ROBERTS
IRRIGATION PRODUCTS, INC.

RO-DRIP® User Manual

1

INTRODUCTION

WHAT IS DRIP IRRIGATION?

Drip irrigation is about delivering water, nutrients and chemicals where you want them, when you want them. Using a network of pipes and drip laterals, a drip system releases water and nutrients uniformly, through precision manufactured emitters, directly into the root zone. Near-optimum soil moisture levels are maintained and rapid response can be made to a variety of crop needs.

The precise delivery of water and nutrients made possible by drip irrigation gives you a level of control over the soil environment that is not possible with traditional sprinkler or furrow irrigation. This means better control of crop health, water and fertilizer usage, harvest time and your bottom line. Following are some of the many benefits reported by growers who have converted from sprinkler and furrow irrigation to drip irrigation:

- **Improved crop yield, quality, and uniformity**
- **Better control over harvest time and market timing**
- **Reduced water consumption**
- **Reduced energy consumption**
- **Reduced cost of chemicals and fertilizer**
- **Reduced field-labor cost**
- **Reduced disease**
- **Better weed control**
- **Better utilization of uneven terrain**
- **More land can be utilized if water is a limiting factor**
- **Reduced environmental impact from runoff and percolation of chemicals, fertilizers, and salts**

This is a remarkable set of benefits for any single technology to deliver. However, it is only with careful attention and commitment to the unique requirements of your drip irrigation system that you can enjoy its many potential benefits.

The Roberts Difference: Roberts Irrigation Products, Inc. has been bringing the benefits of efficient irrigation to growers for over thirty years.

THE ROBERTS DIFFERENCE

An ongoing commitment to tradition, integrity, and innovation have made Roberts Irrigation Products one of the world's leading producers of micro and drip irrigation products, including RO-DRIP and RO-DRIP XL drip irrigation tapes. We have spent enough time in the field to recognize the practical needs of row crop growers like you, and have applied the latest precision manufacturing methods to produce a drip tape system that meets these needs.

Our RO-DRIP and RO-DRIP XL drip tapes represent the practical application of today's latest technologies to the long-felt needs of growers. Throughout this manual you will find short captions titled "The Roberts Difference" located in the margins of each section. These captions describe some of the unique benefits of RO-DRIP products for drip irrigation users.

IS DRIP IRRIGATION FOR YOU?

Each year large numbers of growers around the world convert from traditional irrigation methods to drip irrigation. Some are attracted by the promise of higher yields, some by the promise of higher profits, and some by the simple appeal of using the latest technology. Drip irrigation is capable of delivering on each of these promises. However, you should carefully consider your unique goals and situation when deciding whether drip irrigation will work for you.

A drip irrigation system requires a significant investment in time and money. The first step in this investment begins here, by taking time to become fully informed before initiating your drip irrigation project. Your goals for this "initial investment" in time should be to:

- **Develop awareness about what it takes to design, install, and operate a system**
- **Determine your ability - financial and otherwise - to proceed**
- **Assess the level of commitment you are willing to make to develop a properly designed and managed drip irrigation system**
- **Locate a qualified irrigation dealer with drip experience**

You are the most important component in the success of your drip irrigation system.

CULTIVATING A LONG-TERM VIEW

Growers are naturally inclined to take a long-term view on things. This common-sense wisdom is especially valuable when applied to the planning of a drip irrigation system. Your initial investment in terms of equipment and know-how may take 2 or more years to recover. However, your investment should be seen not only in terms of crop quality and yield, but as an intelligent response to global trends in diminishing natural resources, reduced government subsidies, and increased environmental regulation.

ACCESS THE EXPERTS

If you are like most growers, you have vast experience with traditional sprinkler or furrow irrigation practices. You recognize the value of this accumulated expertise and probably would not think of irrigating your fields without applying that knowledge to get the best result. If you are new to drip irrigation, you can be sure there is a great deal to learn - from quick tips and techniques to fundamental changes in your procedures. Until you reach a comfortable level of expertise in drip irrigation, it makes sense to get in touch with someone who can share their expertise with you. Specifically, you should be prepared to contact qualified experts in hydraulic engineering, filtration, chemical treatment, pest control and installation.

What you learn from these experts in one season will pay off for years to come. In a recent survey of experienced growers, all confirmed the value of becoming fully informed, especially by consulting experts, before initiating their own drip irrigation program.

MANAGING NEW CULTURAL PRACTICES

Drip irrigation allows precision response to changes in crop need, environmental conditions, and even market timing. All of these benefits require a well-functioning system. Unlike traditional irrigation methods that use fewer, larger applications of water, successful drip irrigation is based on many small applications. This requires a new way of thinking: collecting and recording better and more frequent information on your crop status and water quality,, monitoring system performance, and making minor adjustments whenever needed. Fortunately, there is now a full line of products, know-how, and automation equipment available to help you in this process.

While drip irrigation can deliver significant savings on labor and resources, you should expect some increase in management time, especially in the first year as you learn to operate the system. There is no substitute for a competent farm manager who fully understands the drip irrigation system and is available to make adjustments as needed.

The Roberts Difference: **Roberts Irrigation has set up a special system of support-after-sale to help you use and maintain your drip irrigation system. Our in-house technical staff, our network of competent dealers and our library of drip irrigation publications and referrals are all at your disposal to help you get the job done.**

USING THIS GUIDE

This guide covers all the basic requirements for drip tape irrigation in row crop, nursery and greenhouse operations. It has been written to be a useful reference for almost any drip irrigation question you may have, regardless of what drip tape you decide to use. However, since Roberts Irrigation considers RO-DRIP the most advanced and cost effective drip tape available, special sections are included that describe features and requirements unique to RO-DRIP and RO-DRIP XL wherever applicable.

NOTE: This guide is intended to provide information about RO-DRIP and generally accepted knowledge in drip irrigation and crop production. Roberts Irrigation Products, Inc. is not engaged in rendering engineering, hydraulic, agronomic, or other professional advice in this guide. Consultation with qualified local irrigation dealers and agronomists is recommended.

This guide is specifically written for irrigation with drip tape - thin walled collapsible emitting hose. While many of the concepts are applicable to other forms of drip irrigation such as hard-wall hose with inserted or in-line emitters, this guide does not specifically address such products.

All of the steps involved in assembling and managing a successful drip irrigation system are covered in the following sections: Planning, Design, Installation and Startup, Management, and Retrieval. We recommend that you read the guide completely before beginning your drip irrigation program. At a minimum, review the following summary of Important Cautions and Notes. Also consider reviewing the Key Concepts listed at the beginning of each section.

IMPORTANT CAUTIONS AND NOTES

Observe the following important cautions and notes when designing, installing, and managing your drip irrigation system:

- **Carefully design and engineer all parts of your drip irrigation system before installation and use. Consult specialists in irrigation, water quality, pest control, agrochemicals and other areas as necessary.**
- **Always use proper filtration for your water source. Inadequate filtration or filter maintenance may severely damage your drip irrigation system.**
- **Where ground pests are a potential problem always implement pest controls before installing drip tape.**
- **Do not step on drip tape or drag it across the soil surface. Ensure that all installation equipment is free of burrs and other sharp edges.**
- **When using clear plastic over drip tape, always bury the tape.**
- **Operate all systems before any planting begins.**
- **Chemicals used in irrigation, fertigation, and water treatment can be extremely hazardous. Use extreme caution when mixing, handling, and injecting any chemicals.**

2 PLANNING

Before you begin a design, you need to identify clear and specific goals based on the answers to questions such as: What crops will you grow? How often will you rotate? Will the system deliver fertilizer and chemicals, or only water? Will you use plastic mulch? These are the starting points for gathering the information you will need to properly plan your system.

It is also important to know what you have to work with and what other factors will affect the design. Soil type, climate, water quality and availability, field topology, crop water requirements, and indigenous pests can all influence system design, as can legal concerns such as environmental and land-use regulations. Finally, proper planning will help you design a system that makes maximum use of your existing infrastructure to reduce both capital and labor costs.

KEY CONCEPTS

- **Your drip system design should reflect a careful consideration of soil type, water quality, evapotranspiration, topography, crop choice, and indigenous pests. Collect all of the necessary information before starting.**
- **Know the look, feel, and soil moisture content that corresponds to field capacity. Your drip irrigation system should be designed to keep the soil moisture close to this value.**
- **Obtain a chemical and physical analysis of your irrigation water from an independent laboratory. This information will be critical in determining filtration, water treatment and fertigation requirements.**
- **Have a soil sample tested to determine the nutrient content of your soil. This will be the first step in developing your fertigation program.**
- **Make use of your existing infrastructure whenever possible.**

The Roberts Difference: The broad RO-DRIP product line has been successfully used with a diverse variety of crops and field conditions.

SOIL TYPE

Soil type, both texture and structure, influences your system design by determining field water requirements and, in some cases, by limiting your choice of crops. Soil type has a great effect on water movement and therefore on root development, plant growth, and, ultimately, crop yield and profits. Because of its effect on water movement, soil type has a major influence on the emitter spacing, tape placement depth, and flow rates of a good system design.

DRAINAGE

Inadequate drainage leads to inadequate aeration of soil, increased incidence of disease, limited root zone size and limited ability to leach salts away from the root zone. Drainage problems can be caused by perched water tables, compaction layers, and stratified soils. Adding gypsum or organic amendments to heavy soils can improve drainage, although amendments that contain salt should be avoided when possible.

Where drainage is poor, deep (30 in, 76 cm) subsoiling and chiseling every 1 to 4 years may be necessary. In some cases, deep plowing can maintain good drainage for longer periods of time. If a high water table inhibits drainage, drainage channels or subsurface drain systems may be required.

WATER AVAILABILITY

Water availability and quality are central factors in the design of your drip system. Unlike traditional sprinkler and furrow irrigation, drip irrigation places very specific demands on the quality and availability of your water source.

It is important to design your system so that optimum soil moisture is maintained throughout the growing season. The system must be capable of supplying your crop's peak needs plus any additional amounts needed for flushing.

Although drip irrigation may use less water than required by other irrigation methods, it requires it on a consistent and reliable basis. Typical drip systems irrigate several times a week, or even several times a day. In addition, because drip irrigation promotes more localized root growth, even a short lapse in water availability can cause serious crop damage. It is important to confirm that your water source will be available whenever you need it, throughout the growing season. If necessary, arrange for a supplementary water source that can be used in the event that your primary source becomes unavailable. If a supplementary water source is required, confirm that your system design includes filtration appropriate for the additional water source.

WATER QUALITY

Water quality refers to the physical and chemical composition of your irrigation water. It has important effects on the type of filtration to use, chemical water treatment that may be necessary, the frequency of cleaning and line flushing, and the management of salt and chemical buildup in the soil.

The effect of water quality on your system's performance should not be underestimated. System designs that do not account for the quality of their specific water source can become completely debilitated by emitter plugging and can result in serious crop damage. These problems can be easily prevented through proper filtration and / or water treatment. Before designing your system, order a complete physical and chemical analysis of your water source. This analysis should quantify the amounts of the following matter commonly found in water sources:

Physical components

- Inorganic matter
- Organic matter

Chemical components

- Dissolved minerals
- Minor elements
- Salt
- Acidity

Since all of these factors interact in complex ways to affect the operation of your drip system, consult a water quality specialist and an irrigation engineer when designing your drip system. Also, because water sources can change with time, perform water quality tests periodically and make adjustments as necessary. See appendix A for tables to assist you in understanding your water quality report.

Inorganic Matter

Inorganic matter found in water sources includes sand, pipe scaling, and other large particles, all of which can lead to plugged emitters and other damage to your system. Since these particles are usually heavier than water, they can often be removed using a centrifugal sand separator (see DESIGN: Filtration). Smaller inorganic particles, such as silt and clay, can become cemented together by bacteria and algae which results in a slimy buildup that can clog emitters. Since these smaller particles are more difficult to remove, media filters and / or settling basins may be required to protect your system.

Organic Matter

Organic matter found in water sources includes algae, slime, plants, and particles from other living organisms. While some of these can be removed by standard filtration equipment, chemical treatment of the water and lines is usually required for more complete control of organic matter (see MANAGEMENT: Maintenance). Since organic matter is typically lighter than water, it cannot be removed by a centrifugal sand separator. Sand media filtration is the most effective method for removing most forms of organic matter.

Dissolved Minerals

Dissolved minerals are found in most water sources and, since they are dissolved, would not be expected to cause emitter plugging . However, there are a number of factors that can cause these solids to "precipitate" or settle out. These include changes in pH, changes in temperature, and reactions with commonly used fertilizers and chemicals. The most common cause of precipitation-induced plugging is calcium carbonate (lime) precipitation. Iron or manganese, which may be dissolved in well water, will precipitate when exposed to air or chlorine; these precipitates are troublesome because they can lead to bacterial growth that can readily clog filters and emitters. Sulfides can lead to similar bacterial growth and emitter plugging.

Interaction of dissolved solids with your drip irrigation system can be highly complex, and can change throughout the season. In addition to their effects on the performance of your drip system, dissolved ions can be both beneficial and detrimental to soil properties and plant health. Perform a careful assessment of the dissolved solids in your water before designing your system and especially before adding any chemicals or fertilizer to your water.

The Roberts Difference: RO-DRIP drip tape is manufactured to exacting technical specifications to produce a uniform wall thickness, which means less breakage on installation and retrieval.

Table 2.1 Soil Solution Salinity Level to Cause 10% Yield Reduction.

Crop	Salinity (EC) of Soil Exctract (dS/m)
Strawberry	1.3
Bean	1.5
Lettuce, Pepper, Raddish, Onion, Carrot	2.0
Cabbage, Cucumber, Muskmelon, Potato	3.0
Corn, Artichoke, Sweet Potato	2.5
Sugar Cane (some varieties)	2.6
Tomato, Broccoli	4.0
Cotton (after germination)	4.7

Salinity

Most water sources and many fertilizers carry some level of dissolved salt that accumulates in the soil during regular irrigation. In arid regions where salinity is a significant problem, this buildup can affect the health of your plants. In such cases, your system design and operation must account for and properly manage salt buildup. Your water quality analysis should include a report of the salt content and type. See appendix A for tables to assist you in interpreting a water quality report. Table 2.1 gives the salt tolerance of several popular crops in terms of the salinity of the soil solution.

NOTE: In areas with low rainfall, salinity of the soil solution is typically higher than the salinity of your irrigation water. Even with good irrigation management, soil solution salinity can be 1.5 to 3 times the irrigation water salinity.

The initial effects of salt buildup can be subtle. It is important to understand that salt damage to your crop may not be apparent until it is too late to prevent. Fortunately, proper drip irrigation practices include ways to manage salinity and to keep it out of the root zone. See MANAGEMENT: Managing Soil Salinity for guidance on monitoring and managing salt buildup in the soil.

WATER REQUIREMENTS

Your system must be designed to supply enough water to exceed your crop's water requirements during the hottest day of the season, while also providing enough water for line flushing and salt leaching where needed. Water requirements are influenced by the following factors:

- **Plant size**
- **Soil type**
- **Solar radiation**
- **Ground cover**
- **Ambient temperature and humidity**
- **System efficiency**
- **System operations (e.g., leaching, flushing, filter backwashing)**
- **Leaf canopy**
- **Water quality**
- **Growth stage**
- **Rainfall**
- **Wind conditions**
- **Fertilizers and chemicals used**

The Roberts Difference:

The highly plug-resistant design of RO-DRIP makes it the right choice when water quality is a concern.

The interaction of these factors can be complex. However, by making a few measurements, and by referring to standard formulas and tables, it is relatively easy to calculate your actual irrigation requirements and develop a proper irrigation schedule.

Most crops reach their full potential if the soil in the root zone is at all times maintained at a moisture content that is near the soil's maximum water holding capacity. The goal of a drip irrigation system throughout most of the growing season is to maintain this level by replacing soil water as it is lost to evapotranspiration. With some adjustments to account for local weather, minor crop differences, salinity, and system inefficiency you can develop a good prediction of water requirements.

Note: Applying more water than is needed can increase root disease and operating cost, while applying less than needed can stress or burn your crop and cause your soil to dry, destroying its ability to move water. A properly designed and managed irrigation system will deliver just enough water to maximize both yield and profit.

Field Capacity

Field capacity is an estimate of the amount of water that is held by the soil after it has been completely drained by gravity. Field capacity is dependent on soil type, and represents optimum soil moisture conditions for most crops because of its ideal balance between aeration and available water.

In order to keep soil moisture conditions ideal for crop growth, you must be able to determine when your soil is at field capacity. If you have a moisture-sensing device available, you can obtain a quantitative measurement of field capacity with the following procedure:

1. Determine the proper monitoring depth for your crop.
2. Prepare the field and install the moisture sensor at the proper depth. More accurate results can be obtained by installing 4 sensors in a 10 x 10 ft (3 x 3 m) test area.
3. Irrigate until the soil under the moisture sensors is saturated. If tensiometers are used, this should produce a reading of 0 cb.

4. Monitor the sensor readings daily. When the readings level off (usually after 2-3 days), read and record the displayed values. (If using several sensors, take the average of the 3 closest readings.) The result is the measured water content at field capacity. If your sensor measures soil water tension the reading will generally be between 10 cb and 25 cb depending on soil type. If your sensor measures moisture content, the field capacity reading may range from 10% to 50% depending on soil type.

The optimum soil moisture level for most crops during vegetative growth stages is at or slightly below field capacity. In general, your system must be capable of replacing all water used by the crop since the last irrigation and must be used frequently enough to minimize depletion below field capacity.

Evapotranspiration

Evapotranspiration (ET) is a measure of how much water is used by your crops for transpiration and how much is lost through evaporation from the plant and soil surface; it is expressed in inches (mm) of water used per day or inches (mm) of water used per month. ET measurements allow you to anticipate how the weather in your area will interact with your crop to determine water requirements. ET values based on a reference crop for your region are usually available from local water resource and agricultural agencies. ET is affected by:

- Local climate
- Size of leaf canopy
- Ground cover
- Crop type
- Stage of growth cycle
- Size of wetted area

Research has shown that, for vegetative crops, yield is generally proportional to transpiration. For given weather conditions, transpiration is maximized when the water content in the root zone is near field capacity at all times. Therefore it is important that, as water leaves the root zone as a result of ET, your irrigation system is able to replace it as soon as possible. The ability to keep the root zone near field capacity at all times is an important benefit of drip irrigation.

To realize this benefit, your system design must be capable of supplying water at the rate of ET at all times during the growing season. You can anticipate what peak demand will be by referring to historical ET data, and use this information to design a system that can supply enough water under any conditions. If ET information is not available for your area, refer to MANAGEMENT: Scheduling, Determining your crop’s daily requirement for methods of estimating ET.

Flushing Requirement

Since filtration cannot remove all contaminants, silt and clay may settle in drip laterals and, if not removed, may build up and plug emitters. In areas where water quality is a problem or when drip tape laterals will be used for multiple growing seasons, your system design must allow for periodic flushing of the laterals. If flushing is necessary, the system should be designed so that the ends of the laterals are accessible. Consider using end caps or flushing manifolds.

In systems where flushing is necessary, the capacity of the upstream components is often determined by the flushing requirement alone. It is recommended to maintain a minimum flushing velocity of 1 foot per second in the laterals, which requires flow rates at the end of laterals to be at least 1 GPM (3.8 LPM) in standard 5/8-in. (16 mm) drip tape, or 2 GPM (7.6 LPM) for 7/8-in. (22 mm) drip tape. Substantially higher flow rates at the beginning of the laterals are required to achieve these flow rates at the end of the laterals.

CROP CHOICE

The crops you grow will have a great effect on system design and cultural practices. Any and all crops can be grown under drip irrigation, but your choice of crops and their planting method (direct seeded or transplanted) will have an important impact on your drip system design.

An important question about your crops is whether they will be direct seeded or transplanted. The germination of seeds places special requirements on your drip system design and management. If these requirements are not met, sprinklers will be required for germination and initial plant growth. See MANAGEMENT: Germinating Seeds.

TOPOGRAPHY

While topography clearly influences system design, it can also be a motivating factor in the decision to implement a drip irrigation program. Drip irrigation allows cultivation of uneven terrain that cannot be cultivated using furrow irrigation or certain types of sprinklers. Drip irrigation is uniquely suited to growing on uneven terrain due to its flexibility in placement and its use of pressure to move water directly where it is needed. Consider performing a survey to document your field's geometry and topography since this information will be useful in developing a complete system design.

PEST CONTROL

Insects such as ants, crickets and wire worms; and animals such as rodents and coyotes can all cause damage to drip tape laterals. Pest control should be initiated before placing drip tape laterals in the field, and periodically thereafter as needed. Where pests are a significant problem, consider using thicker drip tape and / or buried placement. Consult a pest control advisor for guidance on controlling the specific pests found in your region.

CHEMIGATION/FERTIGATION

Chemigation

Chemigation refers to the combination of irrigation and chemical water treatment into a single process, and is recommended to maintain a well-functioning drip irrigation system. Chemical treatment includes the use of chemicals to prevent plugging of the drip tape emitters. For example, chlorine and / or acid may be injected to kill microorganisms and to prevent precipitation of dissolved minerals. Chemical treatment may also include injection of pesticides, herbicides or systemic fungicides to improve the health of your crops, or gypsum or acid to improve the physical characteristics of your soil. MANAGEMENT: Water Treatment describes how to use chemical injection to prevent emitter clogging by organic matter and precipitates.

CAUTION: all personnel who use or otherwise come in contact with fertilizers and chemicals should be thoroughly trained and qualified in the safe and effective storage, use and application of these potentially dangerous substances.

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Fertigation

One of the outstanding benefits of a well-designed drip irrigation system is the ability to precisely control the nutrient environment in the root zone of your plants for optimum yield and quality. Drip fertigation can apply N, P, K and minor nutrients exactly where and when they are needed, throughout the season. To take advantage of this high level of control, it is necessary to closely monitor the nutrient level in the soil and plant tissue, and make adjustments as necessary.

Determining nutrient requirements

Before installing your drip irrigation system, have a soil sample tested to determine its nutrient content. This should include nitrogen, phosphorus, potassium and minor nutrients.

The nutrient requirements of your plants change throughout the season, and your fertigation program should reflect this. If possible, obtain data on the nutrient requirements of your crop at each growth stage. In combination with tissue testing throughout the season (see MANAGEMENT: Fertigation), this information will allow you to maximize the efficiency of your fertigation program.

EXISTING INFRASTRUCTURE

Installing a drip irrigation system inevitably requires changes in equipment, training, and cultural practices. However, a new system design does not always require completely new infrastructure. In fact, a good system design should identify and make use of as much existing infrastructure as possible, such as the existing water source, distribution systems, electrical supply, and access roads.

PLASTIC MULCH

The term "plasticulture" refers to methods of growing under plastic using drip tape. Drip irrigation is uniquely suited to cultural practices that use plastic mulch. For some crops, the combination of drip tape and plastic mulch results in optimum yield and water usage through improved control of soil temperature and moisture level. While growing under plastic has been a barrier to water delivery using traditional sprinkler and furrow irrigation, plastic mulches and crop tunnels do not present a problem with drip irrigation. Plasticulture is used for a number of reasons, including:

- Control of soil temperature
- Water conservation
- Control of weeds, pests, and erosion
- Control of production timing
- Improved processing of nutrients by beneficial microbes
- Control of the wetted area
- Protection of fruit from soil moisture
- Improved yields
- Prevention of nutrient leaching due to rainfall

If you plan to use clear plastic mulch or crop tunnels, your system design should specify buried drip tape, since the heat trapped by these plastics may cause wandering of the tape as a result of increased expansion and contraction. Note that plastic mulch is not optimal or even practical for all crops – see appendix B for information on specific crops.

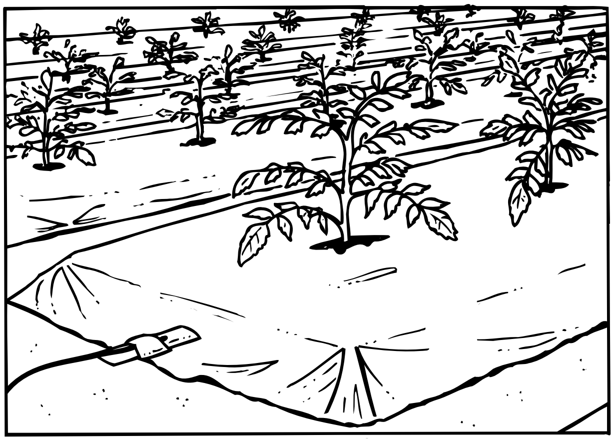


Figure 2.1 Plastic Mulch

3 DESIGN

Drip irrigation delivers the highest efficiency and uniformity of any commonly used form of irrigation. This can directly result in reduced consumption of water, chemicals, and fertilizer. High uniformity in combination with the low application rates of drip irrigation makes possible the precise control of soil water content at the root zone which leads to more effective application of nutrients, better salinity control, and increased yields.

Only by designing, installing and maintaining an efficient system can you achieve all of the benefits of drip irrigation. Selecting the right drip tape product, properly sizing supply manifolds, and selecting appropriate filtration components are all necessary to maximize efficiency and to meet the irrigation needs of your crops under any field conditions.

This section will help you design a high-efficiency drip irrigation system that meets the unique needs of each of your crops. It starts by defining irrigation efficiency and explaining how it is affected by your choice of drip tape and other system components, and how it can change with time. After developing this background, the section takes you through the steps of specifying components and designing the right system for your field.

The Roberts Difference: Precision-manufactured RO-DRIP products provide the quality and consistency needed for high uniformity and efficiency.

KEY CONCEPTS

- **Have a laboratory analysis of your irrigation water performed before beginning your system design.**
- **Select a high quality drip tape. This is a key decision in your drip system design.**
- **To design drip laterals it is necessary to specify length of run, emitter spacing, placement depth, position relative to plant rows, and flow rate. All of these decisions require in-depth knowledge of your growing operation.**
- **Your design must provide enough water to meet the needs of your crop under any conditions, and must not require more than your water supply can deliver.**
- **Proper filtration is crucial to prevent plugging of your drip system—don't skimp on filtration components.**
- **A good design includes pressure gauges, flow meters, and other instrumentation at key locations.**

NOTE: The guidelines in this section are general recommendations and are not intended to suggest complete design or production practices. Please consult your local Roberts Irrigation Products dealer for specific design applications.

DESIGN GOALS

Before designing your drip irrigation system, use the information collected in the PLANNING section to establish clear design goals. Because of the conflicting requirements of a drip irrigation system, some of the following goals may need to be adjusted after you begin the design process.

- **Uniformity. Define the minimum uniformity your design will need to achieve, keeping in mind that higher uniformity designs may result in higher cost. See Irrigation Efficiency, in this section.**
- **Application Rate. Know what the application rate requirements will be to replace peak ET.**
- **System Life. Decide whether your drip tape laterals will be used for a single season or for several years. Also determine how long the other system components should last.**
- **System Cost. Know your sensitivity to cost, which may influence your decisions about target uniformity and system life.**

Your challenge will be to design a system that meets these conflicting goals. You will need to make tradeoffs between uniformity, system life, and system cost. System cost encompasses both one-time installation costs and ongoing operating costs, which also may conflict.

RD3.1

The Roberts Difference: RO-DRIP employs an advanced emitter design which delivers unparalleled discharge uniformity and resistance to plugging.

COMPONENTS

While there are many differences in individual drip systems, most have the components shown in figure 3.1.

Components of a Typical Drip Irrigation System (see fig. 3.1):

1. System controller
2. Pump
3. Back flow prevention valve
4. Fertilizer injector / tank
5. Filter tanks
6. Butterfly valve or ball valve

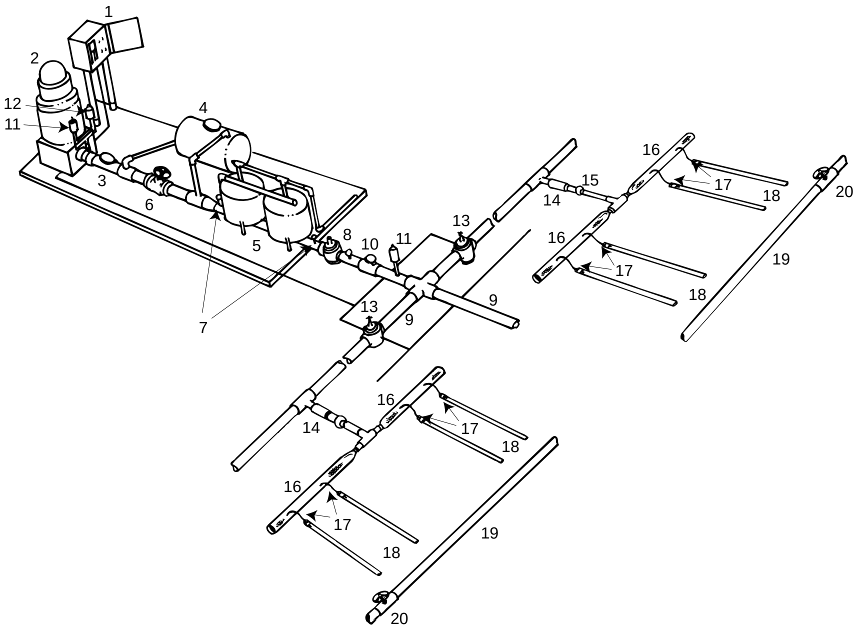


Figure 3.1 Components of a Typical Drip Irrigation System

7. Pressure gauges
8. Mainline control valve
9. Mainline
10. Flow meter
11. Air vents at high points, after valves and at ends of lines
12. Pressure relief valve
13. Field control valve
14. Submain secondary filters
15. Pre-set pressure regulator
16. Submain
17. Lateral hookups
18. Laterals
19. Flushing manifolds
20. Flush valves

IRRIGATION EFFICIENCY

What is Irrigation Efficiency?

The Irrigation Efficiency (IE) of your system is a measure of the proportion of water used for intended purposes. If your system is 90% efficient, then 90% of the water it applies is used by your plants, or for other intended purposes, and 10% of the water is not used productively. Irrigation Efficiency is affected by both the design and management your irrigation system.

Distribution Uniformity

Distribution Uniformity (DU) is a measure of how uniformly your irrigation system applies water to all parts of your field. A non-uniform irrigation system delivers less water to some parts of the field and more to others. Drip irrigation can deliver very high uniformity and this is one of the keys to its high potential efficiency. A well-designed drip system can achieve DU of 90% or higher.

Poor distribution uniformity leads to non-uniform crop growth and poor irrigation efficiency. Poor uniformity can be caused by:

- Drip emitters becoming plugged with dirt, algae or other material
- Pressure variations caused by uneven terrain
- Pressure variations caused by friction losses
- Excessive drip tape run lengths
- Use of poor quality drip tape

All of the above factors can be controlled with careful design and management.

