

Site Selection for Subsurface Drip Irrigation Systems in the Humid Region

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Abstract

Site selection for subsurface drip irrigation (SDI) in the humid region must be carefully considered to ensure optimum system performance and crop yield while minimizing unnecessary expenses. SDI has been shown to result in similar or higher crop yields on many crops while reducing water use. However, characteristics of the field, soil, crop, cropping system, water resource available, managerial and farm labor resources, economic factors, and industry support infrastructure affect decisions about the appropriateness of SDI in a given situation. These topics are discussed with emphasis on their effect on the humid regions of the United States.

Introduction

Supplemental irrigation is commonly practiced in the humid regions of the United States despite the fact that average annual rainfall exceeds evapotranspiration (ET). Irrigation is desirable because of the nonuniform distribution of rainfall (temporally and spatially), the limited water-holding capacities of soils (e.g., sandy soils in the southeastern coastal plains), and the extreme sensitivity of some specialty and horticultural crops to water stress. These factors and the economic losses from under-or-over-irrigation require that irrigation systems apply water uniformly, and efficiently in terms of both water and economics.

Subsurface drip irrigation (SDI) is a relatively new practice in the humid region. Thus, it is important that the selection of sites appropriate for use of SDI be carefully considered and weighed against other possible alternative systems. The water supply and pumping considerations; soil considerations; field size, shape and topography; producer preferences, practices and experiences; crops and cropping

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systems; maintenance aspects all affect the ultimate economic success or failure of the SDI system. The pros and cons of SDI are not always realized in a given situation, but it is useful to recognize they can occur. A review of the advantages and disadvantages of SDI is provided by Lamm, (2002). Failure to recognize a significant constraint or to give excess positive weight to one particular aspect may result in a system doomed to failure. This paper discusses some of the considerations most crucial in the humid region. The scope of the paper must be limited to a brief overview, but it should provide good primary information for those considering adoption of SDI in the humid region.

Water Supply and Pumping Considerations

The water supply is often the limiting factor in determining whether irrigation is appropriate for a particular farm. A potential water source is judged by the volume and the quality of the water available for irrigation. The volume criteria include not only information about the flow rate that can be sustained but the reliability of the water supply, both during the season it will be used and from year to year. A lake or pond that is recharged by the surrounding watershed should be able to store all the water needed for irrigation. However, it is often not reasonable to depend on rain to recharge the reservoir during the growing season and an additional recharge source may be necessary. This can be a surface water source such as a river or stream or a groundwater source such as a well. Groundwater sources often have plenty of water volume, but the flow can be limited by the characteristics of the aquifer and/or by the size of the well.

Water supply reliability is extremely important because water supplies in humid areas generally depend upon rainfall (with the exception of deep aquifers) and tend to diminish in capacity or fail during drought. Unfortunately, this is the time of most critical need for irrigation. Many water supplies are replenished at some time during a year, but during extended periods (several years) of low rainfall, some water supplies will continue to decline. Irrigation systems should be designed based on the water supply flow rate for the most probable limiting condition, considering both flow rate and reliability.

The quality of the source water must be a prime consideration because SDI systems require clean water to reduce emitter clogging. Algae and sediment are often found in surface water sources, likewise dissolved iron, manganese, sulfur and carbonates may be found in groundwater. Each of these hazards can make a water source unsuitable for subsurface drip irrigation.

Creeks and streams are often used for irrigation. However, these are flowing water sources and therefore, have very limited storage. The flow of the source must be greater than the pumping rate of the irrigation system at all times to make the source useful for irrigation. The maximum rate of water consumption by crops in the humid Southeast can approach 5 mm per day (Irmak et al., 2003). Since irrigation systems are not 100% efficient, water must be replaced at a rate greater than the withdrawal rate to prevent crop water stress.

