# ADVANTAGES AND DISADVANTAGES OF SUBSURFACE DRIP IRRIGATION

Dr. Freddie R. Lamm
Professor and Research Irrigation Engineer
Northwest Research-Extension Center
Kansas State University
Colby, Kansas
flamm@oznet.ksu.edu

## ABSTRACT

The advantages and disadvantages of subsurface drip irrigation (SDI) as compared to alternative irrigation systems are conceptually discussed. Each category (advantages and disadvantages) is subdivided into three groups: 1) Water and soil issues; 2) Cropping and cultural practices, and 3) System infrastructure issues. The adaptation and adoption of SDI systems into diverse cropping systems, geographical regions, soils and climate depends, to a large extent, on how potential advantages are balanced against potential disadvantages. In some cases, just a few advantages are expressed for a given cropping system, but are expressed so strongly that they provide a good counterbalance to the potential disadvantages. Future research and development will probably add to the list of potential advantages while addressing and reducing the disadvantages. However, this current listing can be used to devise and adapt other possible uses for SDI. Specific examples of SDI use in maize (*Zea mays L.*), alfalfa (*Medicago sativa*), almonds (*Prunis dulcis*), cantaloupe (*C. melo*) and wastewater applications are discussed with respect to balancing advantages and disadvantages.

## ADVANTAGES OF SDI

The following list should be considered as potential advantages of subsurface drip irrigation (SDI) when properly managed and/or when site conditions and cropping systems allow the advantage to be realized. Additionally, some growers might see an aspect as an advantage, while another might see an aspect as a disadvantage. For example, there are opportunities for improved cultural practices with SDI, while at the same time, there might be fewer tillage alternatives. These advantages may be further subdivided along the lines of water and soil issues, cropping and cultural practices and system infrastructure issues.

### Advantages related to water and soil issues

**More efficient water use –** Soil evaporation, surface runoff, and deep percolation are greatly reduced or eliminated. Infiltration and storage of seasonal precipitation can be enhanced by drier soils with less soil crusting. In some cases, the system can be used for a small irrigation event for use in germination, depending on dripline depth, flow rate and soil constraints. The inherent ability to apply small irrigation amounts can allow better water-efficient decisions about irrigation events near the end of the cropping season. In widely spaced crops, a smaller fraction of the soil volume can be wetted, thus further reducing unnecessary irrigation water losses.

**Less water quality hazards –** Runoff into streams is reduced or eliminated, and there is less nutrient and chemical leaching due to deep percolation.

**Improved opportunities for use of degraded waters –** Smaller and more frequent irrigation applications can maintain a more consistent and lower soil matric potential that may reduce salinity hazards. Subsurface wastewater application can reduce pathogen drift and reduce human and animal contact with such waters.

**Greater water application uniformity –** Improved in-field uniformities can result in better control of the water, nutrients and salts. Widely spaced crops may benefit from water application closer to the crop, provided sufficient soil wetting is achieved.

## Advantages related to cropping and cultural practices

**Enhanced plant growth, crop yield and quality –** A number of crops respond positively.

**Improved plant health –** Less disease and fungal pressure occurs due to drier and less-humid crop canopies. The system can also be used for some types of soil fumigation.

**Improved fertilizer and pesticide management –** Precise and more timely application of fertilizer and pesticides through the system can result in greater efficacy and, in some cases, reduction in their use.

**Better weed control –** Reductions in weed germination and weed growth often occur in drier regions

**Improved double cropping opportunities –** Crop timing may be enhanced since the system need not be removed at harvesting and reinstalled prior to planting the second crop.

**Improved farming operations and management –** Many field operations can occur during irrigation events. Field operations result in less soil compaction, and soil crusting caused by irrigation is greatly reduced. Variability in soil water regimes and redistribution are often reduced with SDI as compared to surface drip irrigation (DI). Additionally, weather-related application constraints such as high winds, freezing temperatures and wet soil surfaces are less important. Needed fertilization can be applied in a small irrigation event even when irrigation needs are low. The ability to irrigate during freezing conditions can be particularly beneficial where preseason irrigation is used to effectively increase seasonal irrigation capacity. There is also less irrigation equipment exposed to vehicular damage. Hand laborers benefit from drier soils by having reduced manual exertion and injuries.

## Advantages related to system infrastructure

**Automation –** The closed-loop pressurized characteristic of the system that can reduce application variability and soil water and nutrient redistribution variability make the system an ideal candidate for automation and advanced irrigation control technologies.

**Decreased energy costs –** Operating pressures are often less than some types of sprinkler irrigation. Any water savings attributable to SDI will also reduce energy costs.

