DESIGN AND MANAGEMENT CONSIDERATIONS FOR SUBSURFACE DRIP IRRIGATION SYSTEMS

Freddie R. Lamm
flamm@oznet.ksu.edu
Research Agricultural Engineer
K-State Research and Extension
Northwest Research-Extension Center
105 Experiment Farm Road,
Colby, Kansas 67701

Danny H. Rogers
drogers @ksu.edu
Extension Agricultural Engineer
K-State Research and Extension
Dept. of Biological & Agricultural Engineering
Seaton Hall
Manhattan, Kansas 66502

William E. Spurgeon
spurgeon@www.wncc.net
Agricultural Engineering Consultant
Spurgeon Engineering & Consulting
1719 Avenue X
Scottsbluff, Nebraska 69361

INTRODUCTION

If the goal of the irrigator is to develop and operate a successful subsurface drip irrigation (SDI) system, what is the purpose? Water conservation and water quality protection have often been cited as possible purposes to consider SDI. If so, it is imperative that the SDI system be designed and operated in a manner so that there is a realistic hope to satisfy those purposes. It should also be noted that an improperly designed SDI system is less forgiving than an improperly designed center pivot sprinkler system. Water distribution problems may be difficult or impossible to correct for an improperly designed SDI system.

The intent of this paper is not to show the producer how to step-by-step design and manage their SDI system. Rather, it is to discuss some of the concepts necessary in a properly designed and management system. The hope is this discussion will enable the producer to *ask* the right questions of those designing or selling them an SDI system. As with most any new technology in a region, there are unscrupulous individuals trying to take advantage of unknowledgeable buyers. These SDI systems could easily end in failure. At the same time there are many reputable distributors, sales people and installers that are trying to promote the successful use of SDI technology. System failures hurt all those involved with SDI, the enduser, the industry selling it, and the university and government entities promoting it. *Don't be afraid to ask questions and to seek clarifications. Time spent now will be rewarded down the road.*

