Irrigation Systems, Subsurface Drip

Carl R. Camp, Jr.
United States Department of Agriculture (USDA), Florence, South Carolina, U.S.A.

Freddie R. Lamm
Kansas State University, Colby, Kansas, U.S.A.

INTRODUCTION

Subsurface drip irrigation (SDI) is generally defined as the application of water below the soil surface through emitters, with discharge rates in the same range as drip irrigation.[1] While this definition is not specific regarding depth below the soil surface, most SDI laterals are installed at a depth sufficient to prevent interference with surface traffic or tillage implements, and to provide a useful life of several years as opposed to annual replacement of surface or near-surface drip laterals.

Development of drip irrigation accelerated with the availability of plastics following World War II, primarily in Great Britain, Israel, and United States. SDI was part of drip irrigation development in the United States beginning about 1959, especially in Hawaii and California. While early drip irrigation products were relatively crude by modern standards, SDI devices were being installed in both experimental and commercial farms by the 1970s. As drip irrigation products improved during the 1970s and early 1980s, surface drip irrigation grew at a faster rate than SDI, probably because of emitter plugging problems and root intrusion. However, interest in SDI increased during the early 1980s, increased rapidly during the last half of the 1980s, and continues today, especially in areas with declining water supplies, with environmental issues related to irrigation, and where wastewater is used for irrigation. Initially, SDI was used primarily for sugarcane, vegetables, tree crops, and pineapple in Hawaii and California. Later, SDI use was expanded to other geographic areas and to agronomic and vines crops, including cotton, corn, and grapes.

SDI has the advantage of multiple-year life, reduced interference with cultural practices, dry plant foliage, and a dry soil surface. Multiple-year life allows amortization of the entire system cost over several years, often more than ten. If all system components are installed below tillage depth, surface cultural practices can be accomplished with minimal concern for system damage. Dry soil surfaces can reduce weed growth in arid climates and may reduce evaporation losses of applied water. Because the plant canopy is not irrigated, the foliage remains dry, which may reduce incidence of disease. SDI is also very adaptable to irregularly shaped fields and low-capacity water supplies that may provide design limitation with other irrigation systems.

The major disadvantages of SDI include system cost, difficulty in locating and repairing system leaks and plugged emitters, and poor soil surface. Most system components are installed below the soil surface and are neither easy to locate nor directly observable. In a properly designed and managed SDI system, the soil surface should seldom be wet. Consequently, seed germination, especially for small seeds, can be very difficult.

SDI systems offer considerable flexibility, both in design and operation. For example, SDI systems can apply small, frequent water applications, often multiple times each day, to very specific sites within the soil profile and plant root zone. Fertilizers, pesticides, and other chemical amendments can be applied via the irrigation system directly into the active root zone, often at a modest increase in equipment cost. In many cases, the operational cost may be less than that for applying these chemicals via conventional surface equipment.

SYSTEM DESIGN

Site, Water Supply, and Crop

Design of subsurface drip systems is similar to that of surface drip systems, especially with regard to hydraulic characteristics.[2] Specific crop and soil characteristics are used in the design process to select emitter spacing and flow rate, lateral depth and spacing, and the required system capacity. Emitter properties and lateral location are influenced by soil properties such as texture, soil compaction, and soil layering because these affect the rate of water movement through the soil profile and the subsequent wetting pattern for each emitter.

The water supply capacity directly affects the design of a SDI system. The size of the irrigated field or zone is often

Encyclopedia of Water Science
DOI: 10.1081/E-EWS 120010066
Published 2003 by Marcel Dekker, Inc. All rights reserved.

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

Copyright © Marcel Dekker, Inc. All rights reserved.

determined by the water supply capacity. For example, in some humid areas, high-capacity wells are not available but multiple low-capacity wells can be distributed throughout a farm. Fortunately, the design of SDI systems can be economically adjusted to correspond to the field size and shape, to the available water supply capacity, and to other factors. Water supply quality should be tested by an approved laboratory before proceeding with system design. This information is needed for the proper design and management of the water filtration and treatment system. Some water supplies require frequent or intermittent injection of acids and/or chlorine. Other saline and/or sodic water supplies may require treatment or special management. As water supplies become more limited, treated wastewater is becoming an increasingly important alternative water supply that can be applied through SDI systems. Camp[3] listed several reports that emphasized water supplies (saline, deficit, and wastewater) for SDI systems.