**System integrity issues –** There are fewer mechanized parts in an SDI system as compared to mechanical-move sprinkler irrigation systems. Most components are plastic and are less subject to irrigation system corrosion. SDI systems do not need to be removed and installed between crops and, thus, can experience less damage. The potential for vandalism is also reduced.

**Design flexibility –** There is increased flexibility with SDI in matching field shape and field size as compared to center pivot sprinkler irrigation systems. The SDI system can be easily and economically sized to the available water supply. In widely spaced crops, driplines can be placed for optimum water and nutrient uptake. Pressure compensating SDI systems have fewer slope limitations than surface gravity irrigation.

**System longevity –** SDI installations can have a long economic life when properly designed and managed. Long system life allows for amortizing investment costs over many years, thus allowing lower-value commodity crops to be economically grown with SDI.

**Less pest damage –** In some cases, there may be less pest damage to SDI systems from wildlife and insects than for DI systems. However, this must be tempered with the fact that pest damage to SDI systems may take more effort to detect and to repair.

# DISADVANTAGES OF SDI

Similarly, there are circumstances and situations that present disadvantages to selection of an SDI system. These disadvantages also may be subdivided along the lines of water and soil issues, cropping and cultural practices, and system infrastructure issues.

## Disadvantages related to water and soil issues

**Smaller wetting pattern –** The wetting pattern may be too small on coarse-textured soils, resulting in too small a crop root zone. This situation can make system capacity and system reliability extremely critical issues as there is less ability to buffer insufficient irrigation capacity or system breakdown.

**Monitoring and evaluating irrigation events –** Water applications may be largely unseen, and it is more difficult to evaluate system operation and application uniformity. System mismanagement can lead to underirrigation and crop yield and quality reductions or overirrigation, resulting in poor soil aeration and deep percolation problems.

**Soil/Application rate interactions –** Emitter discharge rates can exceed the ability of some soils to redistribute the water under normal redistribution processes. In such cases, water pressure in the region around the outside of the emitter may exceed atmospheric pressure, thus altering emitter flows. Water may inadvertently "surface" (tunneling of the emitter flow to the soil surface) causing undesirable wet spots in the field. In "surfacing" problems, small soil particles may be carried with the water, causing a "chimney effect," that provides a preferential flow path. The "chimney" may be difficult to permanently remove, since a portion of the "chimney" remains above the dripline even after tillage.

**Reduced upward water movement –** Using the SDI system for germination may be limited, depending on installation depth and soil characteristics. This may be particularly troublesome on soils with vertical cracking. Salinity may be increased above the dripline, increasing the salinity hazard for emerging seedlings or small transplants.

## Disadvantages related to cropping and cultural practices

**Less tillage options –** Primary and secondary tillage operations may be limited by dripline placement.

**Restricted plant root development –** Smaller crop root zones can make irrigation and fertilization more critical issues from both a timing and amount perspective. Smaller crop root zones may be insufficient to avoid diurnal crop water stresses even when the root zone is well watered. Application of nutrients through the SDI system may be required for optimum yields. Application of micronutrients may also become more important as the smaller soil volume becomes depleted of these nutrients sooner.

**Row spacing and crop rotation issues –** Since SDI systems are fixed spatially, it may be more difficult to accommodate crops of different row spacing. Some crops might require a very close dripline spacing that might be economically impractical. Additional care must be taken at the time of annual row-crop planting to ensure crop orientation and spacing are appropriately matched to the dripline location.

**Plant development issues –** Some crops may not develop properly under SDI in some soils and climates. Peanuts may not peg properly into dry soil. Tree crops may benefit from a larger wetting pattern.

## Disadvantages related to system infrastructure

**Costs –** SDI has a high initial investment cost compared to some alternative irrigation systems. In many cases, the system has no resale value or a minimal salvage value. Lenders may require a higher equity level and more collateral before approving SDI system loans. Such large investments may not be warranted in areas with uncertain water and fuel availability, particularly if commodity price outlook is poor. SDI systems typically have a shorter design life than alternative irrigation systems which means the annualized depreciation costs must increase to provide for system replacement.

**Filtration issues –** As with all microirrigation systems, water filtration is a critical issue in ensuring proper system operation and system longevity. However, the issue can become more critical for long term SDI systems where a system life of greater than ten years is desired. SDI may require more complex water quality management than some surface microirrigation systems, since there are no opportunities to manually clean emitters.

**Other maintenance issues –** Timely and consistent maintenance and repairs are a requirement. Leaks caused by rodents can be more difficult to locate and repair, particularly for deeper SDI systems. The driplines must be monitored for root intrusion, and system operational and design procedures must employ safeguards to limit or prevent further intrusion. Roots from some perennial crops may pinch driplines, eliminating or reducing flows. Periodically, the driplines need to be flushed to remove accumulations of silt and other precipitates that may occur in the driplines.

