage lateral lines, apparently in search of water. If present in sufficient numbers, these animals are able to heavily damage a micro irrigation system.

Basic Solutions for Pest Problems

The four basic solutions for pest problems are:

1. Using repellents to keep animals away from the lateral lines
2. Baiting or trapping to control the animal population
3. Elimination of the animals' food supply
4. Providing a drinking water source other than the lateral lines

Repellents

Repellents keep animals away through some type of chemical that tastes or smells bad to the animal. Repellents may either be injected through the system or laid down with the laterals during installation. Generally speaking, injection of the chemical through the system is the preferred technique, since chemicals applied during installation will eventually lose their potency or be leached away over time. There are a number of chemicals available which are noxious to animals, including anhydrous or aqua ammonia and a number of insecticides.

Trapping

Trapping is often effective on smaller installations, but may be impractical for large acreages because of the high labor requirement. Trapping may be valuable in determining what species of animal is responsible for the damage. Baiting is often achieved manually, by injecting bait underground with a tractor, or by ground or aerial application, and is effective and economical in most cases.

Food Supply

Weeds or the crop itself may provide a food supply for burrowing animals. If the food supply is weeds, weed control may eliminate the problem. If the food supply is the crop, then control of the animal population will probably be beneficial in terms of the health and yield of the crop.

Thirsty animals may damage surface or buried laterals by chewing in search of water. Some farmers have reduced this damage by placing water buckets in strategic locations. These may be kept full by means of an emitter plugged into a lateral line. (Boswell, 1990).