The required pumping rate is a function of the dripline output, dripline spacing, the area to be simultaneously irrigated, and the depth of water applied. For example, if the dripline is rated at 6 liters per minute per each 100 m of dripline (6 L

$\text{min}^{-1} 100 \text{ m}^{-1}$), and the line is placed on a 1.8 m spacing (5,556 m of dripline per hectare), then the water source will need to provide 333 L/min or 5.56 L/s for each ha. If 50 ha are to be irrigated, then a pumping rate of 278 L/s is required. If this 50 ha can be irrigated in two sets of 25 ha, then only 139 L/s is required. If 25 mm of water is to be applied during each irrigation event, then 12.5 hours are needed per set.

For SDI, groundwater is usually the first choice as a water supply when there is an aquifer below the field. The aquifer must be able to transmit water to the well at the design pumping rate. Drilling a well can be a large initial investment. Information about the likelihood of finding an adequate groundwater supply can be obtained from regional offices of the United States Geologic Survey (USGS). The cost of the well is a function of aquifer depth, borehole diameter, and casing material. Additional costs include the pump and power source, along with the purchase of any permits.

A SDI system can be supplied by one well or a series of smaller wells. Generally speaking, the greater the capacity of the well, the more it costs. In most situations, a high-production well must be drilled deep into the aquifer and have a large diameter borehole. It may be less expensive to install a series of low-capacity wells rather than one well to supply the entire system, but care must be used in the hydraulic design to ensure the combined pumping plant system is efficient. A system with multiple wells can lower the overall risk to the crop when only one of the pumps needs repair.

Groundwater is often of very high quality. This is an advantage for SDI use because it reduces the cost of filtration. However, in many locations, the groundwater has high concentrations of dissolved ions (such as iron, manganese, magnesium, or calcium). These ions can react with oxygen and form precipitants capable of damaging the irrigation system. Water treatment may be required to prevent mineral precipitants from forming. (Pitts et al., 1990)

Ponds, lakes, rivers and streams are excellent sources of irrigation water if they are located near the area to be irrigated. If the source is not adjacent to the field, then the cost of moving water can be prohibitive. Open-ditch canals are the least expensive water conveyance method; however, the water source must be up-gradient from the field, and considerable percolation losses may occur if the canals are not lined. Evaporation losses in canals should also be considered. Pressurized pipe conveyance has two significant costs: the purchase and installation of the pipe and pump, and the annual energy cost of operating the pump. Generally speaking, the quality of surface water will be poor compared to groundwater. Ponds, lakes and slow-moving streams will tend to have high concentrations of algae and floating debris. Fast moving streams may have higher sediment loads during storm events. Sand media filters and/or disc filters are recommended for removing heavy concentrations of algae and sediment. Filtration will improve the water quality but filters must be properly flushed and maintained.

Water harvesting is the process of collecting water when it is available and storing it until it is needed. Embankment-ponds built in the lower parts of watersheds are small-scale examples of water harvesting. The storage is used to buffer the inability of the water source to provide either the volume or flow required for irrigation. A common example is to use a low production well with inadequate flow

rate for irrigation to fill a reservoir in between irrigation events, and then irrigate from the reservoir. One cost of water harvesting is the lost crop production in the area of the reservoir. This may be an important factor in areas where land is scarce or expensive.

Effluent from municipalities might also be a source of irrigation water. Using effluent for irrigation has three positive features: first, it is a source of water for the crops, it can provide some of the crop nutrients, and the soil will provide additional treatment as it percolates through the soil profile. Of course, there are several drawbacks that must be addressed. The water can contain high-levels of nutrients that can cause microbial growth in driplines. Water from treatment plants may need additional filtration, chemical treatment, and possible disinfection to protect workers. Permits may also be required to use recycled water.

The availability of energy sources for pumping can be an important factor in site selection. Many electric irrigation pumps suitable for irrigation may require three phase electricity which is not always available in rural areas. Petroleum products can be substituted but they may be more costly on an annual basis. Petroleum-based engines may also limit some of the automation and management techniques desirable with SDI.