Drip Emitters and their Effects on Distribution Uniformity [fig. 3.2]

A drip tape emitter consists of an inlet, a flow channel, and an outlet. The inlet allows water into the flow channel from the main chamber of the drip tape. The flow channel is a narrow path with a complex shape designed to slow down the flow of water and create turbulence, which prevents contaminants from settling. The emitter outlet is a small opening at the end of the flow channel through which the water drips into the soil.

A well-engineered emitter does three things very well:

- It emits water at a predictable and consistent rate
- It emits water at nearly the same rate for a range of supply pressures
- It resists plugging

Two important numbers quantify how well a drip tape emitter does its job: the Coefficient of Variation (Cv) and the Discharge Exponent (x). Most drip tape manufacturers publish Cv and x values for all of their products or will provide them upon request. Several independent test labs also rate emitters and publish this information. See appendix C for definitions of Cv and x and explanations of how they affect system performance.

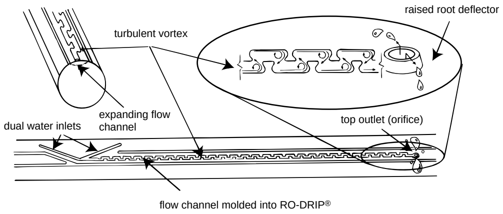


Figure 3.2 Anatomy of a Drip Emitter

RD3.2

The Roberts Difference: RO-DRIP is manufactured with an advanced, high-precision process that results in an emitter coefficient of variation of 0.03 or lower. This translates to better distribution uniformity and higher irrigation efficiency in your field.

RD3.6

The Roberts Difference: The RO-DRIP emitter has a unique expanding flow channel which can open up to pass trapped debris. If a clog occurs it can often be removed by temporarily increasing the supply pressure until the expanding flow channel flexes open and allows it to pass.

RD3.7

The Roberts Difference: The comprehensive RO-DRIP product line provides a broad selection of wall thickness, emitter spacing, flow rate and diameter that will allow you to select the right drip tape for your application.

RD3.8

The Roberts Difference: The advanced emitter design and smooth inside walls of RO-DRIP products allow long lateral runs with high uniformity. RO-DRIP performance charts are available in the Roberts Irrigation Products publication RO-DRIP PERFORMANCE SPECIFICATIONS.

Plugging resistance

Drip tape can become non-uniform to a point where it is completely debilitated in the midst of a growing season if emitters become plugged. This can result from any of the following:

- Organic or inorganic sediment in the irrigation water
- A vacuum condition inside of the drip tape causing dirt to siphon back in through the outlet
- Root intrusion
- Mineral buildup in the flow channel or at the outlet

The primary features of an emitter that determine its likelihood of plugging are the cross-sectional area of its flow channel and the amount of turbulence created within the flow channel. A large cross-section gives plenty of room for contaminants to pass through without accumulating into clogs. A highly turbulent channel keeps dirt particles suspended as they move through the emitter.

Other emitter features also play important rolls in plugging resistance. Some drip tape products have emitter outlets that resist root intrusion. The design of the emitter inlet can also affect clog resistance. Finally, some emitters provide mechanisms that help to remove clogs if they should occur.

DRIP LATERAL DESIGN

To design your drip laterals, you need to specify the following:

- Run length
- Placement of laterals (depth, spacing, position, and run length)
- Emitter spacing
- Flow rate
- Drip tape wall thickness
- Drip tape diameter

Table 3.1 summarizes these parameters and their effect on performance. Each is discussed in greater detail in the remainder of this section.

Lateral Run Length and its Effect on Uniformity

Length of run has a direct effect on the uniformity (DU) of each drip lateral. If laterals are too long, pressure losses cause a higher application rate at the beginning of the run than at the end. In general, longer run lengths with good uniformity are possible with low flow rate and / or large diameter drip tapes, although all drip tapes have their limits.

The DU of a single lateral is determined by its length, slope, operating pressure, flow rate, x, and Cv. Performance Charts published by most drip tape manufacturers summarize all of these effects, and tell you how long your drip tape runs can be for a given set of conditions. Consult the Roberts Irrigation performance charts for all RO-DRIP products.

Example

You plan to use a 13 mil RO-DRIP product with a performance chart in appendix D to irrigate cotton. There is a 0.5% downhill slope, and the distance from the supply manifold to the end of the field is 1000 ft (305 m). You require a DU of 85% for each lateral, and the average pressure of the supply manifold is 8 PSI (.55 bar).

Solution

Pressure = 8-PSI (.55-bar)
Target EU = 85%
Run Length = 1000-ft (305-m)
Slope = -0.5%
Soil: Sandy loam

Using the charts in appendix D, RO-DRIP 13-12-24 has a DU of slightly more than 80% for a

Parameter	Effect on Performance	Notes
Wall thickness	•thicker walls improve resistance to damage from pests and/or installation •thicker walls allow higher operating and flushing pressures •thicker walls make longer-term installation possible	Thicker drip tape is more costly and is usually used where the field is rough, for sub-surface placement, and for long-term placement. Thick tape is also used for better pest resistance. Thinner tape is used for single-season crops.
Emitter spacing	•closer emitter spacings result in higher flow rates •closer emitter spacings are sometimes required for seed germination •closer emitter spacings can provide a better wetting pattern in some light soils •larger emitter spacings can deliver low flow rates without increasing the risk of plugging	Choice of spacing is based on planting method (germinating or transplanting), soil texture, and crop selection.
Nominal flow rate	•higher flow rates result in more lateral movement of water in sandy soils •higher flow rates reduce the risk of emitter plugging •lower flow rates allow longer lateral runs •lower flow rates allow improved infiltration of water in heavy soils	Choice of flow rate depends on water availability, ET requirements, length of drip tape laterals, soil texture, and crop selection.
Diameter	•large diameters allow longer lateral runs	Standard drip tape is 0.625-in diameter. Larger diameter drip tape products allow longer lateral runs, but are more costly.

Table 3.1 Drip Tape Design Parameters and their Effect on Performance

1000-ft (305-m) run at 8-PSI (.55-bar), which does not meet your requirements. RO-DRIP 13-24-17 has a DU over 85%, and 13-12-24XL has a DU over 90%, both of which meet your requirements.

RO-DRIP 13-12-24 XL will work well in this application. You may be able to save cost by using the smaller diameter 13-24-17, but it may be difficult to achieve sufficient lateral movement of the wetted pattern with a 24-in (61-cm) emitter spacing in sandy loam soil. Try a small test area first. You can also realize initial cost savings by lowering your uniformity target to 80%, which allows you to use 13-12-24, also with a 5/8-in ID. However, the initial savings may be offset by increased water usage to compensate for the lower uniformity. The correct answer depends on the specifics of your growing operation.

Placement of laterals

The placement of drip tape defines its depth and distance from the plants, and the distance between laterals. In all cases, the drip tape must be oriented with the emitters facing up to resist plugging from sediment settling. Proper placement is determined by several factors, including:

- Crop grown
- ET requirements
- Soil texture and structure
- Salinity management

- General cultural practice
- Use of plastic mulch
- Equipment availability
- Seeding vs. transplanting
- Crop rotation
- Field topography

Each field situation has many variables, and the best solutions come from experience. Experiment with small trial plots to find the best lateral placement and application rates to meet the needs of your crop. Refer to the crop examples in appendix B to see how experienced drip tape users have made lateral placement decisions. Following are a few general guidelines.

Position of laterals

The placement of drip tape relative to each plant row depends on the amount of lateral movement of water allowed by your soil type and the requirements of your plants. In general, lateral movement of water in light (high sand content) soils is difficult to achieve, so drip tape should be placed close to the plant row (usually 2-12 in, 5-30 cm). Conversely, larger distances (up to 24-in, 61-cm) are acceptable for high clay content soils, which promote easy lateral water movement and which may result in ponding due to low infiltration rates.

Drip tape should also be placed close to the plant row if plants are direct seeded. This provides the high soil moisture required by the seeds, as well as additional salt leaching which may be necessary during the early, salt-sensitive growth stages. When direct seeding in sandy soil, laterals should be placed as close as possible to the plants. See MANAGEMENT: Germinating Seeds.

Spacing between laterals

The spacing between laterals is determined to a large extent by the distance between centers of your crop rows. Depending on your soil type and ET requirements, however, it may be possible to irrigate more than one row with each lateral, resulting in reduced system cost and lower application rates. Other combinations, such as using three laterals to irrigate a four-row bed, are also possible. **In such cases it is important to be sure that the edge of the wetting pattern from each lateral does not coincide with the position of the plant row. Salts that accumulate at the edge of the wetting pattern can damage or kill plants.**

To calculate the total length of drip tape, L, which will be required to cover your field at a given spacing between laterals, use the following formula:

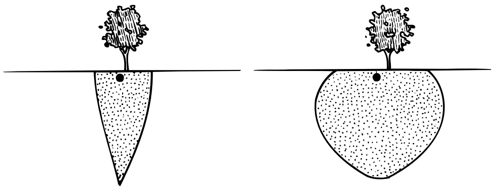


Figure 3.3 Lateral Placements

$$L\text{ (feet)} = \frac{(\text{number of acres x } 43{,}560)}{(\text{bed spacing in feet})} \text{ x (number of tape rows per bed)}$$

or

$$L\text{ (meters)} = \frac{(\text{number of hectares x } 10{,}000)}{(\text{bed spacing in meters})} \text{ x (number of tape rows per bed)}$$

If your field is flat, set "number of tape rows per bed" to 1, and use the lateral spacing in place of "bed spacing" above.

Surface vs. subsurface (depth of laterals)

There are four common methods of depth placement for drip tape:

- **Surface placement on flat ground**
- **"V-Ditch" placement**
- **Shallow sub-surface: 1-4 in (2.5-10 cm)**
- **Deep sub-surface: deeper than 5 in (13 cm)**

Depending on your specific situation and crop, any of the above placement methods may be appropriate. Table 3.2 presents some typical applications for each.

NOTE: When drip tape is installed deep enough that the wetted area does not reach the surface, salt buildup may occur just under the surface of the soil. This can create a situation in which rain can leach salt into the root zone and stress or even kill the crop. Refer to MANAGEMENT: Managing Soil Salinity for information on managing salt buildup.

NOTE: Depth of laterals is critical if they are used to germinate crops. Depending on soil type, deep subsurface laterals may not be able to supply the water to the surface required by the seeds. In such cases, sprinklers are required.[fig. 3.4]

Raised beds

Raised beds are not necessary in drip applications. However, they should be considered where salinity or drainage around the plants is a serious problem. Raised beds can also facilitate harvesting of short stature crops such as strawberries. Finally, raised beds can increase soil temperature, resulting in increased yield and earlier harvest.

Where possible, consider a large bed width of 60 or 80 inches (150-200 cm) and use 2 drip laterals per bed to increase the percentage of production area and yield potential.

NOTE: When two laterals are used, the middle of the bed should be left open for salt accumulation. Laterals should not be placed so that the edge of the wetting pattern is under the center of a row.

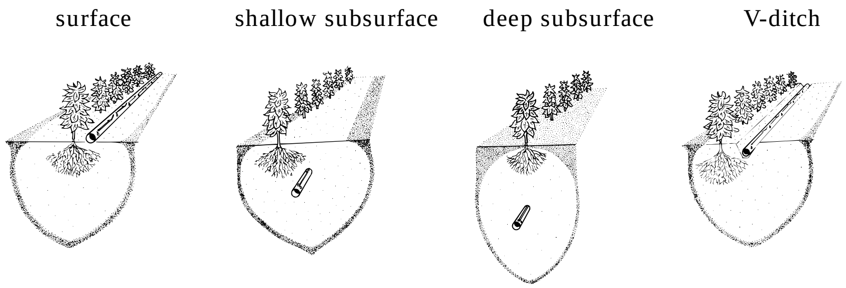


Figure 3.4 Lateral Depth Placement

Uneven terrain

Drip tape in hillside applications should be placed on the uphill side of the plant row to ensure a balanced wetted area in the root zone. On steep slopes, the laterals should be placed parallel to the contour lines of the terrain to minimize pressure differences caused by uphill or downhill runs.

Table 3.2 Typical Applications for Drip Tape Placement Depths

Placement	Application	Advantages	Disadvantages	Notes
Surface (above ground)	•Single season •Retrieval and re-use •Applications where installation equipment is unavailable or the field is small	•Easy, low-cost installation •Easy to confirm uniformity and operation •Easy to locate and repair damage •Easy to retrieve	•Increases risk of mechanical damage •Tape may wander due to heat or wind •Surface wetting increases weed growth and may promote disease •Increases runoff in heavy soils •Increases evaporation	•Requires anchoring of tape •Should not be used with clear plastic coverings to avoid burning or overheating of tape
V-Ditch (2-3 in deep, 5-8 cm deep)	•Same as surface placement	•Easy, low-cost installation •Easy to confirm uniformity •Easy to locate and repair damage •Reduced runoff	•More exposure to damage than with sub-surface placement •Increased weed growth •Increased evaporation	•A compromise between the characteristics of surface and shallow sub-surface placement •Mechanical or manual installation is possible •Common with plastic mulch
Shallow sub-surface (1-4 in, 2-10 cm)	•Single or multi-season	•Prevents tape wandering from heat or wind •Reduced evaporation •Reduced damage from cultural operations •Reduced pest damage •Improved water movement •Reduced weed growth •Prevents damage from clear plastic coverings	•More difficult to visually detect damage	•Usually requires mechanical installation via tractor and toolbar •Rodent and insect problems are greatest in new fields where adequate control measures have not been used
Deep sub-surface (deeper than 5 in, 13 cm)	•Multiple year	•Can be used for several seasons without retrieval •Reduced damage from cultural operations •Reduced pest damage •Reduced weed growth •Reduced loss to evaporation	•Salt accumulates just below the soil surface and may be carried into the root zone by rain •More difficult to repair damaged tape •Installation equipment required •Sprinklers may be required to germinate crops or to leach salt from the root zone	•Requires careful design and maintenance •The system should be designed for easy flushing of laterals •Operation of system during light rain may be required to prevent salt from leaching into the root zone

Selection of Emitter Spacing

Common drip tape emitter spacings are 4, 8, 12, 16 and 24 inches (10, 20, 30, 40, and 60 cm). Narrowly spaced emitters are useful in sandy soil, or where high flow rates are desired. Wider spacings provide lower flow rates that make longer lateral runs possible.

See table 3.3 for guidelines on selecting emitter spacing. These are general descriptions only.

Table 3.3 Guidelines for Emitter Spacing

EMITTER SPACING		APPLICATIONS AND FEATURES	CROPS*
4 inch	10 cm	•greenhouse and field flower applications •short lateral runs •results in good wetting patterns in sandy soils •very high flow rate	•Flowers •Potted plants
8 inch	20 cm	•results in good wetting patterns in sandy soils •aids in germination of seeds •provides a relatively high flow rate	•Flowers •Potted plants •Strawberries •Most vegetables
12 inch	30 cm	•crops in most soils •lower flow rate than 8-in (20 cm) spacing •longer runs are possible due to lower flow rates	•Potted plants •Strawberries •Most vegetables •Sugar cane •Potatoes •Melons
16 inch	41 cm	•lower flow rate for improved infiltration of heavy soils •longer runs possible than with 8 or 12in (20 or 30-cm) spacing •may not effectively germinate seeds in light soils	•Melons •Corn •Cotton •Sugar cane •Some vegetables
24 inch	61 cm	•provides lower flow rate for improved infiltration of heavy soils •very long runs are possible •may not effectively germinate seeds in light soils	•Corn •Cotton •Sugar cane

* General guidelines only. Actual spacing will depend on soil type, run length and other specifics of your operation.

Selection of Flow Rate

As illustrated in the previous section, drip tapes with narrow emitter spacing deliver higher flow rates due to the larger number of emitters per unit of length. In addition, many drip tape products are available with two flow rates for each emitter spacing, referred to as Standard Flow and Low Flow products. Table 3.4 provides a comparison of Standard Flow and Low Flow emitters.

Examples of Standard Flow and Low Flow RO-DRIP products are given in table 3.5. Consult the RO-DRIP Product Data Sheets for a complete listing of flow rates and emitter spacings.

When you select a drip tape flow rate, emitter spacing, and lateral spacing, you need to ensure that, during irrigation,

- **The system does not require a higher flow rate than your water supply can provide**
- **The system can sustain the application rate required by your field**

Table 3.4 Standard Flow and Low Flow Emitters	
EMITTER FLOW RATES	
TYPE	FEATURES
Standard Flow	•provides a better wetting pattern in some light soils •higher application rate for a given emitter spacing •less susceptible to emitter plugging than low-flow products
Low Flow	•improved infiltration on heavy soils •longer lateral run lengths are possible •more susceptible to emitter plugging •higher flushing requirements

Table 3.5 Standard Flow and Low Flow RO-DRIP Products

UNITS	EMITTER SPACING	STANDARD FLOW	LOW FLOW
US	8-in	40 GPH/100 ft	20 GPH/100 ft
Metric	20-cm	497 LPH/100m	248 LPH/100m
US	12-in	24 GPH/100 ft	15 GPH/100 ft
Metric	30-cm	298 LPH/100m	186 LPH/100m
US	16-in	20 GPH/100 ft	10 GPH/100 ft
Metric	41-cm	248 LPH/100m	124 LPH/100m

If your system requires a higher flow rate than your water supply can provide, it will not work. It will be necessary to divide your field into smaller zones that can be irrigated independently, or reduce the number of acres you are irrigating. Use the following formula to calculate the total flow rate, Q, each zone of the system will require of your water supply, or use the tables in appendix E:

$$Q = \frac{\text{(tape flow rate, GPH/100') x (feet of tape)}}{6000} = \frac{\text{(tape flow rate, LPH/100m) x (meters of tape)}}{6000}$$

If US units are used in the above formula, Q will be in gallons per minute. If metric units are used, Q will be given in liters per minute.

Calculate the application rate, AR, of your system as follows, or use the tables in appendix E:

$$AR = \frac{(\text{tape flow rate, GPH/100'})}{62 \times (\text{lateral spacing, feet})} = \frac{(\text{tape flow rate, LPH/100m})}{100 \times (\text{lateral spacing, meters})}$$

If US units are used, AR will be in inches per hour. If metric units are used, AR will be in mm per hour.

The application rate delivered by your system must be capable of replacing water lost to ET during the peak months of the season. It is good practice to apply a safety factor when estimating your peak water requirements, to account for system inefficiency as well as the possibility of equipment failure or extreme weather conditions.

EXAMPLE

You plan to increase the output of your quarter-section (160-acre, 65-hectare) corn field by replacing an existing center pivot with drip irrigation. The corn is planted on 36-in (91-cm) centers and you will use one RO-DRIP 13-24-17 XL lateral for every two rows, resulting in a 6-ft (1.8-m) lateral spacing. The peak ET for corn in your area is 8.5-in (216 mm) in the month of July. The capacity of your water supply is 1200 GPM (4500 LPM).

SOLUTION

The peak daily ET requirement is 8.5/31 = 0.274 in per day (6.95 mm per day). Using a 25% factor of safety to account for system inefficiency and possible interruptions in the water supply, the system must be capable of an application rate of 0.274 x 1.25 = 0.343 in per day (8.71 mm per day), or at least 0.014 in per hour (0.36 mm per hour) if operated for 24 hours.

$$L = \frac{(160\text{ acres}) \times 43{,}560}{6\text{ feet}} = \frac{160 \times 43{,}560}{6} = 1{,}161{,}600\text{ feet }(354{,}056\text{m})$$

The system will be capable of delivering an application rate of

$$AR = \frac{(17\text{ GPH per }100')}{(6\text{ feet}) \times 62} = \frac{17}{6 \times 62} = .046\text{ inches per hour }(1.17\text{ mm per hour})$$

or 1.1 in per day. The required flow rate will be

$$N\text{ (acres)} = \frac{(\text{lateral spacing in meters}) \times (\text{water supply capacity, LPM})}{1.67 \times (\text{tape flow rate, LPH/100 m})}$$

From the above, the system is capable of delivering more than three times the application rate required during peak ET, but it requires a higher flow rate than your water supply can provide. A possible solution to this problem is to divide the field into three equally sized zones, and irrigate one zone at a time. Doing this, the maximum application rate to the field will be 1.1 / 3 = .37 in per day (.94 mm per day), and 1097 GPM (4512 LPM) will be required of your water supply. See Dividing Your Field Into Independent Zones, in this section.

Table 3.6 Guidelines for Selecting Wall Thickness for Drip Tape

THICKNESS		APPLICATION AND FEATURES
5 mil	0.127 mm	•minimum number of rocks and pests •applications where installation cost is very important
6 mil	0.152 mm	•first time drip tape users who desire a thin-walled drip tape •experienced drip tape users in multiple season applications
8 mil	0.200 mm	•first time drip tape users •experienced drip tape users in multiple season applications
10 mil	0.254 mm	•portable applications (may be relocated) •multiple year buried applications
13 mil	0.325 mm	•portable applications (may be relocated) •multiple year buried applications •maximum resistance to pests and mechanical damage
15 mil	0.375 mm	•portable applications (may be relocated) •multiple year buried applications •maximum resistance to pests and mechanical damage

Selection of Wall Thickness

Drip tape products are available with a variety of wall thicknesses ranging from 4 mil to 25 mil. The thinnest walled products are lower cost, but are more susceptible to mechanical and pest damage. They are typically used in single season applications by experienced growers. The thicker walled products are more resistant to damage and can be used for multiple seasons. Their higher tensile strength also makes them well suited for retrieval and re-installation in the field. See table 3.6 for general guidelines on selecting wall thickness.

Run-Length and Selection of Diameter

For a given flow rate, larger drip tape diameters allow longer lateral runs. The standard diameter of most drip tape products is 5/8 in (16 mm). Most manufacturers also offer larger-diameter drip tape for applications requiring extremely long lateral runs. RD3.12

RD3.12

The Roberts Difference: RO-DRIP XL is a premium quality 7/8 in-diameter drip tape product designed for long lateral runs. It is available in several emitter spacings and flow rates and has been successfully used for lateral runs over 1/4 mile (0.4 km) long.

Table 3.7 Considerations for Selecting Drip Tape Diameters

TYPE	FEATURES
Standard Diameter (5/8-in, 16-mm)	•lower cost than 7/8-in (22-mm) diameter products •run lengths are sufficient for most field layouts •larger variety of emitter spacings and flow rates are available
Large Diameter (7/8-in, 22-mm)	•very long lateral runs with high uniformity are possible •less problems with high water application at head of field on heavier soils •allows use of fewer submains, possibly resulting in cost savings •fewer submains may also result in fewer tractor turns •higher cost than standard diameter •fittings and other components may cost more than with standard diameter

Table 3.7 provides background on the selection of tape diameter. Actual design decisions may require run length information from performance charts and price information from your irrigation dealer. See the Roberts Irrigation Products publication RO-DRIP PERFORMANCE SPECIFICATIONS.

MAINLINES AND SUBMAINS

Field Uniformity

The previous section explained how to use performance charts to select a drip tape product and run length that meet your uniformity goals along the length of each lateral. It is equally important to select mainlines, submains, and other components to ensure that the supply pressures to all of the laterals are consistent so the distribution uniformity over the entire field will meet your goals.

Figure 3.1 shows the major components of a typical field layout.

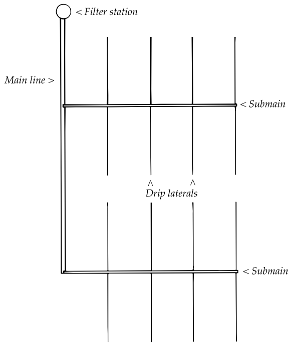


Figure 3.5 Typical Field Layout

Design of Submains

The function of a submain or supply manifold is to distribute water uniformly to a number of laterals. For surface or shallow subsurface systems, submains are commonly made of polyethylene hose or reinforced flexible PVC (layflat) on the surface, or buried PVC. The submains for a deep subsurface system should be PVC. When PVC is installed on the surface, use a light cover of soil to protect it from UV degradation and algae growth within the pipe that can result from exposure to sunlight. Table 3.8 summarizes the features of each type of submain.

Each submain in your system should supply consistent pressures to all of the laterals attached to it. Consult a qualified irrigation designer to specify submain diameters that can meet this requirement as cost effectively as possible.

Design for Flushing

If your system is used for multiple seasons, or water quality is poor, it may be necessary to periodically flush the laterals by opening the ends to remove sediment with the resulting water flow. If flushing is infrequent, this may not require any special consideration in the design stage, although removable end caps can make the procedure easier.

In large systems that require frequent flushing, flushing manifolds, as shown in figure 3.6, can save time and labor. Several laterals terminate to a single flushing manifold, and a valve can be opened or an end cap can be removed to flush them all simultaneously. If flushing manifolds are used, their diameters must be large enough to allow sufficient flow velocity from the ends of the laterals. In addition, the connection from each lateral to the flushing manifold should not significantly restrict flow.

To effectively remove sediment, the flushing velocity should be at least 1 ft/sec at the end of each lateral. This translates to approximately 1 GPM (3.8 LPM) for a 5/8-in (16 mm) lateral or 2 GPM (7.6 LPM) for a 7/8-in (22 mm) lateral. Depending on run length, this may require 2 to 3 GPM (7.6 to 11 LPM) from the supply manifold to flush a single 5/8-in lateral, or 3 to 5 GPM (11 to 19 LPM) for a 7/8-in lateral. When designing a manifold to

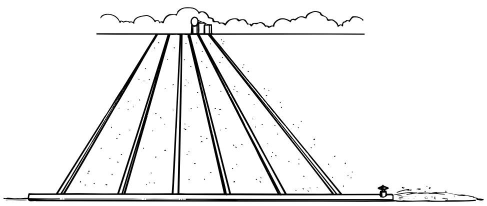


Figure 3.6 Design for Lateral Flushing

Table 3.8 Types of Submains			
Material	**Description**	**Advantages**	**Disadvantages**
PVC	Rigid PVC pipe	•Long life, if buried	•Degrades if exposed to sun-light; should be buried •More difficult to work with than PE hose or layflat •Not easily portable
Polyethylene Hose	Flexible polyethylene hose with round or oval-shaped cross-section	•Long life (3-5 yrs) in above or below-ground applica-tions •Easy to install - simply unroll from coil •Easy to attach laterals and fittings •Portable	•Requires more storage space than vinyl layflat •Thermal expansion and con-traction can cause movement •Can flatten in a buried trench
Vinyl Layflat	Collapsible vinyl hose which inflates under water pres-sure	•Very compact for shipping and storage •Relatively long life in above-ground applications (2-4 yrs) •Easy to install – simply unroll from coil •Portable	•Shorter life than poly hose or buried PVC •Often moves due to internal water velocity

flush several laterals simultaneously, it is important to ensure that the capacity of your water supply will not be exceeded. If it is, the flow requirements during flushing can be reduced by using several smaller flushing manifolds at the end of the field, which can be opened individually.

Submains on Uneven Terrain

When drip laterals are in a level orientation across a steep slope, the submains run up or down the slope. Pressure variations will occur within the submains if they are long and/or the

Table 3.9 Minimizing the Effects of Submain Pressure Variations	
Method	**Description**
Short submains	If submains are short, the elevation change along each is less than 5 feet (1.5 m), and a pres-sure regulator is installed at the beginning of each submain, pressure variations will be within acceptable limits.
Flow restrictions	A flow restriction is installed on the submain at each 5-foot (1.5 m) change in elevation. The flow restriction can be an in-line valve on a PVC or poly hose submain, or a clamp on a layflat submain. This method requires some trial and error to adjust the restrictions properly.
Telescoping submains	Submains are carefully sized so that pressure lost due to friction offsets pressure gained due to elevation change. This results in larger diameter pipe at the top of the slope, "telescoping" down to smaller diameters further down the slope. Telescoping submains can also be used on flat ground to reduce cost of pipe.
Variable length transfer tubes	If small-diameter transfer tubes are used to connect laterals to submains, their lengths can be set to vary the amount of flow restriction they provide. Short tubes are installed at the top of the slope and long tubes are installed at the bottom. Charts and formulas are available that give the friction loss caused by a given length of transfer tube, or trial and error can be used.

slope is severe. Every 5 feet (1.5 m) of elevation change will cause approximately 2 psi (0.14 bar) pressure change, which is enough to affect uniformity. There are several ways to minimize the effects of slope on uniformity. The submain should run downhill, with the water supply at or near the top. Refer to table 3.9 for methods to minimize the effect of submain pressure variations.

Air/vacuum relief at the high points of sloping submains is critical to prevent vacuum conditions that can suck dirt particles into the emitters and cause plugging when the system is drained.

Design of Mainlines

Mainlines distribute water from the source to one or more submain risers which supply the individual submains in the system. They are most commonly made from buried PVC, although poly hose or layflat can be used in small or portable installations. Do not use metal pipe (especially aluminum) because it can react with chemicals that are injected through the system and plug emitters. Important considerations in the design of mainlines include the following:

- Mainlines should be carefully laid out to minimize both material cost and pumping cost.
- Tradeoffs between initial material cost and ongoing pumping cost must be made when sizing mainlines.
- Thrust blocks should be installed on large mainlines at points where flow changes direction.
- Mainline sizes should be specified such that flow velocities do not exceed 5 ft/sec (1.5 m/sec). Up to 8 ft/sec (2.4 m/sec) is acceptable in some cases where water is free of sand and care is taken to open and close valves slowly.
- Pressure relief valves should be installed at low points and at the end of mainlines.
- Air/vacuum relief valves should be installed at high points and downstream of any valves.
- Flush valves should be included at the end of mainlines.

Consult a qualified irrigation designer to design mainlines that meet these requirements as

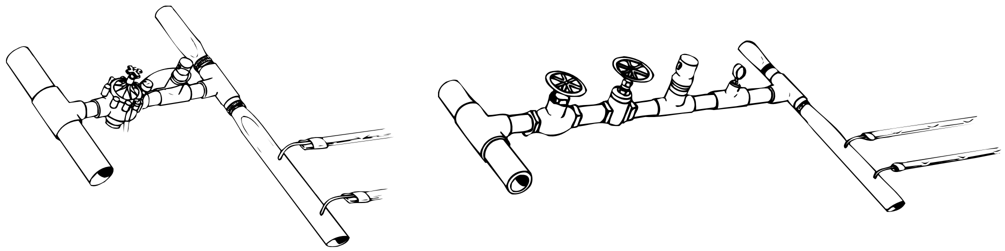


Figure 3.7 Connection of a Submain to a Mainline

cost effectively as possible.