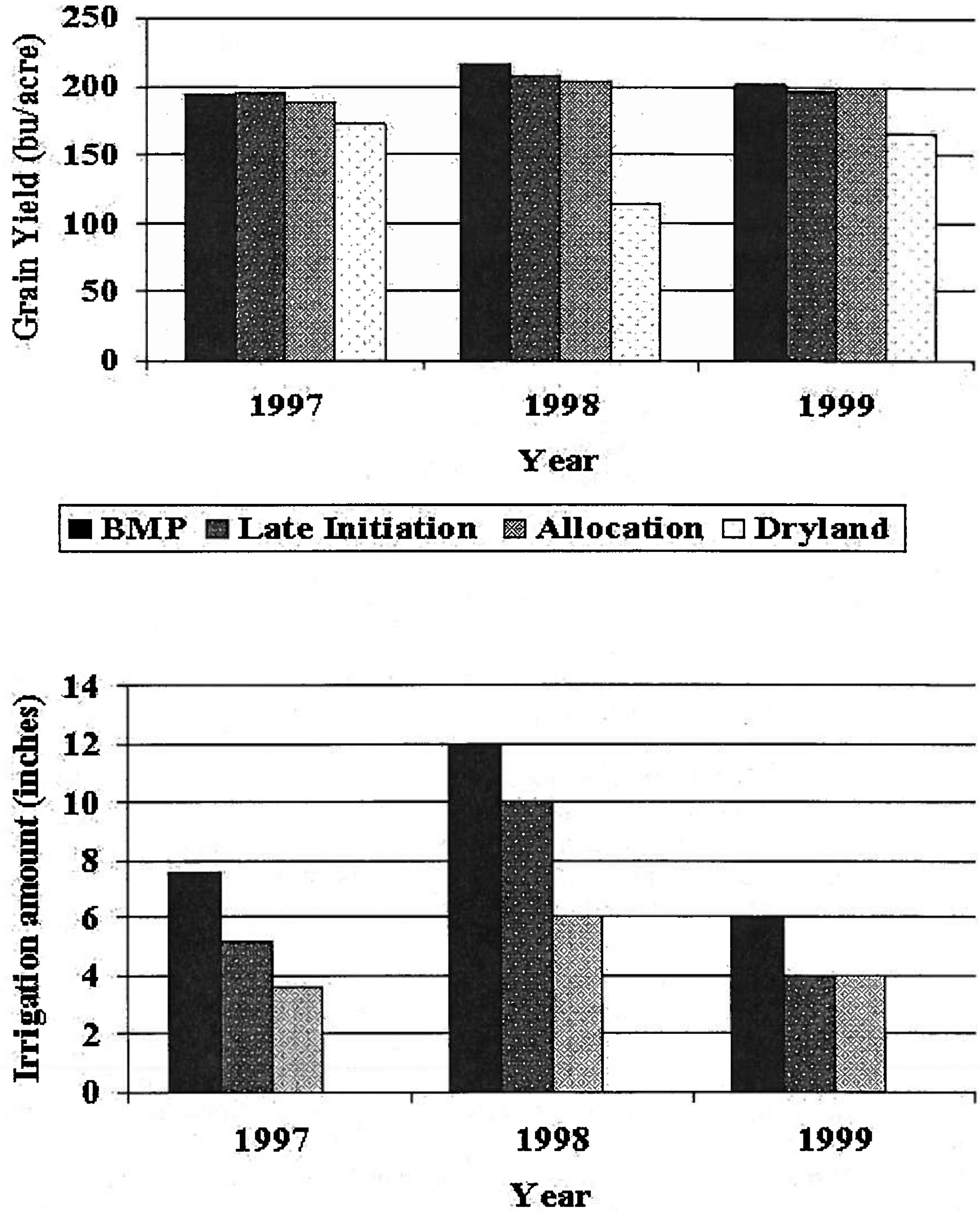

Figure 6. Grain yield and irrigation amounts at North Platte for 1997 to 1999

HYDRAULIC DESIGN

A schematic of a typical SDI system showing the necessary components is shown in Figure 1. The actual requirements in equipment, their sizes and their location is dependant on the actual design, but elements of all these components should be present in all systems.

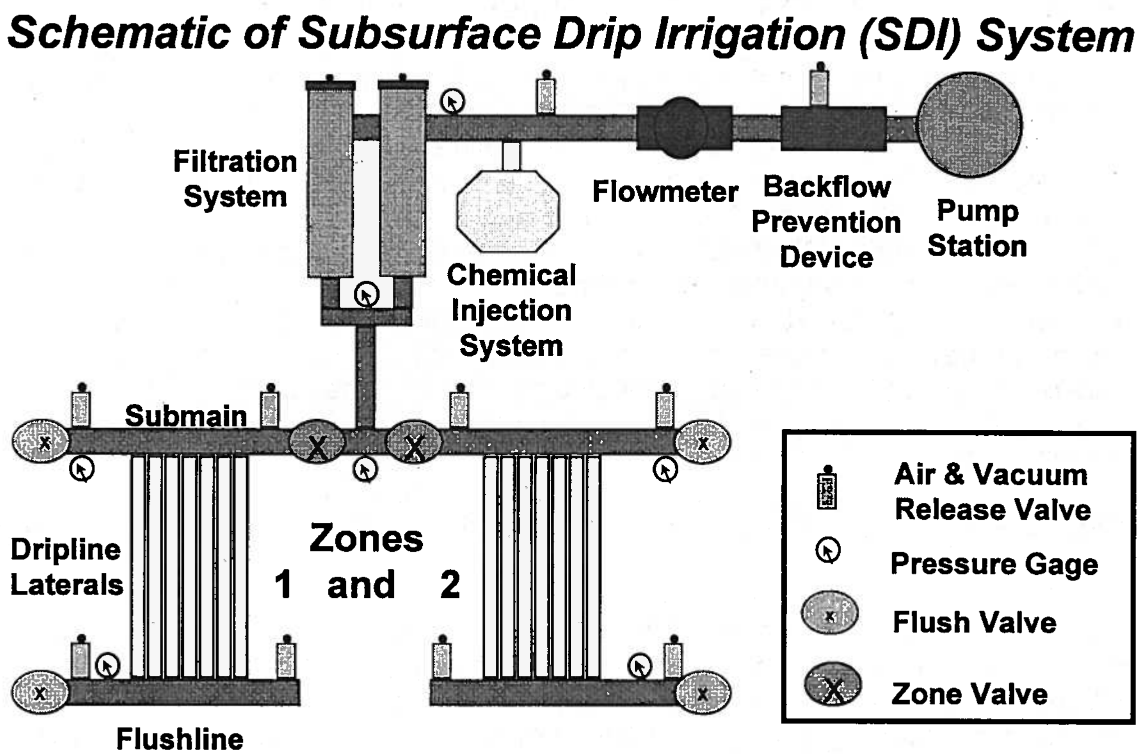

Figure 1. Component requirements of a SDI system.

