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APPLICATION AND UTILIZATION OF LIVESTOCK EFFLUENT THROUGH SDI SYSTEMS

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Abstract: Subsurface drip irrigation (SDI) can be successfully used for application of livestock effluent to agricultural fields with careful consideration of design and operational issues. Primary advantages are that exposure of the effluent to volatilization, leaching, runoff into streams, and humans can be reduced while the primary disadvantages are related to system cost and longevity, and the fixed location of the SDI system. An engineering study with beef feedlot effluent has indicated that driplines with discharge of 1.5 to 2.3 L/hr-emitter can be used successfully with little clogging. SDI tended to have greater corn yields and better nutrient utilization than low-energy precision application (LEPA) center pivot sprinklers when using swine effluent in a two-year field study.

Keywords: Microirrigation, drip irrigation, subsurface drip irrigation, low -energy precision application, LEPA, irrigation management, corn production, biological effluent.

Introduction

The use of livestock effluent through agricultural irrigation systems can have positive or negative impacts on the environment, depending on the method and intensity of use. The effluent can also be an inexpensive fertilizer resource for crop producers, providing nutrients in a timely fashion to the crop in a readily plant-available form. Lagoon-based livestock effluent as used through irrigation systems is approximately 98% water and 2% solids, although there are a few high-pressure, mechanical-move irrigation systems that can apply much thicker slurries. This paper will not concern itself with slurry-based effluents that would be unsuitable for subsurface drip irrigation. Subsurface drip irrigation (SDI) has been shown to be technically feasible with beef feedlot runoff effluent in Kansas State University research performed in western Kansas (Trooien et al., 2000; Lamm et al., 2002). The use of SDI with effluent has both advantages and disadvantages (Trooien et al., 2000; Trooien et al., 2002, Lamm et al., 2002, Trooien and Hills, 2007). Potential advantages include saving fresh water for other uses, reducing groundwater withdrawal in areas of low recharge; providing a source of N, P, and K, for crop growth; reducing human contact with effluent; reducing odor and eliminating sprinkler aerial pathogen drift; eliminating effluent runoff into surface waters; subsurface placement of phosphorus-rich water reduces hazards of P movement into streams by surface runoff and soil erosion; increasing water application uniformity resulting in better control of the water, nutrients, and salts; reducing irrigation system corrosion; reducing weather-related water application constraints (especially high winds and freezing temperatures); increasing flexibility in matching field and irrigation system sizes, and better environmental aesthetics. Disadvantages include high initial SDI system cost, concerns about SDI system longevity, limited experiences with this application method, and the fixed location nature of the SDI system that can lead to nutrient overloading.

SDI design and operational considerations for livestock effluent

Historically, clogging of the emitters leading to reduced and nonuniform discharge has been the primary reason for microirrigation system failure, so it may seem ironic to discuss using a particle-rich water source through an SDI system. However, as it is with all microirrigation systems, the problem is attacked through standard design and operational considerations (Trooien et al., 2002): (1) Selecting and installing the proper system components; (2) Filtering the effluent effectively; (3) Suppressing biological growth and chemical precipitation; (4) Flushing materials that may accumulate in the distribution systems, and (5) Monitoring system performance to assure that partial clogging is treated before it becomes catastrophic.

Emitter Selection

Emitter selection was discussed thoroughly by Trooien et al. (2002) and Trooien and Hills (2007) and will be briefly summarized here. Limited research has been conducted on emitter selection when using livestock effluents. Using emitters with larger discharge rates can reduce clogging (Trooien et al., 2000; Lamm et al., 2002) but must be balanced against the reduced zone size and length of run when using larger discharge rates. Shorter and wider emitter flow paths may be subjected to less clogging than longer, labyrinth-style emitters (Adin and Sacks, 1991). Emitters that were molded or attached to the dripline were superior to driplines where emitter pathways were formed by indentation when using pretreated secondary effluent (Hills and Brenes, 2001). Effluent particles that inadvertently increase discharge of pressure compensating (PC) emitters have been reported anecdotally, and some manufacturers discourage their use for effluent water applications (Lamm and Camp, 2007). New computational procedures to analyze emitters may become very useful in designing emitters that can handle the increased levels of particles in effluent (Yongxin et al., 2005).