Connection of Mainlines to Submains

A pressure regulator at the start of each submain can improve distribution uniformity in many cases. In addition, the submain connection to the mainline (fig. 3.7) may include a control valve, an air relief valve and, if necessary, a secondary screen filter.

DIVIDING YOUR FIELD INTO INDEPENDENT ZONES

Most large drip irrigation systems are comprised of several zones that can be independently scheduled. Each zone typically has one or more submains, and a control valve that allows it to be turned on and off. Automatic irrigation controllers are helpful if several zones are implemented, each with a different schedule. More than one independent zone may be required if one of the following situations apply:

- The capacity of your water supply is not sufficient to irrigate your entire field at the flow rate and lateral spacing specified in your design (see the example in Selection of Flow Rate)
- Fields are staggered for different planting and harvesting dates
- Several different crops are being irrigated with different water requirements

- Topography varies throughout your operation
- Drainage or soil texture vary throughout your operation

Maximum Zone Size

The maximum size of any one zone is determined by the capacity of your water supply:

$$N \text{ (acres)} = \frac{\text{(lateral spacing in feet) x (water supply capacity, GPM)}}{\text{7.26 x (tape flow rate, GPH/100')}}$$

or

$$N \text{ (acres)} = \frac{\text{(lateral spacing in meters) x (water supply capacity, LPM)}}{\text{1.67 x (tape flow rate, LPH/100 m)}}$$

Ideally, each zone should be sized to fully utilize your water supply, although this is not always practical. In some cases it is desirable to irrigate more than one zone at a time, but it is never possible to simultaneously irrigate more acres (hectares) than the number given above.

FILTRATION

Filtration Requirements for Drip Irrigation

The main purpose of filtration is to keep your emitters clean and working properly. Maintaining clean emitters is as important to your drip system as water is to your crops. Two common sources of emitter clogs, in-line particulate (suspended soil, algae, etc.) and chemical precipitates, can and should be prevented by proper filtration and water treatment.

NOTE: Filtration equipment is a crucial component of your drip system. Resist the temptation to save money on unreliable or inappropriate filtration equipment-it is the heart of your system and should be the right equipment for your farm water source.

In addition to filtration, chemical water treatment may be necessary to control pH or to remove algae, bacterial slime, and mineral participates that can clog emitters. See MANAGEMENT: Water Treatment for more on water treatments.

Filter Types and Filter Selection

There are several types of filter systems available. Your choice among them should be based on careful consideration of the following factors:

- A thorough analysis of your water supply including particle size and concentration
- Filtration requirements of the drip irrigation tape
- Seasonal or other changes in potential contaminants
- Potential for precipitation of dissolved solids due to chemical reactions
- Consultation with a qualified irrigation specialist

Table 3.10 summarizes the filter types and their proper use.

PUMPS

There are a variety of pump types available. Each has a performance profile represented by a pump performance curve. Pump lift, capacity, and discharge pressure are all factors to consider. The particular balance of these factors will be determined by the pressure and flow rate required by your system, and by the type and location of your water source.

Table 3.10 Filter Types

Filter Type	Application	How it Works	Specifications	Notes
Sand Media Filter	•Required for any open or surface water source where large amounts of organic matter are present •Frequently used for well water	Fine sand particles within pairs of closed tanks create a three-dimensional filtering surface. Removes algae, slime, and fine suspended solids. Filters are backflushed one at a time, while remaining units continue filtration.	•Filtration to 74 microns (200 mesh) •Sizes: 12-48 in (30-120 cm) •Use at least 3 tanks if possible to avoid backflushing problems	•Cleaned by backflushing • Available in carbon steel, stainless steel, and fiberglass •A settling basin may be required if large amounts of silt or clay particles are present •Several tanks can be used in parallel for large flow rates
Screen Filter	•Usually a secondary filter, as a back-up for a media filter •May be used as a primary filter for very clean water sources	Fine-meshed screen enclosed in a pressurized tank traps organic and inorganic particulate.	•Available screen mesh: 50 to 200 (300 to 74 micron) •Available sizes 0.75-10 in (1.8 - 25 cm)	•Clean by flushing •Easily clogged by organic matter
Centrifugal Sand Separator	•Used to remove sand, well casing and other inorganic material •Can be used as a pre-filter to reduce backflushing of main filters	Centrifugal action creates a vortex that pushes away particulate that is heavier than water. Removes well casing scale, sand, and other inorganic particulate.	•Removes particles heavier than water, down to 74 microns (200 mesh) •Works with 5-7 psi pressure loss	•Self cleaning •Low maintenance •Does not remove organic matter •Not 100% effective - usually used as a pre-filter
Gravity-Flow Filters	•For low or medium levels of particulate •Used to deliver a large volume of water at a low pressure	Water falls on a screen separator which catches particulate. Particulate is washed into a collection tank.	•Available from 100-200 mesh	•Cleaned by water flow and additional spray nozzles •Booster pump is usually necessary after this filter
Disc Filter	•Primary filtration •Used in many of the same applications as media filters	Filters water through microscopic grooves on densely packed discs.	•Available from 20-600 mesh	•Cleaned by backflushing •Can handle high flow conditions by installing several banks of disk filters •Not for use with large amounts of sand
Suction Screen Filter	•Used for pre-filtration at pump intake	Relatively coarse screen traps debris.	•Available in 10-30 mesh	•Cleaned by rotating water jets
Settling Pond	•Pre-filtration to remove silt or other inorganic particles	Allows suspended particles to settle. Removes high quantities of silt and clay particles. Also provides aeration to remove some dissolved solids and iron suspension.	•Sized according to peak water requirement and particulate type	•Cleaned by draining and removing buildup •Care must be taken to control algae growth •Inlet must be away from outlet

Your choice among pump types and sizes should be determined by the optimum operating pressure and flow rate of your system. Once you have determined the requirements of your system, you can choose the most efficient combination of pump and power source by consulting catalogs of pump performance curves. Pump specification is an in-depth topic that is not covered in detail here. Many pump manufacturers provide detailed guidelines on sizing pumps for irrigation applications.

OTHER COMPONENTS

Fittings and Connectors

Connecting laterals to submains

Three basic methods used to connect drip tape laterals to submains are:

- Direct connection using twist-lock connectors
- Connection via transfer tubes and fittings
- Connection via transfer tubes without fittings

Each of these methods is described in detail in INSTALLATION AND STARTUP: Connecting Laterals to Submains. Refer to the Accessories section of the Roberts Irrigation Product Catalog for information on the fittings and tubing that are available from Roberts Irrigation Products, Inc. Table 3.11 summarizes the advantages and disadvantages of each connection method.

Terminating laterals

Laterals can be terminated into flushing manifolds (see Mainlines and Submains, in this section), or they can be individually terminated with or without fittings. The best method of terminating laterals is usually determined by the flushing requirements of your system.

The lowest cost method of terminating an individual lateral is to fold it over and use a short length of drip tape as a sleeve to slip over the fold. This method is described in detail in INSTALLATION AND STARTUP. Threaded end cap fittings can be used to simplify flushing of laterals. Automatic flushing end caps are also available, although they should not be used in place of a regular flushing program because they do not allow sufficient flushing velocity. See the Accessories section of the Roberts Irrigation Catalog for more information on the end-caps available from Roberts Irrigation Products, Inc.

Valves and Pressure Regulators

Drip systems rely on uniform emission rates from all emitters. While pumps provide a basic level of pressure and flow volume, many more minor adjustments are required to keep your system operating at optimum efficiency and safety.

The following types of valves may be required for your system:

Pressure-regulating valve

Pressure-regulating valves keep downstream pressures constant in the presence of varying upstream pressures. They do not affect water flow directly. They can be of great value in limiting pressure differences across the field, especially when installed at the beginning of each submain. Pressure regulators must be sized according to the flow rates they will be subjected to, and not according to submain size. Be careful when installing pressure regulators since they can be damaged by water hammer. Avoid low cost units that do not regulate downstream pressure but only maintain a pressure drop.

Pressure-relief valve

Use pressure-relief valves when the pressure in your system has the potential to increase beyond a safe level. Temporary high pressure conditions may occur with sudden opening or closing of valves or air vents, or may occur due to water hammer. The optimal location for pressure relief valves can be difficult to establish. They generally should be included at low points and at the end of lines, but also at any other point that can be subjected to large pressure surges.

Table 3.11 Lateral Connections to Submains	
Connection Method	**Notes**
Direct connection via Twist-Lock fitting	•Simple and reliable - only one fitting per lateral •Most common in surface applications •In subsurface applications, laterals must be buried at the same depth as submains
Connection via transfer tube using fittings	•Allows surface placement of laterals with buried submains •Small diameter transfer tubes may result in pressure losses •Requires up to two fittings and a transfer tube for each lateral
Connection via transfer tube without fittings	•Lowest cost method of connecting a lateral to a submain •Small diameter transfer tubes may result in pressure losses •Greater risk of leaks

Field control valve

A field control valve is usually included at the beginning of each submain. Gate valves, butterfly valves, and globe valves are commonly used, and field control valves may be automatically controlled. Field control valves are usually used as on/off valves, with in-line pressure regulators or pressure reducing valves used to control the pressure in each submain.

Mainline control valve

Control valves used on mainlines may be simple on/off valves, or may be used to partially restrict flow or reduce pressure. Gate valves and butterfly valves are commonly used, with globe valves sometimes used in smaller systems. Gate valves should only be used for for on/off operation and not to partially restrict flow, since the valve may wear while partially open and may not seat properly when closed.

Air vent/vacuum relief valve

Air that accumulates in mainlines and submains can restrict flow and lead to damage from water hammer. Vacuum conditions, which can occur in drip laterals when the system is shut down, can cause contaminants to be sucked into the emitters and lead to plugging. In addition, the vacuum that forms downstream of control valves when they are suddenly closed can damage pipes or the valves. Install air/vacuum relief valves

- At all high points on mainlines and submains
- At the ends of mainlines and submains
- Downstream of all control valves
- Upstream of pump check valves

Check valve

Check valves only allow flow in one direction. If chemical injection is used, a check valve should be installed at the output of the chemical holding tank to prevent irrigation water from flowing into the tank. Check valves are also installed downstream of pumps to prevent water from flowing in the wrong direction when the pump is turned off.

Backflow prevention valve

A backflow prevention valve prevents water from flowing back into the supply from the irrigation system. There are several types of backflow prevention valves that use different mechanisms to operate. Backflow prevention valves prevent chemicals and other contaminants from entering the water supply. They should be installed in drip systems that are used for chemigation and / or fertigation, and are required by law in many areas.

Instrumentation

The two most important devices for measuring water movement between the water source and your field are flow meters and pressure gauges. Close monitoring and accurate record keeping with these devices will allow you to make the most fundamental adjustments to your system operations and detect problems before they can have serious effects on your crop.

Flow meters

Flow meters allow you to directly measure application rates, and can help you detect problems such as clogging or line breakage. Install at least one flow meter on the main supply line to indicate the total amount of water being applied to the field. Read this meter and record the information for the new system a regular basis thereafter. Flow meters are available that show total and instantaneous flow rates.

There are several types of flow meters to choose from, the most popular being the propeller-type flow meter due to its reliability and low cost. The reliability of flow measurements is highly dependent on the flow meter location. Propeller flow meters should be located downstream from a straight, unobstructed length of pipe at least eight times the diameter in length. For accurate readings, the pipe must flow full.

Pressure gauges

The performance of your system depends on consistent control of water pressure. Regardless of how well your system is designed, or how well your drip tape is manufactured, operating pressures must remain at design specifications to maintain the desired distribution uniformity. Changes in pressure can indicate a variety of problems. A pressure drop may indicate a leak, a component or line break, a blocked filter, or a malfunctioning pump. A pressure increase usually indicates a block in the filters, valves, or lines.

Install pressure gauges on the mainline both before and after the filters. You can obtain additional information by installing a pressure gauge directly downstream of each pressure regulator to indicate the actual pressure supplied to the submains. As with flow meters, read all pressure gauges and record the information when the system is new and on a regular basis during operation

CHEMIGATION/FERTIGATION

Controlled injection of chemicals and fertilizers may be the most important benefit of your drip irrigation system. Substances commonly injected into drip systems include chlorine, acids, fungicides, herbicides, pesticides and fertilizers. This section describes the design aspects of chemical injection. Use of your injection system for treating your irrigation water and fertilizing your crops is described in MANAGEMENT: Maintenance, Water Treatment, and MANAGE-MENT: Fertigation.

Precision application of high quality fertilizers is especially important and can improve crop response to essential nutrients, while using less fertilizer than traditional irrigation methods. Drip fertigation can also efficiently fertilize crops that are covered by plastic mulch.

Injection Methods

Locate injection equipment downstream of your pump and upstream of your filters, which aid in mixing and can prevent emitter plugging due to particulate buildup or chemical precipitation. The only exception to this rule is strong acids, which may corrode filter components, and should be placed downstream of the filters.

Caution: Serious plugging can occur to drip tape from unpredictable mixing of your water, fertilizers, and chemicals that may form precipitates. Always inject fertilizers and chemicals before the filters and know how they will react. Have a water quality analysis performed to help you recognize and address potential incompatibilities.

When specifying and / or installing injection equipment, always do the following:

- **Include a backflow prevention device to prevent backflow of chemicals into the water source and a check valve to prevent flow of irrigation water into chemical tanks**
- **Use injector pumps and components that resist corrosion from fertilizers and acids**
- **If using an electric injection pump, include an interlock circuit to ensure the injection pump automatically turns off when the system pump shuts down**
- **Select an injector that is easy to operate and adjust during system operation**
- **Confirm that the injector you specify is capable of low flow rates; rates as low as 0.1% of the total irrigation flow may be required**
- **Check with regulatory agencies for specific requirements regarding backflow prevention**

It may be necessary to use several injectors to achieve desired flow rates and to allow separate injection of incompatible chemicals. Before adding anything to your pipelines, test its compatibility with your water using a jar test, which is a simple test of precipitation risk. See MANAGEMENT: Fertigation for instructions on performing a jar test.

There are many types of injectors to choose from (fig. 3.12). Table 3.13 summarizes the features of some common injection equipment.

Injection System Materials

Highly concentrated acids and other corrosive chemicals are commonly injected into drip irrigation systems. Be sure the components of your injection system, including tubing and fittings, are made from suitable materials. While PVC and other commonly used materials are highly resistant to diluted acids, concentrated acids can degrade them over time. Injection should be into the center of the water flow in the mainline or in a mixing chamber, so the chemical is diluted before it makes contact with the inside wall of the pipe.

Tubing and fittings made from Kynar“ (PVDF) plastic are resistant to concentrated acids and other chemicals used in irrigation systems. Kynar is a registered trademark of Elf Atochem North America.

CAUTION: Never inject acid into aluminum pipe.

Injection Rates

One of the primary benefits of drip fertigation over other fertilizer application methods is the accurate control of application rate. In addition the effectiveness of chlorine, acid, and other chemicals depends heavily on concentration. As a result, it is important to design an injection system that allows good control over injection rates. Pressure differential tanks, in particular, are not recommended where accurate control of injection rate is required.

Backflow Prevention

If you inject fertilizer or chemicals into your system it is essential, and in some cases is required by law, to install a backflow prevention device upstream of the injection point. Depending on local your regulations, this may require a pressure-reduced backflow preventer or a double check valve assembly.

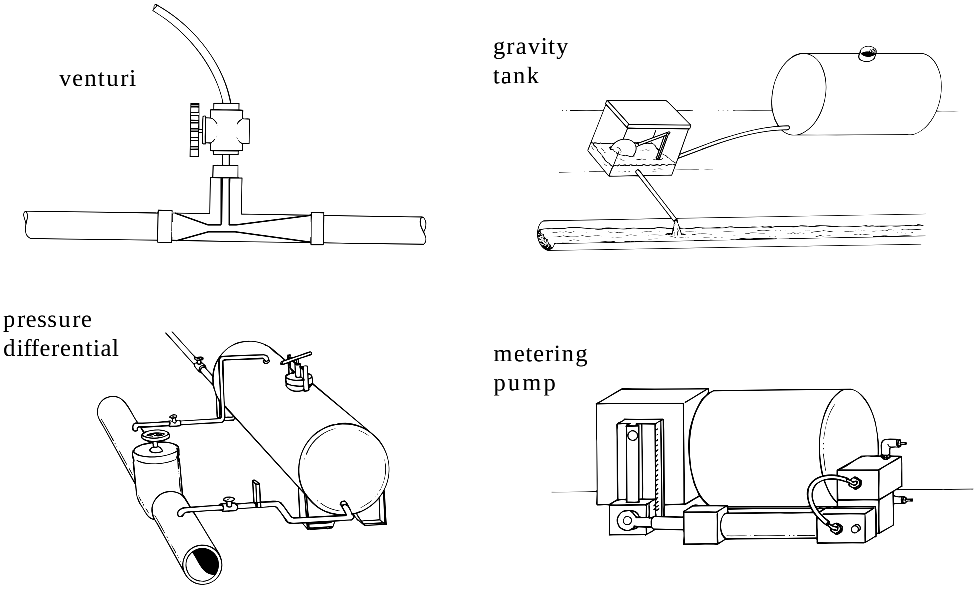


Figure 3.12 Common Injector Types

Table 3.12 Common Injector Equipment and Their Features		
Type	**How it Works**	**Notes**
Batch or Pressure Differential Tank	A pressure differential caused by a valve or other restriction is used to force water into a tank containing the chemical. The chemical then mixes with the water, exits the tank, and re-enters the water flow downstream of the restriction.	•Simple •Does not allow control of injection rates: the initial concentration is higher than the final concentration •Causes a pressure drop in the main irrigation line
Gravity Tank	A tank stored above the water flow drips the chemical into the water at a constant rate.	•Allows control of injection rates •Simple •Requires a float valve and a metering valve
Venturi Device	Water passing over a narrow opening causes a vacuum which pulls the chemical into the water path.	•Allows control of injection rates •There is a 10-30% pressure drop caused by friction in the venturi •Can be used in conjunction with a small pump to reduce pressure loss
Metering Pump	Many types available; all require power to push liquid forward.	•Allows precise control of injection rates •Water-powered models are available

4 INSTALLATION AND STARTUP

Drip tape installation methods range from manual placement of single laterals without the use of tractors or other equipment, to automated injection of several laterals simultaneously in combination with other operations such as bed shaping and mulch laying. The right method for your operation depends on a variety of factors including the size of your field, lateral placement depth, and the equipment available to you.

Careful installation and startup of your system can reduce initial cost and enhance long term performance. Experience has shown that most damage to drip irrigation systems occurs during tape installation. If you use mechanical tape laying equipment, it should be carefully designed and free of burrs, sharp edges, mud, sticks and stones. Whatever method you use to install your system, following a few well-tested procedures can help you avoid expensive and time-consuming repairs.

Accurate placement of laterals can result in increased water distribution uniformity and better movement of water through the soil, allowing you to take advantage of the full potential of your system. This section explains how to install drip laterals, how to connect them to submains, and how to properly start up and check your system for trouble-free operation over the long run.

The Roberts Difference: RO-DRIP's unsurpassed uniformity, simple installation and retrieval, reduced infrastructure, and lower cultivation costs make it the performance leader for any length of run in the field.

KEY CONCEPTS

- **Precise installation of your system can result in more uniform performance and easier retrieval.**
- **Always install drip tape with the outlets facing up to prevent plugging by sediment that may settle during operation.**
- **The installation shank is the main tool used for mechanized drip tape installation.**
- **All equipment that makes contact with the drip tape during installation must be free of burrs and other sharp edges.**
- **Before irrigating, test the entire system to confirm proper functioning.**

Table 4.1 summarizes several important guidelines for proper installation.

Table 4.1 Installation Guidelines	
DO	**DO NOT**
•Store drip tape in a protected area and leave wrapping in place until ready to install •Prepare soil and beds before planting. Particle size should be small and uniform •Install laterals with emitters facing up •Maintain a low constant tension on drip tape roll •Test the system before irrigating	•Begin installation before carefully planning and engineering your system •Step on laterals or drag drip tape across soil surface •Apply uneven tension or jerks that can stretch tape and alter flow rates •Handle drip tape using any tools or equipment with burrs or other sharp edges

Note: Always install tape with the emitters facing up, in both surface and subsurface applications. This prevents sediment from settling to the bottom of the tape and clogging the emitters.

INSTALLING DRIP TAPE LATERALS

Manual Tape Installation

Manual drip tape installation is common in small fields and greenhouses where laterals are placed on the surface, because it is often the most cost-effective choice. Manual installation is less practical in large fields or in subsurface applications. It is generally not practical to manually install deep subsurface drip systems.

Use PVC, vinyl layflat or poly hose for submains. If using PVC submains above ground, protect them from sunlight with a light covering of dirt. Do not use steel or aluminum pipe.

Use the following steps to install drip laterals.

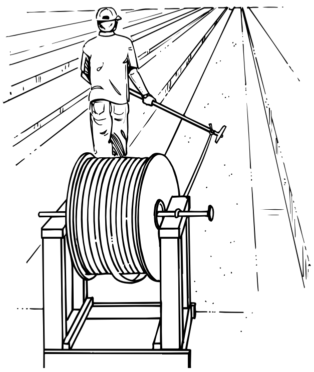


Figure 4.1 Pulling Drip Tape Along a Row

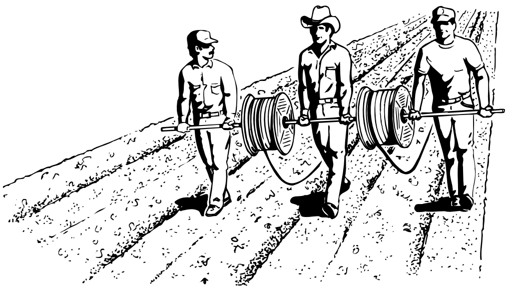


Figure 4.2 Walking Spools Along a Row

1. Mount the spool on a low stand at the front end of the row.

2. Pull the lateral along the row, taking care not to drag it on the soil surface (fig. 4.1). Lay the drip tape with the emitters facing up.

Note: If the ground is rocky or there is stubble in the field, install the drip tape by carrying the spool down the row. This avoids damage caused by dragging the drip tape (fig. 4.2).

3. Place a shovel full of dirt on the drip tape every 10 to 15 ft (3 to 4.5 m) to prevent twisting or wandering (fig 4.3). Avoid stretching or jerking the lateral during installation.

4. Leave extra length at both ends of each lateral to allow for expansion and contraction and to connect to the manifolds.

Mechanical Tape Installation

Installation equipment: an overview

The basic component used in all mecha-

Figure 4.3 Placing Dirt on a Lateral

nized installation is the injection shank. Its purpose is to accurately locate the drip tape to the point of installation, either on or below the surface and, in subsurface installations, to dig a trench for the lateral. One or more spools and injection shanks can be mounted together on a tool bar. Figure 4.4 shows a Tube Type injection shank, which is popular because of its simple and functional design. Simple injectors such as the Tube Type Shank are easy to build, although extreme care must be taken to eliminate all sharp surfaces. More advanced injectors, which allow high-speed installation of thin-walled tapes, can be purchased from a number of suppliers.

Pay attention to the following important factors when you design or purchase an injection shank:

- The installation tube should have a flared opening and should be free of burrs, nicks, sharp edges, weld lines or seams that can cause damage to the drip tape
- The diameter of the installation tube should be as small as possible. 1-in Schedule 40 steel for standard 5/8-in drip tape or 1.25-in for 7/8-in drip tape
- The bottom of the installation tube should be at the same depth as the bottom of the shanking tool
- The drip tape spool should be positioned close to the injection tube - directly above it if possible
- The drip tape spool should be mounted on a shaft that can spin freely; stationary shafts will be damaged by the spool hubs, or can damage spool hubs
- The shaft should have a braking system that can provide drag to prevent overspinning of the spool when the tractor stops
- Wood or metal disks should be used to support the cardboard drip tape spools

RD4.2

The Roberts Difference:

RO-DRIP spools utilize an industry standard bore for a 1-in shaft, making it an easy fit for all commercially available injection equipment.

The injection shank can be mounted on a toolbar with other equipment to perform several tasks simultaneously. In fact, it is possible–and now fairly common–to shape beds, install drip tape laterals, install plastic mulch, and even side dress beds with fertilizer all in a single pass (fig. 4.5). These operations are often performed on several rows at once. Packaged systems that install drip tape while performing other operations are available from a number of vendors.

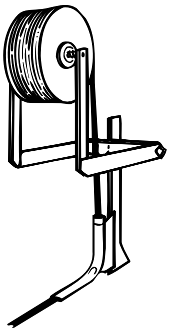


Figure 4.4. Tube-type injection shank, Courtesy of Andros Engineering

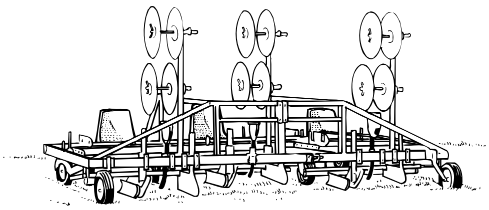


Figure 4.5 Combination Bed Shaper, Plastic Layer, and Drip Tape Installer

Tape installation procedure - subsurface

For shallow subsurface systems, mainlines and submains can be above ground vinyl layflat, poly hose, or buried PVC. Deep subsurface systems should use PVC for mainlines and submains. If using PVC submains above ground, protect them from sunlight with a light covering of dirt. Do not use steel or aluminum pipe. Use the following steps to install drip laterals.

1. **Mount the spool on the shaft that feeds the injection shank.**
2. **Setup and align the shanking tool so that, when installed, the drip tape emitters face upward.**

3. **Secure the beginning of the lateral(s) with a weighted object or a stake.**
4. **Start and stop the tractor smoothly to prevent stretching or jerking of the drip tape through the installation tube. Do not apply excessive drag on the spool. Avoid stretching the drip tape.**
5. **Leave extra length at both ends of the laterals to allow for expansion and contraction and for connection to the manifold.**
6. **After the first lateral is installed, evaluate it for excess drag set on the spool. Check the tension of the lateral by hand. Periodically re-evaluate drag throughout the installation.**

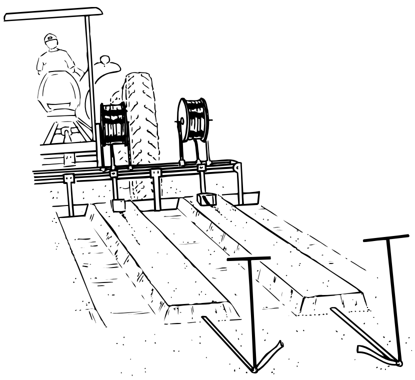


Figure 4.6 Mechanical Installation of Tape

Tape installation procedure - surface

Use the same basic procedure as with subsurface installation. With surface installation, however, the means of securing the laterals are different. Place a shovel full of dirt over each laterals every 10-15 ft (3-4.5 m) to minimize their movement by wind or thermal expansion and contraction as shown in figure 4.3 (Manual Installation, above).

Installation of Tape with Plastic Mulch

For many crops, the combination of drip irrigation and plastic mulch gives the greatest degree of control over the root zone environment, and results in higher yields and more efficient use of water and chemicals.

Injection shanks can be mounted on tool bars along with plastic layers and bed shapers. Packaged systems are available from several vendors that lay plastic and inject tape (fig. 4.7). Some of these systems also shape beds.

Note:Drip tape should be buried if it is used with clear plastic mulch. Water droplets on the surface of the plastic act as magnifying lenses which can focus sunlight to burn and damage drip tape.

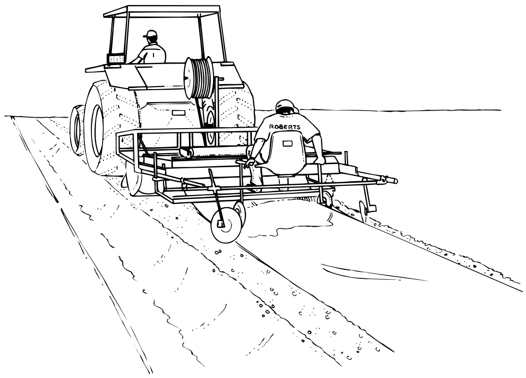


Figure 4.7 Simultaneous Installation of Drip Tape and Plastic Mulch

Greenhouse/Nursery Installations

Drip tape is an effective method of irrigating nursery and greenhouse plants. It is commonly used to irrigate both potted plants and field plants. The increased level of control made possible with drip tape results in higher quality crops with reduced incidence of disease.

Potted plants

To irrigate potted plants, drip tape is laid across pots or containers and secured tightly at each end (fig. 4.8). In some installations it helps to string a wire over the containers and fasten the drip tape to the wire rather than laying it directly on the containers. Emitters should face to one side (instead of facing up), to prevent water from running along the tape and missing the pots.

Field nurseries

In field nursery applications, drip tape is either laid on the surface or buried 2-3 in (5-8 cm) below the surface.
(see figure 4.9)

RD4.3

The Roberts Difference: RO-DRIP is available with the wide variety of emitter spacings required for nursery and greenhouse applications. This includes a 4-in emitter spacing for closely spaced plants.

Figure 4.8 Direct Use of Dip Tape for Potted Plants

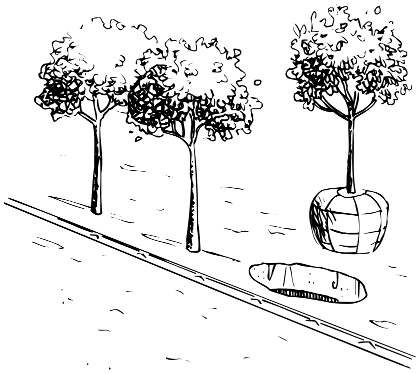


Figure 4.9 Field Nursery Installation

CONNECTING LATERALS TO SUBMAINS

Drip tape laterals can be connected to submains using fittings and / or transfer tubes. Connect laterals to the submains as part of an integrated startup procedure that includes flushing mains and submains (See Startup Procedure later in this section).

Drip tape laterals can connect to rigid PVC, layflat, or polyethylene hose submains with a few basic fitting types. See the Roberts Irrigation Product Catalog for a complete list of Roberts fittings and tubing.

Connecting to PVC submains

Drip laterals can be connected to PVC submains either directly with fittings or through transfer tubing (fig. 4.10). Both glued fittings and gasketed fittings can be used. In either case, fittings are available that directly connect PVC submains to the following:

- **Drip tape using a lock-sleeve fitting**
- **Transfer tubing using an external compression fitting**
- **Transfer tubing using an internal barb**

See Connecting a Transfer Tube to a Lateral below for instructions on connecting a transfer tube to a drip tape lateral once it has been connected to the submain.