Successful operation of a SDI system begins with a proper hydraulic design which satisfies constraints dictated by crop, soil type and characteristics, field size, shape, and topography, water source and supply. Disregarding design constraints will likely result in a system that is costly in both time and money to operate and will likely increase the chance of system failure. System failure might result in the loss of the total capital investment.

Crops and Soils Considerations

The crop and soil type will dictate SDI system capacity, dripline spacing, emitter spacing, and installation depth. The SDI system capacity must be able to satisfy the peak water requirement of the crop through the combination of the applied irrigation amount, precipitation, and stored soil water. The system capacity will influence the selection of the dripline flowrate and the zone size (area served by each submain). Improper selection of these items can result in more expensive systems to install and operate.

The dripline spacing is obviously an important factor in system cost, and economics suggest wider spacings. However, wide spacing will not uniformly supply crop water needs and will likely result in excess deep percolation on many soil types. The dripline spacing is dictated by the lateral extent of the crop root zone, lateral soil water redistribution, and in-season precipitation. Studies on silt loam soils in western Kansas conducted by Kansas State University have indicated that a 60-inch dripline spacing is optimal for a corn-row spacing of 30 inches. It may be feasible and logical to use a 72-inch dripline spacing for corn planted in 36-inch spaced corn rows. However, this might limit successful use of the system for crops grown in a narrow row pattern. A 72-inch dripline spacing would not be recommended in the Central Great Plains region for corn grown in a 30-inch row culture even though some dripline installers may recommend this as a way to cut investment costs. Soils that have a restrictive clay layer below the dripline installation depth might allow a wider dripline spacing without affecting crop yield. Wider spacings may also be allowable in areas of increased precipitation as the dependency of the crop on irrigation is decreased. The emitter spacing is dictated by the same factors affecting dripline spacing. However, generally, the emitter spacing is less than the dripline spacing. As a rule of thumb, dripline spacing is related to crop row spacing while emitter spacing is more closely related to crop plant spacing. One of the inherent advantages of a SDI system is the ability to irrigate only a fraction of the crop root zone. Careful attention to dripline spacing and emitter spacing are, therefore, key factors in achieving the purpose of water conservation and water quality protection.

The installation depth is also related to the crop and soil type. Deep installations reduce the potential for soil evaporation and also allow for a wider range of tillage practices. There may also be some reduced potential for chemical, biological and root plugging of the emitters for the deeper installations. However, deep installations may limit the effectiveness of the SDI system for germination and may restrict availability of surface-applied nutrients. Acceptable results have been obtained with depths of 16-18 inches in KSU studies in western Kansas on deep silt loam soils. Some producers in the Central Great Plains region are opting for installations in the 12-14 inch depth range to give more flexibility in germination. Dripline should probably be installed above any restrictive clay layers that might exist in the soil. This would help increase lateral soil water redistribution. K-State initiated a research study to determine the optimum dripline depth (8, 12, 16, 20 or 24 inches) for long term corn production in 1999. The results are not sufficient to report at this time, but the reader is encouraged to watch for the results of this study in the coming years.

The orientation of driplines with respect to crop rows has not been a critical issue with SDI systems used for corn production on the deep silt loam soils. Traditionally, a parallel orientation is used. This may be advantageous in planning long term tillage, water, nutrient and salinity management schemes. However, K-State research has shown either parallel or perpendicular orientations are acceptable.

Field Size, Shape, and Topography
The overall field size may be limited by the available water supply and capacity. The ability to economically adjust the size of the irrigated field to the available water supply is a distinct advantage of SDI systems compared to center pivot sprinklers. If sufficient water supply is available, the field size, shape, and topography, along with the dripline hydraulic characteristics, will dictate the number of zones. Minimizing the number of necessary zones will result in a more economical system to install and operate.