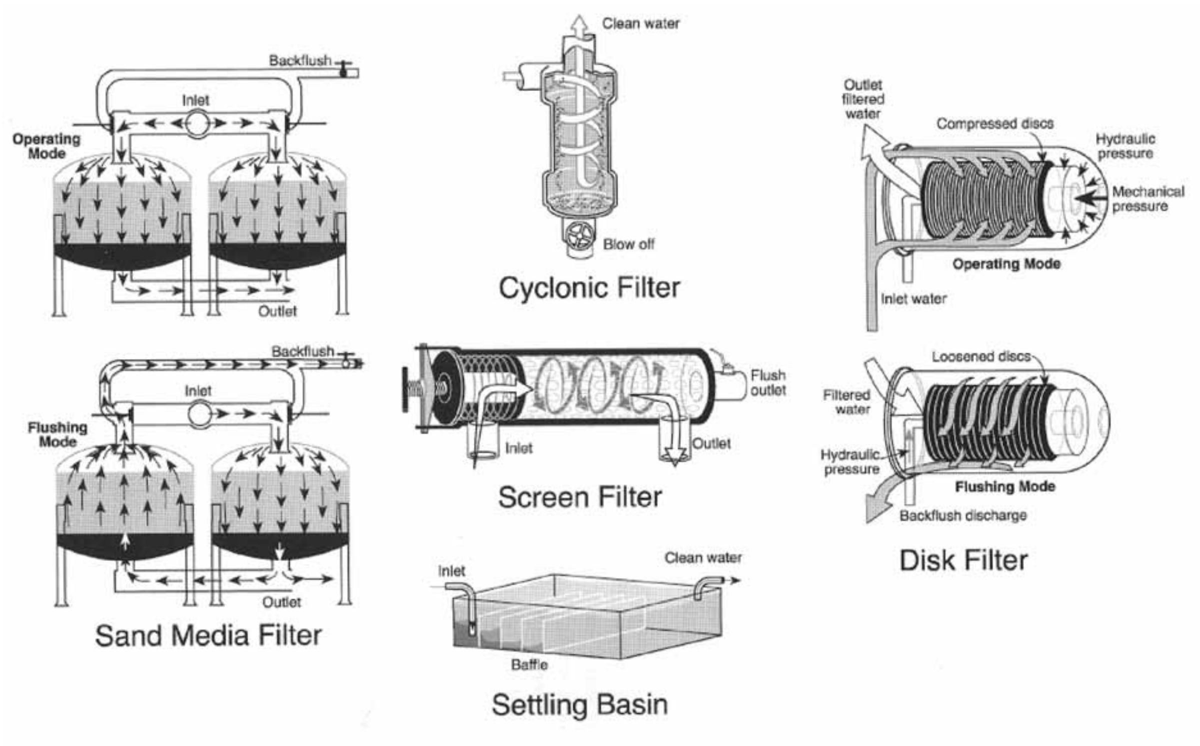
Pest Control

To control pests, Burt et al (2007) recommends 1) using thick wall tape, 2) turning the irrigation system on as soon as the tape is installed, 3) killing insects with chemicals, 4) using owl boxes to control gophers, 5) using "noise" to frighten animals away, 6) providing water basins in the hope that critters will drink from them rather than chew on drip lines, 7) providing cow bones to play with rather than drip lines, and 8) eliminating the animals.

As always, before chemigation is performed, ensure that the product is labeled for the application and that all safety requirements and best management practices requirements are met.
Lamm (2007) provides specific information on burrowing depths and habitat preferences of some burrowing mammals in the United States, and reports that many burrowing mammals of concern in the U.S. have a typical activity depth range of less than 0.5 meters. Thus, burying drip lines below 0.5 meters may avoid some rodent damage.

7.4 Service the Filtration System

Maintaining the filtration system is central to overall system maintenance. Sand media, cyclonic, screen and disk filters, as well as settling basins, all require routine attention during and at the end of the irrigation season. The illustration below shows many of the filters typically used in drip systems (Lamm, 2007). They can all perform well in any given application providing they are sized properly to filter the given water quality to the degree required to protect the emission devices. Toro provides filtration requirements for all their emission devices, and most filter manufacturers rate the level of filtration achieved in screen size mesh.



Monitoring Pressure Differential

Most filters incur increasingly higher friction losses between the filter inlet and outlet as the filter becomes clogged. Monitor the filter pressure differential frequently, especially as water conditions change through the season. Excessive pressure differential may lead to debris passing through the filters and/or poor irrigation system performance. Many filter systems are automated and will self-clean via an electric or hydraulic 3-way backflush valve when a pre-set filter differential is reached. For this procedure, the water flow is reversed for a short time to carry away debris through a backflush line. Filters may also be serviced manually by activating 3-way backflush valves by hand, or by taking the screen or disk cartridge out of the filter housing and cleaning it with pressurized water and/or brushes.

> All filters should be thoroughly inspected and serviced at least once a year.

Inspecting the Filters

Care should be taken that the system is off and unpressurized when filters are serviced. Screen filters should be inspected for clogging, tears or corrosion, and disk filters inspected for wear or clogging of the grooves within the disk stack. O-rings should also be inspected for wear. Sand media filters should be drained and allowed to dry so that the sand level can be checked, and the sand inspected for signs of caking or other problems. Many irrigators replace the sand media as often as once a year. The flush water control valve setting should also be inspected to verify that excess sand is not exiting the filter during backflush. A clear sight glass, as shown to the left, is often installed for this purpose. If filters are automated, valve, solenoid and controller functionality should be verified. Finally, filters and settling basins should be chlorinated periodically to prevent the growth of microorganisms.

Filter maintenance

The main maintenance operations for keeping the filtration systems operating correctly are described below.

If highly contaminated sources of water are drawn up, a self-cleaning basket should be installed on the pump intake pipe with a 2-3 mm screen which is equipped with jets that can remove the particles that adhere to the screen basket. This will reduce the number of cleaning and maintenance operations.

Common operations for all types of filtration systems

Install pressure gauges upstream and downstream from each filter to monitor the pressure differential between the inlet and outlet of the filter. This value must not exceed 0.5 bar (with the exception of hydrocyclone filters). Vertical dry case and liquid glycerine filled pressure gauges with open upper caps are the preferred types. It is good practice to replace the pressure gauges every year if they are exposed to direct sunlight. The replacement interval is longer if they are in a protected environment.