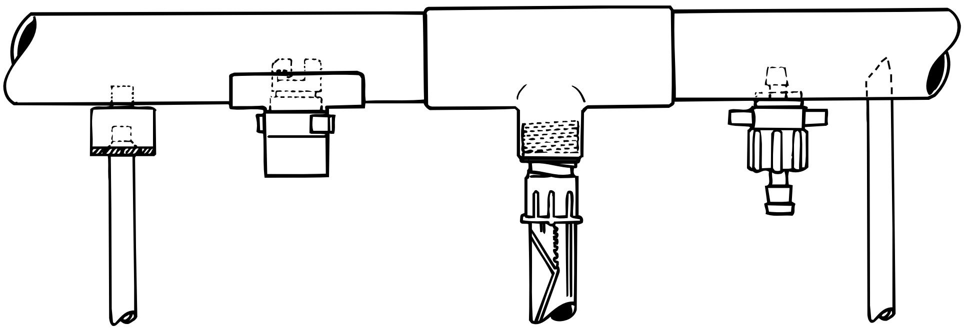


Figure 4.10. Common Fittings for PVC Submains

For either fitting type, an appropriately sized hole must be drilled that is free of gaps, cracks or splits (fig. 4.11). Only clean holes will allow a proper connection.

Use the procedure shown in figure 4.12 to connect a fitting or 4.13 to directly connect a transfer tube to a PVC submain.

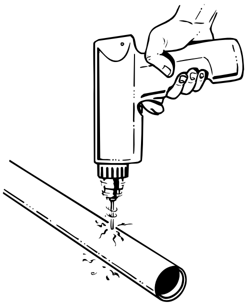


Figure 4.11 Creating a Hole in a PVC Submain

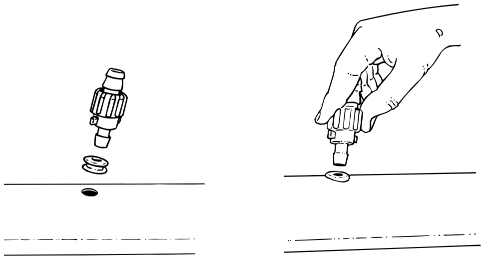


Figure 4.12a-b Connecting a Gasketed Fitting to a PVC Submain

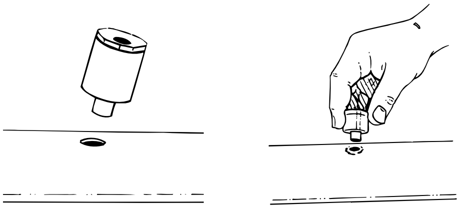


Figure 4.12c-d Connecting a Glued Fitting to a PVC Submain

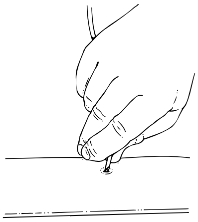


Figure 4.13 Directly Connecting a Transfer Tube to a PVC Submain

Connecting to Polyethylene Hose Submains

There are 2 basic methods for connecting a drip lateral to a poly hose submain: using a direct transfer tube or using a fitting. Fittings are available that directly connect polyethylene hose submains to the following:

- Drip tape using a lock-sleeve fitting
- Transfer tubing using an external compression fitting
- Transfer tubing using an internal barb

Figure 4.14 shows several fittings available for connecting laterals to poly hose submains.

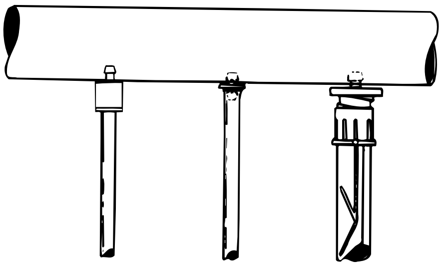


Figure 4.14 Common Fittings for Poly Hose Submains

Create a hole in the poly hose submain that is slightly smaller than the outside diameter (OD) of the transfer tube or barb fitting (fig. 4.15).

Use the procedure shown in figure 4.16 to connect a fitting to a poly hose submain or figure 4.17 to directly connect a transfer tube. See Connecting a Transfer Tube to a Lateral below for instructions on connecting the transfer tube to a drip tape lateral once it has been connected to the submain.

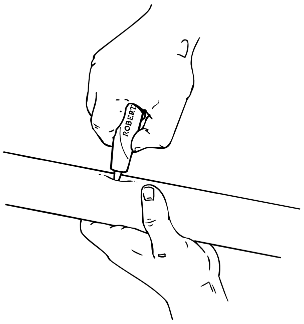


Figure 4.15 Creating a Hole in a Poly Hose Submain

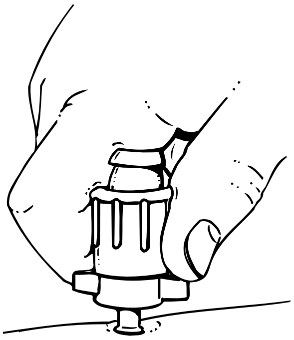


Figure 4.16 Connecting a Fitting to a Poly Hose Submain

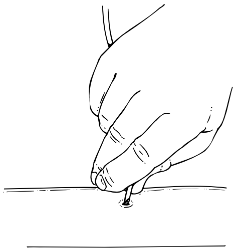


Figure 4.17 Connecting a Transfer Tube to a Poly Hose Submain

Connecting to Layflat Hose Submains

There are 2 basic methods for connecting a drip lateral to a layflat hose submain: using a direct transfer tube or using a fitting. Figure 4.18 shows some common fittings for connecting a layflat hose submain to a transfer tube or lateral.

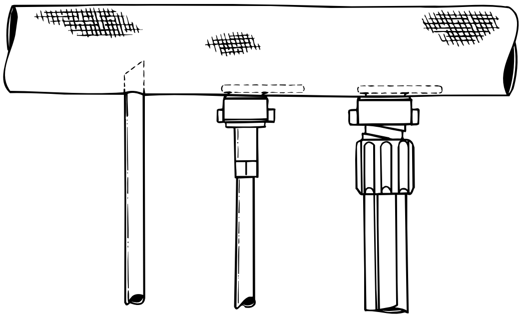


Figure 4.18 Common Fittings for Layflat Submains

Use the procedure shown in figure 4.19 to connect a fitting to a layflat submain or figure 4.20 to directly connect a transfer tube. See Connecting a Transfer Tube to a Lateral below for instructions on connecting the transfer tube to a drip tape lateral once it has been connected to the submain.

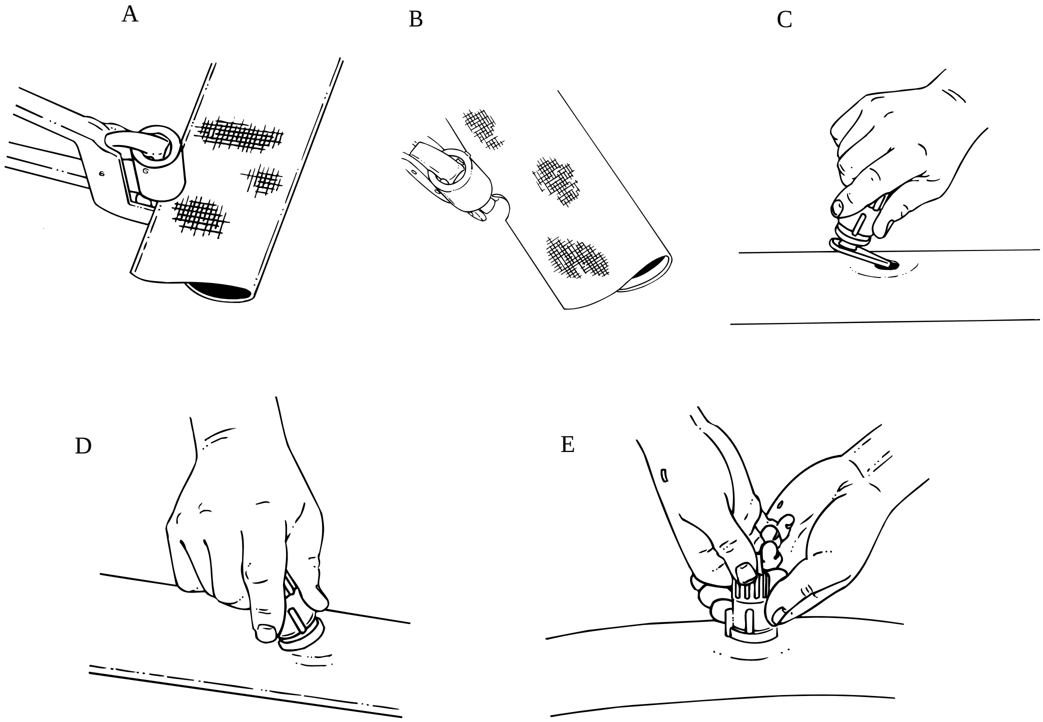


Figure 4.19 Connecting a Fitting to a Layflat Submain

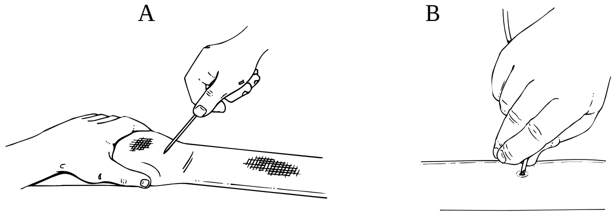


Figure 4.20 Directly Connecting a Transfer Tube Layflat Submain

RD4.4

The Roberts Difference:

Roberts Irrigation Products manufactures a premium quality line of polyethylene hose products which are available in all of the sizes commonly used for drip irrigation transfer tubes.

CONNECTING A TRANSFER TUBE TO A LATERAL

Transfer tubes connect submains to laterals. Smaller transfer tubes (1/8" to 3/8" tubing) can be directly connected to laterals. Larger tubes (0.510"x0.610" for standard 5/8-in drip tape) are connected using wire ties. Finally, a lateral can be connected to a transfer tube with a barbed lock sleeve fitting.

Use the procedure shown in figure 4.21 to directly connect a small-diameter transfer tube to a lateral.

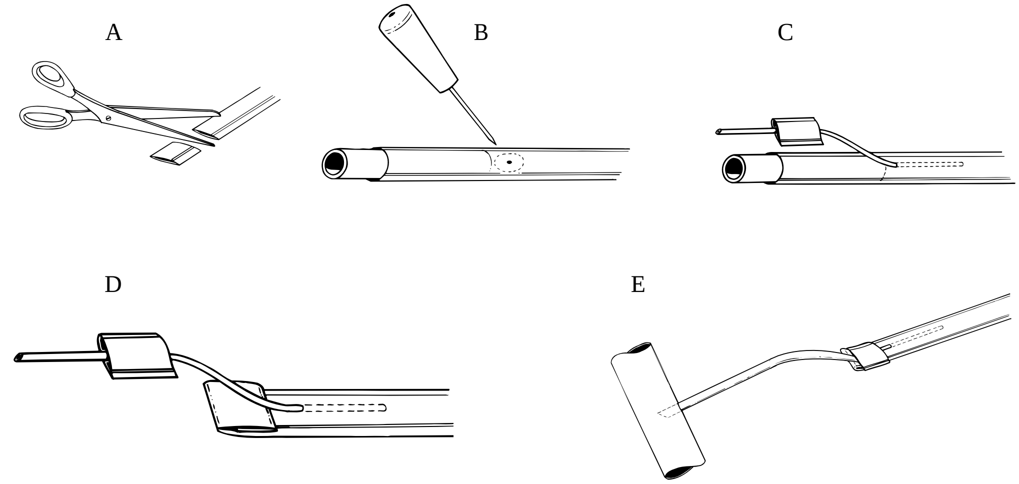


Figure 4.21 Steps for Connecting a Lateral to a Transfer Tube Without Fittings

Use the procedure shown in figure 4.22 to connect a transfer tube to a lateral using a wire tie.

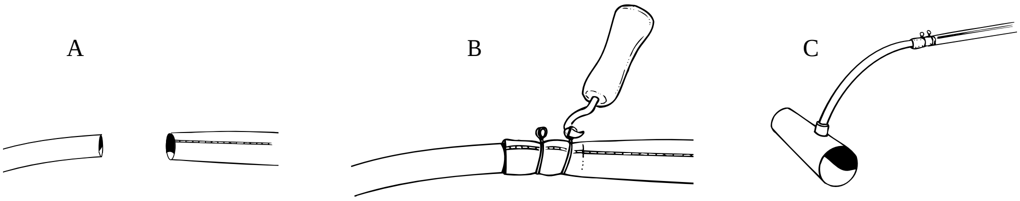


Figure 4.22 Steps for Connecting a Lateral to a Transfer Tube Using a Wire Tie

Use the procedure shown in figure 4.23 to connect a transfer tube to a lateral using a lock sleeve fitting.

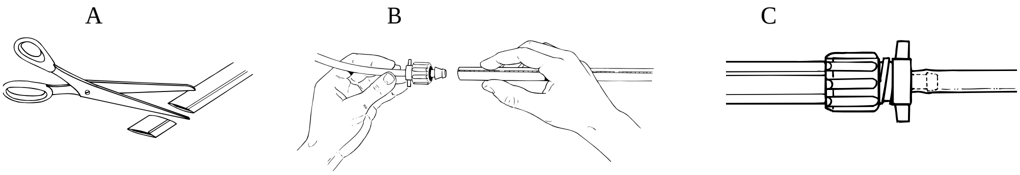


Figure 4.23 Steps for Connecting a Lateral to a Transfer Tube with a Fitting

RD4.5

The Roberts Difference:

The unique polyethylene material blend used to make RO-DRIP provides strength as well as flexibility and memory. The result is reliable, leak-free connections to transfer tubes and fittings.

SPLICING LATERALS

Drip tape laterals can be spliced using tubing (.510" x .610" OD) and wire ties (fig. 4.24), or by using a locking sleeve fitting (fig. 4.25).

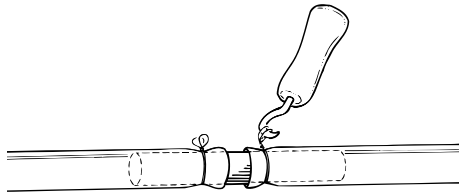


Figure 4.24 Splicing a Lateral Using Poly Hose and Wire Ties

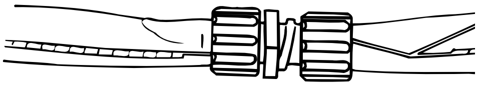


Figure 4.25 Splicing a lateral Using a Locking Sleeve Fitting

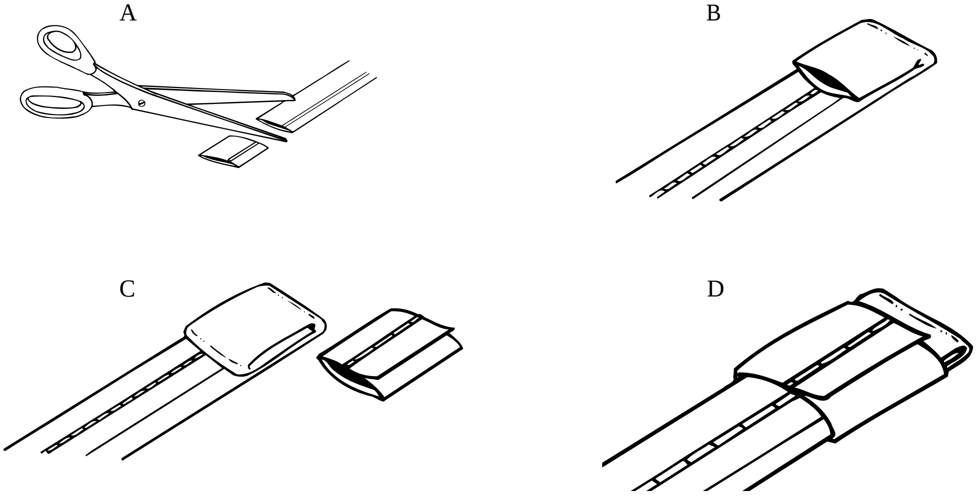


Figure 4.26 Closing a Lateral Using a Closing Band

TERMINATING LATERALS

Drip tape laterals can be terminated using a closing band (fig. 4.26) or a lock sleeve end cap fitting (fig. 4.27).

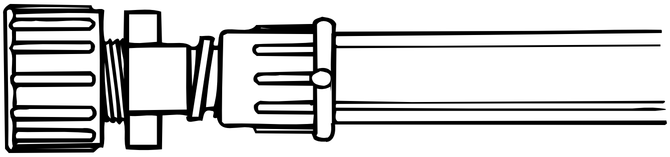


Figure 4.27 Closing a Lateral Using an End Cap

STARTUP PROCEDURE

Before you begin irrigating it is important to thoroughly flush the system, check for leaks or breaks, and ensure that all components are working properly. Make sure you have gone through all of the following steps before you use your drip system to irrigate your field.

1. **Open mainline flushing valves with submain valves closed until discharge water runs clear for 5 minutes. Close the mainline flushing valves. In large systems, dye can be added in the filter station – when the dye is no longer visible at the end of the line, flushing is complete.**
2. **Connect laterals to the submains, without terminating the ends.**
3. **For each submain, open the control valve until the discharge water at the end of each lateral runs clear. If the capacity of your water supply is not high enough to flush all laterals simultaneously, it may be necessary to terminate some of the laterals so that you can flush only a few laterals at a time. Close the submain control valves.**
4. **Close the laterals or connect the ends of the laterals to the flushing manifold, if used.**
5. **Operate the system until it is fully pressurized and all air is discharged.**
6. **Check the system for leaks and repair them if necessary.**
7. **Re-flush after all leaks are repaired.**
8. **Check all pressure gauges and adjust pressure regulators or regulating valves, if necessary.**
9. **Check for proper operation of all system components: pumps, controllers, valves, air vents, pressure regulators, pressure gauges, flow meters, filters, and chemical injectors.**
10. **Record readings from all pressure gauges and flow meters.**

5 MANAGEMENT

The three critical components of a drip system management program are scheduling, monitoring, and maintenance. Each has requirements that differ from traditional furrow and sprinkler irrigation. Scheduling must be carefully planned to keep the soil in the root zone near field capacity, providing ideal conditions for plant growth. Monitoring of pressures, flow rates, and soil moisture is necessary to continually fine tune your irrigation schedule. Finally, a regular maintenance program is required to keep the drip emitters clean and free of clogs that can reduce efficiency and damage your system.

This section tells you how to schedule, monitor, and maintain your drip irrigation system for years of successful operation. Emphasis is placed on diligent planning and adjustment of your program to maximize crop performance and avoid potentially costly problems. The section finishes with management and maintenance issues associated with chemical/fertilizer injection and salinity management.

The Roberts Difference: RO-DRIP® and RO-DRIP® XL provide the most reliable, cost-effective solution for subsurface and above ground irrigation.

KEY CONCEPTS

- **Take the time to learn, train and implement some new ways of irrigation management.**
- **The three components of a successful drip irrigation management program are scheduling, monitoring, and maintenance.**
- **The goal of drip irrigation scheduling is to replace soil moisture as it is lost to evapotranspiration. Small amounts of water are applied frequently, often daily.**
- **Regularly monitor pressures, flow rates, soil moisture, and other factors to take full advantage of the high level of control that drip irrigation offers.**
- **The central goal of a drip irrigation maintenance program is to keep the emitters clean, so they will continue to deliver water and nutrients uniformly to your plants.**

SCHEDULING

The goal of drip irrigation scheduling is to select an irrigation duration and frequency that results in a properly sized wetted area around plants and keeps the soil in the root zone at or near field capacity. The right schedule for your system depends on your specific crop requirements, soil texture, field preparation and weather conditions. Adjustments throughout the season based on monitoring of field conditions allow you to fine-tune the irrigation schedule to the needs of your crop.

NOTE: Deficit irrigation can be used to increase the soluble solid content of fruits or vegetables by deliberately maintaining soil moisture below field capacity. This is usually done at the end of the growing season, shortly before harvest, and is common with grapes, sugar cane, tomatoes, cotton and several other crops. Precise control of application rates make drip irrigation ideally suited for deficit irrigation when necessary.

To determine how much water to apply during irrigation, first calculate the amount needed by your crop for evapotranspiration, and use this as a starting amount. After irrigating, you will be able to fine-tune the schedule by examining the wetted pattern, measuring soil moisture, and making adjustments accordingly.

Determining Your Crop's Daily Requirements

For most crops, the soil in the root zone should be kept near field capacity at all times (see PLANNING: Water Requirements). This means that irrigation should be frequent, and the amount of water applied each time should be equal to the amount used by the plants since the last irrigation. Therefore, it is important to know the rate at which water is lost to Evapotranspiration (ET).

The ET rate of a reference crop for you area is usually available from a local agricultural agency or, in some areas, through the Internet. Portable weather stations are also available which can be more accurate, since ET can vary from field to field. Use the following formula to calculate the ET rate of the specific crop in your field:

$$ET = K_c \times ET_o$$

where ETo is the reference crop evapotranspiration and Kc is a crop factor, or crop coefficient that depends on the specific crop you are irrigating.

The value of the crop factor varies throughout the season as your crop matures. You can estimate it by starting with the value shown in table 5.1 and multiplying it by the percent of ground covered by your plants. If the resulting number is less than 0.2, use a value of 0.2. Calculate the percent ground coverage as the distance across the bed that is covered by the crop divided by the bed spacing times 100. For example, cucumbers early in the season which cover 50% of the ground surface will have a crop coefficient of 0.5 x 0.9 = 0.45.

Table 5.1 Estimated Peak Crop Factors for Various Plants

ESTIMATED PEAK CROP FACTORS (K_C) FOR VARIOUS PLANTS

Crop	K_C	Crop	K_C
Cabbage	.95	Pepper	.95
Cantaloupe	.95	Potato	1.05
Carrot	1.00	Strawberry with plastic mulch	1.05
Celery	1.00	Strawberry without plastic mulch	1.10
Cotton	1.05	Sugar cane	1.05
Corn	1.00	Squash	.90
Cucumber	.90	Tomato	1.05
Lettuce	.95		

If you do not find your crop in table 5.1, you can estimate Kc as the percentage of ground covered. Both crop coefficients and reference ETo values are now available on the Internet for many areas. These web sites provide both real-time and historical information and can be very useful design and management tools.

If a reference evapotranspiration (ETo) rate is not available for your area, use a potential evapotranspiration rate (PET) from table 5.2 as an approximation of ETo.

Table 5.2 Potential Evapotranspiration (PET)

POTENTIAL EVAPOTRANSPIRATION (PET)		
Climate	in per Day	mm per Day
Cool humid	0.10 - 0.15	2.5 - 3.8
Cool dry	0.15 - 0.20	3.8 - 5.1
Warm humid	0.15 - 0.20	3.8 - 5.1
Warm dry	0.20 - 0.25	5.1 - 6.4
Hot humid	0.20 - 0.30	5.1 - 7.6
Hot dry	0.30 - 0.45	7.6 - 11.4

Developing and Maintaining a Proper Wetted Area

In general, short irrigation cycles with high application rates help promote lateral movement of water, resulting in better wetting patterns for light soils. "Pulse irrigation," where the system is operated several times a day for short durations, can further widen the wetted pattern. Long duration at a low application rate results in better infiltration of water in heavy (high clay content) soils. The right irrigation cycle depends on the specifics of your field – experiment to find out what works best.

Determining Your Irrigation Schedule

How often to irrigate (irrigation frequency)

The irrigation frequencies used in drip irrigation are typically quite different from those used in other methods of irrigation. The increased control offered by drip systems allows you to apply small amounts of water daily or several times a week without significant loss to evaporation or surface runoff. As a result, irrigation can be scheduled to replace water as it is used by the plant on a daily basis. This ability to use frequent irrigation to keep the soil moisture level near field capacity is a unique advantage of drip irrigation.

In most cases, irrigation can take place several times a day, once a day, or several times a week. Research has shown that there is little difference between these as long as enough water is applied each time, although there are some exceptions. During consecutive days of hot dry weather, or when young seedlings are grown in coarse textured soil, daily irrigation is good practice to ensure your plants are not stressed. Irrigating several times daily may result in reduced distribution uniformity, since the repeated filling and draining of submains and laterals with each irrigation results in heavier irrigation at the low points of the field. As described above, however, "pulse irrigating" can help with the development of a good wetting pattern, making it a good choice in some cases.

NOTE: Drip irrigation only wets soil near the plants. Roots only develop in the wetted area and, as a result, can be more localized than with other irrigation methods. This normally does not cause problems, but it makes irrigation frequency critical. Because the water holding capacity in the root zone is smaller, an extended period of time without irrigating can easily cause plant stress. During hot weather conditions, daily irrigation may be necessary to avoid crop damage from water stress.

How long to irrigate (irrigation duration)

Once you have determined an irrigation frequency, you must determine the duration of each

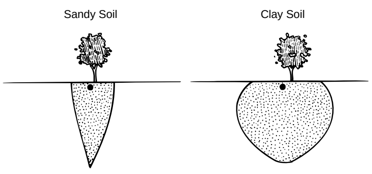
RD5.1

The Roberts Difference: Roberts Irrigation manufactures several high flow rate products with close emitter spacings that are specially designed to form good wetted patterns in soils with high sand content. These include 8-in 40 GPH RO-DRIP (20 cm 497 LPH) and 4-in 60 GPH RO-DRIP (10 cm 745 LPH).

RD5.2

The Roberts Difference: Roberts Irrigation manufactures several low flow rate products with wider emitter spacings which are specially designed to form good wetted patterns in heavy soils with high clay content. These include 12-in 15 GPH RO-DRIP (30-cm 186 LPH), 16-in 10 GPH RO-DRIP (41-cm 124 LPH) and 24-in 17 GPH RO-DRIP (61-cm 211 LPH).

Table 5.3 The Effect of Wetted Area on Crops

Small Wetted Area	Large Wetted Area
•Restricts roots to a small volume of soil •Reduces uptake of needed minor nutrients from soil •Increases potential for plant water stress during periods of high temperature and wind	•Wastes water and fertilizer •Increases the number of weeds •Does not improve crop performance
Ideal Wetted Area	
•The ideal wetted area is shaped as shown •The wetted area should be maintained at the same size throughout the season to prevent salts near the edges from damaging the crop •Soil type and field preparation affect the shape of the cross section dramatically	

irrigation that will apply enough water to replace evapotranspiration (ET) and compensate for system inefficiency (see DESIGN: Irrigation Efficiency). Use the following steps to determine the proper irrigation duration:

1. **Estimate the amount of water used by your crop between irrigation cycles by multiplying the daily ET rate (see Determining you crop's daily requirements, in this section) by the number of days between irrigation cycles.**
2. **Compensate for irrigation inefficiency by dividing the resulting application amount by the irrigation efficiency (IE). Estimate IE as being equal to the distribution uniformity (DU) that you have designed for.**
3. **Divide the amount of water to be applied by your system application rate (AR; see DESIGN: Lateral Design).**

The resulting irrigation duration, given in hours, is a starting estimate for your irrigation schedule. After irrigating, it will be necessary to make adjustments as described later in this section.

EXAMPLE

Cantaloupes will be irrigated every other day using a drip irrigation system with the following specifications:

ET	0.19 in / day
Spacing between laterals:	60 in (152 cm)
Emitter spacing:	12 in (30 cm)
Drip tape flow rate:	24 GPH per 100 ft (298 LPH per 100 m)
Distribution uniformity:	90%

Determine the required irrigation duration.

SOLUTION

Since irrigation is performed every other day, .19 x 2 = .38 in (9.7 mm) of water must be replaced at each irrigation.

The distribution uniformity is 90%, so .38 / .9 = .42 in (10.7 mm) must be applied by the drip system at each irrigation.

Using the formula in DESIGN: Lateral Design, the application rate (AR) of the system is calculated as:

$$AR = \frac{\text{(tape flow rate, GPH per 100ft)}}{\text{62 x (lateral spacing, feet)}} = \frac{\text{(24 GPH per 100ft)}}{\text{62 x (feet)}} = \frac{24}{62 \times 5} = .077 \text{ in per hr (1.96 mm per hr)}$$

The required duration, T, is the amount of water to be applied at each irrigation divided by the application rate:

$$T = \frac{\text{Amount to be applied}}{AR} = \frac{.42 \text{ in}}{.077 \text{ in per hr}} = \frac{.42}{.077} = 5.45 \text{ hr}$$

or approximately 5½ hours.

Adjusting your irrigation schedule

Confirming the amount of water applied

It is important to verify your irrigation schedule by taking direct readings from flow meters. Confirm that the system is applying the amount of water each day that you intended it to in your schedule, as described in Monitoring, below. Make adjustments as necessary.

Adjusting your schedule

Since ET can vary from day to day and even from field to field within the same geographic area, it is always necessary to adjust your schedule based on observations of the wetted pattern and measurements of soil moisture.

The section below: Monitoring, Soil Moisture, describes how to use moisture sensing devices to measure the amount of water in your soil. If soil moisture measurements in the middle of the root zone indicate the water level is consistently below field capacity or the soil is consistently saturated, adjust your irrigation schedule by changing the irrigation duration as shown in table 5.4.

Try making small modifications over several cycles before making any drastic revisions to the schedule.

Table 5.4 Adjusting Your Schedule with Soil Moisture Response

Sensor Response	Cause	Scheduling Change
Consistent high moisture (low tension) readings indicating field is saturated	Too much water applied	Decrease duration
Moisture level does not return to field capacity after each irrigation	Too little water applied	Increase duration

MONITORING

To achieve the high yields and water savings possible with drip irrigation, it is necessary to monitor your system and make adjustments to fine tune the amount of water and nutrients applied. In addition, careful system monitoring gives advance warnings of potential problems.

Monitoring Performance

Monitor the performance of your system by taking readings from all of the flow meters and pressure gauges at regular intervals.

Flow meters

There should be at least one flow meter installed on the mainline to indicate the total amount of water being applied to the field. Once your irrigation schedule has been determined, read the flow meter to confirm that the system is applying the amount of water it was designed to apply.

Because of the large number of variables at play in an irrigation system, the measured application rate cannot be expected to be exactly the same as the predicted rate. However, a large difference indicates either a problem in your calculations or a physical system problem such as a broken or clogged line. If the results are not what you expect, identify and fix the problem.

Flow meter readings can also indicate problems that can occur mid-season. To make use of this valuable information, to measure and record flow meter readings for the new system, and on a regular basis thereafter. Table 5.5 shows some of the problems that can be diagnosed by keeping track of system flow rates. Any of these problems should be addressed immediately to avoid serious crop damage.

Note: Tables 5.5 and 5.6 are intended to present examples of problems that can be diagnosed through regular monitoring. They are not a comprehensive list of problems that can occur with your specific drip irrigation system.