The SDI system is usually designed to satisfy peak crop water requirements, which vary with specific site, soil, and crop conditions. When properly designed and managed, SDI is one of the most efficient irrigation methods, providing typical application efficiencies exceeding 90%. In comparison with other methods of irrigation, reported yields with SDI were equal to or greater than those with other irrigation methods. Generally, water requirements with SDI are similar or slightly lower than those with other irrigation methods. In some cases, water savings of up to 40% have been reported.[3] However, unless more specific information is available, it is usually best to use standard net water requirements for the location when designing SDI systems.

Lateral Type, Spacing, and Depth

SDI lateral depth for various cropping systems is normally optimized for prevailing site conditions and soil characteristics.[3] Where systems are used for multiple years and tillage is a consideration, lateral depths vary from 0.20 m to 0.70 m. Where tillage is not a consideration (e.g., turfgrass, alfalfa) depth is sometimes less (0.10 m–0.40 m). Lateral spacing also varies considerably (0.25 m–5.0 m), with narrow spacing used primarily for turfgrass and wide spacing used for vegetable, tree, or vine crops. In uniformly spaced row crops, the lateral is usually located under either alternate or every third midrow area (furrow). For crops with alternating row spacing patterns, the lateral is located about 0.8 m from each row, usually in the narrow spacing of the pattern.

The lateral should be installed deep enough to prevent damage by tillage or injection equipment but shallow enough to supply water to the crop root zone without wetting the soil surface. Generally, laterals in SDI systems are placed at depths of 0.1 m–0.5 m, at shallower depths in coarse-textured soils and at slightly deeper depths on finer-textured soils. The selection of emitter spacing and flow rate are influenced by crop rooting patterns, lateral depth, and soil characteristics. It is also desirable to select an emitter spacing that provides overlapping subsurface wetted zones along the lateral for most row crops. For wider spaced crops such as trees and vines, emitters are normally located near each plant and may have wider spacings that do not provide overlapping patterns. Lateral spacing is determined primarily by the soil, crop, and cultural practice, and should be narrow enough to provide a uniform supply of water to all plants.

Special Requirements

Site topography must be considered in system design and selection of components as with any irrigation system, but SDI is suitable for most sites, ranging from flat to hilly. For sites with considerable elevation change, especially along the lateral, pressure-compensating emitters should be used.

Two special design requirements for SDI systems, which are significantly different from those for surface drip systems, are the needs for flushing manifolds and air entry valves. Flushing manifolds are needed to allow frequent flushing of particulate matter that may accumulate in laterals. Air relief valves are needed to prevent aspiration of soil particles into emitter openings when the system is depressurized. These valves must be located in sufficient number and at the higher elevations for each lateral or zone to prevent negative pressures within the laterals.

Emitter plugging caused by root intrusion is a major problem with some SDI systems, but can be minimized by chemicals, emitter design, and irrigation management. Chemical controls include the use of herbicides, either slow-release compounds embedded into emitters and filters or periodic injection of other chemical solutions (concentrated and/or diluted) into the irrigation supply. Periodic injection of acid and chlorine for general system maintenance can also modify the soil solution immediately adjacent to emitters and reduce root intrusion. In some cases, emitters plugged by roots may be cleared via injection of higher concentrations of chemicals, such as acids and chlorine.

Emitter design may also affect root intrusion. Smaller orifices tend to have less root intrusion but are more susceptible to plugging by particulate matter. Some emitters are constructed with physical barriers to root intrusion. Root intrusion appears to be more severe when emitters are located along dripline seams, which can be an area of preferential root growth. However, root intrusion problems appear to be greater for emitters, driplines, and porous tubes that are not chemically treated.

Copyright © Marcel Dekker, Inc. All rights reserved.

Irrigation management can also be used to influence root intrusion by controlling the environment immediately adjacent to the emitter. High frequency pulsing that frequently saturates the soil immediately surrounding the emitter can discourage root growth in that area for some crops but not others. Conversely, deficit irrigation sometimes practiced to increase quality or maturity, or to control vegetative growth, can increase root intrusion in lower rainfall areas because of high root concentrations in the soil zone near emitters.