Along with sufficient volume and flow, it must be determined whether the quality of the source water is suitable for irrigation. The narrow passage way of emitters can become clogged by material suspended in the water, precipitation of dissolved minerals in the water, and biological material.

Physical clogging factors include inorganic particles such as sand, silt, and clay, and various forms of organic material. Chemical clogging factors include minerals such as calcium, magnesium carbonate, calcium sulfate, iron, copper, zinc, and manganese. Fertilizers can also react with chemicals in water to form precipitates. In particular, phosphorus fertilizer sources are very susceptible to precipitation. Biological elements that can cause clogging are growth of algae and slime as well as microbial decomposition and the reduction of iron, sulfur, or manganese in the presence of bacteria (Nakayama and Bucks, 1986).

The larger suspended solids are handled by settling basins and by the primary filtration system, but silt and clay particles are generally too small for most filtration systems. Rather, the smaller suspended solids are pumped through the driplines and periodically the sediments may require flushing from the lines. A rule of thumb for filtration is to provide filtration to 1/10 the size of the smallest emitter passageway (Gilbert and Ford, 1986).

Dissolved solids are chemically bound to the water molecules and will simply pass through the irrigation system. However, the chemistry of the source water will often change as it is being moved through the system and dissolved solids can form insoluble particles and precipitate out of solution. An irrigation water quality test can provide needed information about total dissolved solids, calcium, magnesium, and conductivity that can be used to formulate a treatment strategy. Treatment processes are available that will either force the precipitation of dissolved solids before water enters the irrigation system through oxidation (e.g. chlorination), or keep dissolved solids in suspension through the irrigation system (sequestering). High calcium and

magnesium concentrations (hard water) can be treated with injection of acid (lowering pH of water) to avoid precipitation (Nakayama and Bucks, 1991).

Microorganisms in the water can also be a problem. Certain species of bacteria can metabolize dissolved metals (such as iron, manganese, or sulfur). As these bacteria multiply, a jelly-like slime forms that can block off the emitters. Periodic flushing of the laterals and disinfection of the system will help to keep this problem under control (Alam et al., 2002).

The soil and the crop can also be affected by the quality of the water. Source water pH can change the pH of the soil and cause nutrients to become unavailable to the plant. Source water pH can be adjusted by adding acidic compounds to lower the pH. Source water pH is typically not raised by adding alkaline compounds since this increases the potential for clogging.

Dissolved salts can precipitate out in the soil and increase the salinity of the soil-water solution. Moderate concentrations of salt compounds can be leached out of the root zone by applying excess water or in the humid region by rainfall.

Water treatment needs are determined by the severity of the clogging potential and/or the hazard to the crop. In general, treatment can filter out physical and biological solids, change the chemistry, and/or disinfect the water.

Soil Considerations

Soil type is a primary consideration for designing and implementing SDI. Generally on heavier soils, driplines can be deeper and spaced farther apart. In a review of research results, Camp (1998) reported SDI depth ranging from 0.02 m to 0.70 m and spacing varied from 0.25 to 5.0 m. In recent studies on sandy soil, Dukes and Scholberg (2005) reported the lateral spacing of 0.76 m and depth of 0.23 m was optimum for sweet corn production. The shallow depth required for SDI on coarse soils of the Southeastern Coastal Plain prevents deeper tillage and can lead to compaction (Camp et al., 1999). The reader considering SDI is encouraged to contact local university sources or cooperative extension for guidelines on SDI depth and spacing for local conditions.

The water holding capacity of the soil is an important factor in site selection as it affects the required irrigation frequency and amount, the dripline depth and spacing. Understanding how water is held and moves through the soil allows for an educated decision about the depth of placement and the spacing of the driplines. For narrow-spaced row-crops such as corn and soybeans, the goal is to have a continuous wetted-zone beneath the surface. For crops grown in widely spaced rows, such as fruits and vegetables, the wetted-zone is usually about one-half the distance between rows or less for coarse soils.