Whenever possible, dripline laterals should be installed downslope on slopes of less than 2%. On steeper terrain, the driplines should be made along the field contour and/or techniques for pressure control should be employed.

Dripline Hydraulic Characteristics
Pressure losses occur when water flows through a pipe due to friction. These friction losses are related to the velocity of water in the pipe, the pipe inside diameter and roughness, and the overall length. The emitter flowrate (Q) can generally be characterized by a simple power equation

$$Q = k H^x$$

where k is a constant depending upon the units of Q and H, H is the pressure and x is the emitter exponent. The value of x is typically between 0 and 1, although values outside the range are possible. For an ideal product, x equals 0, meaning that the flowrate of the emitter is independent of the pressure. This would allow for high uniformity on very long driplines, which would minimize cost. An emission product with an x of 0 is said to be fully pressure compensating. An x value of 1 is noncompensating, meaning any percentage change in pressure results in an equal percentage change in flowrate. Many lay-flat drip tape products have an emitter exponent of approximately 0.5. A 20% change in pressure along the dripline would result in a 10% change in flowrate if the exponent is 0.5. As a rule of thumb, flowrates should not change more than 10% along the dripline in a properly designed system. Most manufacturers can provide the emitter exponent for their product. *Irrigators would be well advised to compare the emitter exponent among products and be wary of manufacturers that cannot provide this information.*

Friction losses increase with length (Figure 2). For this example, the dripline has a design flowrate of 0.25 gpm/100 ft. at 10 psi on a level slope. The variation in flows, Q_{var}, are 6, 16, and 29% for the 400, 600 and 800 ft. runs, respectively. Using general criteria for Q_{var}, these systems would be classified as desirable, acceptable, and not acceptable (Table 1). It should be noted that this example is based on 5/8 inch diameter dripline. Longer lengths of run would be obtainable with larger dripline diameters. The industry has responded well to the needs of the producer and now are producing larger dripline diameters. However, the producer is encouraged to carefully compare investment and anticipated management costs for the various dripline sizes before concluding what is the optimal dripline size for their installation. Larger diameters are not always more desirable, as they increase the filling and purging times for the system, which could affect water and chemical application uniformity.

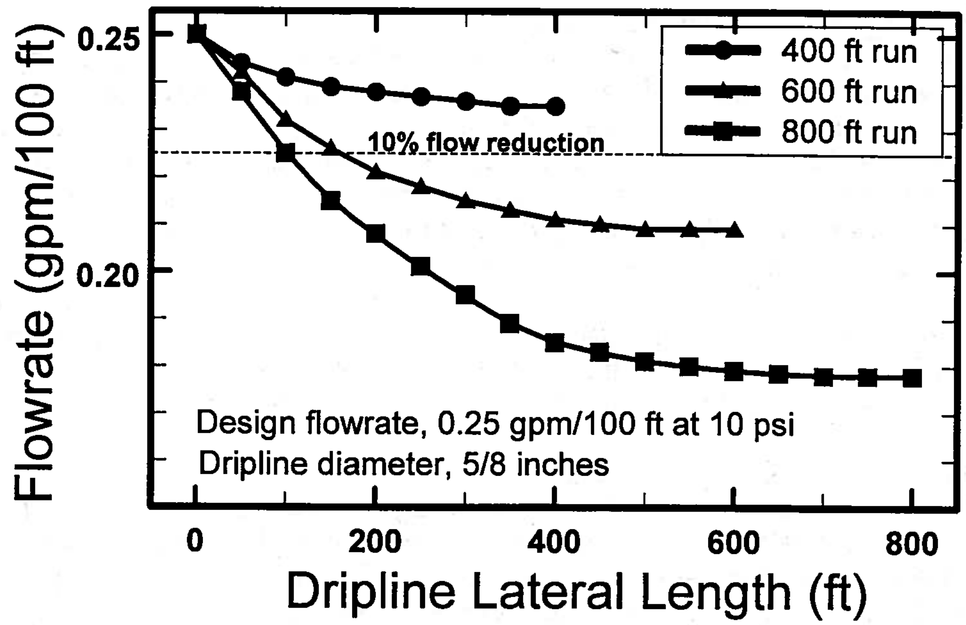

Figure 2. Calculated dripline flowrates on level slopes as affected by length of run. For this example dripline, only the 400 ft lateral length meets the desired criteria of maintaining flow variations less than 10%.