Once they are cleaned and filtering has restarted, all filter types must have the same pressure differential between the inlet and outlet as they originally had (record the head loss value at the time of commissioning of the filtration system). If this is not the case, either the washing process wasn't effective or the filtering elements are damaged and must therefore be repaired or replaced.

a. Hydrocyclone sand separators

Regularly empty the sand accumulation chamber when the container is half full (perform one discharge every hour down to a minimum of one every 24 hours). Alternatively, leave the valve located below the hydrocyclone partially open. If this operation is not done in a timely manner, the performance of the hydrocyclone will suffer.

The hydrocyclone walls will also erode faster, especially at the joint between the separation cone and the accumulation chamber.

The discharge can be automated using timers and automatic valves. Alternatively, a continuous discharge can be created by means of a valve installed on the flush pipe that is kept partially open and connected to a small diameter (8-10 mm) straight tube that is a few metres long.

b. Manual disc and screen filters

Every day check that the filtering mass is intact and that there are no cracks or deformations.

Check that the filter is not leaking.

Check the pressure differential between the inlet and outlet at appropriate intervals.

When it exceeds 0.5 bar:

- Stop the pump.
- Close the shut-off valves upstream and downstream of the filter.
- Open the blow-off valve and depressurize the filter.
- Open the cover and remove the filter casing.
- To prevent the dirt that has accumulated on the bottom of the filter from flowing into the system, make sure that the water level on the bottom of the filter does not exceed the stop level for the filtering mass.
- Clean the filtering screen with a brush or a pressure washer and check the condition of the gaskets; if disc filters are being used, decompress the discs of the filtering mass and clean them with a jet of water.
- Reassemble the filtering mass and close the filter.
- Open the shut-off valves upstream and downstream of the filter.
- Restart the system and check that the head loss between the inlet and the outlet of the filter is like that of a newly installed filter.

In any case, the filtering mass should be cleaned (even by immersing it in acidified water or water with added oxidizing agents) and the gaskets should be lubricated with silicon-based products at the end of the season.

c. Automatic disc and screen filters

Every day check that the filters are not leaking and that the filtering elements are intact and are not cut or deformed.

If the controller allows it, check the number of backwashes that have been done since the last inspection in order to find and identify any abnormal situations in the water source or in the operation of the filter.

Regularly check (every 7-10 days) that the automatic units are operating correctly by performing a manual start-up and a semi-automatic start-up of the filter cleaning devices. Finally, when the cleaning cycle is completed, check that the filtration process has restarted and that the inlet/outlet pressure differential is as it was originally.

Besides the previously mentioned end of season operations, open and empty the filtration system and check the condition of all the gaskets. Replace the gaskets that appear damaged and lubricate them with appropriate silicone based products before installation.

For disc filters, if washing with water was not sufficient, remove them and wash them with acids (for bicarbonate, iron or mineral deposits) or with oxidizing agents (sodium hypochlorite or other substances to remove deposits of organic substances). On a more frequent basis, check that the differential pressure gauge responds correctly to the inlet/outlet pressure changes.

d. Sand filters

Every day check that the filters are not leaking and that the pressure differential between the inlet and outlet does not exceed the limit of 0.5 - 0.6 bar. Perform a backwash when this value is reached, checking that filtering sand is not discharged in the backwash drainage water. Also, periodically check that the level of the sand inside the filters remains constant.

When the washing cycle is completed, restart the filtration process and check that the inlet/outlet pressure differential is as it was originally.

If the original pressure differential is not obtained after repeated backwashes, the sand bed may need to be replaced or otherwise investigate the reasons as to why the washing cycle was not effective (insufficient washing times, low backwash flow rate due to excessively large filter, no pressure support valve downstream

of the filter, imperfect opening of the valves or others).
If the sand is replaced, remember to add the sand after the filter has been partially filled with water in order to prevent the sand from hitting and damaging the diffusers on the bottom of the filter.
If the irrigation water is rich in organic substances, inject oxidizing agents at the end of the cycle to prevent bacterial growth or a "surface crust" from forming during the standby period between one filtration and the next.
For checking the automation of the automatic sand filters, follow the same procedure for automatic disc and screen filters.