SYSTEM COMPONENTS

Pumps, Filtration, and Pressure Regulation

Pump requirements for SDI are similar to those for other drip irrigation systems, meaning water must be supplied at a relatively low pressure (170 kPa–275 kPa) and flow rate in comparison to other irrigation methods. Because of the flushing requirement for SDI systems, a flow velocity of about 0.3 m $\sec^{-1}$ must be achievable, either by reducing the zone size while using the same pumping rate or by increasing the pumping rate without changing the zone size.

Water filtration is more critical for SDI systems than for surface drip systems because the consequences of emitter plugging are more severe and more costly. Generally, the better the water quality, the less complex the filtration system required. Surface and recycled or wastewater supplies require the most elaborate filtration systems. However, good filtration is the key to good system performance and long life, and should be a major emphasis in system design. Filtration systems range from simple screen filters for relatively clean water to more elaborate and complex disc and sand media filters for poorer quality water.

The pressure regulation requirement in SDI systems is similar to that in surface drip systems. When nonpressure-compensating emitters are used on relatively flat areas, pressure is typically regulated within the system supply lines (main and/or submain) using pressure-regulating valves. When pressure-compensating emitters are used, typically on more hilly terrain, the pressure within the system supply lines is controlled at a higher, but more variable, pressure that is within the recommended input pressure range for the emitters used. Water pressure should be monitored on a regular basis at the pump or supply port and at various locations throughout the SDI system, especially at the both ends of laterals.

Laterals and Emitters

Many types of driplines have been used successfully for SDI and most have emitters installed as an integral part of the dripline. This is accomplished by one of three methods: 1) molded indentions created during the fusing of dripline seams; 2) prefabricated emitters welded inside the dripline; or 3) circular prefabricated in-line emitters installed during extrusion. Regardless of the emitter used, dripline wall thickness and expected longevity must be considered along with other design factors in selecting the lateral depth. Flexible, thin-walled driplines typically are installed at shallow depths and normally have a shorter expected life. Thicker-walled, flexible driplines have been used successfully for several years provided they are installed deep enough to avoid tillage, cultivating, and harvesting machinery, but shallow enough to prevent excessive deformation or permanent collapse of the dripline by machinery or soil weight. Rigid tubing with thicker walls can be installed at deeper depths without deformation, and is often used on perennial crops or on annual crops for longer time periods (> 10 yr). Some driplines are impregnated with bactericides or other chemicals to reduce the formation of sludge or other material that could plug emitters.

Chemical Injection

Subsurface drip systems offer the potential for precise management of water, nutrients, and pesticides if the system is properly designed and managed. The marginal cost to add chemical injection equipment is generally competitive with other, more conventional application methods. Water and fertilizers can be applied in a variety of modes, varying from multiple continuous or pulsed applications each day to one application in several days. Choice of application frequency depends upon several factors, including soil characteristics, crop requirements, water supply, system design, and management strategies. If labeled for the purpose, some systemic pesticides and soil fumigants can be safely injected via SDI systems. Use of the SDI system for chemical applications has the potential to minimize exposure to workers and the environment, to reduce the cost of pesticide rinse water disposal, and improve precision of application to the desired target (root pests). Injection of other chemicals, such as acids and chlorine, is often required to clean and maintain emitters in optimum condition. However, a high level of management with system automation and feedback control is required to minimize chemical movement to the ground water when chemicals are used.

Air Entry and Flushing

Air entry valves must be installed at higher elevations in SDI systems to prevent the emitter from ingesting soil particles that could plug emitters when the system is depressurized. Typically, air entry valves are located in

Copyright © Marcel Dekker, Inc. All rights reserved.

water supply lines near the head works or control station, and in both the supply and flushing manifolds. In some cases, such as turf or pasture, air entry valves may be installed below the soil surface and enclosed within a protective box. Flushing valves installed on the flushing manifold are required to control periodic system flushing.

OPERATION AND MAINTENANCE

Operation

SDI systems can be operated in several modes, varying from manual to fully automated. Overall, SDI systems are probably more easily automated than many other types of irrigation. One reason is that most are controlled from a central point using electrical or pneumatic valves and controllers that vary from a simple clock system to microprocessor systems, which are capable of receiving external inputs to initiate and/or terminate irrigation events.