Table 1. Uniformity criteria established by ASAE Engineering Practice EP-405.

Flow variation, Qvar = 100 x ((Qmax -Qmin)/Qmax)		
Desirable	< 10%	
Acceptable	10 - 20%	
Unacceptable	> 20%	
	Statistical Uniformity, Us	**Emission Uniformity, Eu**
Excellent	95-100%	94-100%
Good	85-90%	81-87%
Fair	75-80%	68-75%
Poor	65-70%	56-62%
Unacceptable	< 60%	< 50%

Friction losses also increase with the velocity of water in the dripline. For a given inside diameter of line, friction losses will be greater for driplines with higher flowrates (Figure 3). Some designers prefer higher capacity driplines because they are less subject to plugging and allow more flexibility in scheduling irrigation. However, if larger-capacity driplines are chosen, the length of run may need to be reduced to maintain good uniformity. Additionally, the zone area may need to be reduced to keep the flowrate within the constraints of the water supply system. Decreasing the length of run or the zone area increases the cost of both installation and operation.

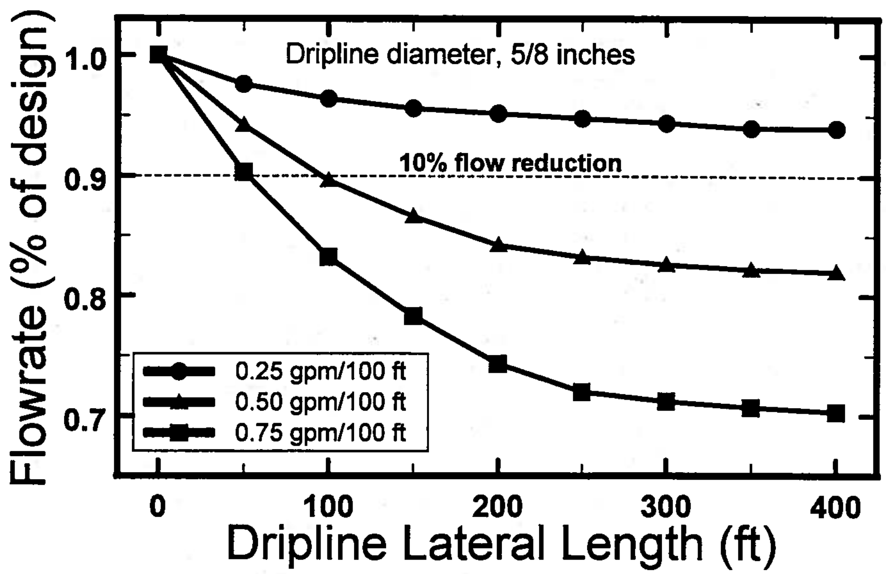

Figure 3. Calculated flowrates on level slopes as affected by dripline capacity. In this example only the 0.25 gpm/100 ft dripline capacity meets the desired criteria of maintaining flow variations less than 10%.

The land slope can have either a positive or negative effect on the pressure distribution along the dripline lateral (Figure 4). Irrigating uphill will always result in increasing pressure losses along the lateral length. If the downhill slope is too large, the flowrate at the end of the line may be unacceptably high. In the example shown, the most optimum slope is either 0.5 or 1.0% downslope. Both slopes result in a flowrate variation of approximately 10% for the 600 ft. run. If slopes are too great, there is the opportunity to run the driplines cross slope or along the contour. Pressure compensating emitters can also be utilized on greater slopes but may not be cost competitive for relatively low value crops such as corn.

The overall effect on uniformity is specific to the field slope, length of run, dripline capacity and diameter. Many of the manufacturers have computer programs that can quickly compare many design alternatives. The producer is encouraged to utilize this service to determine the overall effect on design his circumstances may dictate.