Most flow meters provide instantaneous readings of flow rate, as well as a reading of total flow. The totalized reading is more accurate than the instantaneous reading and can be used to calculate the average flow rate or application rate over a given time. This reading can also be used to indicate the total water usage during an entire season.

Table 5.5 Problems Diagnosed from System Flow Rates

Indication	Possible Problem
Gradual decrease in flow rate	•Emitter plugging •Could indicate pump wear or filter clogging - check pressures
Sudden decrease in flow rate	•Stuck or plugged control valve •Other flow restriction - check pressures •Water supply failure - check pressures
Gradual increase in flow rate	•Incremental damage to laterals from insects or other pests
Sudden increase in flow rate	•Damaged or broken lateral •Damaged or broken submain •Damaged or broken mainline •Pressure regulator failure

Table 5.6 Problems Diagnosed from System Pressures

Indication	Possible Problem
Large pressure drop across filters	•Debris buildup in filters •Inadequate flushing of filters
Gradual pressure decrease at filter input	•Pump wear •Other water supply problems
Sudden pressure decrease at filter output	•Damaged or broken lateral •Damaged or broken submain •Damaged or broken mainline •Pressure regulator failure •Water supply failure - check flow rates
Gradual pressure increase at filter output	•Emitter plugging •Other flow restriction - check flow rates
Sudden pressure increase at filter output	•Stuck control valve •Other flow restriction - check flow rates
Sudden pressure decrease at submain	•Damaged or broken lateral - check flow rates

Pressure gauges

Pressure gauges, or ports for a pressure gauge, should be installed on the mainline both before and after the filters. The pressure gauge or port after the filters should be located near the mainline flow meter, since flow and pressure changes can work together to reveal a variety of potential problems. Additional information can be obtained by installing a pressure gauge at each submain riser. As with flow meters, all pressure gauges should be read and recorded for the new system, and on a regular basis thereafter.

Table 5.6 (previous page) shows some of the problems you can diagnose by keeping track of system pressures. Act on any of these problems immediately to avoid serious crop damage.

Note: Table 5.6 is intended as an example of some problems that can be diagnosed through regular monitoring. It is not a comprehensive list of problems that can occur with your specific drip irrigation system.

Monitoring Soil Moisture

Soil moisture measurements should be made at the following times:

- **Before the first use of the system to determine field capacity (see PLANNING: Field capacity)**
- **After the first few irrigation cycles to verify your irrigation schedule and to make necessary adjustments**
- **Periodically throughout the season to make schedule adjustments as the water requirements of your plants change**

Soil moisture content and tension

Most commercial moisture sensors provide a reading either of tension (matric potential) or moisture content. Tension is a measure of the work a plant must do to remove water from the soil and is usually expressed in bar or centibar (1 bar = 100 centibar). The drier the soil is, the more work plants must do to remove water, and the higher the tension. Tension is a useful measurement, since it is the aspect of soil moisture that directly affects your crops.

Moisture content is a measurement of the water contained in the soil as a percentage of the volume of the entire soil solution. Moisture content can directly indicate how much water you need to apply at the root zone to return it to field capacity.

Sensor placement

Measure soil moisture at several depths and locations in the field. With a portable moisture sensor, you can accomplish this by taking a number of measurements with the same sensor. If you are using a low-cost sensor such as a tensiometer or gypsum block, you can install several

Table 5.7 Important Soil Moisture Levels

Condition	Tension	Moisture Content
Saturation	0-3 cb	15-60% depending on soil type
Field Capacity	10-25 cb depending on soil type	10-50% depending on soil type
Permanent Wilting	15 bar (approx.)	2-30% depending on soil type

sensors in the field, each at a different depth and location. Take readings in sets of three measurements - just below the surface, in the middle of the root zone, and below the root zone in the row between plants (table 5.8). Use two or more sets within an irrigation block to verify that measurement sites are representative. Additional sites may be helpful in non-uniform soil.

Soil moisture sensors

A variety of sensors are commercially available for measuring soil moisture. Each sensor either measures moisture content or tension directly. Table 5.9 summarizes several types of moisture sensors. Numerous other types are available (fig. 5.1) .

Table 5.8 Sensor Depth	
Depth below surface*	Result
6 in (15 cm)	Reflects soil moisture conditions in the root zone during early plant growth or throughout the season for shallow rooted crops.
12 in (30 cm)	Monitors the root zone as plants mature and their roots enlarge. Use this depth to monitor irrigation during most of the plant's life.
18 or 24 in (46 or 61 cm)	Monitors the degree of leaching below the root zone – should not change during normal irrigation.

* Actual depth may vary depending on crop type and rooting depth.

Monitoring Soil Salinity

Even with low-salinity water, salt can accumulate in the soil unless some leaching occurs. In addition to the salts that are part of almost all irrigation water, fertilizers can also add to salt content. Relatively low concentrations can damage some crops by making the soil water less available to the plant root system. By the time the effects of salinity are actually seen in the plants, damage to yield has already occurred. In problem areas, periodically send samples of the soil solution to a lab for analysis of salt concentration. Several commercial EC sensors are also available that can give reasonably accurate results in a short amount of time.

MAINTENANCE

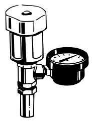
Maintenance of your drip irrigation system is critical. Drip systems require more diligent attention than other forms of irrigation, and failure to properly maintain all components can lead to system failures that result in expensive repairs or even crop damage. The purpose of most maintenance functions is to keep emitters clean, although other functions such as pest control and repair of damaged laterals are also important.

Keeping the emitters clean

Great care must be taken to prevent drip emitters from plugging with dirt, organic matter or precipitates. A slight plugging problem will eventually result in greatly reduced distribution uniformity. A serious plugging problem can result in complete failure of your drip irrigation system. Such a failure can occur mid-season when it is not possible to make repairs or replacements. Include the following steps in your maintenance program to prevent this from happening.

Filter maintenance

The importance of proper filtration was discussed in the DESIGN section. Once your filters

Table 5.9 Moisture Sensors				
Method or Device	**How it works**	**Advantages**	**Disadvantages**	**Notes**
"BY FEEL" (moisture content)	With experience it is possible to learn, with a fair degree of accuracy, how your soil looks and feels when it is at field capacity. Look and feel includes observation of the soil as well as the crops for signs of stress.	•No instrumentation cost •Observation of soil and plants may reveal problems that could be missed with automatic sensors	•Cannot be automated •Will yield inconsistent results if several people are taking measurements	•Currently the most common method
TENSIOMETER (Tension) 	Soil capillary action removes water from a cup through a porous material creating a vacuum that is equal to the tension of the soil matrix. A vacuum gauge gives tension readings in bar or centibar.	•Low cost •Reliable for tension below 80 cb •Not affected by salinity	•Not accurate in dry soil (above 80 cb) •Relatively high maintenance requirement	•Accurate in the moisture range of interest to irrigation •Can use electronic vacuum transducer for remote reading
GYPSUM BLOCK (Tension)	Soil water permeates a porous block of gypsum with two embedded electrodes that measure resistance. A resistance meter is calibrated to give readings of tension in bar or centibar.	•Very low cost •Can easily be read remotely	•Poor accuracy in wetter soil (below 1.0 bar) •Readings can be affected by salinity •High maintenance requirement	•Provides a qualitative reading of "wet" or "dry" •Limited effectiveness for drip irrigation, since soil is kept near field capacity
TDR SENSOR (moisture content)	Measures the dielectric constant of the soil solution by measuring the time required for an electrical pulse to travel through a spike or probe. Uses this measurement, along with the known dielectric constant for water, to report percentage moisture content.	•High accuracy •Fast measurement time •Can easily be read remotely •Low maintenance requirement	•Relatively high cost •Readings can be affected by salinity •Calibration required	•Cost is becoming lower
FDR SENSOR (moisture content)	Measures the dielectric constant of the soil solution by measuring the change in frequency of an RF pulse. Uses this measurement, along with the known dielectric constant for water, to report percentage moisture content.	•High accuracy •Readings not affected by salinity •Can easily be read remotely •Low maintenance requirement	•Relatively high cost •Calibration required	•Cost is becoming lower
NEUTRON PROBE (moisture content)	Uses measurements of the permeation of soil by a radioactive source to determine hydrogen content, which is proportional to moisture content.	•High accuracy •Non-destructive •Tests a relatively large volume of soil	•High cost •Calibration required •Must be installed in field for each reading •Radioactive – requires licensing	•Generally too expensive and complex for practical farm use

are operational, it is critical that you maintain them properly. This includes a regular program of backflushing and / or cleaning filters to keep contaminants out of your drip laterals. Regular monitoring of pressure differentials across filters is important to indicate whether your backflushing program is adequate. In addition, sand media should be replaced periodically as it becomes worn. Check the owners' manual of your specific filter.

Water treatment

Algae, bacteria, and mineral deposits can build up inside of laterals and eventually plug emitters, even if a very high level of filtration is used. The rate at which this occurs depends on your water source and climate. In many cases, buildup of organic matter and minerals can be reduced or eliminated with regular injection of chlorine or acids, or both.

Chlorine Injection

RD5.3

The Roberts Difference: RO-DRIP employs the largest emitter cross-section available on the market to deliver unmatched resistance to plugging. While this does not eliminate the need for maintenance, it can mean the difference between success and expensive failure in applications where water quality is a problem

The best defense against buildup of algae and many types of bacteria is chlorine. Chlorine is available in three forms: sodium hypochlorite (liquid chlorine commonly used for household bleach), calcium hypochlorite (dry chlorine used for swimming pools), and gas chlorine. Sodium hypochlorite and calcium hypochlorite are high in salts and must be used carefully with salt-sensitive plants or in soils that are already high in salt. Gas chlorine is an extremely hazardous substance and must be contained and used with great care.

Use chlorine as follows:

- **To control algae, iron bacteria, and sulfur, add chlorine until a concentration of 2-10 ppm free chlorine is achieved at the end of the furthest lateral from the injection point. Maintain this level for 30-60 minutes. This can be done once every two to three weeks or as frequently as after each irrigation cycle, depending on the chlorine concentration used and level of organic material in the irrigation water.**
- **Alternatively, chlorine can be applied continuously to obtain concentrations of 0.5 to 1 ppm at the ends of the furthest lateral.**
- **Use higher concentrations if the organic material content of the irrigation water is high.**
- **Use higher concentrations of chlorine if the pH of the water is 7.5 or greater, or lower pH by injecting acid.**
- **To eliminate severe algae growth, consider using a one-time "superchlorination" of up to 50 ppm for 4-6 hours at elevated pressure and pH below 6.5, followed by thorough flushing with clear water.**

Chlorine is more effective at killing algae and bacteria when the pH of the water is 6.5 or lower. Alkaline water should be acidified for effective chlorination (see Acid Injection below).

NOTE: Always inject chlorine and other chemicals upstream of filters to avoid problems from chemical precipitation and to clean filter elements.

CAUTION: Inject acid and liquid chlorine through two different injection ports. Mixing acid and chlorine in the same tank will release dangerous chlorine gas. Acids and chlorine should never be mixed together.

Acid Injection

It may be necessary to add acid to irrigation water to lower its pH to prevent the precipitation of calcium carbonate ($CaCO_3$), calcium phosphatic compounds, or iron oxides (Fe_2O_3) that can plug emitters. In addition, low concentrations of acid can increase the effectiveness of chlorine in alkaline water. The three acids generally used are sulfuric, muriatic, and phosphoric. Extra care should be taken when using phosphoric acid because precipitation of minerals in the water can occur. Care should also be take with muriatic acid, which is high in salt.

NOTE: When adding acids for extended periods of time (as part of irrigation) inject them downstream of filters to avoid corrosion of metal filter components. Always perform a "jar test" before injecting chemicals into your system to ensure they do not precipitate when added to your irrigation water. This is particularly important with acids that are injected downstream of any filtration.

NOTE: Some filters, such as stainless steel media filters, are specifically designed to resist corrosion from acids. These filters are ideal because they allow acids to be injected upstream. Consult your filter supplier.

NOTE: Some filter media materials can buffer back acids and reduce their effectiveness.

NOTE: Inject acid into the center of the mainline flow or into a mixing chamber to prevent it from damaging pipe walls before it becomes diluted in the irrigation water.

CAUTION: Never inject acid into aluminum pipe.

Injecting acids in high concentrations can sometimes correct problems that have occurred due to poor quality irrigation water or mismanagement of a drip system. See Clearing Clogs if they Occur, below.

NOTE: Acid is heavier than water. When high concentrations are added, it can "lay down" and remain in your drip system after injection is complete. If high pH fertilizers are later added, precipitation can occur.

Flushing laterals

Even when a properly designed filtration system is used, fine silt and clay particles can get past the filters and settle in the laterals. If they are allowed to build up, they can eventually plug emitters and damage the system. In multiple year subsurface applications, the system should be run with the ends of the laterals open after each season, in order to flush these particles out. In areas where water quality is a problem, lateral flushing may be required more often. Systems using extremely dirty water may require flushing as often as every 2 weeks or even after each irrigation. Paying extra attention to prevention of plugging is always less costly than having to replace an entire system once it becomes plugged.

Flush laterals by opening the ends and running the system until the discharge water runs clear. Opening the ends is easier if removable end caps or flushing manifolds were specified in the design stage (fig. 5.2). The flow velocity at the end of each lateral should be at least one foot per second (0.3 meters per second) which is achieved with a flow rate of 1 GPM (3.8 LPM) at the end of each 5/8-in (16 mm) lateral or 2 GPM (7.6 LPM) at the end of each 7/8-in lateral. A rule of thumb that has been successfully used by many growers is that a stream of water should squirt 2 to 3 feet from the end of the lateral. You can flush several laterals simultaneously as long as your water supply capacity is sufficient.

Clearing clogs if they occur

You can almost always avoid emitter plugging through proper system design and maintenance. In the event that plugging does occur, however, it is sometimes possible to dislodge or dissolve clogs by adding chemicals.

Injecting acids in higher concentrations can sometimes correct plugging problems caused by

RD5.4

The Roberts Difference: The emitters of RO-DRIP drip tape incorporate a unique expandable flow channel (fig. 5.3) which provides a second line of defense against plugging during high-contaminant conditions. If plugging occurs, increase the supply pressure to the maximum recommended pressure (see RO-DRIP PERFORMANCE SPECIFICATIONS for maximum pressure values) for several minutes. In most cases the channel will expand open to purge obstructions and restore flow.

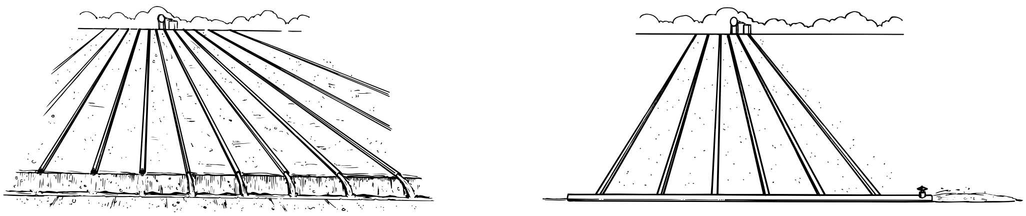


Figure 5.2. Open Laterals and a Flushing Manifold in Action

algae and bacterial growth or mineral deposits. High acid concentrations can also kill roots that have grown into lateral outlets (root intrusion).

Note: acid is very dangerous and extreme care must be taken. Always add acid to water. Never add water to acid. When possible, have your chemical company mix acids for you.

Note: Many states require permits for the use and storage of concentrated acids (usually over 52% concentration). Storage, labeling and safety equipment requirements are often specified by law.

Use the following procedure to correct plugging problems with acid. Only use this procedure between crops.

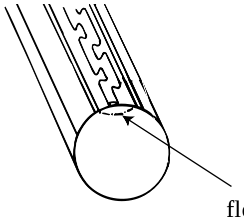


Figure 5.3. RO-DRIP's Expandable Flow Channel

1. Flush all mains, submains, and laterals with clear water before injecting acid.
2. Inject sufficient sulfuric, phosphoric, or muriatic acid to achieve a pH below 4.0 for a period of 30-60 minutes.
3. Leave the acid solution in the system for 24 hours.
4. Increase the system pressure to the maximum pressure allowed for your drip tape for several minutes.
5. Flush mains and submains first. Close mains and submains and flush laterals.
6. Run the system for one hour at elevated pressure.
7. Repeat the procedure if plugging or contamination is severe.

Pest Control

Pests and small animal populations must be controlled. Ants, crickets, wire worms, other insects, rodents, coyotes, and other small animals can cause severe damage to drip tape laterals.

Irrigating as soon as drip tape is buried can often reduce damage from wire worms by keeping the soil moist enough that they do not seek out the tape. Injecting certain pesticides can also help reduce insect damage – consult a pest control advisor. Damage from larger pests such as coyotes is more difficult to avoid. Often a bucket of water placed in the field for animals will help keep them away from the drip tape. Burying drip tape can also reduce damage from animals.

If pests are present in the field, consult a pest control advisor before installing and using your drip system.

Repairing Damaged Laterals

Laterals that are damaged by pests, equipment, or inexperienced field workers can be repaired by cutting out the damaged portions and splicing the ends together. This can be done with twist-lock couplings or with polyethylene hose and wire ties, as described in INSTALLATION AND STARTUP: Splicing Laterals.

System Shut-Down Between Crops (multi-season subsurface)

When a drip system is shut down between crops, extra maintenance is required to kill the roots of the crop. If the roots of the previous crop are not killed, they will seek the water remaining in the laterals and may plug emitters, making them unusable in the future. In addition, laterals should be opened and thoroughly flushed at the end of each season.

If you plan to use your laterals for more than one crop, use the following procedure to shut down your subsurface drip irrigation system at the end of each season. Follow the procedure whether the laterals are permanently installed or are to be removed and re-installed.

1. As soon as the crop is no longer in production, inject a soil fumigant to kill roots around the drip tape to prevent root intrusion.
2. If algae is present in the system, inject chlorine at a concentration of 50 ppm ("superchlorination"). If algae and mineral deposits are both present, inject a concentration of acid that is sufficient to lower the pH to 4.0 at the ends of the laterals.
3. Allow the chlorine or acid to remain in the system for 4-6 hours.
4. Run the system for at least 1 hour with clear water.
5. Open the ends of the laterals and flush the system thoroughly, or open the flushing valve if a flushing manifold is used.
6. Close the ends of the laterals.

GERMINATING SEEDS

The successful use of your drip irrigation system for seed germination depends on your soil texture, soil structure, soil salinity, the depth of your laterals, the emitter spacing, and the preparation of your beds. To germinate seeds, enough water must reach the surface for the individual seeds or plants to receive water. In addition, salt buildup must be kept away from the seeds or plants.

Drip tape can generally be used to germinate seeds of salt-tolerant crops under the following conditions:

- The laterals are less than 8-in deep
- The emitter spacings are 12-in or less
- The soil is not excessively coarse or sandy
- Salinity is not a major problem
- The seedbed is uniform and clod free several inches deep

Conditions are further improved if there is at least 6 in (15 cm) of effective rainfall per year to leach salt away from the surface.

When using drip tape to germinate a crop, irrigate frequently enough and with adequate run times to assure that near field capacity conditions are maintained around the seed at all times. Over irrigation, however, can lead to fungal disease and "damping-off" of seedlings.

If laterals are buried deeper than 8 in, emitter spacings are greater than 12 in, or the soil has a high sand content, water may not make it to the surface where it can be used by the seeds. In these cases, sprinklers must be used for germination. Even under ideal water movement conditions, some growers prefer sprinklers because of their physical impact that drives air out of the soil and results in favorable germinating conditions for some crops.

FERTIGATION

One of the principal advantages of drip irrigation is the direct access it provides to the root zone for injection of fertilizer and other chemicals. This allows frequent, accurate, and economical application of nutrients to field crops–even those grown with mulch–throughout the growing season. With proper monitoring and testing, drip irrigation allows you to quickly adjust nutrient levels with precision that is not possible with furrow or sprinkler irrigation.

Liquid Fertilizers

Fertilizers are widely available in liquid form that can be directly injected into your drip irrigation system. Many fertilizer dealers provide liquid fertilizer blends specifically for drip fertigation, which may include N, P, K and minor nutrients. These blends can be region and/or crop specific. While some fertilizer blends can be expensive, drip fertigation maximizes their benefits by applying them precisely and efficiently. Most clear, liquid fertilizers can be injected directly into drip irrigation systems. Only apply a fertilizer through your drip system after testing its compatibility with your local irrigation water (see Jar Test below).

Water Soluble Dry Fertilizers

Non-liquid fertilizers must be mixed with water to form a solution before they are injected. Dry fertilizers must be water-soluble, and it is necessary to consider how they will react with the minerals contained in your water or other fertilizers which are injected (a common problem is phosphate reacting with calcium to form a precipitate). Only apply a fertilizer through your drip system after testing its compatibility with your local irrigation water (see Jar Test below).

NOTE: Some dry fertilizers, which are described as being water soluble, are coated with clay or wax to prevent clumping. This coating material is not water-soluble and can plug filters and drip emitters. It can be removed through a "decanting" process by thoroughly mixing the fertilizer with water and allowing it to settle for 12-18 hours. Pour the clear solution through a 200-mesh screen taking care not to allow the sediment or precipitate to enter the system.

Jar Test

Performing a simple test of your irrigation water and fertilizer mixture before injection can help you avoid the high cost of cleaning or replacing your drip system if precipitation occurs (fig. 5.4). Perform a jar test as follows:

1. Fill a clear, 1-quart (liter) glass container with your irrigation water and add an appropriate amount (about 2 tablespoons) of the fertilizer mixture you intend to apply through the drip system.
2. Mix thoroughly and let it sit overnight.
3. If the mixture is cloudy the next day, or if there is a precipitate in the jar, do not use the fertilizer. It will plug filters and/or emitters.

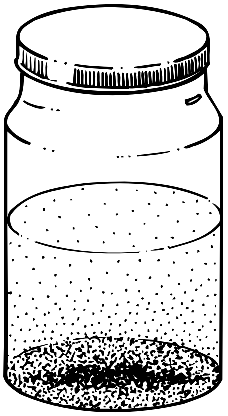


Figure 5.4 Jar Test

Specific Nutrients

Nitrogen (N)

Most nitrogen fertilizers are soluble in water and can be injected into drip systems with minimal problems. Precipitation may occur, however, if they are mixed with other fertilizers. For example, injecting both calcium nitrate and ammonium sulfate into the same irrigation water will result in an insoluble gypsum precipitate that can readily plug emitters.

Phosphorus (P)

In many cases, phosphorus is applied before planting. Phosphorous is especially important for seed emergence and healthy transplant growth, and soluble phosphorus fertilizers can be expensive. Growers often broadcast apply phosphorous before planting, then supplement it later in the season through drip fertigation.

Most dry phosphorus fertilizers for general farm use are insoluble and cannot be injected into irrigation water. Applying soluble phosphorus fertilizers through drip fertigation is challenging because they often react with other nutrients to form precipitates that can clog emitters. In particular, most phosphate fertilizers will form precipitates when injected into water containing calcium or magnesium. Reducing the pH of the irrigation water through acidification or by using phosphoric acid can usually control precipitation. White phosphoric acid can be safely injected into most irrigation water as long as the pH of the solution is low.

Potassium (K)

Soluble potassium is a positively charged ion that easily binds to negatively charged clay particles. As a result, when it is applied from the surface, it usually only penetrates the top few inches where it can not always be used by the plants. Subsurface drip irrigation can help solve this problem by delivering potassium directly to the active part of the root zone. In some cases, foliar sprays of potassium are more effective.

All potassium fertilizers are water soluble, and precipitation problems are infrequent.

Minor Nutrients

Minor nutrient availability to plants is highly pH dependent. Metal micro-nutrients (Cu, Fe, Mn, Zn) become less soluble in high pH soils, while S, Mo, B, C and M become less soluble in low pH soils.

Chelated micro-nutrient metals are a convenient way of making metal ions available to the plant root zone. Chelates are expensive, but they can be very effective – both at delivering injected metal micro-nutrients to the plant root zone, and at making metal ions already resident in the soil available to plants. The ability to utilize expensive fertilizers such as chelated metals as efficiently as possible is one of the many benefits of drip fertigation.

NOTE: Fertilizers containing calcium should be flushed from all tanks, pumps, filters and tubing prior to injecting any phosphorus, urea-ammonium nitrate, urea sulfuric fertilizer, or any sulfate form of fertilizer to avoid precipitation which can cause severe emitter plugging. Always test the compatibility of fertilizers with each other and with your irrigation water before mixing them in your system.

Frequency of Applications

Drip irrigation allows fertilizer to be applied as frequently as your plants need, even daily if necessary. This flexibility allows you to quickly make adjustments to your fertigation program to respond to changes in your plant needs, and use expensive fertilizers as efficiently as possible.

When to Fertilize

Inject fertilizer during the latter part of the irrigation cycle to reduce the possibility of leaching some of it past the root zone. However, be sure to operate the system long enough to completely purge fertilizer from the laterals to avoid algae and bacteria growth. Plugging is likely to occur if algae and bacteria are allowed to grow and feed on the residual fertilizer left in the laterals. The "travel time" required to transport chemicals to the end of a long (over 1000 feet) drip lateral can be up to 60 minutes depending on slope and flow rate. Travel times through mainlines and submains must also be considered. Several software packages are available which calculate travel time within laterals.

Consider using the "25% rule" of fertilizer injection. During the first 25% of the irrigation cycle, only clear water is delivered through the laterals. Fertilizer is injected for the next 50% of the cycle then clear water is again used for the final 25%.

Note: Always inject fertilizers into the water stream before the filter.

Note: Only inject fertilizer if a proper backflow prevention device has been installed upstream of the injector to prevent flow of fertilizer into the water source.

Monitoring Nutrients

Drip fertigated fields require less fertilizer than those using sprinkler or furrow irrigation. Fertilizer is only applied to the root zone, and used as efficiently as possible. Drip fertigation allows you to optimally use your fertilizers by adjusting the application rates throughout the season as the needs of your plants change. To take full advantage of this feature, you will need to know the nutrient levels of your soil and plants throughout the season to make the necessary adjustments.

The first step in determining which nutrients to apply and how much of each to apply is to have a soil test performed at the beginning of the season. Use your drip system to make up the difference between what is available in the soil and what your plants need. Additional information such as the soil pH, EC and base saturation will help you determine which fertilizers can be readily used by your plants when they are injected into the root zone, and what can be done to make existing nutrients more available.

Plant tissue tests can be performed throughout the season to determine the nutrient levels within your plants. These tests are particularly useful because they directly indicate nutrient deficiencies that can be made up through fertigation.

"Quick Tests" for soil nutrient levels are now available and are becoming popular. These tests can be used to monitor soil nutrient levels on-farm and use the information to immediately make adjustments to your fertigation program. Many laboratories can now perform soil sample tests, tissue tests and/or sap tests with a one-day turnaround, also allowing you to make necessary adjustments exactly when they are needed.

MANAGING SOIL SALINITY

In arid regions such as the western US, salinity management is important with all fruit and vegetable crops, and is critical with strawberries. Depending on water quality and soil type, many other crops also require active salinity management, especially during germination. With good management, the salinity of the soil solution can be 1.5 to 3 times the salinity of your irrigation water. If salt is not managed properly, the salinity of the soil extract can reach levels that are lethal to plants.

Symptoms of Salinity Problems

Salt is added to the soil during each irrigation. Adding fertilizers can further increase salinity. Excess salt must be removed from the root zone before it increases to a level that seriously affects yield.

Symptoms of excess salinity depend on the type of crop and the types of salts involved. Mild salinity problems are frequently overlooked because the plant size reduction and change in color are uniform across the field. Excess salinity initially causes a subtle change in color. As salinity stress increases, stunting becomes apparent and leaves are eventually burned at the tip and around the edges. It is important to recognize that yield loss from excess salinity occurs well before the symptoms are visible in your plants.

Patterns of Salt Buildup in the Soil

Most salts are readily soluble and move with water in the soil. The salt content of the root zone varies with depth and distance from the point in the soil where water is applied (application point). Salinity near the application point of irrigation water is usually low. Salt builds up at the outer edges of the wetted area. Figure 5.5 shows salt patterns caused by different lateral placements.

If the drip lateral is installed near the soil surface and the wetted area brings the soil near the surface and plant row to above field capacity, then the salt layer will move away from the seed line or plants. If the lateral is placed deep enough so that the wetted

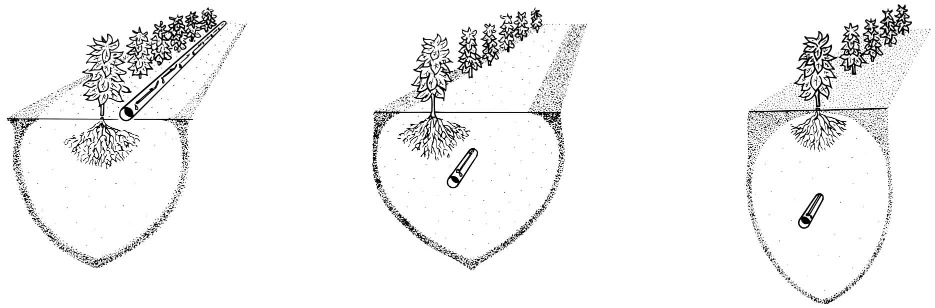


Figure 5.5 Salt Patterns

area does not reach the surface, salt can build up just under the surface of the soil. During periods of light rain, deep subsurface drip systems for salt-sensitive crops must be left running to prevent the rain from leaching salts into the root zone. If rain is heavy enough, salts will be leached below the root zone where they will not cause problems.

NOTE: Where salt buildup is a problem, a surface or shallow subsurface placement will give the best results.

Do not move drip laterals after water application has started on salt-sensitive crops. Moving the laterals will cause the salt buildup to move. If the salt buildup moves into the root zone, it will stress or even kill plants. Also, do not allow the soil in the root zone to dry between irrigation cycles. This can result in reverse movement of soil water, and transfer salt from the perimeter back into the rooted area of the soil.

Salt Leaching

To minimize salt buildup in the root zone, keep the wetted area at or near field capacity at all times. For optimal salinity control, maintain a nearly continuous, slow downward movement of water and salts. This requires more water than is necessary to maintain field capacity. The additional water added to leach salts away from the root zone is commonly referred to as the leaching requirement and, in problem areas, can be as much as 10-20% of the total application rate.

Place drip laterals as close as possible to salt-sensitive plants to continuously leach salts outward from the root zone. Monitor the soil salinity throughout the season to help maintain proper levels and avoid plant stress, which can easily go unobserved. Flood or sprinkler irrigating between crops can be very effective in removing salts and, may be necessary, in some cases.