Irrigation scheduling is as important for SDI systems as for any other type of irrigation. Choosing to initiate an irrigation event and how much water to apply during each event depends on crop, soil, and irrigation system type and design. Factors that affect those decisions include soil water storage volume, sensitivity of the crop to water stress, irrigation application rate, weather conditions, and water supply capacity. Camp[3] discussed several irrigation scheduling methods that have been used successfully with SDI. However, the important point is that a science-based scheduling method can conserve the water supply and increase profit.

If seed germination and seedling establishment and growth are critical, especially in arid climates when initial soil water content is not adequate, either sprinkler or surface irrigation is often used for germination. However, the need for two systems increases cost and decreases economic return. If subsurface drip is used for germination, an excessive amount of irrigation is often required to wet the seed zone for germination, which could result in excessive leaching and off-site environmental effects as well as increased cost. Surface wetting can also occur when the emitter flow rate exceeds the hydraulic conductivity of the soil surrounding the emitter, but wetted areas are often not uniform.

Because salts tend to accumulate above the lateral, high salt concentrations may occur between the lateral and soil surface in arid areas where rainfall is not available to leach the salts downward. Salts may also be moved under the row when laterals are placed under the furrow.[4] Supplemental sprinkler irrigation may be required in some areas to control salinity if precipitation is inadequate for leaching during several consecutive years.

Maintenance

Often, SDI systems must have a long life (>10 yr) to be economical for lower value crops. Thus, appropriate management strategies are required to prevent emitter plugging and protect other system components to ensure proper system operation. Locating and repairing/replacing failed components is much more difficult and more expensive with SDI systems than with surface systems because most system components are buried, difficult to locate, and cannot be directly observed by managers. Consequently, operational parameters such as flow rate and pressure must be measured frequently and used as indicators of system performance. Good system performance requires constant attention to maintain good water quality, proper filtration, and periodic system flushing to remove particulate matter that could plug emitters. Periodic evaluation of SDI system performance in relation to design performance can identify problems before they become serious and significantly affect crop yield and quality.

CONCLUSION

Although there is general consensus that use of SDI is increasing, this growth is difficult to document. A recent survey of irrigation in the United States reported 156,070 ha of SDI, which is about 0.6% of the total irrigated area of 25,501,831 ha.[5] Use of SDI should increase in the future, depending primarily upon the economic and water conservation benefits in comparison to other irrigation methods. As water supplies become more limited, the high application efficiency and water conserving features of SDI should increase its application. Also, SDI offers potential advantages such as reduced odors and exposure to pathogens when using recycled domestic and animal wastewater. The SDI technology offers the capability to precisely place water, nutrients, and other chemicals in the plant root zone at the time and frequency needed for optimum crop production. With proper design, installation, and management, SDI systems can provide excellent irrigation efficiency and reliable performance with a system life of 10 yr–20 yr.

REFERENCES

1. S526.2. Soil and Water Terminology. *ASAE Standards*, 49th Ed.; ASAE: St. Joseph, MI, 2001, 970–990.
2. EP405.1. Design and Installation of Microirrigation Systems. *ASAE Standards*, 49th Ed.; ASAE: St. Joseph, MI, 2001, 903–907.
3. Camp, C.R. Subsurface Drip Irrigation: A Review. Trans. ASAE **1998**, *41* (5), 1353–1367.

Copyright © Marcel Dekker, Inc. All rights reserved.

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

4. Ayars, J.E.; Phene, C.J.; Schoneman, R.A.; Meso, B.; Dale, F.; Penland, J. Impact of Bed Location on the Operation of Subsurface Drip Irrigation Systems. In *Microirrigaion for a Changing World*, Proc. Fifth International Microirrigation Congress, Orlando, FL, April 2–6, 1995; Lamm, F.R., Ed.; ASAE: St. Joseph, MI, 1995; 141–146.
5. Anonymous. 1999 Annual Irrigation Survey. Irrig. J. **2000**, *50* (1), 16–31.

Copyright © Marcel Dekker, Inc. All rights reserved.

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016