Filtration

Filtration is required to prevent large particles from entering driplines and physically clogging emitters. A general guideline for filtration is to provide filtration that will remove particles one-tenth the size of the smallest emitter pathway. This may seem excessive but is based on field experience and also the fact that smaller particles may conglomerate into larger particles as they move through the microirrigation system. This may be of particular importance for effluents where biological constituents may provide the “glue” to create these larger clogging particles. Typically particles accumulate at the distal ends of driplines where flow velocities are reduced (Shannon et al., 1982) unless biological agents intercept them and cause precipitation earlier.

Sand media filtration is often considered to be the standard for protection of microirrigation systems that experience heavy organic loading. Similar to sand media filters, disk filters are also considered to provide a degree of three-dimensional filtration while screen filters only provide that single pane of filtration. Some screen filters also incorporate vortex flow conditions across the mesh screen in an effort to remain operational. These types of screen filters sacrifice to waste a small amount of water and pressure to cleanse the mesh.

Filtration for microirrigation using effluent is discussed in more detail by Trooien et al., 2002 and Trooien and Hills, 2007.

Chemical Injection to Suppress Biological Growth and Chemical Precipitation

Emitters can be clogged by a mixture of organic and inorganic particles, protozoa, or bacteria that grow within the driplines (Ravina et al., 1992; Sagi et al., 1995). Bacterial slimes initiate clogging, then suspended inorganic particles adhere to the slimes and cause physical clogging (Adin and Sacks, 1991). Additionally, bacterial growth within driplines may lead to the formation of biofilms that reduce the flow area and increase roughness, leading to increased pressure losses.

Acidification and chlorination are often used to suppress or stop biological activity in microirrigation systems. Chlorination can be challenging with effluents having high ammonia contents because chlorine reacts with ammonia to form chloramines. These chloramines are up to 80 times less effective than chlorine for biological control (Feigin et al., 1991). In many cases it will be more cost effective to use acidification and chlorination as shock treatments in livestock effluent applications due to the higher cost of continuous chemical application. Flushing is then incorporated as an additional tool to remove the biological and other precipitates. Trooien and Hills (2007) discuss other chemical control techniques that may be appropriate in some circumstances, particularly those that involve non-livestock effluents, such as municipal effluents that could contain pathogens harmful to humans.

Flushing

Silt, clay and biological particles which are common in livestock lagoons are not typically filtered from microirrigation systems because they are too small for cost effective filtration. Over time there will be accumulation of some of these materials in the dripline as they settle to the bottom when the system is shut down or when flow velocities become small enough to allow settling. These accumulations can provide a host or site for larger conglomerations or biological activity. Regular flushing of the SDI driplines through a common flushline is recommended to remove these accumulations. There is much discussion about the proper flushing velocity and whether it is just providing flushing or whether it may provide some additional scouring of the dripline (Lamm and Camp, 2007) but Hills and Brene (2001) concluded the flushing velocity for effluent applications should be at least 0.5 m/s.

Monitoring

Frequent monitoring of system performance can detect clogging before it becomes catastrophic because emitter clogging is progressive and continuous rather than a discrete event (Ravina et al., 1992 and Trooien et al., 2000). Early detection of emitter clogging is important because chlorination of partially clogged emitters is more effective than if the emitters are more severely clogged (Ravina et al., 1992).

Beef Effluent Application with Different Emitter Discharge Rates

Study Description

This study was conducted from 1998 until the spring of 2002 on a commercial feedlot, Midwest Feeders, Ingalls, Kansas. The results from the first two years of the study were published by Trooien et al., 2000. This paper also describes in detail the experimental site, treatments and overall procedures. Only a brief description of treatments will be given here. Plot length was approximately 135 m. Five driplines with emitter discharges of 0.57, 0.91, 1.5, 2.3, or 3.5 L/hr-emitter were tested with beef feedlot runoff effluent pumped directly from a storage lagoon. The beef lagoon effluent received no chemical pretreatment or disinfection. An automated disk filter (plastic grooved-disk filter rings of 200 mesh, with openings of 80 µm) was used, and shock treatments of chlorine and acid were injected periodically. The filtration system was scheduled to flush every two hours or whenever the differential pressure exceeded 48 kPa. During the course of the field study, a total of approximately 1675 mm of effluent water was applied with no blending with freshwater. After three years of operation, two fresh water events were conducted to examine the potential for cleaning the driplines and also to enhance chemical treatment (acid and chlorine are more effective with fresh water). It is estimated that approximately 10,400 kg/ha of total suspended solids passed through the driplines based on periodic water sampling. At the end of the field study in April 2002, an aggressive freshwater flushing, with acid and chlorine injection was performed. Eight driplines approximately 10 m long were excavated at a point about 30 m from the distal flushline on April 18, 2002. Three lines were selected from the lowest flow treatment, three from the medium flow treatment and two from the highest flow treatment. These driplines were refrigerated until discharge from individual emitters could be tested in the lab on August 8, 2002. Discharge was measured for 23, 12, and 12 consecutive emitters resulting from the 0.3, 0.6 and 0.6 emitter spacings, respectively for these three dripline treatments.