**Operational issues –** Operation and management requires more consistent oversight than some alternative irrigation systems. There are fewer visual indicators of system operation and of the system application uniformity. Irrigation scheduling procedures are required to prevent underirrigation and overirrigation. Monitoring of system flowmeters and pressure gages are required to determine if the system is operating properly.

**Design issues –** SDI is a less-developed technology than some alternative irrigation systems. This is particularly so in some regions where growers have little exposure and experience with these systems. There are fewer turnkey systems available for purchase. In some regions, the lack of contractor capacity can result in inadequate timing of installations in wet periods. Design errors are more difficult to resolve since most of the SDI system is below ground. There are typically more components needed for SDI than DI systems. There is the possibility of soil ingestion at system shutdown if a vacuum occurs, so air relief/vacuum breaker devices must be present and operating correctly. As with any microirrigation system, zone size and length of run will be limited by system hydraulics. Compression of the dripline due to soil overburden can occur in some soils and at some depths, causing adverse effects on flow. SDI systems are not typically well suited for Site Specific Variable Application.

**Abandonment issues –** In some cases, there are concerns about waste plastic product (driplines) in the subsoil if the SDI system is abandoned.

# OVERLAP OF ISSUES

The subdivision of the advantages and disadvantages into the three categories

- water and soil issues
- cropping and cultural practices
- system infrastructure issues

is entirely arbitrary. However, it does allow for focusing on the conceptual issues of adoption of SDI. It is apparent that some issues also overlap between the three categories. A case could be made to look at a different subdivision emphasizing first the importance of system infrastructure issues. In this case, the disadvantages of SDI might break in a different manner with a preponderance of issues showing up in this group. The revised system infrastructure group would include these nine disadvantages:

- Monitoring and evaluating irrigation events
- Application rate issues
- Less tillage options
- Costs
- Filtration
- Other maintenance issues
- Operational issues
- Design issues
- Abandonment issues

Many of these nine disadvantages can be addressed through further design, research and development, a clear indication that they are often solvable problems. However, in some cases, solving the problem may make high investment costs become an even greater issue.

# EXAMPLE USES OF SDI AND THEIR BALANCING ACT

There have been many diverse uses of SDI around the world for a multitude of crops on multiple soil types in various climates. The adoption and adaptation of SDI systems is not always predictable since the expression and balancing of advantages and disadvantages can be very site specific. Additionally, cultural differences of peoples, their traditions and their skills and perception can have a large influence on whether SDI will be adopted. Several uses of SDI will be examined in the remainder of this paper to show some of the diversity of SDI uses and to show how advantages and disadvantages were balanced. No attempt is being made to show the predominate uses of SDI in the world, nor to show a typical ideal crop for SDI since probably none exists. Rather, the purpose of this discussion is to show some of the diverse rationale SDI has potential for wider use and to suggest that other uses may be determined by carefully examining the advantages and balancing them against the disadvantages.

## Maize or Field Corn (*Zea mays L.*)

Maize (field corn) is a major irrigated crop in the United States, but traditionally has not been considered of sufficient value to warrant the high microirrigation investment costs. Improved microirrigation components and improved system design and management that can allow long, useful economic SDI system life (> 10 years) are changing this situation. Amortizing the higher SDI investment costs over many years can, in some cases, make SDI economically competitive with more traditional center pivot sprinkler irrigation systems. SDI systems can be easily designed and economically sized for small and irregular shaped fields not readily suited to the economic scale factors of center pivot sprinklers (Bosch et al., 1992; O'Brien et al., 1998, Lamm et al., 2002). For lower value crops, such as maize, important factors in making SDI economically competitive with center pivot sprinkler irrigation systems are field size and shape, system investment costs and life, maize yields and price and any production cost differentials between irrigation systems (Lamm et al., 2002). Field size and shape and SDI system life are the most important factors. In the US Great Plains, water quality from the huge Ogallala aquifer is generally high. Clogging on deeper SDI systems in this region appears to be manageable, and long system life can be obtained. SDI research systems in Kansas have been operating for 13 years with very little performance degradation.

Dripline spacing in maize production is generally one dripline for every two maize rows (e.g. 1.52 m dripline spacing for 0.76 m spaced maize rows). This alternate row dripline spacing helps to reduce SDI system costs, yet has proven acceptable in maize production in numerous locations (Camp, 1998; Camp et al., 1989; Howell, et al., 1997; Lamm et al., 1997a). Camp (1998) concludes that this alternate row dripline spacing can be acceptable for most uniformly spaced row crops.