7.5 Service the Accessory Equipment

Valves, regulators, flow meters, pressure gauges, controls and pumping equipment should be inspected periodically to ensure proper settings and functionality. Make sure valve diaphragms, o-rings, solenoids and control tubing are in good working order, and that any electrical wires are intact. Lubricate mechanical devices as necessary. Flow meters should be professionally calibrated periodically, and pressure gauge readings should be verified with a reliable liquid- or glycerine-filled gauge of known accuracy.

7.6 Winterize the System

Winterizing the system is necessary in climates where water will freeze and expand, possibly damaging plastic and metal system components. Polyethylene drip laterals are not subject to damage from freezing since emission devices provide drainage points and polyethylene is somewhat flexible. However, water from filters, valves, chemigation equipment, pressure regulators, risors and buried pipelines should be evacuated with a pump or air compressor, especially at low ends of the field where water typically accumulates. In addition, systems are often cleansed prior to a winter shut-down period. This normally includes chemical injection, flushing of all pipelines, and cleaning the filter.

7.7 Startup Procedures

Startup procedures after a period of inactivity are similar to those performed after system installation.
In summary, the system should be carefully pressurized and inspected for leaks and system integrity.
This includes verifying the functionality of all system components including filters, valves, controllers, chemigation equipment, flow meters, pressure gauges, pressure regulators and flush valves. Once the system is operational, chemicals should be injected if necessary, and then the system should be thoroughly flushed. Baseline readings should then be recorded and compared with specifications, and adjustments made if needed.

R

REFERENCES

References

AgriMet, 2009. Pacific Northwest Cooperative Agricultural Weather Network. United States Bureau of Reclamation, http://www.usbr.gov/pn/agrimet/cropcurves/crop_curves.html

Ayers, R.S., 1977. Quality of Water for Irrigation. Am. Soc. Civil Engr. Proc. J. Irrig. & Drain.

Blake, Cary, 2009. Drip Irrigation Increasing Alfalfa Yields. Western Farm Press, www.westernfarmpress.com

Boswell, M., 1990. Micro-Irrigation Design Manual, Hardie Irrigation, El Cajon, CA. toro.com

Bucks, D.A. and F.S. Nakayama, 1980. Injection of Fertilizer and Other Chemicals for Drip Irrigation. Proc. Agri-Turf Irrig. Conf., The Irrigation Association.

Burt, C. and S. W. Styles, 2007. Drip and Micro Irrigation Design and Management for Trees, Vines, and Field Crops, 3rd Edition, Irrigation and Training Resource Center (ITRC), California Polytechnic State University, San Luis Obispo, CA. www.itrc.org

Burt, C and K. O'Conner and T. Ruehr, 1995. Fertigation, Irrigation and Training Resource Center (ITRC), California Polytechnic State University, San Luis Obispo, CA, www.itrc.org

California Irrigation Management Information System (CIMIS), 1999. Reference Evapotranspiration for California. University of California, Davis and California Department of Water Resources.

Carpentier, Dale, 2003. Sedimentation Test of Soil Texture. Edited by the Georgia Agriculture Education Curriculum Office.

Center for Irrigation Technology (CIT), 2009. Waterright scheduling tool, (www.wateright.org).

Hanson, Blaine, Stephen Grattan and Allan Fulton, 2003. Agricultural Salinity and Drainage, University of California Irrigation Program, Davis, CA. Publication #93-01. lawrweb@ucdavis.edu

Hanson, Blaine and L. Schwankl, Stephen Grattan and T. Pritchard, 1994. Drip Irrigation for Row Crops. University of California, Davis, CA. Publication #93-05. lawrweb@ucdavis.edu

Improving Plant Life. www.improvingplantlife.com/information-about-plant-nutrients/

Klauzer, Jim, 2009. Photos of Aqua-Traxx wetting patterns. Clearwater Supply, Othello, Washington. www.cwsupply.com