Emitter Performance with Effluent

By the end of the second year of operation (Trooien et al., 2000), the flowrate of entire plots was reduced by 22% using 0.57 L/h emitters and reduced by 14% for 0.91 L/h emitters (Fig. 1). These smallest emitters tested were manufactured by indentation. When using emitters of 1.5, 2.3, and 3.5 L/h, the plot flowrates were reduced by less than 5%. The emitters with discharge of 1.5 and 2.3 L/h were manufactured by attachment. These results suggest that the smaller emitters manufactured by indentation are more prone to clogging when using effluent and may be risky for use with effluent. The discharge rate of the two smallest emitter sizes, 0.57 and 0.91 L/hr-emitter decreased approximately 40% and 30%, respectively, during the four seasons, indicating considerable emitter clogging (Lamm et al., 2002). The three driplines with the highest discharge emitters (1.5, 2.3, and 3.5 L/hr-emitters) had approximately 7, 8, and 13% reductions in discharge during the 4-year study, respectively.

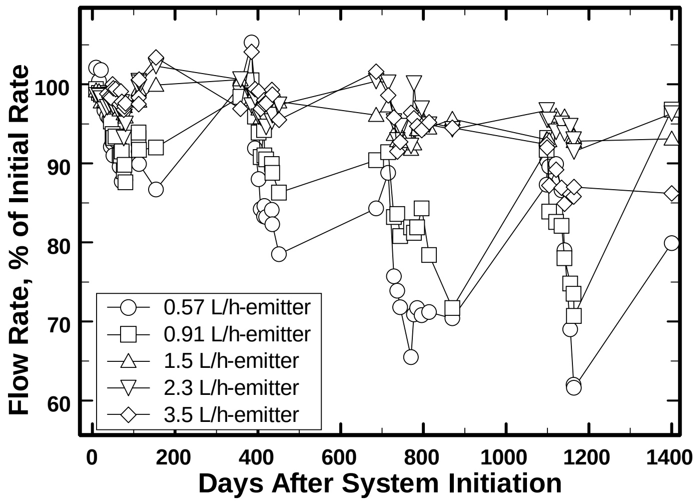

Figure 1. Decrease of flow rates during four seasons of operation of SDI system with biological effluent at Midwest Feeders, Ingalls, Kansas. After Lamm et al. (2002).

Emitter Performance after Aggressive Cleaning

The aggressive flushing, acid and chlorine program in April 2002 restored a significant portion of the discharge reductions experienced by the smallest two emitters. Plot flowrates increased from the August 2001 values of 62 and 71% of the initial flowrates to April 2002 values of 80 and 97% for the 0.57 and 0.91 L/hr-emitter treatments, respectively. This indicates that aggressive management may remediate effluent clogging problems. There was substantially less improvement for the larger discharge emitters and actually no discharge improvement for pressure compensating (PC) emitter (3.5 L/hr-emitter). It is believed that effluent particles were being trapped in the flexible diaphragm of these emitters.

Emitter Clogging and Performance After Excavation

The lowest flow dripline (0.57 L/hr-emitter) had 3 fully clogged emitters in the 3 driplines tested (3 driplines x 23 emitters = 69 total emitters). The average discharge varied from 0.41 to 0.51 L/hr-emitter for these three driplines as compared to two new driplines from the same roll that had an average discharge of 0.55 L/hr-emitter. The Coefficient of Variation (CV) of discharge varied from 7.3 to 36.8% for the effluent driplines while the CV for new driplines was only 2.5%. Likewise the Distribution Uniformity with the Lower Quartile method (DU_{lq}) ranged from 54.3% to 90.7% for the effluent driplines as compared to the new dripline DU_{lq} of 97.1%. Clearly, the lowest flow driplines experienced some significant clogging problems.

Discharge from individual emitters for the effluent medium discharge driplines was very good with only small decreases (<10%) from the average discharge of new driplines. The CV ranging from 2.4 to 2.8% and DU_{lq} ranging from 96.4 to 97.9% for these driplines were excellent and differed very little from the new driplines.