Apply excess water for leaching early in the season, since it may be difficult to apply adequate water during the peak of the irrigation season.

Multiple Row Beds

In many cases you can save money by irrigating more than one crop row with each lateral. In multiple row beds, however, be careful not to place a row directly between two drip laterals. The salts at the edge of the wetted pattern of each lateral can accumulate under the center row and can damage or kill salt-sensitive plants. Figure 5.6 illustrates proper and improper methods of avoiding salt buildup when irrigating multiple rows with a lateral.

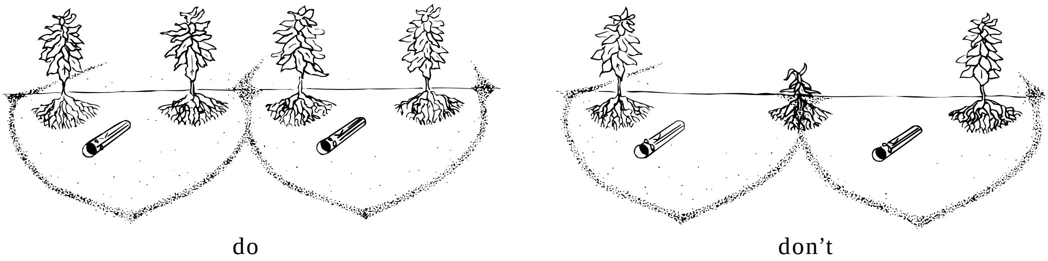


Figure 5.6 Proper and Improper Placement of Laterals for Multiple Rows

MANAGING SOIL PERMEABILITY

Soil permeability is affected by texture, structure, organic material content and chemical content. Good soil preparation and addition of organic amendments can reduce permeability problems caused by compaction. Several permeability problems are caused by the quality of your irrigation water and can often be avoided through chemical water treatment or chemical soil amendments.

The first step in managing permeability is to have a chemical analysis of your irrigation water performed. Table 5.10 shows how to manage certain water quality problems that can lead to problems with soil permeability.

Observe the following cautions when injecting gypsum into a drip irrigation system:

- **Only inject high purity gypsum.**
- **Only inject finely ground gypsum. 98% should pass through a 200-mesh screen.**
- **Always locate the injector before filtration equipment.**
- **Do not inject at excessively high rates that exceed the solubility limit of gypsum in water.**

Table 5.10 Permeability Problems Caused by Poor Water Quality

Water Quality Problem	Description	Possible Solutions
High SARa resulting from high Na/Ca ratio	As proportion of sodium attached to clay particles increases, soil tends to "run together", resulting in reduced water penetration rates. In extreme cases (alkali soil) soil can no longer be used for growing.	•Increase calcium content of water by injecting gypsum •If damage to soil is already done, soil amendment with gypsum may be required
High SARa resulting from high bicarbonate (HCO3) content	HCO_3 removes calcium from the soil by binding with it to form $CaCO_3$ (calcium carbonate). The calcium removed from the soil complex is replaced with sodium, and the soil becomes sodium-rich.	•Reduce HCO_3 in water by injecting sulfuric acid, sulfur dioxide, or other acid •If damage to soil is already done, soil amendment with sulfur or gypsum may be required
Pure irrigation water	Interaction between the salinity of water and various ions has an effect on permeability. Appendix B shows that high SARa can cause more of a problem if EC is low. Very pure (EC < 0.2 dS/m) water can cause severe problems even if there is a high proportion of calcium in the irrigation water.	•Injecting or ammending with gypsum can improve permeability of pure water both by increasing EC and by increasing calcium content

6

RETRIEVAL

Your drip irrigation system, or at least the laterals, will ultimately be retrieved from your field. This may be after several years in a subsurface system, or after a single crop in a surface or shallow buried application. In some cases the laterals may be retrieved and disposed of. In other cases they may be re-installed in your field after being stored for a period of time. Still in other cases, they may be moved to another location and re-installed.

The best method of retrieval depends on the specifics of your growing operation. The choice is affected by cultural practices, drip lateral placement, residual crop material, soil moisture and economics. This section helps you evaluate the important variables and decide whether to re-use or dispose of your drip tape after removing it from the field. The basic procedures and equipment used for drip tape retrieval are also described for each method.

KEY CONCEPTS

- **The best retrieval method for you depends on whether you will re-use or dispose of the drip tape after it is removed from the field.**
- **If you plan to dispose of drip tape, it should be compacted and baled as tightly as possible.**
- **The retrieval head is the main tool used for mechanized drip tape retrieval.**
- **The two common retrieval methods are over-the-row retrieval using a tractor and end-of-row retrieval using a fixed retrieval head.**
- **The most common problem encountered during retrieval is damage to the drip tape from stretching. Ensure tape is free of entanglements, and water has been removed. If possible, perform retrieval in the morning before the sun heats up the drip tape.**

DISPOSAL VS. RE-USE

The following options are available at the end of the growing season:

- **Retrieval and disposal of drip tape**
- **Retrieval and re-use of drip tape**
- **Leaving drip tape installed for the next season**

Retrieval and disposal is currently the most common method used, although the other options are becoming more popular. The replacement cost of drip laterals, in combination with ever-increasing disposal costs, weigh in favor of using laterals for more than one season. Multiple year installations, which are not retrieved and re-installed after each season, are usually buried deep below the surface (6-18 in) so cultural operations can be performed without causing damage. Table 6.1 summarizes the advantages and disadvantages of each option.

Table 6.1 Disposal vs. Re-use of laterals

Method	Advantages	Disadvantages	Notes
Single season	•Simple •Low-cost, thin-walled drip tape can be used	•Recurring cost of drip tape •Cost of disposal •Environmental impact	•Currently the most common use •Can be retrieved with or without mechanized equipment
Retrieve and re-use	•Re-using drip tape may save money •Reduced disposal requirements	•Retrieval and re-installation can damage tape	•Proper maintenance is important •Requires a motorized retrieval head
Multi-season buried	•Potential for very long-term use •Retrieval and re-installation is not necessary during most seasons •Reduced disposal requirements	•Requires heavy-gauge drip tape •Between-crop cultural practices require more care	•Proper maintenance is critical

Disposal

Retrieval operations are faster and simpler if the drip tape is disposed of. Stretching and other damage is not important as long it does not interfere with the retrieval.

In most cases, the drip tape must be disposed of in landfills, which are placing stricter requirements on what they will accept. If you are retrieving drip tape onto spools, they should be compact and tightly wound. If not, loose drip tape should be tightly baled and tied. Many landfills will not accept loose drip tape because of the damage it causes to their equipment.

Drip tape is designed to last many years without degrading or decomposing. Disposal issues are likely to become more important as landfill space becomes increasingly scarce. Any steps that can be made to reduce this trend will have a long-term positive impact on the environment.

Re-use

Several steps must be taken to ensure that drip tape intended for re-use is in good condition at the beginning of each season. For best results when re-using drip tape, observe the following important guidelines:

- **Follow a proper shutdown procedure (see MANAGEMENT: System Shutdown Between Crops) to ensure the drip tape is clean and free of roots, bacteria, and algae before it is removed from the ground.**

- **Avoid jerking or excess tension while retrieving drip tape from the ground. Any stretching of the drip tape will result in uneven flow rates and decreased distribution uniformity.**
- **Always store drip tape in a dry, pest free, protected area.**

Retrieval for re-use is a more delicate process than retrieval for disposal. In general, it is easier to retrieve thicker-gauge drip tape without damage. Use a great deal of care when retrieving any tape less than 10-mil thick.

When drip tape is retrieved for re-use it should be rolled onto a suitable spool. Commercial plastic spools are available for retrieving drip tape. Many growers choose to make their own spools by placing wood or metal side plates on the ends of a large-diameter section of PVC pipe, which acts as the core of the spool. When the roll is full, the side plates can be removed and the drip tape can be stored on the PVC core.

Splices

When in-field splices are made, either for repairing damaged laterals or splicing rolls together, special consideration should be taken if the laterals will later be retrieved for re-use. Twist-lock couplings are convenient for making splices, but will not easily go through retrieval equipment and will not roll smoothly on a retrieval spool.

When making an in-field splice, use a piece of 0.510"x0.610" polyethylene hose and two wire ties as described in INSTALLATION AND STARTUP: Splicing Laterals. Be sure to tightly wrap the wire ties around the spliced lateral and remove all sharp points so they will not hang up on installation equipment or damage the drip tape. Wrap the splice with black electrical tape for further protection. Alternatively, several heat-seal splicers are available now for drip-tape.

Figure 6.1 Manual Retrieval of Drip Tape

MANUAL RETRIEVAL

Surface and shallow buried (0-3 in) drip tape is easily retrieved for disposal without the use of mechanical equipment (fig. 6.1). If the drip tape is to be re-used, it can be economically retrieved using an "end of row" operation as described below in Mechanized Retrieval.

To manually retrieve drip tape for disposal, simply pull it from the field and bale it together. As described in the previous section, make the bales as tight as possible, and tie them together with string or drip tape for easy disposal.

MECHANIZED RETRIEVAL

The main tool used for mechanized drip tape extraction is the retrieval head. The retrieval head consists of a driven shaft onto which the spool is mounted, and a guide to bring the drip tape to the spool (fig. 6.2). A means of tension control is usually provided to avoid damage to the tape during momentary hang-ups or during rapid speed changes of the tractor. Some retrieval heads incorporate a level-wind mechanism that places the drip tape evenly on the spool as it rolls . These mechanisms make the roll more compact and easy to re-use. Retrieval heads and complete retrieval systems are available from several

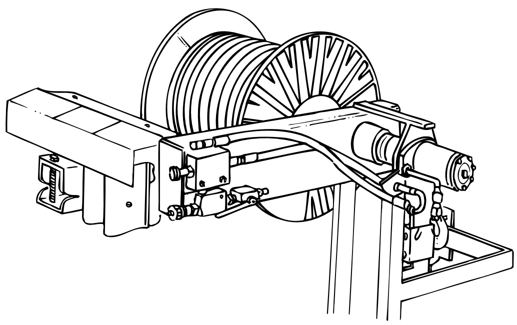


Figure 6.2 Retrieval Head (Courtesy of Andros Engineering)

RD6.1

The Roberts Difference: The RO-DRIP product line includes several heavy-gauge products with high tensile strength which are well-suited for retrieval and re-use. These include products with wall thicknesses of 10, 13, and 15 mil (.254, .330, and .381 mm).

suppliers.

Retrieval heads can either be mounted over-the-row on a tractor tool bar, or end-of-row where the head is stationary and the drip tape is pulled out of the row from one end after it has been picked up and placed on top of the crop.

Surface and Shallow Subsurface Drip Systems

Surface and shallow subsurface (less than 3-in deep) laterals are the simplest to remove, either for re-use or disposal. When laterals are placed on the surface, either end-of-row or over-the-row techniques can be used.

End-of-row extraction

End-of-row extraction is the most common method of retrieval due to several advantages, including

- **End-of-row extraction is not limited by the speed of a tractor, so it can be done faster**
- **When multiple retrieval heads are used, if one head needs to be stopped for any reason, the others can continue operating**
- **Pulling the tape along the row provides cleaning and water removal action which results in less damage and better spooling**

After disconnecting the laterals from the manifolds, remove water by blowing them out with compressed air. Pull the tape out using one or more retrieval heads mounted on a trailer at the end of the field (fig. 6.3).

If laterals are buried, they need to be manually removed from the ground before retrieval. This is usually simple if the burial depth is less than 3 in. In some cases it helps to soften the soil around the laterals by irrigating for a period of time before removal.

If the drip tape will be re-used, avoid stretching it or scraping it on rough soil or field stubble. It sometimes helps to lift the drip tape off the ground and place it on top of the plants before retrieving it. Several retrieval heads can be mounted on a single fixture to retrieve from several rows simultaneously.

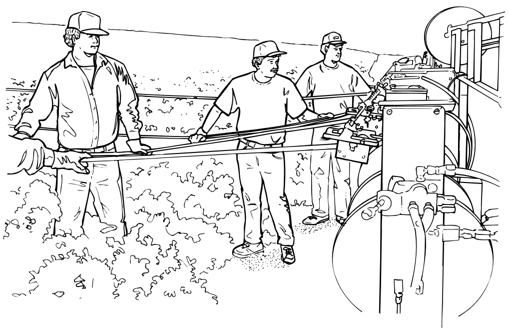


Figure 6.3 End of Row Retrieval

NOTE: The most common problem encountered during drip tape retrieval is damage from stretching. Ensure tape is free of entanglements, and water has been removed. In hot climates, if possible, perform retrieval in the morning before the sun heats up the drip tape.

TIP: If the spool is spinning faster than the tape appears to be coming off of the ground, the tape is stretching. Another way to check for stretching is to stop the retrieval head and unlock the spool. If it backspins, the tape is stretching.

Over-the-row extraction

Over-the-row extraction is not as common as end-of-row extraction, but it is sometimes the best choice when laterals are buried. In over-the-row extraction, one or more retrieval heads are mounted to a tractor tool bar (fig. 6.4). A system of guides brings the tape to the spool as it is pulled off the surface. Over-the-row extraction is less prone to damaging the drip tape by stretching or scraping, but it can be more costly and time consuming than end-of-row extraction.

If the drip tape is buried less than 3-in deep, and is a suitably heavy gauge, it can usually be pulled through the soil. In some cases it helps to soften the soil around the laterals by irrigating for a period of time before removal.

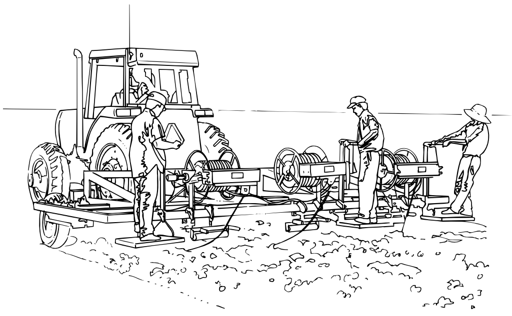


Figure 6.4 Over-the-Row Retrieval

Subsurface Drip Systems

Deep subsurface drip laterals can be removed over-the-row by using an appropriate tool to open the bed above the tape. Use a furrower or a disc-type opener to open the bed down to a depth of 2-3 in (5-7 cm) above the lateral and pull the tape through the remaining soil in the same operation. Retrieval is easier if the drip tape was installed accurately at the beginning of the season. A reliable and consistent burial depth allows you to place the opening tool close to the buried lateral and minimize the amount of soil through which it must be pulled.

Retrieval is simpler if the soil above and around the laterals is loosened and softened beforehand. If possible, turn the last crop and wait a few days for subsurface plant matter to decompose and soften. Immediately before retrieval, soften the soil around the laterals by irrigating for a period of time. Disrupt the bed on either side of the laterals with picks or chisels.

UNDERSTANDING YOUR WATER QUALITY REPORT

The following tables summarize the information that may be presented in your water quality report and give guidelines to help you interpret how it will affect your operations.

Table A.1 Quantities Measured in Your Water Quality Analysis

Determination	Symbol	Units[1]	Typical Range
SALINITY			
Total Salt Content:			
Electrical Conductivity	Ec_w	dS/m	0 - 3
or			
Total Dissolved Solids	TDS	ppm	0 - 2000
Specific Ions:			
Calcium	Ca^{++}	me/l	0 - 20
Magnesium	Mg^{++}	me/l	0 - 5
Sodium	Na^{+}	me/l	0 - 40
Carbonate	CO_3^{++}	me/l	0 - 0.1
Bicarbonate	HCO_3^{--}	me/l	0 - 10
Chloride	Cl^{-}	me/l	0 - 30
Sulfate	SO_4^{--}	me/l	0 - 20
NUTRIENTS[2]			
Nitrate - Nitrogen	NO_3-N	ppm	0 - 10
Ammonium - Nitrogen	NH_4-N	ppm	0 - 5
Phosphate–Phosphorus	PO_4-P	ppm	0 - 2
Potassium	K^{+}	ppm	0 - 2
MISCELLANEOUS			
Boron	B	ppm	0 - 2
Acidity	SAR[3]	pH	6.0 - 8.5
Sodium Adsorption Ratio		-	0 - 15

1 dS/m = deciSiemen per meter (equivalent to mmho/cm)
me/l = milliequivalent per liter

2 NO3-N is nitrogen in the form of nitrate. NH4-N is nitrogen in the form of ammonia. Both may be reported as N.

3 SAR is calculated from the reported Na, Ca and Mg:

$$SAR = \frac{Na}{\left[\sqrt{\frac{Ca + Mg}{2}}\right]}$$

Table A.2 Guidelines to Interpret Your Water Quality Report

Water Quality Problem	Restriction on Water Use		
	None	Some	Severe
SALINITY (affects plants ability to take up water)			
EC_W (dS/m) or TDS (ppm)	$EC_W < 0.7$ TDS < 450	$0.7 < EC_W < 3.0$ 450 < TDS < 2000	$EC_W > 3.0$ TDS > 2000
INFILTRATION (affects rate water enters soil - use SAR and EC_W)[1]			
if SARa = 0-3	$EC_W > 0.7$	$0.2 < EC_W < 0.7$	$EC_W < .2$
SARa = 3-6	$EC_W > 1.2$	$0.3 < EC_W < 1.2$	$EC_W < .3$
SARa = 6-12	$EC_W > 1.9$	$0.5 < EC_W < 1.9$	$EC_W < .5$
SARa = 12-20	$EC_W > 2.9$	$1.3 < EC_W < 2.9$	$EC_W < 1.3$
SARa = 20-40	$EC_W > 5.0$	$2.9 < EC_W < 5.0$	$EC_W < 2.9$
ION TOXICITY (affects sensitive crops)			
Sodium (SAR)	SAR < 3	3 < SAR < 9	SAR > 9
Sodium (me/l)	me/l < 3	3 < me/l < 9	me/l > 9
Chloride (me/l)	me/l < 4	4 < me/l < 10	me/l > 10
Boron (ppm)	ppm < 0.7	0.7 < ppm < 3	ppm > 3
OTHER EFFECTS (affects sensitive crops)			
Nitrogen, NO_3-N (ppm)	ppm < 5	5 < ppm < 30	ppm > 30
Bicarbonate, HCO_3, me/l	me/l < 1.5	1.5 < me/l < 8.5	me/l > 8.5
PH	Normal Range: 6.5 - 8.5		

1 High SARa accompanied with high EC_W allows water penetration, but is unacceptable for production of salt-sensitive crops.

Table A.3 Guidelines for Potential Emitter Plugging from Water Contaminants

Type of Problem	Emitter Plugging Hazard		
	Low	Moderate	Severe
Physical: Suspended solids	50 ppm	50-100 ppm	>100 ppm
Chemical:			
pH	7.0	7.0-8.0	>8.0
Salt	500 ppm	500-2000 ppm	> 2000 ppm
Bicarbonate		100 ppm	
Manganese [1]	0.1 ppm	0.1 - 1.5 ppm	> 1.5 ppm
Total iron [1]	0.2 ppm	0.2 - 1.5 ppm	> 1.5 ppm
Hydrogen Sulfide	0.2 ppm	0.2 - 2.0 ppm	> 2.0 ppm
Biological:			
Bacterial population	2,500/gal 10,000/liter	2,500-13,000/gal 10,000-50,000/liter	>13,000/gal >50,000/liter

[1] When testing for iron and manganese, acidify

CROP PRODUCTION

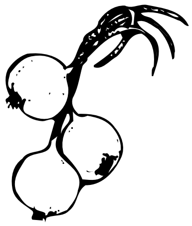
There are many variables involved in specifying a drip irrigation system design, which can interact with each other in complex ways. Coming up with the right combination of lateral placement, drip tape wall thickness, emitter spacing and flow rate is a complex process where experience plays an important role.

This appendix provides examples of how experienced growers have made design decisions for their specific crops. Each page covers one crop, and gives a description of general practices for growing that crop with drip irrigation. The description includes a specific example of how one experienced grower in one geographic region has grown that crop. Due to differences in climate and soil type the best practice for your field may be different, but the examples can give you an idea of what is required. It always helps to learn from the experience of others.

The crops described in this appendix are:

Onions D2
Strawberries D3
Melons D4
Lettuce D5
Celery D6
Sugar Cane D7
Potted Plants D8
Tomatoes D9
Potatoes D10
Cotton D11
Corn D12
Field Flowers D13
Peppers D14

All of the crops that are irrigated with drip tape could not possibly be included in this appendix. If you do not find your crop listed above, contact Roberts Irrigation - we may have it on file.

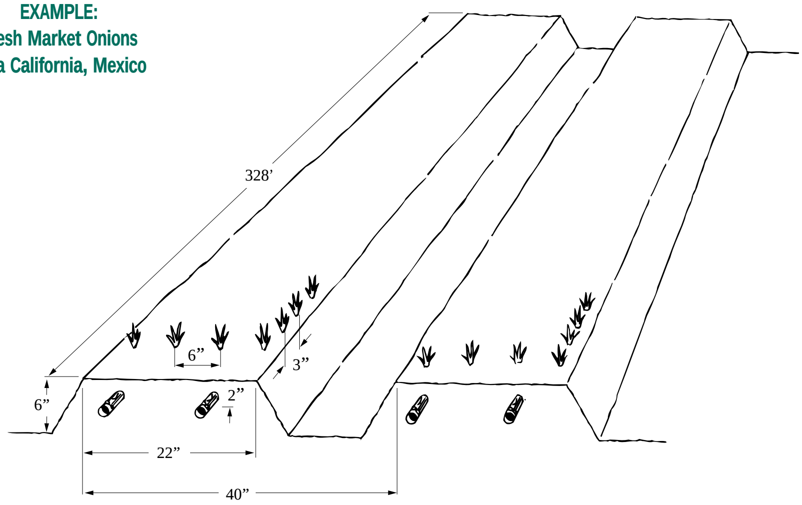


Onions

Onions are usually direct seeded on four row beds, spaced 42-in (106-cm) between centers. Rows are spaced 6 to 12-in (15 to 30-cm) apart with 1 to 4-in (2.5 to 10-cm) in-row spacing. Spacing is closer and populations are higher for smaller bulbing varieties. Onions are extremely shallow rooted and need an easily crumbled, medium texture soil that maintains moisture well. Onions should never be stressed for water once bulbs start to enlarge, or splitting may result. Avoid salty, hard, or weed-infested soils.

In the example below, the grower used a short row length of 328-ft (100-m). Using RO-DRIP 8-12-24, good uniformity can be maintained with run lengths of up to 800-ft (250-m) on flat ground.

EXAMPLE:
Fresh Market Onions
Baja California, Mexico



Operation:

Crop	fresh market onion
Location	Baja California, Mexico
Field size	150-acres (60 ha)
Plants per acre	197,885 (488,975 per ha)
Season	Feb-March
Planting method	direct seeded
Soil type	sandy loam
Maximum ET	0.35 in (9 mm) per day
Water Source	deep well
Ground cover	none
Crops rotated with	broccoli, cauliflower
Time to maturity	180 days
Average yield	60 tons / acre (134 tons / ha)
Duration of tape installation	6 months

Auxiliary Equipment:

Primary filtration	sand separator
Secondary filtration	screen
Submains	layflat
Mulch	none

Management/Operation

Irrigation duration	4-10 hours
Irrigation frequency	3-5 days
Chemigation	yes
Fertigation	yes
Line flushing	at startup
Filter back-flushing	automatic

Drip Tape: RO-DRIP 8-12-24
(8 mil, 12-in spacing, 24 GPH per 100 ft, 5/8-in diameter)
(.200 mm, 30-cm spacing, 298 LPH per 100 m, 16-mm diameter)

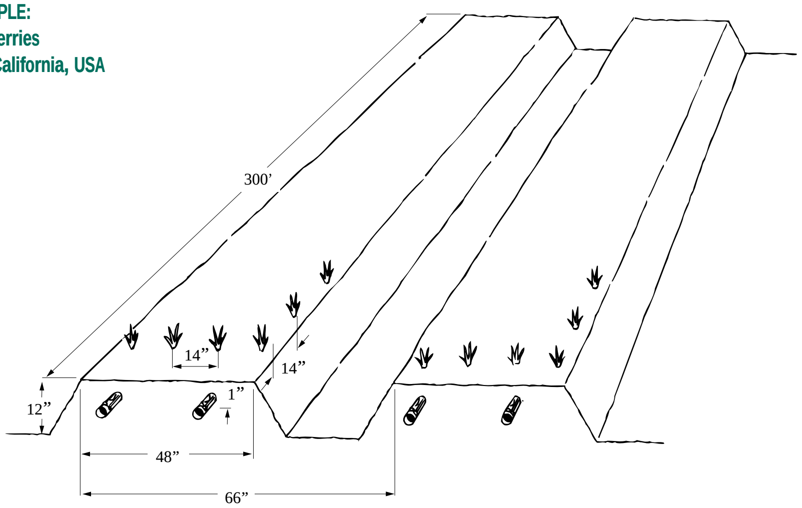
Strawberries

Strawberry plants are extremely salt sensitive. Strawberry production with relatively salty water is a remarkable success story that illustrates the ability of drip irrigation to manage salinity and meet the needs of row crops under adverse conditions.

Transplants are usually planted in the early fall, three or four rows per bed. Beds are spaced 60 to 64-in (147 to 163-cm) between centers, with two drip laterals per bed placed between rows. In-row spacing of 9 to 10-in (23 to 25-cm) is frequently used. Polyethylene mulch is typically used to increase bed temperature and maintain winter growth. Strawberry plants must be protected from frost.

Excessive salinity decreases root development, water uptake, growth rate, and fruit yield. Where salts are a problem, it is important to leach with solid set sprinklers before bed preparation or after transplanting, and prior to putting plastic mulch over the beds. Rain water can be helpful in decreasing salinity around plants during early growth, but only if the holes in the plastic near the plant are large enough to permit infiltration of the rain water.

EXAMPLE:
Strawberries
Central Coast, California, USA



Operation:

Crop	strawberries
Location	Central Coast, California, USA
Field size	40 acres (16 ha)
Plants per acre	150,000 (370,650 per ha)
Season	Sep-Jul / Aug-Dec
Planting method	transplant
Soil type	sandy loam
Maximum ET	0.30 in (7.5 mm) per day
Water Source	well
Ground cover	none
Crops rotated with	celery
Time to maturity	60 days
Average yield	3,500-5,000 cartons / acre
Duration of tape installation	9-10 months

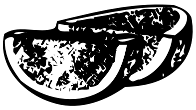
Auxiliary Equipment:

Primary filtration	sand media
Secondary filtration	screen
Submains	layflat
Mulch	plastic mulch

Management/Operation

Irrigation frequency	1-3 times per week
Irrigation duration	2-4 hours
Chemigation	yes
Fertigation	yes
Line flushing	2-4 times per season
Filter back-flushing	automatic

Drip Tape: RO-DRIP 5-8-40
(5 mil, 8-in spacing, 40 GPH per 100 ft, 5/8-in diameter)
(.127 mm, 20-cm spacing, 497 LPH per 100 m, 16-mm diameter)

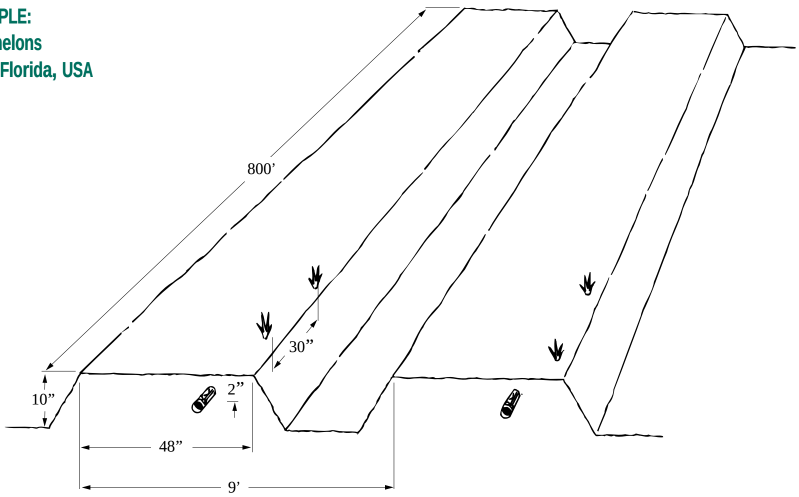


Melons

Melons are typically direct seeded 3 to 4-in (8 to 10-cm) from the drip lateral in single rows at 12-in (30-cm) in-row spacing with 60 to 84-in (152 to 213-cm) between rows. Watermelons will generally have an in-row spacing of 24 to 36-in (61 to 91-cm) with 72 to 108-in (183 to 274-cm) between rows. Laterals are usually placed on or near the surface. Two laterals placed 4 to 6-in (10 to 15-cm) on either side of the seed line may be required in lighter soil if there is difficulty is achieving an adequate wetted area for deep-rooted melon crops.

Heavy watering late in the season can lead to soft, poor-quality melons. This is especially true in heavier soils. Irrigation, as a general rule, should be reduced to about one-half of ET (evapotranspiration) 2 weeks before harvesting is expected to begin. Continue reduced irrigation immediately after each harvest to support subsequent production. The best time to begin reducing irrigation and the amount to cut back depends on soil type, rooting depth, total wetted area, and the usable water reserve in the soil.

EXAMPLE:
Watermelons
North Central Florida, USA



Operation:

Crop	watermelons
Location	North Central Florida, USA
Field size	150 acres (60 ha)
Plants per acre	1,440 (3,550 per ha)
Season	mid Feb - end of June
Planting method	direct seeded
Soil type	sandy
Maximum ET	0.35 in (9 mm) per day
Water Source	well
Ground cover	rye in off-season
Crops rotated with	rye, peanuts
Time to maturity	100 days
Average yield	25 tons / acre (56 tons / ha)
Duration of tape installation	1 year

Auxiliary Equipment:

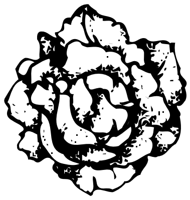
Primary filtration	screen
Secondary filtration	none
Submains	layflat
Mulch	none

Management/Operation

Irrigation frequency	daily
Irrigation duration	1-4 hours
Chemigation	none
Fertigation	yes
Line flushing	none
Filter back-flushing	based on well

Drip Tape: RO-DRIP 8-12-24
(8 mil,12-in spacing, 24 GPH per 100 ft, 5/8-in diameter)
(.200 mm, 30-cm spacing, 298 LPH per 100 m, 16-mm diameter)

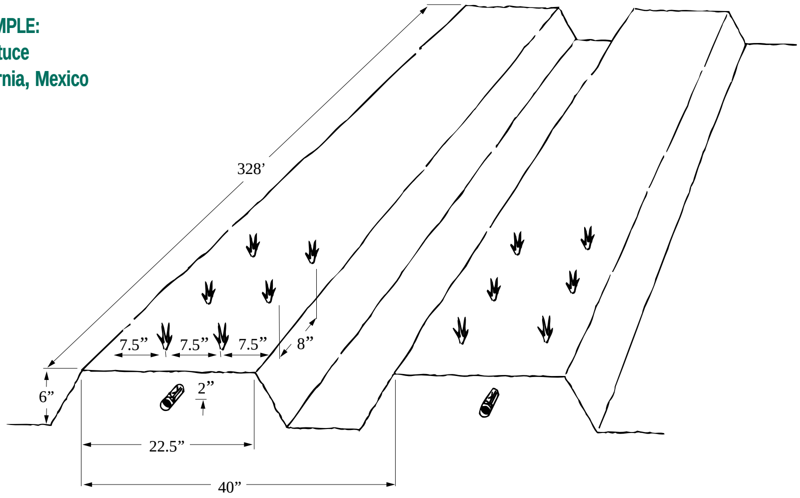
Lettuce



Iceberg and mixed lettuce are typically direct seeded on double-row 40 to 42-in (102 to 107-cm) beds. Rows are spaced 8 to 12-in (20 to 30-cm) apart with a single drip lateral in between the plant rows, placed on or near the surface. Seed is normally planted at 2 to 3-in (5 to 8-cm) spacing using pelleted seed and precision planters.