Yields for maize grown with DI and SDI can be similar (Camp et al., 1989, Howell et al., 1997), but, because of the relatively low value of maize, in the United States only SDI is considered to have any economic competitiveness to the generally cheaper alternative systems (center pivot sprinklers and furrow irrigation). Irrigation requirements by maize grown using SDI can be reduced by 25% or more (Lamm et al., 1995). This is primarily attributed to reduction or elimination of soil evaporation and drainage, elimination of irrigation-induced runoff and greater infiltration of precipitation into drier soil surfaces. Irrigation events can be much smaller with SDI than for alternative irrigation systems, yet can still remain very efficient. On deep soil profiles with good water holding capacity, smaller capacity (flowrate) SDI systems can be used to provide small daily increments of water while other portions of the maize crop water needs can be withdrawn from the soil water reserves. Limiting daily irrigation events to 4.3 mm/day was still effective in producing average yields of 16.1 Mg/ha in semi-arid western Kansas (USA) where peak crop water needs can exceed 9-10 mm/day (Lamm and Trooien, 2001). On these deep soils in this climate, SDI system size can be effectively increased to provide a larger irrigated area. SDI systems are also sometimes used to replenish deep soil water reserves during the dormant season. The smaller irrigation events inherent to SDI are also useful in making correct irrigation decisions at the end of cropping seasons.

Nitrogen fertigation of maize with SDI can be effective in maintaining high grain yields while protecting the environment. In Kansas (Lamm et al., 1997b), maize yield, apparent nitrogen uptake and water use efficiency all plateaued at the same level of total applied nitrogen (180 kg/ha nitrogen inseason fertigation amount and 35 kg/ha nitrogen and 20 kg/ha phosphorous applied preplant broadcast), while irrigation was scheduled to replace approximately 75% of evapotranspiration. Average yields for the 180 kg/ha nitrogen fertigation rate was 13.4 Mg/ha. Maize yield to nitrogen uptake ratio (kg grain/kg nitrogen) for the 180 kg/ha nitrogen fertigation rate was a high 53:1.

Although maize would not be considered a typical crop for microirrigation, the combination of these advantages can be a large counterbalance against the primary disadvantage of high SDI investment cost.

## Cantaloupe (*C. melo*)

Cantaloupe has been shown to be a good crop for SDI. Multiple or double cropping of cantaloupe with vegetables can be easily accomplished with SDI due to not having to remove the system after initial harvest and reinstallation for the second crop (Bucks et al., 1981, Camp et al., 1993.) Yields were similar between DI and SDI in these two studies. The useful economic life of microirrigation systems can be prolonged with subsurface placement, provided root intrusion and emitter clogging can be prevented or reduced to manageable levels.

The use of deep SDI (approximately 45 cm depth) on cantaloupe resulted in earlier and higher marketable yield of cantaloupe in research in arid California (Ayars, et al., 1999). Total marketable yield from the first four pickings from the SDI plots were 10 and 28% higher than for low frequency and high frequency DI plots, respectively. Total marketable yields for the 8 harvest dates in the study were not significantly different between irrigation treatments, but earlier harvest can be very important economically. Growers often do not pick more than three times due to labor costs, decreasing harvest quantity and cantaloupe market price fluctuations. SDI had a quality advantage by keeping the soil dry and, thus, reducing the amount of ground-spotted and rotten cantaloupe. This advantage may be of less importance in areas of higher rainfall.

Cantaloupe has responded well to nutrient management through drip irrigation systems. Cantaloupe responds best when nitrogen concentration in the irrigation water is varied across plant growth stages, with approximately 150 mg N/L for the vegetative stage and approximately 50 mg N/L in the reproductive stage (Bhella and Wilcox, 1985.) SDI offers the potential of better management of nutrients through more precise application in the root zone and better soil water redistribution. Similarly, there is potential to enhance cantaloupe production and quality through application of systemic insecticides with DI or SDI under plastic mulch. Increased cantaloupe yield and less chemical leaching were measured when Imidacloprid insecticide was applied in a shallow SDI placement under plastic mulch as compared to conventional irrigation practices and cultural practices (Leib et al., 2000). The plastic mulch alone resulted in a four-fold increase in yield while the insecticide applied alone increased yields 2.5 times. The plastic mulch combined with the near-surface SDI, provided an optimum soil water balance while protecting the environment from leaching of the insecticide during high rainfall events. This demonstrates how combining other technologies with SDI can positively affect production and reduce environmental hazards.