The preceding discussion has only dealt with theoretical calculations that don't take into account the variability in manufacturing. The coefficient of manufacturing variation, C_V, is a statistical term used to describe this variation. Some dripline products are inherently difficult to manufacture with consistency and, therefore, may have a high C_V. Other products may suffer from poor quality control. The American Society of Agricultural Engineers (ASAE) has established C_V ranges for line-source driplines. A C_V of less than 10% is considered good; from 10 to 20%, average; and greater than 20%, marginal to unacceptable. The C_V of a product should be obtained from the manufacturer to aid in decisions regarding suitability of the product for a particular installation.

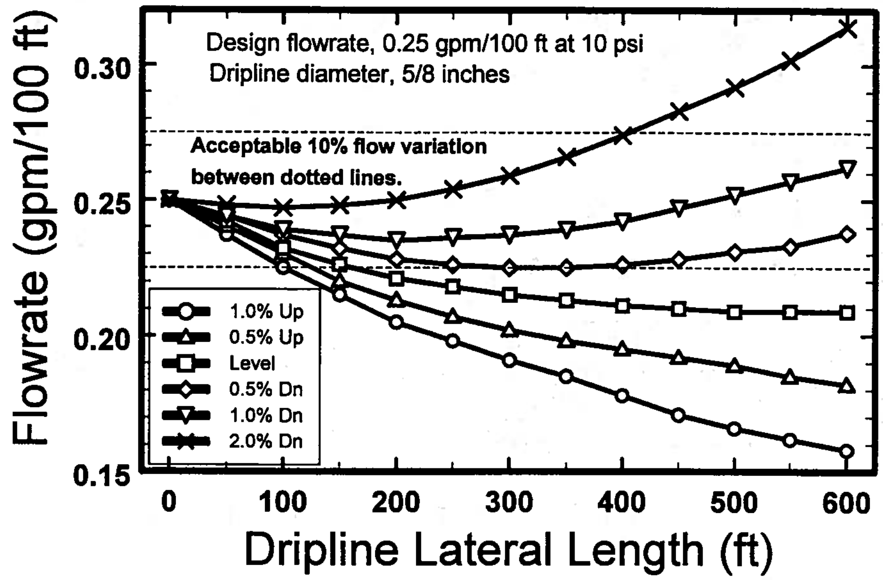

Figure 4. Calculated dripline flowrates as affected by slope. In this example, the 0.5 and 1.0% downslope dripline laterals meet the desired criteria of maintaining flow variations less than 10%.

There are two additional terms to describe system uniformity that can be calculated for a SDI system. They are the emission uniformity Eu and the statistical uniformity Us. The calculations of the terms lies beyond the scope of this discussion, but they may be encountered in the process of developing a SDI system. The criteria for evaluating these uniformities as developed by the ASAE are listed in Table 1.

FILTRATION, FLUSHING, AND WATER TREATMENT

Plugging of the dripline emitters is the major cause of system failure. Plugging can be caused by physical, chemical, or biological materials. <u>The filtration system is one of the most important components of the SDI system.</u> It's operation and maintenance must be well understood by the irrigator to help ensure the longevity of the SDI system. A more complete K-State source on this topic is Alam et al. (1999). There are many different types of filtration systems. The type is dictated by the water source and also by emitter size. Improper filter selection can result in a SDI system which is difficult to maintain and a system prone to failure. The filtration system can be automated to flush at regular time intervals or at a set pressure differential.

Screen or sand media filters are used to remove the suspended solids such as silt, sand, and organic and inorganic debris. Surface water often requires more extensive filtration than groundwater, but filtration is required for all systems.

Chemical reactions in the water can cause precipitates, such as iron or calcium deposits to form inside the driplines. Plugging can be caused by either natural water conditions or by chemicals such as fertilizer added to the water. To avoid chemical clogging, the water must be analyzed to determine what chemicals are prevalent and which chemical additives should be avoided. Chemical water treatment may be required on a continuous or intermittent basis. Acids are sometimes used to prevent plugging and also to help renovate partially plugged driplines. The need for treatment is dictated by the water source and the emitter size. *A thorough chemical analysis of the water source should be made prior to development of the SDI system.*

Biological clogging problems may consist of slimes and algae. Some problems are eliminated in the filtration process, but injection of chlorine into the driplines on a periodic basis is required to stop the biological activity. The water source and composition will determine, to a large extent, the need for chlorination.