Germinating lettuce in hot weather can lead to thermodormancy of the seed and irregular stands. Keep the soil around the seed moist during warm weather germination to provide cooling, and start the germination process in the evening so the seed imbibes water during the coolest part of the day. Plants are thinned to an in-row spacing of 8 to 12-in (20 to 30-cm) depending on the type of leaf lettuce. Plant spacing and fertilization can be varied to control head size.

EXAMPLE:
Lettuce
Baja California, Mexico



Operation:

Crop . . . . .lettuce
Location . . . . .Baja California, Mexico
Field size . . . . .90 acres (36 ha)
Plants per acre . . . . . . .37,100 (91,600 per ha)
Season . . . . .Apr-Aug
Planting method . . . . .direct seeded
Soil type .sandy loam
Maximum ET . . . . . .0.35 in (9 mm) per day
Water Source . . . . .deep well
Ground cover . . . . .none
Crops rotated with . . . .broccoli, cauliflower
Time to maturity . . . . .50-60 days
Ave. yield . . . .500 boxes / acre (1235 per ha)
Duration of tape installation . . . . . . .60 days

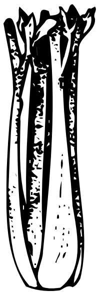
Auxiliary Equipment:

Primary filtration . . . . .sand separator
Secondary filtration . . . . .screen
Submains . . . . .layflat
Mulch . . . . .none

Management/Operation

Irrigation frequency . . . . .3-5 days
Irrigation duration . . . . .4-10 hours
Chemigation . . . . .yes
Fertigation . . . . .yes
Line flushing . . . . .at startup
Filter back-flushing . . . . .automatic

Drip Tape: RO-DRIP 5-12-24
(5 mil, 12-in spacing, 24 GPH per 100 ft, 5/8-in diameter)
(.127 mm, 30-cm spacing, 298 LPH per 100 m, 16-mm diameter)



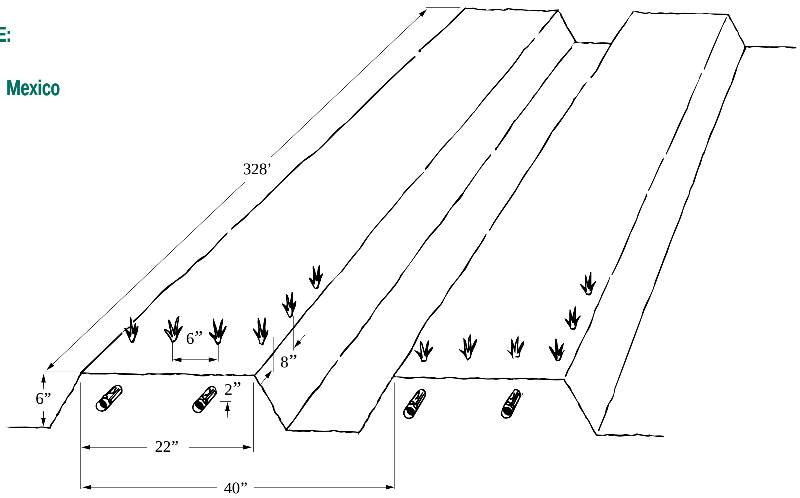
Celery

Celery is usually transplanted on single-row 24 to 30-in (59 to 76-cm) beds or double-row 32 to 40-in (81 to 102-cm) beds. In double-row plantings rows are spaced 10 to 12-in (25 to 30-cm) apart with a singe drip lateral on or near the surface between the plant rows. Plants are spaced 7 to 10-in (18 to 25-cm) apart within each row.

Celery is a biennial that normally produces foliar growth in the first year and seed stalks in the second year. However, celery plants can form seed stalks (bolt) the first year if exposed to temperatures below 55°F (11.5°C) for 7 days or longer. Some varieties are more susceptible to bolting than others. Celery planted early in the year in cooler climates is usually covered with plastic tunnels to increase daytime temperatures and prevent induction of bolting by low night temperatures.

Celery is a shallow-rooted crop; most roots are in the upper 18-in (45-cm) of soil. It is, therefore, very susceptible to drought. Hot, dry periods without water reduce growth and may induce blackheart.

EXAMPLE:
Celery
Baja California, Mexico



Operation:

Crop . . . . .celery
Location . . . . .Baja California, Mexico
Field size . . . . .100 acres (40 ha)
Plants per acre . . . . .120,000 (296,500 per ha)
Season . . . . .Mar-Apr / Sep-Oct
Planting method . . . . .direct seeded
Soil type .sandy loam
Maximum ET . . . .0.35 in (9 mm) per day
Water Source . . . . .deep well
Ground cover . . . . .none
Crops rotated with . . . .
Time to maturity . . . . .50-60 days
Average yield . . .500 boxes / acre (1235 per ha)
Duration of tape installation . . . . . . .60 days

Auxiliary Equipment:

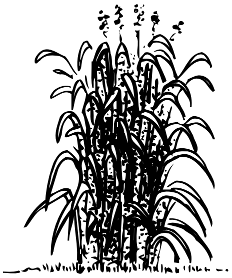
Primary filtration . . . . .sand separator
Secondary filtration . . . . .none
Submains . . . . .layflat
Mulch . . . . .none

Management/Operation

Irrigation frequency . . . . .1-3 days
Irrigation duration . . . . .6-12 hours
Chemigation . . . . .yes
Fertigation . . . . .yes
Line flushing . . . . .at startup
Filter back-flushing . . . . .automatic

Drip Tape: RO-DRIP 5-8-40
(5 mil, 8-in spacing, 40 GPH per 100 ft, 5/8-in diameter)
(.127 mm, 20-cm spacing, 497 LPH per 100 m, 16-mm diameter)

Sugar Cane



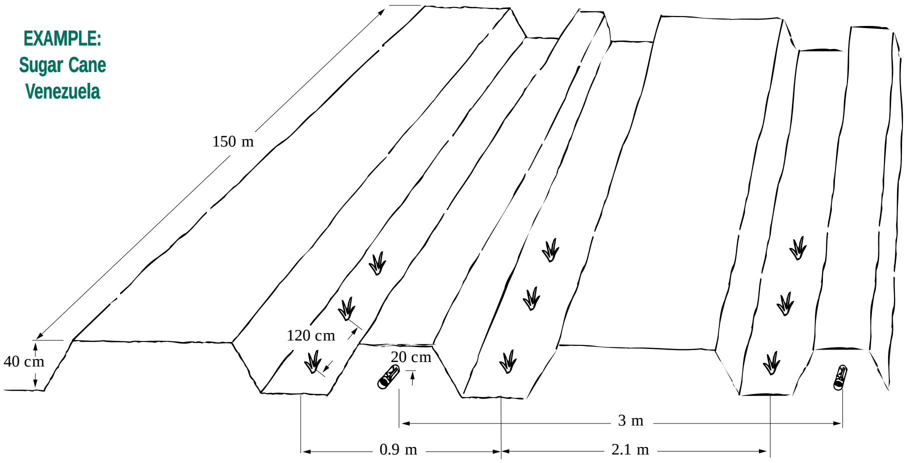
Sugar cane is a 2-year crop in some parts of the world and a 1-year crop in others. It is typically grown from a mechanically planted stalk every 48-in (122-cm) in the row. Rows are spaced in pairs 36-in (91-cm) apart with the drip lateral in the center. The pairs of rows are 72-in (183-cm) apart, resulting in a between-lateral spacing of 108-in (274-cm).

After a crop has been harvested and the ground prepared for the next crop, the soil is very dry. With newly planted stalks, irrigate for 48 to 72 hours to wet the entire area between rows to a depth of 60-in (152-cm). After the first long irrigation, irrigate every other day. Gradually increase the length of the irrigation cycle during the first 6 months. After 6 months irrigate the cane for 24 hours every other day (assuming no significant rainfall) until maturity. Upon maturity, cease irrigation and begin harvesting when the sugar content is at its maximum.

In many areas, including Hawaii, phosphates are applied in granular form at planting time. A typical granular fertilizer would be 10-30-10. A typical liquid nitrogen fertilizer would be Ammonium Nitrate 32%. Fertilizer is generally applied through the system only during the first 10 months. This is necessary to build sugar content. NPK and trace elements can also be applied through the drip irrigation system.

Some varieties of sugar cane are salt tolerant, and brackish water with up to 1500 ppm of total dissolved salts can be used for irrigation. Sugar cane is also relatively drought-resistant; if you miss an irrigation cycle, you can usually apply extra water during the next cycle without much adverse effect.

EXAMPLE:
Sugar Cane
Venezuela



Operation:

Crop .... sugar cane
Location .... Venezuela
Field size .... 10,400 acres (4,200 ha)
Plants per acre .... 27,000 (67,000 per ha)
Season .... year round
Soil type .... sandy loam
Maximum ET ...... 0.28 in (7 mm) per day
Water Source .... deep well
Ground cover .... none
Crops rotated with .... none
Time to maturity .... 30 days
Average yield . . . 46 tons / acre (103 tons / ha)
Duration of tape installation ...... 8 years

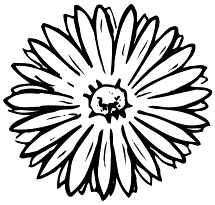
Auxiliary Equipment:

Primary filtration .... sand media
Secondary filtration .... screen & sand separator
Submains .... PVC
Mulch .... none

Management/Operation

Irrigation frequency .... 3-4 days
Irrigation duration .... 24 hours
Chemigation .... yes
Fertigation .... yes
Line flushing .... weekly
Filter back-flushing .... weekly

Drip Tape: RO-DRIP 13-12-24
(13 mil, 12-in spacing, 24 GPH per 100 ft, 5/8-in diameter)
(.330 mm, 30-cm spacing, 298 LPH per 100 m, 16-mm diameter)

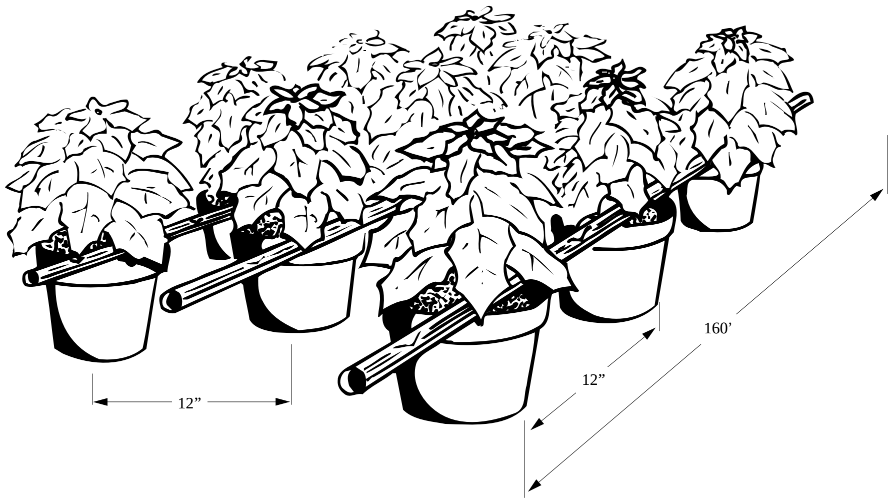


Potted Plants

Potted flowers and other plants can be irrigated with drip tape either directly or with the use of a capillary mat. For direct irrigation, lay heavy-gauge drip tape across pots or containers and secure it tightly at each end. In some installations it is advantageous to string a wire over the containers and fasten the drip tape to the wire rather than laying it directly on the containers. Install the drip tape with the outlets facing out to one side (not straight down). Alternatively, pots or containers can be placed on a capillary mat that is irrigated with drip tape. The water moves laterally across the mat and is drawn up into the container as it is used by the plant.

In the following example the grower successfully uses RO-DRIP drip tape to irrigate potted flowers in a greenhouse.

EXAMPLE:
Potted Flowers (mums)
Sacramento Valley, California, USA



Operation:

Crop . . . . mums (greenhouse)
Location Sacramento Valley, California, USA
Size . . . . 3.5 acres (1.4 ha)
Plants per acre . . . . 35,000 (86,000 per ha)
Season . . . . non-seasonal
Planting method . . . . transplanted
Soil type . . . . pot mix
Water Source . . . . municipal
Ground cover . . . . none
Crops rotated with . . . . none
Time to maturity . . . . 60 days
Average yield . . . . . 35,000 / acre (86,000 / ha)
Duration of tape installation . . . . 2 years

Auxiliary Equipment:

Primary filtration . . . . screen
Secondary filtration . . . . none
Submains . . . . PVC
Mulch . . . . none

Management/Operation

Irrigation frequency . . . . every 3 days
Irrigation duration . . . . 15-30 min
Chemigation . . . . yes
Fertigation . . . . yes
Line flushing . . . . every crop
Filter back-flushing . . . . monthly

Drip Tape: RO-DRIP 8-12-24
(8 mil, 12-in spacing, 24 GPH per 100 ft, 5/8-in diameter)
(.200 mm, 30-cm spacing, 298 LPH per 100 m, 16-mm diameter)

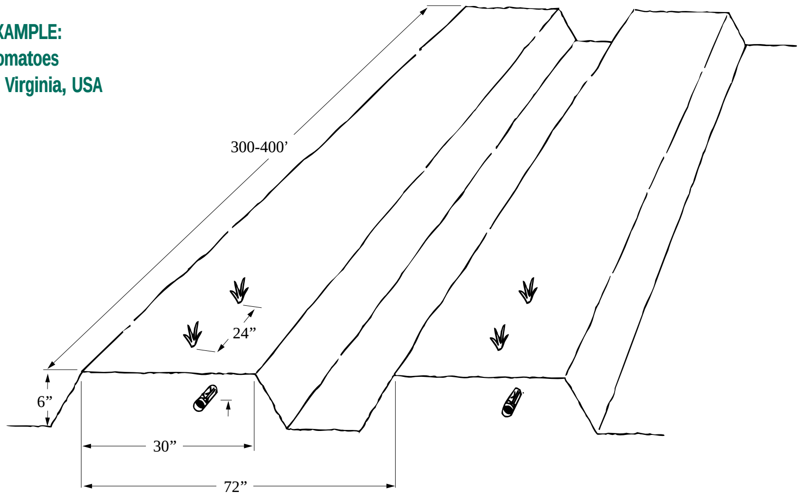
Tomatoes

Tomato transplants are typically planted on single-row beds spaced 60 to 72-in (152 to 183-cm) center-to-center, with 18 to 20-in (46 to 51-cm) in-row spacing. Stakes are placed between every three or four plants. Twine is tied to the stakes and around the tomato plants to support their heavy fruit crop.

Tomatoes can be grown on almost any moderately well-drained soil, from deep sand to clay loam. The highest production is usually achieved from well-drained loamy soil types. You can also use plastic mulch to achieve better control of soil conditions and produce higher yields.

In the following example the grower uses plastic mulch and RO-DRIP drip tape to successfully grow fresh market tomatoes.

EXAMPLE:
Tomatoes
Coastal Virginia, USA



Operation:

Crop	tomatoes
Location	Coastal Virginia, USA
Field size	250 acres (100 ha)
Plants per acre	3630 (8970 per ha)
Season	Spring / Fall
Planting method	transplanted
Soil type	sandy loam
Maximum ET	0.3 in (.75 mm) per day
Water Source	surface water – pond
Ground cover	none
Crops rotated with	soybeans
Time to maturity	80 - 90 days
Average yield	20 tons / acre (45 tons / ha)
Duration of tape installation	5 months

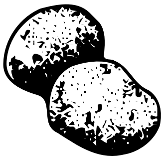
Auxiliary Equipment:

Primary filtration	sand media
Secondary filtration	screen
Submains	PVC
Mulch	plastic, 60" x 1.25 mil

Management/Operation

Irrigation frequency	daily
Irrigation duration	1-3 hours
Chemigation	yes
Fertigation	yes
Line flushing	yes
Filter back-flushing	automatic

Drip Tape: RO-DRIP 8-12-24
(8 mil, 12-in spacing, 24 GPH per 100 ft, 5/8-in diameter)
(.200 mm, 30-cm spacing, 298 LPH per 100 m, 16-mm diameter)

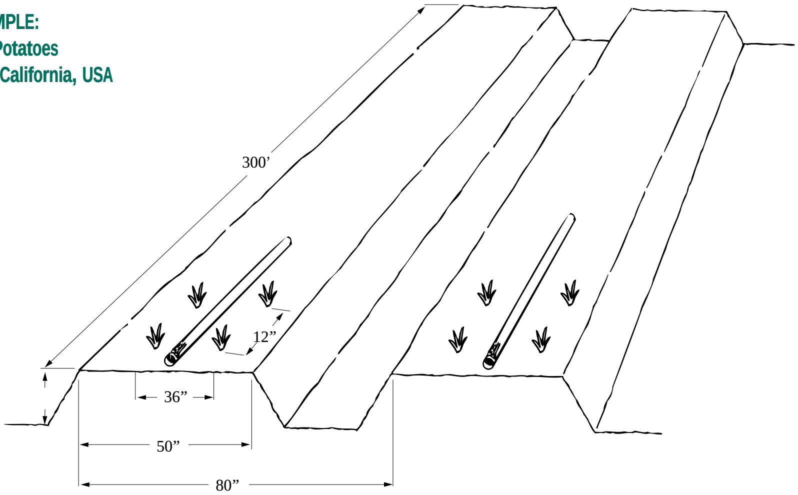


Potatoes

Potato production requires good water penetration and aeration. The soil must also be worked properly for correct tuber formation and growth. Potatoes are seeded on 34 to 40-in (86 to 102-cm) single-row beds. In-row plant spacing is regulated by the placement of the individual seed pieces. Seed piece spacing ranges from 6 to 7-in (15 to 18-cm) for the red varieties, and 8 to 12-in (20 to 30-cm) for the White Rose and Russet varieties.

Proper irrigation scheduling is critical to maintain the root zone at the proper moisture level. When stressed for water between cycles, potatoes tend to develop cracks and become "knobby" and rough. When red varieties are water stressed they tend to develop poor color. When exposed to soil moisture levels above field capacity for extended periods of time, potatoes frequently develop enlarged lenticels and root or tuber diseases. Proper soil moisture during tuber development reduces the severity of scab and is usually adequate to control disease. During tuber initiation and early tuber growth (until tubers are golf-ball sized) maintain available soil moisture between field capacity and 20% depletion. Avoid planting potatoes in fields with severe scab problems.

EXAMPLE:
Sweet Potatoes
Central Valley, California, USA



Operation:

Crop . . . . .sweet potatoes
Location . . . .Central Valley, California, USA
Field size . . . . .50 acres (20 ha)
Plants per acre . . . . . . .13,000 (32,000 per ha)
Season . . . . .Apr-Oct
Planting method . . . . .transplant
Soil type . . . . .sandy to sandy loam
Maximum ET . . . . . .0.35 in (9 mm) per day
Water Source . . . . .well
Ground cover . . . . .fallow with grain
Crops rotated with . . .2-3 yrs, melons / grain
Time to maturity . . . . .90-150 days
Ave. yield . .11-25 tons / acre (25-56 tons / ha)
Duration of tape installation . . . . .1 year

Auxiliary Equipment:

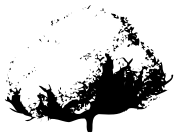
Primary filtration . . . . .sand media
Secondary filtration . . . . .none
Submains . . . . .layflat
Mulch . . . . .none

Management/Operation

Irrigation frequency . . . . .daily
Irrigation duration . . . . .4-6 hours
Chemigation . . . . .yes
Fertigation . . . . .yes
Line flushing . . . . .minimal
Filter back-flushing . . . . .minimal

Drip Tape: RO-DRIP 5-12-24
(5 mil, 12-in spacing, 24 GPH per 100 ft, 5/8-in diameter)
(.127 mm, 30-cm spacing, 298 LPH per 100 m, 16-mm diameter)

Cotton



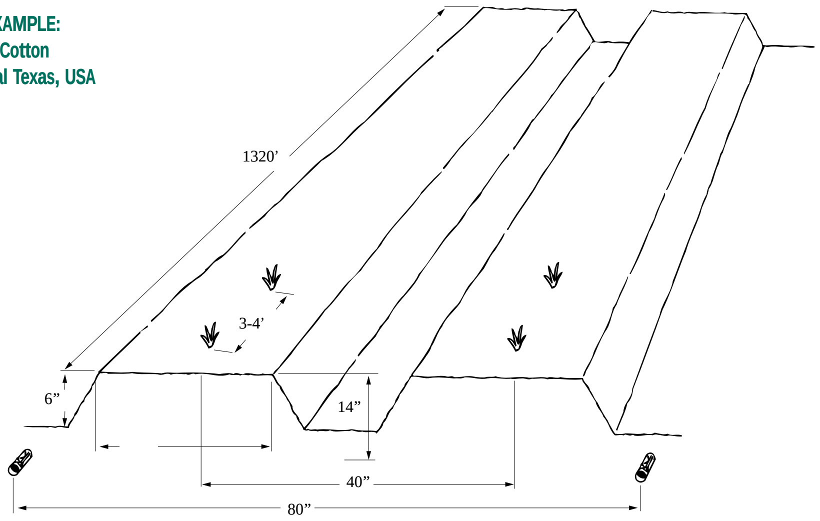
Cotton is a deep-rooted crop (48-in; 122-cm or more) with a 6 to 8 month growing season. Cotton is typically planted in beds spaced 30 to 40-in (75 to 102-cm) apart. Seeds are typically planted 3 to 4-in (8 to 10-cm) apart in single rows.

A carefully managed drip irrigation system will allow you to grow cotton using saline water. However, the seeds should be germinated and the stand established using water of at least average quality (up to 800 ppm total dissolved salts). After the stand is established, poor quality water (800 to 4000 ppm total dissolved salts) can be used until maturity. After harvest, the salt must be leached from the soil before planting the next crop. If there is inadequate rainfall to accomplish leaching, a heavy flood or sprinkler irrigation will be required. When using salty water, lay drip tape on or near the surface to keep buildup away from the plants.

With higher quality water, the laterals can be buried up to 18-in (46-cm) deep and, on heavy soil, can be spaced up to 80-in (203-cm) apart. On sandy soils, space the laterals 40-in (102-cm) apart. When using a deep buried drip system, it is necessary to use a supplemental irrigation system to germinate.

Cotton should not be grown for more than 2 to 3 years on the same land without rotating in another crop such as wheat, sugar beets, process tomatoes, or melons. Drip irrigation can increase yields with all crops and, since you can use the same drip system with successive crops, a well-planned system will allow you to offset the initial installation cost.

EXAMPLE:
Cotton
Central Texas, USA



Operation:

Crop ....upland cotton
Location ....Central Texas, USA
Field size ....100 acres (40 ha)
Plants per acre ....19,000 (47,000 per ha)
Season ....May planting
Planting method ....direct seeded
Soil type ....silt clay loam
Maximum ET ......0.35 in (9 mm) per day
Water Source ....well
Ground cover ....winter wheat
Crops rotated with ....none
Time to maturity ....
Average yield ....2.25 bales / acre
Duration of tape installation ....multi-year

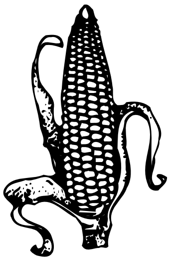
Auxiliary Equipment:

Primary filtration ....sand media
Secondary filtration ....none
Submains ....PVC
Mulch ....none

Management/Operation

Irrigation frequency ....1-2 times per week
Irrigation duration ....4 hours
Chemigation ....yes
Fertigation ....yes
Line flushing ....3 times per year
Filter back-flushing ....automatic

Drip Tape: RO-DRIP 15-12-15 XL
(15 mil, 12-in spacing, 15 GPH per 100 ft , 7/8-in diameter)
(.381 mm, 30-cm spacing, 186 LPH per 100 m, 22-mm diameter)

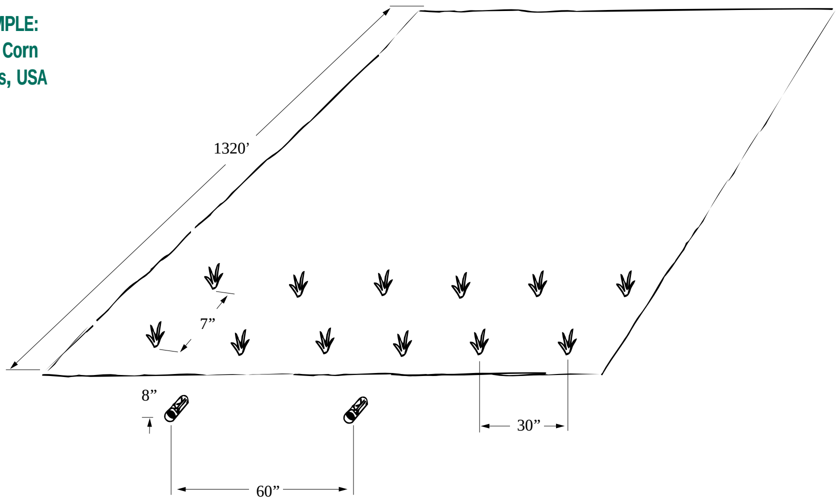


Corn

Corn is typically seeded on 30-in (76-cm) row spacings with 6 to 10-in (15 to 25-cm) in-row spacing. One drip lateral is placed between every other pair of rows, resulting in a 60-in spacing between laterals. Twelve-inch emitter spacings are common, at either 15 or 24 GPH per 100-ft. Since RO-DRIP XL drip tape can deliver good uniformity on runs up to _ mile long, it is often used in grain applications where large filed sizes are common.

Drip irrigation is becoming a method of choice in applications such as corn, which have traditionally been served by center pivots. Center pivot irrigation cannot provide the same per-acre yield or complete utilization of rectangular fields that is possible drip irrigation. In fields where there is already a significant investment in center pivot hardware, yield can be increased by using drip tape to irrigate the corners.

EXAMPLE:
Feed Corn
Kansas, USA



Operation:

Crop	corn
Location	Kansas, USA
Field size	80 acres
Plants per acre	28,000
Season	Spring
Planting method	direct seeded
Soil type	clay loam
Maximum ET	0.4 in per day
Water Source	well
Ground cover	none
Crops rotated with	soybeans
Time to maturity	120 days
Ave. yield	200 bushels / acre (17.5 m3 / ha)
Duration of tape installation	5+ years

Auxiliary Equipment:

Primary filtration	screen
Secondary filtration	none
Submains	PVC
Mulch	none

Management/Operation

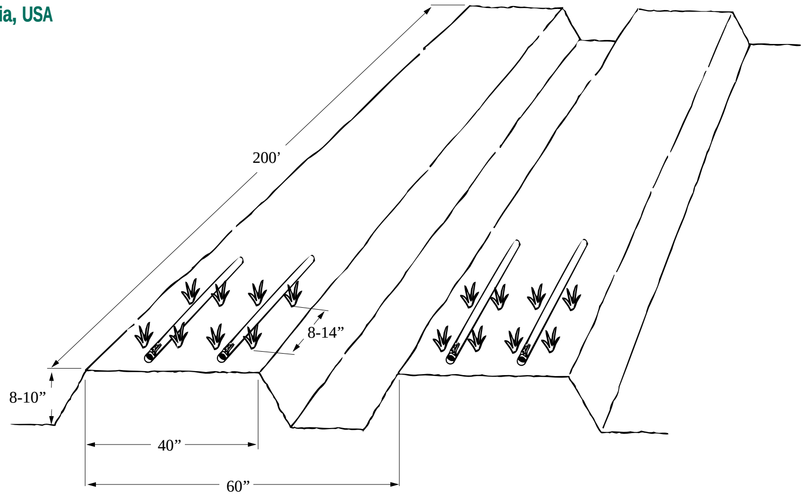
Irrigation frequency	3 days
Irrigation duration	16 hours
Chemigation	yes
Fertigation	yes
Line flushing	yes
Filter back-flushing	yes

Drip Tape: RO-DRIP 13-12-15 XL
(13 mil, 12-in spacing, 15 GPH per 100 ft, 7/8-in diameter)
(.330 mm, 30-cm spacing, 186 LPH per 100 m, 22-mm diameter)

Field Flowers

Outside field flowers are usually grown in single or double rows either on level ground or in beds. The most commonly used tape is 8-mil wall thickness with 8-in emitter spacing. Cut flowers are grown in greenhouses on multiple-row beds. Use three laterals for a typical 36 to 48-in (91 to 122-cm) bed in a greenhouse. For a single or double row of flowers, or for outside bulbs, use a single lateral with an 8 or 10-mil wall thickness and an 8-in emitter spacing.