## Alfalfa (*Medicago sativa*)

Alfalfa, a forage crop, has high crop water needs and, thus, can benefit from highly efficient irrigation systems such as SDI. In some regions, the water allocation is limited by physical or institutional constraints, so SDI can effectively increase alfalfa production by increasing the crop transpiration while reducing or eliminating soil evaporation. Since alfalfa is such a high-water user and has a very long growing season, irrigation labor requirements with SDI can be reduced relative to less efficient alternative irrigation systems that would require more irrigation events (Hengeller, 1995).

A major advantage of SDI on alfalfa is the ability to continue irrigating immediately prior, during and immediately after the multiple seasonal harvests. Continuation of irrigation reduces the amount of water stress on the alfalfa and thus can increase forage production which is generally linearly related to transpiration. Transpiration on SDI plots that did not require cessation of irrigation was 36% higher during this period than plots where irrigation was stopped for the normal harvest interval (Hutmacher et al., 1992). Yields with SDI were approximately 22% higher than surface flood-irrigated fields while still reducing irrigation requirements by approximately 6%. Water use efficiency was increased mainly due to increased yield, not less water use (Ayars et al. 1999). When irrigation can continue, there is less physiological stress on the crown of the plants, and there can be less weed competition. On some soils with some SDI designs, irrigation with SDI may need to be reduced during the harvest interval to avoid wet spots and compaction by heavy harvesting equipment. Possible solutions to these problems might be deeper SDI installations or closer dripline and emitter spacings, thus resulting in more uniform water distribution (Hengeller, 1995; McGill, 1993).

Alfalfa can be very sensitive to foliar leaf burn from sprinkler irrigation of low-quality water. Yields can also be reduced by temporary ponding of irrigation water on the soil surface during periods of hot weather. SDI can avoid both of these issues entirely (Hengeller, 1995).

On some soils under good irrigation management, it may be possible to use a relatively wide dripline spacing for alfalfa because of its extensive and deep root system. In arid California on a silty clay loam, yields from driplines spaced at 2 m were nearly equal to that obtained by a narrower 1 m spacing after the first year of operation. Yields for the wider spacing was reduced approximately 17% during the first year when the root system was not well established. In semi-arid Kansas on a sandy loam soil, yields were 18% lower for 1.5 m spacing as compared to the narrower 1 m spacing for the second and third years of production (Alam and Dumler, 2002). It was concluded in this study that it was more economical to use the 1 m spacing. However, it may be possible that irrigation applications with SDI on this soil were too marginal to allow the alfalfa to fully develop under the wider 1.5 m spacing. SDI applications were only approximately 50% of the average reference evapotranspiration.

In drier regions, annual weed competition can also be reduced with SDI compared to surface and sprinkler irrigation since the soil surface is not wetted by irrigation. This advantage is difficult to quantify in alfalfa but has been noted by numerous investigators (Hengeller, 1995; Bui and Osgood, 1990; Alam and Dumler, 2002). Fewer weeds can result in better quality hay which then can receive a premium price in some regions.

## Almonds (*Prunus dulcis*)

Almonds, a tree crop, are well suited to SDI as compared to alternative irrigation systems such as DI, microsprinklers, solid set sprinkler irrigation and border surface irrigation. Weed control with SDI on almonds is enhanced by not wetting up the soil surface. This helps reduce herbicide applications by up to 66% and mowing costs by 50% (Edstrom and Schwankl, 1998) resulting in easier harvest operations (tree shaking, windrowing, drying and sweeping). Hand labor associated with raking almonds away from irrigation components and piping was eliminated with SDI.

Growers often need to irrigate during the extended harvest period while the almonds are being allowed to dry on the soil surface. Irrigating at this time with alternative irrigation systems without rewetting and damaging the almonds is difficult, but can be accomplished with SDI. Irrigation during this period helps keep the trees healthy and prevents premature senescence. This is particularly important if there are multiple varieties in the grove having different maturity dates (Schwankl, 2002).

SDI can be a cost-effective alternative to solid set sprinkler irrigation, saving approximately 50% in investment costs. Fertilizers can be applied near the center of the crop root zone with SDI.

The advantages of using SDI for almonds must be balanced against some disadvantages that can occur. In some coarse or gravelly soils, the wetted area/volume may not be sufficient with SDI as compared to microsprinklers. On these soils, almond yields may be reduced under SDI (Edstrom and Schwankl, 1998). In some cases, this problem can be alleviated by using two SDI lines for each tree row. SDI also cannot be used for frost protection in production areas where it may be needed.

Clogging of the emitters through root intrusion is a problem with SDI on almonds. Growers have addressed this problem by selecting trifluralin-impregnated emitters or by trifluralin applications through the system (Schwankl, 2002). Although damage to irrigation components on the soil surface by wildlife is eliminated, this must be balanced against the increased difficulty of SDI repairs below the soil surface when they do occur.