A flushing system is recommended at the distal end of the dripline laterals (Figure 1) to assist in removing sediment and other materials that may accumulate in the dripline during the season. This is in addition to a proper filtration system. A useful way to provide for flushing is to connect all the distal ends of the driplines in a zone to a common submain or header that is called the flushline. This allows the flushing to be accomplished at one point. Two other distinct advantages exist for this method. If a dripline becomes plugged or partially plugged, water can be provided below the plug by the interconnected flushline. Additionally, if a dripline break occurs, positive water pressure on both sides of the break will limit sediment intrusion into the line. Generally, a minimum flow velocity of 1-2 ft/second is considered adequate for flushing dripline laterals. This flow velocity may often require careful sizing of the mains, submains, flushline mains, and valving.

MANAGEMENT CONSIDERATIONS

A thorough discussion of the management for SDI systems lies beyond the scope of this paper. However, a brief discussion with regards to system longevity and also with regards to satisfying the stated purposes is in order.

Managing a SDI system is not necessarily more difficult than managing a furrow or sprinkler irrigation system, but it does require a different set of management procedures. <u>Improper management of a SDI system can result in system failure, which might mean the loss of the total capital investment.</u> Proper day-to-day management requires the operator to evaluate the component performance, to determine crop irrigation needs, and to make adjustments as needed. The performance of the SDI system components can be evaluated by monitoring the flowrate and pressures in each zone. Pressure gages should be installed on riser pipes from the submain and flushline at each of the four corners of the zone. Comparison of the flowrate and pressures from one irrigation event to the next can reveal any problems that are occurring. For instance, if the flowrate has increased and the pressure is lower, the irrigator needs to investigate for a possible leak in the system. Conversely, if the flowrate is lower and the pressure is higher, the irrigator needs to check the filtration system or look for possible plugging. Disregarding day-to-day management can result in problems such as poor water distribution, low crop yields, and even system failure.

SDI systems are typically managed to frequently apply small amounts of water to the crop. If properly managed, there are opportunities to save water and to provide a more consistent soil water environment for the crop. However, irrigation scheduling must be employed as some of the visual indicators of overirrigation, such as runoff, no longer exist with this type of irrigation. Overirrigation with a SDI system can lead to reduced yields because of aeration problems exacerbated by the higher irrigation frequency and also perhaps by the more concentrated crop root system. Overirrigation can dramatically increase deep percolation, which can increase groundwater contamination.

SDI systems are often used to provide all or a portion of the crop nutrient needs. The ability to spoon feed the crop its nutrients reduces the potential for groundwater contamination. However, fertigation is only recommended on SDI systems with good or excellent uniformity. Irrigation and nutrient amounts must be managed together to prevent leaching.

CONCLUDING STATEMENT

The initial investment costs for a SDI system are high. Efforts are justified to minimize, investment costs whenever possible and practical. However, if water conservation and water quality protection are important, proper design procedures must be employed. The SDI system must also be properly designed to ensure system longevity. Minimizing investment costs through cheaper designs can be a double-edged sword, as a cheaper system may increase operating costs and/or possibly increase the chance of system failure.

K-State continues to develop appropriate methodology for successful utilization of SDI technology in the US Central Great Plains. Much of this technology is summarized on the K-State SDI website which can be accessed by pointing your Internet web browser to **http://www.oznet.ksu.edu/sdi/**

REFERENCES CITED

Alam, M., T. P. Trooien, F.R. Lamm and D. H. Rogers. 1999. Filtration and management considerations for subsurface drip irrigation (SDI) systems. KSU Cooperative Extension Irrigation Mgmt. Series, MF-2361. 4 pp. Also at http://www.oznet.ksu.edu/library/ageng2/mf2361.pdf

This material was first presented at the Central Plains Irrigation Shortcourse and Equipment Exposition, Kearney, Nebraska, February 7-8, 1994. Slight revisions were made in January 1997. Significant revisions were made in January 2000.

Comments or questions about this paper can be directed to:
Freddie Lamm, Research Agricultural Engineer
KSU Northwest Research-Extension Center, 105 Experiment Farm Road, Colby, Kansas 67701
Phone: 785-462-6281 Fax: 785-462-2315 Email: flamm@oznet.ksu.edu