EXAMPLE:
Field Flowers
Central Coast, California, USA



Operation:

Crop . . . . .field flowers
Location . . . .Central Coast, California, USA
Field size . . . . .50 acres (20 ha)
Plants per acre . . . . .175,000 (450,000 per ha)
Season . . . . .year round
Planting method . . . .
. . . . .direct seeded and transplanted
Soil type . . . . .clay to clay-loam
Maximum ET . . . .30 in (7.5 mm) per day
Water Source . . . . .well
Ground cover . . . . .none
Crops rotated with . . . . .none
Time to maturity . . . . .20-60 days
Average yield . . . . .depends on market
Duration of tape installation . . . .3-6 months

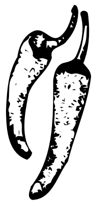
Auxiliary Equipment:

Primary filtration . . . . . . .sand media filters
Secondary filtration . . . . .none
Submains . . . . .layflat
Mulch . . . . .none

Management/Operation

Irrigation frequency . . . .1-3 times per week
Irrigation duration . . . . .1-2 hours
Chemigation . . . . .fungicides
Fertigation . . . . .yes
Line flushing . . . . .monthly
Filter back-flushing . . . . .automatic

Drip Tape: RO-DRIP 8-8-40
(8 mil, 8-in spacing, 40 GPH per 100-ft, 5/8-in diameter)
(.200 mm, 20-cm spacing, 497 LPH per 100 m, 16-mm diameter)

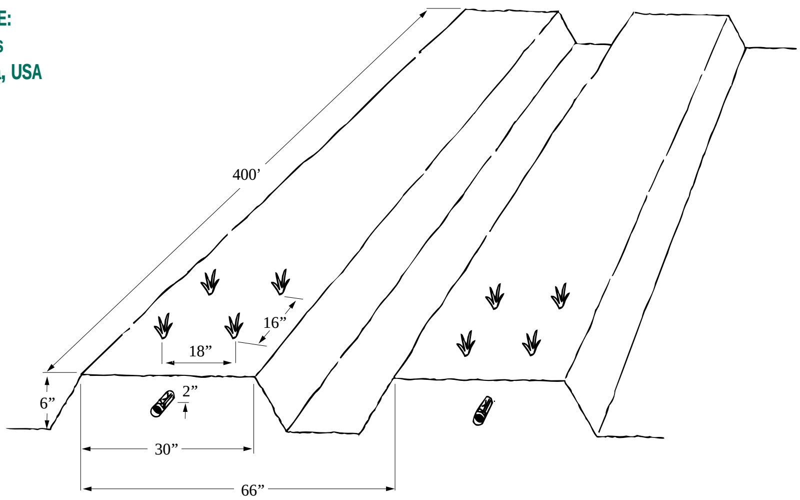


Peppers

Peppers are a warm-season crop. Pepper plants can be injured or killed by frost and grow best in soil temperatures above 65°F (17°C) and in air temperatures of 70 to 80°F (20 to 25°C). Transplanted peppers root only to a depth of about 2-ft (60-cm), but use soil moisture efficiently. Young pepper plants are relatively resistant to water stress but may show slower development and reduced yields.

Peppers are usually transplanted in single rows on 36-in (91-cm) beds with 12-in (130-cm) in-row spacing; or on 72-in (183-cm) beds with double rows spaced 12 to 18-in (30 to 46 cm) apart and staggered on either side of the drip lateral, with 12 to 18-in (30 to 46-cm) in-row spacing. Plastic mulch in combination with drip irrigation can be used to increase yields.

EXAMPLE:
Peppers
Pennsylvania, USA



Operation:

Crop . . . . .peppers
Location . . . . .Pennsylvania, USA
Field size . . . . .25 acres (10 ha)
Plants per acre . . . . . . .12,000 (30,000 per ha)
Season . . . . .summer
Planting method . . . . .transplant
Soil type . . . . .silty loam
Maximum ET . . . . .0.30 in (7.5 mm) per day
Water Source . . . . .deep well
Ground cover . . . . .plastic mulch
Crops rotated with . . .cabbage, corn, tomato
Time to maturity . . . . .60 days
Average yield. . .22.5 tons / acre (50 tons / ha)
Duration of tape installation . . . . . .120 days

Auxiliary Equipment:

Primary filtration . . . . .screen filter
Secondary filtration . . . . .none
Submains . . . . .2" layflat
Mulch . . . . .black plastic

Management/Operation

Irrigation frequency . . . .1-2 times per week
Irrigation duration . . . . .4-6 hours
Chemigation . . . . .yes
Fertigation . . . . .yes
Line flushing . . . . .yes
Filter back-flushing . . . . .yes

Drip Tape: RO-DRIP 8-12-24
(8 mil, 12-in spacing, 15 GPH per 100 ft, 5/8-in diameter)
(.200 mm, 30-cm spacing, 186 LPH per 100 m, 16-mm diameter)

COEFFICIENT OF VARIATION AND EMITTER DISCHARGE EXPONENT

Coefficient of variation

If you randomly select several emitters from a section of drip tape, apply the same water pressure to each, and measure the discharge rate from each, the *Coefficient of Variation (Cv)* is a measure of how consistent the results will be. If the emitters were manufactured with a high precision production process and good quality control, the discharge rates of all of the emitters will be nearly identical and the *Cv* will be low. On the other hand, emitters made from a poor design, an inconsistent manufacturing process, or with little or no quality control will have wide variations in discharge rate and a high *Cv*.

Cv can be calculated by measuring the discharge rate from each emitter in a sample of drip tape (usually long enough to provide 25 emitters), then using the following formula:

$$Cv = \frac{S_q}{\overline{q}}$$

where S_q is the *standard deviation* of the discharge rates measured in the sample, and $\overline{q}$ is the average discharge rate of the sample. Most drip tape manufacturers publish the *Cv* of their products. Several independent labs also test *Cvs*, and compare them among manufacturers.

A perfect manufacturing process is impossible, so emitters with zero *Cv* (all identical flow rates) do not exist. However, since good Distribution Uniformity is impossible if emitter flow rates are not consistent, you should select a drip tape with a low *Cv*. Table C1 gives an idea of *Cv* values you can expect and what they mean.

The Roberts Difference: RO-DRIP is manufactured with an advanced, high-precision process which results in an emitter coefficient of variation of 0.03 or lower. This translates to better distribution uniformity and higher irrigation efficiency in your field.

Table C1 Emitter Cv Values and their Classification

Cv	Classification*
≤ 0.05	Excellent
0.05 - 0.07	Good
0.07 - 0.11	Marginal
> 0.11	Poor

*As designated by American Society of Agricultural Engineers ASAE EP405.1 DEC94

It is important to realize that the *Cv* values published by manufacturers are for new product; and that long-term performance of your installed drip system can be as much affected by how well the emitters resist plugging as by the *Cv*.

Emitter discharge exponent (the x-factor):

When a drip tape emitter is operating at its recommended pressure, it generally discharges water at its published rate (with minor variations resulting from its *Cv*). If you increase pressure from that point, the discharge rate will increase. If you decrease pressure, the discharge rate will decrease. The quality of the emitter determines how much the discharge rate changes in response to pressure changes.

The *Discharge Exponent (x)* of an emitter is a measure of how much its discharge rate varies as supply pressure varies. An *x* of 1 means that the discharge rate varies directly with pressure (i.e., if supply pressure doubles, discharge rate doubles). A low *x* means that the discharge rate does not vary greatly when pressure varies. Most high-quality drip tape products have *x* values in the range of 0.4 to 0.7. Some lower-quality products have *x* values greater than 1.

The discharge exponent of a drip emitter can be calculated by measuring its discharge rate at two different pressures. The equation which relates pressure to discharge rate for a drip emitter is

$$q = KP^x$$

where *P* is the pressure applied to the emitter, q is the discharge rate, *x* is the discharge exponent and *K* is a constant. By measuring discharge rates at two different pressures, you can calculate the exponent as follows:

$$q_1 = KP_1^{\,x} \qquad q_2 = KP_2^{\,x}$$

$$\frac{q_2}{q_1} = \left(\frac{P_2}{P_1}\right)^x$$

$$x = \frac{\log(q_2 / q_1)}{\log(P_2 / P_1)}$$

where q_1 is the discharge rate measured at pressure P_1 and q_2 is the discharge rate measured at pressure P_2. Most drip tape manufacturers publish the discharge exponent of their products. Several independent labs also test discharge exponents, and compare them among manufacturers.

This user guide tells you how to design your drip system to have minimal pressure variations from elevation changes and friction losses. Even a well-designed system, however, can have higher pressures in some parts of the field than in others. If you select a drip tape product with a low *x* value, you can avoid the problems of higher discharge rates in some parts of the field than in others and low distribution uniformity.

SAMPLE RO-DRIP®
PERFORMANCE CHARTS

Following are sample performance charts for three RO-DRIP products, XX-12-24 (12 inch emitter spacing, 24 GPH per 100 ft), XX-24-17 (24 inch emitter spacing, 17 GPH per 100 ft)and XX-12-24 XL (12 inch emitter spacing, 24 GPH per 100 ft, 7/8-in ID). The "XX" term denotes the wall thickness, and can be 5, 8, 10, 13 or 15 mil. For a complete set of performance charts for all RO-DRIP products, see the Roberts Irrigation Products publication *RO-DRIP PERFORMANCE DATA*.

Table D.1 Sample Performance Charts															
Maximum Run Length, feet															
	RO-DRIP XX-12-24					RO-DRIP XX-24-17					RO-DRIP XX-12-24 XL				
	Cv = 0.03 x = 0.52			q = 0.40 k =.018396		Cv = 0.03 x = 0.52			q = 0.28 k =.115311		Cv = 0.03 x = 0.52			q = 0.40 k =.081396	
Slope	Inlet Pressure - psi					Inlet Pressure - psi					Inlet Pressure - psi				
	EU	6	8	10	12	EU	6	8	10	12	EU	6	8	10	12
-1.5%↓	80%	1078	1088	1088	1081	80%	1335	1355	1363	1366	80%	1830	1896	1928	1939
	85%	936	941	939	930	85%	1153	1177	1183	1178	85%	1551	1632	1664	1677
	90%	735	754	754	750	90%	872	935	947	944	90%	304	1240	1306	1333
-1.0%↓	80%	1076	1069	1056	1044	80%	1349	1349	1339	1328	80%	1871	1895	1898	1894
	85%	929	921	907	898	85%	1169	1167	1157	1143	85%	1615	1640	1643	1634
	90%	747	740	731	720	90%	940	939	934	917	90%	1260	1308	1313	1311
-0.5%↓	80%	1022	1001	986	973	80%	1298	1273	1256	1239	80%	1805	1788	1766	1749
	85%	877	857	845	833	85%	1119	1092	1077	1063	85%	1557	1534	1514	1499
	90%	701	686	676	662	90%	900	872	856	846	90%	1248	1227	1211	1193
0.0%	80%	834	843	850	852	80%	1039	1052	1057	1063	80%	1370	1393	1412	1430
	85%	717	721	729	734	85%	897	902	905	911	85%	1172	1192	1209	1222
	90%	566	574	577	578	90%	708	713	717	724	90%	920	938	949	959
+0.5%↑	80%	605	656	689	716	80%	702	771	823	857	80%	831	939	1018	1078
	85%	510	556	586	610	85%	591	655	700	729	85%	682	784	854	909
	90%	379	419	445	471	90%	431	489	531	556	90%	477	564	621	675
+1.0%↑	80%	465	530	577	614	80%	514	600	667	715	80%	560	678	773	851
	85%	382	441	486	519	85%	413	494	551	601	85%	441	548	627	699
	90%	264	315	354	380	90%	281	346	403	436	90%	287	367	428	484

Cv = coefficient of variation ; q = discharge rate, GPM/100’ ; x = emitter exponent ; k = flow constant ; required filtration: 140 mesh.

LENGTH, APPLICATION RATES, AND FLOW RATES

The tables in this appendix summarize the results of the equations given in DESIGN: Lateral Design for several drip tape flow rates and lateral spacings. Lateral spacings and flow rates must be specified for an application rate sufficient to meet irrigation requirements during peak ET (Tables E1 and E3) without exceeding the capacity of the water supply (Tables E2 and E4).

Table E.1 Length and Flow Rate Requirements, US Units

Distance Between Laterals (in)	Length of Drip Tape per Acre (ft)	Drip Tape Flow Rate per 100 ft at 8 PSI				
		40 GPH	24 GPH	20 GPH	17 GPH	15 GPH
		.67 GPM	.40 GPM	.33 GPM	.28 GPM	.25 GPM
		GPM Required per Acre				
30	17,424	117	70	58	49	44
32	16,335	109	65	54	46	41
34	15,374	103	62	51	43	38
36	14,520	97	58	48	41	36
38	13,756	92	55	45	39	34
40	13,068	88	52	43	37	33
42	12,446	83	50	41	35	31
44	11,880	80	48	40	33	30
46	11,363	76	46	28	32	28
48	10,890	73	44	36	31	27
54	9,680	65	39	32	27	24
60	8,712	58	35	29	24	22
66	7,920	53	32	26	22	20
72	7,260	49	29	24	20	18
84	6,223	42	25	21	17	16
96	5,445	37	22	18	15	14
120	4,356	29	17	14	12	11

Table E.2 Length and Application Rates, US Units

Distance Between Laterals (in)	Length of Drip Tape per Acre (ft)	Drip Tape Flow Rate per 100 ft at 8 PSI				
		40 GPH	24 GPH	20 GPH	17 GPH	15 GPH
		.67 GPM	.40 GPM	.33 GPM	.28 GPM	.25 GPM
		Application Rate (in per hour @ 8 PSI)				
30	17,424	0.258	0.155	0.131	0.108	.096
32	16,335	0.242	0.145	0.123	0.101	.090
34	15,374	0.228	0.136	0.115	0.095	.085
36	14,520	0.215	0.129	0.109	0.090	.080
38	13,756	0.204	0.122	0.103	0.085	.076
40	13,068	0.193	0.116	0.098	0.081	.072
42	12,446	0.184	0.110	0.093	0.077	.069
44	11,880	0.176	0.105	0.089	0.074	.066
46	11,363	0.168	0.101	0.085	0.070	.063
48	10,890	0.161	0.093	0.082	0.067	.060
54	9,680	0.143	0.086	0.073	0.060	.054
60	8,712	0.129	0.074	0.065	0.054	.048
66	7,920	0.117	0.070	0.059	0.049	.044
72	7,260	0.107	0.064	0.055	0.045	.040
84	6,223	0.092	0.055	0.047	0.039	.034
96	5,445	0.081	0.048	0.042	0.034	.030
120	4,356	0.064	0.039	0.033	0.027	.024

Table E.3 Length and Flow Rate Requirements, Metric Units						
Distance Between Laterals (cm)	Length of Drip Tape per Acre (m)	Drip Tape Flow Rate per 100 m at .55 bar				
		497 LPH	298 LPH	248 LPH	211 LPH	186 LPH
		8.3 LPM	5.0 LPM	4.1 LPM	3.5 LPM	3.1 LPM
		M3/hr Required per Acre				
80	12,500	62	38	31	26	23
90	11,110	55	33	27	23	21
100	10,000	50	30	25	21	19
110	9,090	45	27	22	19	17
120	8,333	42	25	21	18	16
130	7,692	38	23	19	16	14
140	7,143	36	21	18	15	13
150	6,667	33	20	16	14	12
160	6,250	31	19	15	13	12
170	5,882	29	18	15	12	11
180	5,556	28	17	14	12	10
190	5,263	26	16	13	11	10
200	5,000	25	15	12	11	9
210	4,762	24	14	12	10	9
220	4,546	23	14	11	10	9
230	4,348	22	13	11	9	8
240	4,167	21	13	10	9	8

Table E.4 Length and Application Rates, Metric Units						
Distance Between Laterals (cm)	Length of Drip Tape per Acre (m)	Drip Tape Flow Rate per 100 m at .55 bar				
		497 LPH	298 LPH	248 LPH	211 LPH	186 LPH
		8.3 LPM	5.0 LPM	4.1 LPM	3.5 LPM	3.1 LPM
		Application Rate (mm3/hr @ .55 bar)				
80	12,500	6.25	3.75	3.12	2.61	2.30
90	11,110	5.55	3.31	2.77	2.34	2.06
100	10,000	5.00	2.98	2.50	2.11	4.86
110	9,090	4.54	2.71	2.27	1.91	1.68
120	8,333	4.16	2.48	2.08	1.76	1.55
130	7,692	3.84	2.29	1.92	1.62	1.43
140	7,143	3.57	2.13	1.78	1.51	1.33
150	6,667	3.33	1.99	1.66	1.41	1.24
160	6,250	3.12	1.86	1.56	1.32	1.16
170	5,882	2.94	1.72	1.47	1.24	1.09
180	5,556	2.77	1.66	1.38	1.17	1.03
190	5,263	2.63	1.57	1.31	1.11	0.99
200	5,000	2.50	1.49	1.25	1.06	0.93
210	4,762	2.38	1.42	1.19	1.01	0.89
220	4,546	2.27	1.35	1.13	0.96	0.85
230	4,348	2.17	1.30	1.08	0.92	0.81
240	4,167	2.08	1.24	1.04	0.88	0.78

ENGINEERING CONVERSION FACTORS

APPENDIX F
ENGINEERING CONVERSION FACTORS

LENGTH

To Convert	To	Multiply by	To Convert	To	Multiply by
Miles	inches	63,360	kilometers	meters	1,000
miles	feet	5,280	kilometers	feet	3,280.8
miles	yards	1,760	kilometers	yards	1,093.6
miles	nautical miles	0.87	kilometers	miles	0.6214
miles	meters	1,609.34	kilometers	nautical miles	0.54
miles	kilometers	1.609	meters	centimeters	100
feet	meters	0.3048	meters	inches	39.37
feet	centimeters	30.48	meters	feet	3.281
inches	centimeters	2.54	meters	yards	1.094
inches	millimeters	25.4	centimeters	inches	0.3937
inches	mils	1,000	millimeters	inches	0.03937
mils	microns	25.4	millimeters	microns	1,000
			microns	mils	0.03937

APPENDIX F
ENGINEERING CONVERSION FACTORS

AREA

To Convert	To	Multiply by	To Convert	To	Multiply by
sq miles	acres	640	sq kilometers	hectares	100
sq miles	hectares	259	sq kilometers	acres	247.1
sq miles	sq kilometers	2.59	sq kilometers	sq miles	0.3861
acres	sq feet	43560	hectares	sq meters	10,000
acres	sq yards	4840	hectares	acres	2.471
acres	hectares	0.4047	sq meters	sq centimeters	10,000
sq feet	sq inches	144	sq meters	sq feet	10.764
sq feet	sq yards	0.111	sq centimeters	sq inches	0.1549
sq feet	sq meters	0.0929			
sq inches	sq centimeters	6.452			

APPENDIX F
ENGINEERING CONVERSION FACTORS

VOLUME

To Convert	To	Multiply by	To Convert	To	Multiply by
Acre Feet	Gallons	325851	Cubic Meters	Liters	1000
Acre Inches	Cubic Feet	3630	Cubic Meters	Gallons	264.2
Cubic Yards	Cubic Meters	0.765	Cubic Meters	Cubic Feet	35.32
Cubic Yards	Liters	769	Cubic Meters	Cubic Yards	1.308
Cubic Yards	Cubic Feet	27	Liters	cubic Meters	0.001
Cubic Yards	Cubic Inches	46656	Liters	Cubic Yards	0.0013
Cubic Yards	Gallons	200	Liters	Cubic Feet	0.035
Cubic Feet	Gallons	7.48	Liters	Gallons	0.264
Cubic Feet	Cubic Inches	1728	Liters	Cups	4.22
Cubic Feet	Cubic Yards	0.037	Liters	Quarts	1.057
Cubic Feet	Cubic Centimeters	28317	Liters	Pints	2.11
Cubic Feet	Cubic Meters	0.0283	Liters	Cubic Inches	61
Cubic Feet	Liters	28.32	Liters	Cubic Centimeters	1000
Cubic Feet	Acre Inches	0.000275	Cubic Centimeters	Cubic Feet	3.53×10^{-5}
Cubic Feet	Acre Feet	0.0000230	Cubic Centimeters	Gallons	0.000264
Gallons	Acre Feet	0.00000307	Cubic Centimeters	Pints	0.00211
Gallons	Cubic Feet	0.134	Cubic Centimeters	Cubic Millimeters	1000
Gallons	Cubic Inches	231	Cubic Centimeters	Cubic Inches	0.061
Gallons	Cubic Yards	0.005	Cubic Centimeters	Liters	0.001
Gallons	Cubic Centimeters	3785	Cubic Centimeters	Quarts	0.0011
Gallons	Cubic Meters	0.0038	Cubic Centimeters	Ounces	0.0338
Gallons	Liters	3.785	Cubic Centimeters	Tablespoons	0.067
Gallons	Quarts	4	Cubic Centimeters	Fluid Ounces	0.0333
Gallons	Pints	8	Cubic Millimeters	Cubic Centimeters	0.001
Gallons	Ounces	128			
Quarts	Gallons	0.25			
Quarts	Pints	2			
Quarts	Liters	0.946			
Quarts	Cubic Centimeters	946.4			
Quarts	Cubic Inches	57.75			
Quarts	Pints	2			
Pints	Gallons	0.125			
Pints	Quarts	0.5			
Pints	Ounces	16			
Pints	Liters	0.4732			
Pints	Cubic Centimeters	473.2			
Pints	Cubic Inches	28.88			
Cups	Liters	0.237			
Cubic Inches	Cubic Feet	0.00058			
Cubic Inches	Cubic Yards	2.14×10^{-5}			
Cubic Inches	Cubic Centimeters	16.4			
Cubic Inches	Gallons	0.00433			
Cubic Inches	Liters	0.0164			
Cubic Inches	Quarts	0.0173			
Cubic Inches	Pints	0.0346			
Fluid Ounces	US Gallons	0.00781			
Fluid Ounces	Pints	0.0625			
Fluid Ounces	Cubic Centimeters	30			
Tablespoons	Cubic Centimeters	15			

APPENDIX F
ENGINEERING CONVERSION FACTORS

WEIGHT AND MASS

To Convert	To	Multiply by	To Convert	To	Multiply by
Ounces	Grams	28.35	Grams	Ounces	0.0353
Ounces	Pounds	0.0625	Grams	Pounds	0.0022
Ounces	Kilograms	0.0284	Grams	Kilograms	0.001
Pounds	Grams	453.6	Kilograms	Grams	1000
Pounds	Ounces	16	Kilograms	Ounces	35.21
Pounds	Kilograms	0.454	Kilograms	Pounds	2.205
Pounds	Tons (short)	0.0005	Kilograms	Tons	0.0011
Pounds	Tons (long)	0.00045	Kilograms	Metric Tons	0.001
Pounds	Metric Tons	0.000454	Metric Tons	Kilograms	1000
Tons (short)	Tons (metric)	0.907	Metric Tons	Pounds	2205
Tons (short)	Tons (long)	0.893	Metric Tons	Tons (Long)	0.984
Tons (short)	Kilograms	907.2	Metric Tons	Tons (Short)	1.1
Tons (short)	Pounds	2000			
Tons (long)	Metric Tons	1.02			
Tons (long)	Tons (short)	1.12			
Tons (long)	Pounds	2240			

APPENDIX F
ENGINEERING CONVERSION FACTORS

YIELD

To Convert	To	Multiply by	To Convert	To	Multiply by
Metric Tons per Hectare	US Tons per Acre	0.446	US Tons per Acre	Metric Tons per Hectare	2.24
Kilograms per Hectare	Pounds per Acre	0.892	Pounds per Acre	Kilograms per Hectare	1.12
Cubic Meters per Hecare	Bushels per Acre	11.48	Bushels per Acre	Cubic Meters per Hectare	0.087

APPENDIX F
ENGINEERING CONVERSION FACTORS

FLOW

To Convert	To	Multiply by	To Convert	To	Multiply by
Acre Inches per 24 Hours	Gallons per Minute	18.86	Cubic Meters per Hour	Liters per Second	0.278
Cubic Feet per Second	Gallons per Minute	448.8	Cubic Meters per Second	Cubic Feet per Second	35.31
Cubic Feet per Second	Acre-in per Hour (approx)	1	Cubic Meters per Second	Gallons per Minute	15850
Cubic Feet per Second	Acre-Ft per Day (approx)	2	Liters per Minute	Cubic Feet per Second	$5.89x10^{-4}$
Cubic Feet per Second	Liters per Second	28.32	Liters per Minute	Cubic Gallons per Second	$4.40x10^{-3}$
Cubic Feet per Second	Liters per Minute	1699	Liters per Minute	British Gallons per Minute	13.2
Cubic Feet per Second	Cubic Meters per Second	0.0283	Liters per Second	Cubic Meters per Hour	3.6
Gallons per Minute	Cubic Meters per Second	$6.39x10^{-5}$	Liters per Second	Cubic Feet per Second	0.0353
Gallons per Minute	Liters per Second	0.0631	Liters per Second	Gallons per Minute	15.85
Gallons per Minute	Cubic Feet per Second	0.00223			
Gallons per Minute	Acre Inches per 24 Hours	0.053			
Gallons per Second	Liters per Minute	0.0631			
British Gallons per Minute	Liters per Minute	0.0757			

APPENDIX F
ENGINEERING CONVERSION FACTORS

VELOCITY

To Convert	To	Multiply by	To Convert	To	Multiply by
Miles per Hour	Feet per Second	1.467	Kilometers per Hour	Feet per Minute	54.68
Miles per Hour	Feet per Minute	88	Kilometers per Hour	Feet per Second	0.91
Miles per Hour	Meters per Second	0.447	Kilometers per Hour	Meters per Second	0.28
Miles per Hour	Centimeters per Second	44.7	Kilometers per Minute	Meters per Second	16.67
Miles per Hour	Meters per Minute	27.0	Meters per Minute	Miles per Hour	0.037
Miles per Minute	Feet per Minute	5280	Meters per Second	Kilometers per Hour	3.6
Miles per Minute	Meters per Second	26.82	Meters per Second	Kilometers per Minute	0.06
Miles per Minute	Centimeters per Second	2682	Meters per Second	Miles per Hour	2.237
Feet per Minute	Kilometers per Hour	0.0183	Meters per Second	Miles per Minute	0.037
Feet per Minute	Meters per Second	0.00508	Meters per Second	Feet per Minute	196.8
Feet per Minute	Miles per Hour	0.0114	Meters per Second	Feet per Second	3.281
Feet per Minute	Miles per Minute	0.000189	Centimeters per Second	Miles per Hour	0.0224
Feet per Second	Meters per Second	0.305	Centimeters per Second	Miles per Minute	0.000373
Feet per Second	Miles per Hour	0.68			
Feet per Second	Kilometers per Hour	1.10			
Feet per Second	Miles per Minute	0.0114			

APPENDIX F
ENGINEERING CONVERSION FACTORS

PRESSURE AND HEAD

To Convert	To	Multiply by	To Convert	To	Multiply by
Pounds per Square Inch	Kg per Square Meter	703.1	Atmospheres	Pounds per Square Inch	14.7
Pounds per Square Inch	Bar	0.0689	Atmospheres	Inches of Mercury	29.9
Pounds per Square Inch	Atmosphere	0.068	Atmospheres	Feet of Water	33.9
Pounds per Square Inch	Pounds per Square Foot	144	Atmospheres	Bar	0.9869
Pounds per Square Inch	Feet of Water	2.31	Bar	Pounds per Square Inch	14.5
Pounds per Square Inch	Inches of Mercury	2.036	Bar	Atmosphere at Sea Level	1.013
Pounds per Square Inch	Inches of Water (60o F)	27.68	Kg per Square Meter	Inches of Mercury	0.0029
Pounds per Square Foot	Pounds per Square Inch	0.00694	Kg per Square Meter	Pounds per Square Foot	0.2048
Pounds per Square Foot	Kg per Square Meter	4.88	Kg per Square Meter	Pounds per Square Inch	0.00142
Inches of Mercury	Atmosphere at Sea Level	0.0334			
Inches of Mercury	Kg per Square Meter	345.3			
Inches of Mercury	Feet of Water	1.13			
Inches of Mercury	Inches of Water (60o F)	13.60			
Inches of Mercury	Pounds per Square Inch	0.491			
Feet of Water	Inches of Mercury	0.883			
Feet of Water	Pounds per Square Inch	0.4335			
Feet of Water	Atmosphere at Sea Level	0.0295			
Inches of Water (60o F)	Inches of Mercury	0.0736			
Inches of Water (60o F)	Pounds per Square Inch	0.0361			

APPENDIX F
ENGINEERING CONVERSION FACTORS

WORK AND POWER

To Convert	To	Multiply by	To Convert	To	Multiply by
Horsepower	Foot-Pounds per Second	550	Calories per Second	Horsepower	0.0056
Horsepower	Watts	745.7	Calories per Second	Kilowatts	0.00419
Horsepower	Kilowatts	0.7457	Watts	Kilowatts	0.001
Horsepower	Calories per Second	178.1	Watts	Horsepower	0.00134
Foot-Pounds per Second	Kilowatts	0.000738	Kilowatts	Watts	1000
Foot-Pounds per Second	Horsepower	0.00182	Kilowatts	Foot-Pounds per Second	1356
Foot-Pounds	Calories	0.3239	Kilowatts	Calories per Second	238.9
Foot-Pounds	BTUs	0.00129	Kilowatts	Horsepower	1.341
Foot-Pounds	Kilowatt-Hours	3.77¥10-7	Calories	Foot-Pounds	3.09
BTUs	Foot-Pounds	778	Kilowatt-Hours	Calories	$8.60x10^{5}$
BTUs	Calories	252	Kilowatt-Hours	BTUs	3413
BTUs	Kilowatt-Hours	0.00029	Kilowatt-Hours	Horsepower Hours	1.341
Horsepower-Hour	Kilowatt-Hours	0.7457	Kilowatt-Hours	Foot-Pounds	$2.66x10^{6}$

APPENDIX F
ENGINEERING CONVERSION FACTORS

CONCENTRATION

To Convert	To	Multiply by	To Convert	To	Multiply by
Milligrams per Liter	Parts per Million	1	Millimho per Centimeter	Decisiemens per Meter	1.00
Milligrams per Liter	Grams per Cubic Meter	1	Millimho	Milliequivalents per Liter	10
Decisiemens per Meter	Millimho per Centimeter	1	Milligrams per Liter	Parts per Million (ppm)	1
Decisiemens per Meter	Parts per Million Salt	640	Grams per Cubic Meter	Parts per Million (ppm)	1.00
Parts per Million (ppm)	Milligrams per Liter	1			
Parts per Million (ppm)	Grams per Cubic Meter	1			
Parts per Million (ppm)	Tons per Acre Foot	0.00136			
Parts per Million (ppm)	Grains per Gallon	0.0584			
Parts per Million Salt	Decisiemens per Meter	0.00156			
Tons per Acre Foot	Parts per Million (ppm)	735			
Grains per Gallon	Parts per Million (ppm)	17.1			

APPENDIX F
ENGINEERING CONVERSION FACTORS

TEMPERATURE

To Convert	To	Formula	To Convert	To	Formula
Degrees Celcius (°C)	Degrees Fahrenheit (°F)	1.8x°C+32	Degrees Fahrenheit (°F)	Degrees Celcius (°C)	(°F-32)/1.8

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