A major disadvantage to almond growers is the lack of visual indicators of proper irrigation performance (Schwankl, 2002). This tends to be a recurring issue for many high-value crops where net returns from both yield and quality can be impaired with even slight underperformance problems. Growers often perceive that they need to use more sophisticated and costly management procedures with SDI. They often feel the technical capability of their laborers is insufficient to monitor the SDI system and to detect and correct deficiencies in an appropriate timeframe. Growers can reduce some of these uncertainties by consistent periodic monitoring of flowrates and pressures. In some cases, small, inexpensive flowmeters can be installed on individual driplines and read weekly to determine proper operation.

Most of the disadvantages associated with SDI on almonds can be classified as being related to system infrastructure. The present growth of SDI for almonds is slow but is likely to increase as system design is improved, allowing both better and more failsafe operational and management procedures.

## Wastewater application

Wastewater application through SDI is growing across the world for a number of reasons. Excellent discussions on the advantages and disadvantages of SDI for wastewater application are available (Gushiken, 1995; Trooien et al., 2002; Trooien et al., 2000) and will not be repeated here. However, a few issues of particular importance from these lists will be discussed.

Irrigation is a large user of freshwater resources around the world, and in many places these resources are being overused. The recycling of wastewater through irrigation systems can save freshwater for higher-value uses such as domestic consumption. Wastewater from municipalities, and sometimes even water from confined animal feeding operations, can present health hazards when humans are exposed to them. Application of these wastewaters through SDI limits human exposure and often can reduce the sanitary treatment requirements of the wastewater.

Reclaimed municipal wastewater has been successfully and legally applied through SDI to golf courses in Hawaii (USA), but application constraints would have greatly reduced or eliminated the utilization of the wastewater through sprinkler irrigation (Gushiken, 1995).

In Israel, wastewater reuse has been a part of national resource planning policy for nearly 50 years (Oron et al., 1991). As understanding of human health issues with wastewater reuse has grown over the years, so have the regulations and restrictions on wastewater application through irrigation systems. Application of wastewater through SDI systems has been shown to greatly reduce pathogen transfer to edible crops (Oron et al., 1995; Oron et al., 1991, Oron et al., 1992). It seems likely that with further research and development, there will be even greater use of SDI for wastewater applications in edible crops.

In the United States, there has been increasing nationwide concern about problems associated with livestock wastewater generated by confined animal feeding operations. Three of the more significant problems are odor, seepage into groundwater and runoff into surface water supplies. SDI is a potential tool that can alleviate all three problems while still utilizing livestock wastewater as a valuable resource for crop production. Research in Kansas has looked at evaluating different emitter sizes for application of livestock wastewater. After four years of operation, it appears that molded emitter sizes greater than or equal to 1.5 L/h are sufficient when beef lagoon wastewater is filtered to 200 mesh (Lamm et al., 2002). Operational procedures and management of livestock wastewater reuse through SDI are in the much earlier stages of development as compared to municipal wastewater, but are expected to progress.

As it is with any water source in any microirrigation system, clogging is a potential concern when wastewater is utilized. However, the problems can be exacerbated, by the particle-rich, biologically active wastewater. Considerable research has been conducted and will continue to be conducted to prevent, solve and remediate clogging problems associated with wastewater application (Hills and Brenes, 2001; Ravina et al., 1992; Sagi et al., 1995; Adin and Sacks, 1991; Ravina et al., 1997; Norum et al., 2001).

# CONCLUDING STATEMENT

SDI systems have been adopted and adapted in many diverse geographical regions for many crops under various soil types and climates. An examination of the potential advantages and disadvantages is a possible means of determining other new uses for SDI in addition to understanding the reasons for and against SDI adoption in the current uses. In some cases, strong, but less obvious, advantages are the overriding factor in adoption, providing a good counterbalance to the disadvantages.

# REFERENCES


Adin, A. and M. Sacks. 1991. Dripper-clogging factors in wastewater irrigation. J Irrigation and Drainage Engineering, ASCE 117(6):813-826.

Alam, M. and T. Dumler. 2002. Using subsurface drip irrigation for alfalfa. In Proc. of the Central Plains Irrigation Shortcourse, Feb. 5-6, 2002, Lamar, CO. Available from CPIA, 760 N. Thompson, Colby, Kansas. pp. 102-109.

Ayars, J. E., C. J. Phene, R. B. Hutmacher, K. R. Davis, R. A. Schoneman, S. S. Vail and R. M. Mead. 1999. Subsurface drip irrigation of row crops: A review of 15 years of research at the Water Management Research Laboratory. Agric. Water Management 42(1999):1-27.