The upward movement of water is dependent on the capillary action of the soil. Shallow placement is recommended if irrigation is needed for seed germination on coarse soils. Shallow placement also allows more of the root zone to be filled with water and irrigation events can be less frequent. Deep installations may not require any changes in cultural practices (except for deep ripping). This installation may limit the ability to rotate shallow-rooted crops and will not provide water for crop establishment on coarse soils where vertical movement is limited. Less of the root

zone will receive water and therefore, less water can be applied during an irrigation event or water will be lost to deep percolation.

Field size, shape, and topography

Many producers have been able to increase irrigation efficiency by moving from surface irrigation to center pivot sprinkler irrigation. However, irregular field shape and sizes limit the use of center pivot irrigation. SDI is easily sized to the field and water resource constraints. Whereas SDI system cost is almost entirely proportional to field size, center pivot sprinkler cost on a per acre basis increases rapidly as field size decreases below 100 acres (Bosch, et al. 1992, O'Brien et al. 1998).

If sufficient water supply is available, the field size, shape, and topography, along with the dripline hydraulic characteristics, will dictate the number of irrigation zones. Minimizing the number of necessary zones will generally result in a more economical system to install and operate. Therefore, it is wise to consider the effect of system layout, component selection and field parameters carefully before installing a system.

Topography can complicate system design and limit feasibility of SDI. Whenever possible, dripline laterals should be installed downslope on slopes of less than 2% (Lamm et al., 2003). Pressure changes along the lateral of approximately 20% will result in flow changes of approximately 10%. A maximum of 10% flow change is a general rule of thumb for an acceptable maximum flow variation along the lateral (Bralts et al., 1987). On steeper terrain, the driplines should be placed along the field contour and/or techniques for pressure control should be employed. Pressure compensating emitters can be utilized for pressure control, but they are generally more expensive which may limit use of SDI for commodity type crops (e.g. corn, soybeans, cotton and peanuts). Shorter lateral runs can also aid in pressure control, but will decrease zone size and increase the overall number of zones resulting in the overall higher cost of the system.

The presence of field slope may also cause inadvertent backsiphoning when the SDI system is shutdown. Checkvalves, air vents, and vacuum breakers may be required at various points in the SDI system to prevent back-siphoning of chemically treated water into the water supply and also to prevent ingestion of soil into the driplines at system shutdown. Undulating slopes can present problems in economical prevention of backsiphoning into the dripline laterals and may limit application of SDI if the backsiphoning hazard is great.

Producer Preferences, Practices, and Experiences

When considering SDI, one must first consider the size of the system to be installed and the rate at which the system will be expanded. One of the major factors affecting this decision is the availability of design, installation, and management criteria for the specific enterprise (soil, crop, climate, market, etc.) being planned. These criteria vary considerably among sites and, especially, among regions of the country. If little local or regional information is available, it would probably be prudent to start with a smaller SDI system and reduce risk. Based on experience with

the smaller system, the design and management criteria could be modified before investing resources in a larger system.

Another factor to be considered is the time available for the management staff to learn the proper operation and maintenance of a new technology. Growers must familiarize themselves with the basic components of an SDI system (Figure 1). Required components include a pump and motor, a filtration system, distribution pipe (i.e. PVC mains, submains, or manifolds), drip lateral pipelines, control valves, and pressure regulators. Since SDI systems are buried, the normal operational feedback such as visual inspection of the system components is not adequate to assess system operation. When placed in strategic locations, flowmeters and pressure measurements are necessary to maintain peak system performance. SDI systems are often connected in manifolds at the lateral ends to facilitate flushing. If fertilizers are to be injected then, fertilizer reservoirs, injection system, and proper backflow prevention systems are required. Automation can be achieved by adding an irrigation controller and automatic (solenoid or hydraulic) valves. This can reduce the labor requirements and possibly increase the system efficiency. The inability to visually evaluate and have confidence in SDI performance has limited its adoption for high-value crops in some regions. Growers adopting SDI must adopt rigid and consistent strategies to evaluate performance and make timely adjustments of components to ensure high crop yields and long SDI system life. Additional design information can be found in Howell et al. (1980); Nakayama and Bucks (1986); Smajstrla and Zazueta (1985); Rogers et al., 2003; Lamm et al. (2003).