Lamm, F and James Ayers and Francis Nakayama, 2007. Microirrigation for Crop Production: Design, Operation and Management. Elsevier, Oxford, UK. www.oznet.ksu.edu

Lamm, F and Danny H. Rogers, 2009. Keys to Successful Adoption of SDI: Minimizing Problems and Ensuring Longevity. Proceedings of the 21st Annual Central Plains Irrigation Conference, Colby, Kansas. www.oznet.ksu.edu

Mikkelsen, Rob, 2009. Fertilizer Efficiency with Drip and Microsprinklers. International Plant Nutrition Institute. rmikkelsen@ipni.net

NASA/EOS project. Average ET for North America.
http://secure.ntsg.umt.edu/projects/files/images/mod16/global_ET/ET_avg_NACP.png

NASA GSFC Water and Energy Cycle website.
http://nasascience.nasa.gov/images/oceans-images/water_cycle.jpg/image_preview

Phene, C.J., K.R. Davis, R.L. McCormick, R. Hutmacher, J. Pierro. 1988. Water-fertility management for subsurface drip irrigated tomatoes. Proceedings, International Symposium on Integrated Management Practices for Tomato and Pepper Production in the Tropics, Shanhua, Taiwan, ROC.

Plaster, Edward J., 2003. Soil Science and Management, 4th Edition. Delmar Learning, Lifton Park, NY

Rogers, Danny and Freddie Lamm and Mahbub Alam, 2003. Subsurface Drip Irrigation Systems (SDI) Water Quality Assessment Guidelines. Kansas State University Publication #2575. www.oznet.ksu.edu

Schwankl, L. and T. Prichard, 2001. Chemigation in Tree and Vine Micro Irrigation Systems, Publication 21599, University of California Division of Ag & Natural Resources.

Simonne, Eric et al., 2008. Drip-irrigation Systems for Small Conventional Vegetable Farms and Organic Vegetable Farms. University of Florida, IFAS Extension document #HS1144. www.edis.ifas.ufl.edu

Snyder, et al. Using Reference Evapotranspiration (ETo) and Crop Coefficients to Estimate Crop Evapotranspiration (ETc) for Trees and Vines. University of California Cooperative Extension, Leaflet #21428.

Techalive, 2009. http://techalive.mtu.edu/meec/module01/images/transpiration.jpg

Thien, S.J. 1979. A Flow Diagram for Teaching Texture-By- Feel Analysis. Journal of Agronomic Education. 8:54-55.

Truog, Emil, 1943. The Liming of Soils. USDA Yearbook of Agriculture, 1943 – 1947.
http://naldr.nal.usda.gov/NALWeb/Agricola_Link.asp?Accession=IND43893966)

Toro Micro-Irrigation, 2009. toro.com, dripirrigation.org

United States Bureau of Reclamation (USBR), 2000. Achieving Efficient Water Management: A Guidebook for Preparing Agricultural Water Conservation Plans.

United States Department of Agriculture (USDA), 1997. Irrigation Guide: National Engineering Handbook. NRCS.

United States Department of Agriculture (USDA), 1998. Estimating Soil Moisture by Feel and Appearance.

Van der Gulik, T.W., 1999. B.C. Trickle irrigation Manual. B.C. Ministry of Agriculture and Food, and the Irrigation Industry Association of British Columbia, Abbotsford, B.C. Canada

Westcot, D.W. and R.S. Ayers, 1984. Irrigation Water Quality Criteria. Report No. 84-1, California State Water Resources Control Board.

Wolfram, William L. (Bill), 2008. New Developments in Drip Irrigation. Presentation to American Society of Plasticulture. Toro Micro-Irrigation, El Cajon, CA. toro.com

I.S.E. S.r.l.
Via dell'Artigianato, 1-3
00065 Fiano Romano (Rome) - Italy
Tel. (+39) 0765 40191
Fax (+39) 0765 455386
www.toro-ag.it

IT-QOM-E

YouTube www.youtube.com/ISEontheweb

Member of CISQ Federation
RINA
ISO 9001:2008
Certified Quality System

TORO Count on it