Bhella, H. S. and G. E. Wilcox. 1985. Nitrogen fertilization and muskmelon growth, yield and nutrition. In proceedings of the Third International Drip/Trickle Irrigation Congress, Fresno, CA. Nov. 18-21, 1985. ASAE. pp. 339-345.

Bosch, D. J., N. L. Powell and F. S. Wright. 1992. An economic comparison of subsurface microirigation and center pivot sprinkler irrigation. J. Prod. Agric. 5(4):431-437.

Bucks, D. A., L. J. Erie, O. F. French, F. S. Nakayama and W. D. Pew. 1981. Subsurface trickle irrigation management with multiple cropping. Trans. ASAE 24(6):1482-1489.

Bui, W. and R. V. Osgood. 1990. Subsurface irrigation trial for alfalfa in Hawaii. In Proc. Third National Irrig. Symp., Oct. 28 – Nov. 1, 1990, Phoenix, AZ. ASAE pp. 658-660.

Camp, C.R.. 1998. Subsurface drip irrigation: A review. Trans ASAE 41(5):1353-1367.

Camp, C. R., T. J. Garrett, E. J. Sadler and W. J. Busscher. 1993. Microrrigation management for double-cropped vegetables in a humid area. Trans. ASAE. 36(6)1639-1644.

Camp, C. R., E. J. Sadler and W. J. Busscher. 1989. Subsurface and alternate-middle micro irrigation for the Southeast Coastal Plain. Trans ASAE 32(2):451-456.


Camp, C.R.. 1998. Subsurface drip irrigation: A review. Trans ASAE 41(5):1353-1367.


Edstrom, J. and L. Schwankl. 1998. Micro-irrigation system comparison for almonds. In proceedings of the 19th annual Irrigation Association international exposition and technical conference, San Diego, CA. Irrigation Assn., Falls Church, Va. Pp. 63-70.

Edstrom, J. P. and L. J. Schwankl. 1998. Weed suppression in almond orchards using subsurface drip irrigation. Abstract for 1998 Weed Science Meetings. pp. 35-36.

Gushiken, E. C. 1995. Irrigating with reclaimed water through permanent subsurface drip irrigation systems. In Microirrigation for a Changing World. Proc 5th Int. Microirrigation Congress, 269-274, ed. F. R. Lamm. St. Joseph, MI: ASAE.

Hengeller, J. 1995. Use of drip irrigation on alfalfa. In Proc. of the Central Plains Irrigation Shortcourse, Feb. 7-8, 1995, Garden City, Kansas. Kansas State Univ. Extension Biol. and Agric. Engr. Dept., Manhattan, KS. Pp 160-167.

Hills, D. J. and M. J. Brenes. 2001. Microirrigation of wastewater effluent using drip tape. Appl. Engr. in Agric. 17(3):303-308.

Howell, T. A., A. D. Schneider and S. R. Evett. 1997. Subsurface and surface microirrigation of corn, Southern high plains. Trans ASAE 40(3):635-641.

Hutmacher, R. B., C. J. Phene, R. M. Mead, D. Clark, P. Shouse, S. S. Vail, R. Swain, M. van Genuchten, T. Donovan and J. Jobes. 1992. Subsurface drip irrigation of alfalfa in the Imperial Valley. In Proc. of the 22nd California/Arizona Alfalfa Symp., Dec. 9-10, 1992, Holtville, CA. Univ. of CA and Univ. of Ariz. Coop. Extension. 22:20-32.

Lamm, F. R., D. M. O'Brien, D. H. Rogers and T. J. Dumler. 2002. Sensitivity of center pivot sprinkler and SDI economic comparisons. Presented at the Mid-Central ASAE mtg., St. Joseph, MO, April 12-13, 2002. ASAE Paper No. MC02-201. ASAE, St. Joseph MI. 10 pp. Also available at http://www.oznet.ksu.edu/sdi/Reports/2002/CP_SDI_MCR.pdf

Lamm, F. R., T. P. Trooien, G. A. Clark, L. R. Stone, M. Alam, D. H. Rogers and A. J . Schlegel. 2002. Using beef lagoon wastewater with SDI. In Proc. Irrigation Assn. Int'l. Irrigation Technical Conf., Oct. 24-26, 2002, New Orleans, LA.. Irrigation Assn., Falls Church VA. Also available at http://www.oznet.ksu.edu/sdi/Reports/2002/MWIAPaper.pdf

Lamm, F. R. and T. P. Trooien. 2001. Irrigation capacity and plant population effects on corn production using SDI. In Proc. Irrigation Assn. Int'l. Irrigation Technical Conf., Nov. 4-6, 2001, San Antonio, TX. Pages 73-80. Irrigation Assn., Falls Church, VA. Also available at http://www.oznet.ksu.edu/sdi/Reports/2001/icpp.pdf