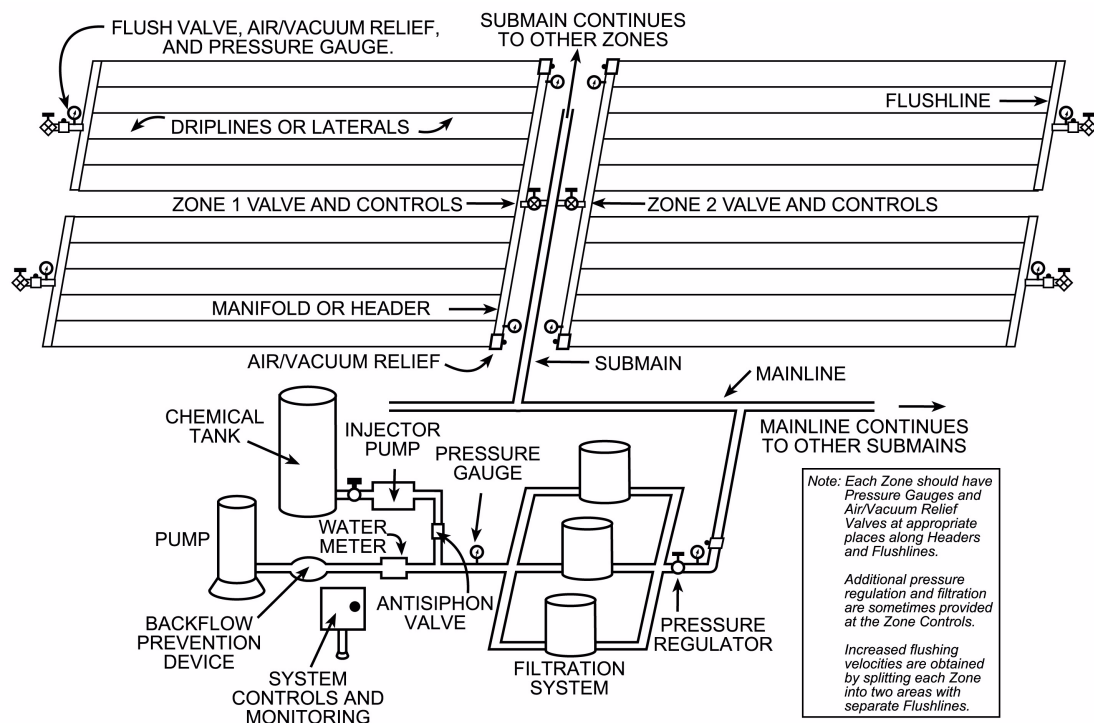


Figure 1. General SDI system layout (Courtesy Freddie Lamm, Kansas State University).

Crops and cropping systems

Many of the crops that are suitable for irrigation in the humid region are also suitable for SDI. Some crops may even be better suited for SDI than for other irrigation methods. For example, melons produced on bare soil are less susceptible to diseases and some rotting problems that are eliminated with the drier SDI soil surfaces. This benefit would be minimal under conditions where rainfall is substantial during the growing season and or where plasticulture is used for crop production. Other crops such as peanut may have pegging problems due to the drier soil surface. Tillage and planting patterns may need adjustment to ensure proper irrigation distribution to the plants and to avoid damaging the SDI system. Specialized planting and tillage implements can be adapted to the SDI method. As the crop and cropping system integrate a large number of soil physical and plant biological variables, it is sometimes difficult to predict the response of a crop to SDI beforehand. It is wise to seek out regional information from research and other growers' experience before adopting SDI for a new crop. A more comprehensive discussion of the many crops suitable for SDI lies beyond the scope of this paper, but additional discussion can be found in Camp (1998).