Lamm, F. R., L. R. Stone, H. L. Manges and D. M. O'Brien. 1997a. Optimum lateral spacing for subsurface drip-irrigated corn. Trans. ASAE 40(4):1021-1027. Also available at http://www.oznet.ksu.edu/sdi/Reports/1997/OptSpacing.pdf

Lamm, F. R., A. J. Schlegel and G. A. Clark. 1997b. Nitrogen fertigation for corn using SDI: A BMP. Presented at the 1997 int'l. ASAE meeting. Paper no. 972174 from ASAE, St. Joseph, MI. 17 pp. Also available at http://www.oznet.ksu.edu/sdi/Reports/1997/Nfertigation.pdf

Lamm, F. R., H. L. Manges, L. R. Stone, A. H. Khan and D. H. Rogers. 1995. Water requirement of subsurface drip-irrigated corn in northwest Kansas. Trans. ASAE, 38(2):441-448. Also available at http://www.oznet.ksu.edu/sdi/Reports/1995/WaterReq.pdf

Leib, B. G., A. R. Jarrett, M. D. Orzolek and R. O. Mumma. 2000. Drip chemigation of Imadacloprid under plastic mulch increased yield and decreased leaching caused by rainfall. Trans ASAE 43(3):615-622.

McGill, S. 1993. Buried drip for alfalfa. The Furrow 98(7)26-27.

Norum, E. M., L. U-Kosaramig and R. Ruskin. 2001. Reuse of dairy lagoon wastewater through SDI in forage crops. ASAE Meeting Paper 012266. St. Joseph, MI: ASAE.

O'Brien, D. M., D. H. Rogers, F. R. Lamm and G. A. Clark. 1998. An economic comparison of subsurface drip and center pivot sprinkler irrigation systems. App. Engr. in Agric. 14(4):391-398. Also available at http://www.oznet.ksu.edu/sdi/Reports/1998/EconSDICP.pdf

Oron, G., M. Goemans, Y. Manor and J. Feyen. 1995. Poliovirus distribution in the soil-plant system under reuse of secondary wastewater. Water Res. 29(4):1069-1078.

Oron, G., Y. DeMalach, Z. Hoffman and Y. Manor. 1992. Effect of effluent quality and application method on agricultural productivity and environmental control. Water Sci Tech. 26:1593-1601.

Oron, G., Y. DeMalach, Z. Hoffman, Y. Keren, H. Hartman and N. Plazner. 1991. Wastewater disposal by sub-surface trickle irrigation. Water Sci Tech 23:2149-2158.

Ravina, I., E. Paz, Z. Sofer, A. Marcu, A. Schischa, G. Sagi, Z. Yechialy and Y. Lev. 1997. Control of clogging in drip irrigation with stored reclaimed municipal effluent. Agric. Water Man. 33:127-137.

Ravina, I., E. Paz, Z. Sofer, A. Marcu, A. Schischa and G. Sagi. 1992. Control of emitter clogging in drip irrigation with reclaimed wastewater. Irrig. Sci. 13(3):129-139.

Sagi, G., E. Paz, I. Ravina, A. Schischa, A. Marcu and Z. Yechiely. 1995. Clogging of drip irrigation systems by colonial protozoa and sulfur bacteria. In Microirrigation for a Changing World. Proc 5$^{th}$ Int. Microirrigation Congress, 250-254, ed. F R Lamm. St. Joseph, MI: ASAE.

Schwankl, L.J. 2002. Personal communication. Univ. of California-Davis.

Trooien, T. P., D. J. Hills and F. R. Lamm. 2002. Drip irrigation with biological effluent. In Proc. Irrigation Assn. Int'l. Irrigation Technical Conf., October 24-26, 2002, New Orleans, LA.. Irrigation Assn., Falls Church VA. Also available at http://www.oznet.ksu.edu/sdi/Reports/2002/DIBioEff.pdf

Trooien, T. P., F. R. Lamm, L. R. Stone, M. Alam, G. A. Clark, D. H. Rogers and A. J. Schlegel. 2000. Subsurface drip irrigation using livestock wastewater: Dripline flow rates. Appl. Engr. in Agric. 16(5):505-508. Also available at http://www.oznet.ksu.edu/sdi/Reports/2000/SDILWaste.pdf

*This paper was first presented at the International Meeting on Advances in Drip/Micro Irrigation, Puerto de La Cruz, Tenerife, Canary Islands, December 2-5, 2002. Sponsored by Instituto Canario de Investigaciones Agrarias.*