Because SDI system components are not visible and the process of irrigation is not visible, it is important to monitor various system parameters to maintain optimum performance. When system parameters such as excessive flow or a large drop in pressure occur, the system operator must be willing to take immediate action to correct the problem to ensure optimum performance. Regardless of the level of system automation, some level of monitoring and maintenance is required to maintain optimum performance.

Subsurface drip irrigation is not a new technology. However, the implementation of this technology is not widespread in the humid region. Producers are apprehensive about SDI because the lines are buried and water cannot be seen. The success of a SDI system depends on good design, proper installation, and regular maintenance. The presence or lack of knowledgeable consultants can be a deciding factor as to the suitability of a farm for SDI.

There are time lags associated with applying irrigation water. SDI systems like most microirrigation systems apply water to a smaller portion of the root zone than surface or sprinkler irrigation systems. There is less margin for delay in irrigation with SDI and thus the need to irrigate must be anticipated. This problem is compounded in by the low water-holding capacities of sandy soils and by the shallow root zones of many crops.

Because of the limitations of scheduling irrigations based on plant indicators, irrigations are most often scheduled based on the soil water status. Three procedures may be used: 1) a water balance procedure based on the estimated crop water use rate (e.g. evaporation pan, James, 1988; Jensen, 1980; Pair et al., 1983) and soil water storage, 2) a direct measurement procedure based on instrumentation to measure the soil water status, and 3) a combination of the above two methods in which soil water status instrumentation is used with a water balance procedure. These procedures require knowledge of the crop water requirements, effective root-zone, soil water-holding capacity, and irrigation system capabilities in order to schedule irrigations effectively.

Maintenance Aspects

SDI systems are susceptible to damage from insects, rodents, and other animals. These insects and animals may seek water in times of drought by chewing or otherwise cutting thin walled drip tubing. It is essential to implement pest control programs early before damage to the irrigation system requires excessive time and labor to repair. Discussion of pest problems in the humid region can be found in Stansly and Pitts (1990), Childers et al. (1992), Boman, (1995), and Boman and Bullock (1994).

The primary challenges of utilizing subsurface drip irrigation for long term applications is the potential for internal clogging of the emitter devices and external root intrusion into the drip tubing. Internal clogging caused primarily by sediment, algae, and bacterial slime can usually be effectively controlled by proper filtration, emitter designs with larger discharge orifices and flow paths, and proper chlorination of the SDI system.

External root intrusion into the drip tubing tends to occur when there is crop water stress. Attempts to prevent root intrusion are primarily by three methods, limiting crop water stress and saturating the root zone around the emitter, physical barriers surrounding the emitter, and chemical methods (chemical injection or impregnation of SDI components with herbicide).

Chemical treatment of the irrigation water is often required to prevent emitter clogging due to microbial growth and/or mineral precipitation. Microbial activity can generally be controlled with chlorine, while acid injection can remove scale deposits, reduce or eliminate mineral precipitation, and create an environment unsuitable for microbial growth.

Summary

This paper has outlined aspects that must be considered for site selection of subsurface drip irrigation in the humid region. In particular, water supply and pumping considerations; soil considerations; field size, shape and topography; producer preferences, practices and experiences; crops and cropping systems; maintenance aspects were explored. SDI application in the humid region is similar to the arid region with some distinct differences. The soils on the Coastal Plain are fairly coarse and will require SDI to be placed at shallow depths. This could lead to reduced crop performance due to the compaction or increased maintenance requirements due to the close proximity to tillage activities. Excess rainfall in the humid region tends to minimize salinity problems. In the warmer climate areas within the humid region excess biological growth can lead to dripline clogging and damage to driplines from insects and other pests. Finally, perhaps one of the largest challenges is the adoption of SDI by producers. This will force cultural changes such as managing a system where the water can not be observed directly and the requirement of more intense practices such as filtration and monitoring with water meters and pressure gauges.

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