Table 1. Emitter discharge, coefficient of variation (CV%) and lower quartile distribution uniformity DU_{lq} for selected excavated used driplines as compared to new unused driplines.

Emitter and dripline type	Mean discharge L/h-emitter	CV%	DU_{lq}	Number of fully clogged emitters
Low discharge emitter, nominal 0.57 L/hr-emitter				3
Effluent dripline #1	0.51	7.3	90.7	
Effluent dripline #2	0.45	25.2	69.9	
Effluent dripline #3	0.41	36.8	54.3	
New dripline	0.55	2.5	97.1	
Medium discharge emitter, nominal 1.51 L/hr-emitter				0

Effluent dripline #1	1.44	2.8	96.8	
Effluent dripline #2	1.45	2.5	96.4	
Effluent dripline #3	1.44	2.4	97.9	
New dripline	1.48	2.5	97.1	
High discharge emitter, nominal 3.5 L/hr-emitter				0
Effluent dripline #1	3.44	20.5	87.1	
Effluent dripline #2	3.49	10.8	92.8	
New dripline	3.52	2.3	96.7	

Agronomic Study with Swine Effluent

Study Description

This agronomic study was conducted in 2000 and 2001 at the KSU Northwest Research-Extension Center, Colby, Kansas. The experimental site, treatments, and overall procedures were summarized by Lamm et al. (2006). Only a brief description of treatments will be given here. The water was hauled to the research site from Scott City, Kansas (distance approximately 120 km) and immediately applied. The effluent was stored temporarily in a tank prior to application.

The two irrigation methods were SDI and a sprinkler irrigation treatment using low energy precision application (LEPA). The LEPA sprinkler irrigation method was simulated by providing water to individual furrow basins through surface tubing to approximate the application rate of LEPA nozzles. Each irrigation method had three different nutrient application levels. The treatments were as follows: (1) SDI control treatment (No application of effluent, but SDI fertigation of commercial fertilizer, 224 kg/ha N/acre in-season through dripline.); (2) Application of 25.4 mm of effluent per year with SDI, 12.7 mm per application; (3) Application of 50.8 mm of effluent per year with SDI, 12.7 mm per application; (4) Application of 15.2 mm of effluent per year with simulated LEPA; (5) Application of 25.4 mm of effluent per year with simulated LEPA, 25.4 mm per application, and (6) Application of 50.8 mm of effluent per year with simulated LEPA, 25.4 mm per application. Additional freshwater irrigation was scheduled as needed using a calculated water budget approach.

Representative plant samples were harvested in the fall for grain yield, biomass, and nutrient uptake. Soil samples were taken in a horizontal (1 crop row width, 0.76 m) and vertical (depth of 2.4 m) grid to characterize residual nutrient levels within the soil profile.

Corn Yield and Biomass

There were no significant differences in corn yields due to irrigation method or effluent application in 2000, though SDI yields tended to have slightly higher yields (Tab. 2).

Table 2. Corn grain yield, biomass, and water use data as affected by irrigation system and swine effluent, KSU Northwest Research Extension Center, Colby, Kansas, 2000-2001.

Irrigation system & effluent amount	Irrigation mm	Applied N[1] kg/ha	Grain yield Mg/ha	Biomass Mg/ha	Water use[2] mm	WUE[3] Mg/ha-mm
Year 2000						
SDI, Control	495	275	15.9	23.8	765	0.0208
SDI, 25.4 mm effluent	495	257	15.8	25.6	772	0.0205
SDI, 50.8 mm effluent	495	435	16.3	24.4	749	0.0218
LEPA, 15.2 mm effluent	508	174	14.9	24.4	843	0.0176
LEPA, 25.4 mm effluent	508	257	15.7	24.9	833	0.0188
LEPA, 50.8 mm effluent	508	435	15.4	24.0	843	0.0183
LSD P=0.05			NS	NS	38	0.0023
Year 2001						
SDI, Control	457	273	16.4	25.8	724	0.0227
SDI, 25.4 mm effluent	457	234	16.9	27.8	696	0.0244
SDI, 50.8 mm effluent	457	399	16.8	25.8	714	0.0235
LEPA, 15.2 mm effluent	457	160	13.4	20.0	716	0.0188
LEPA, 25.4 mm effluent	457	234	15.8	22.9	729	0.0216

LEPA, 50.8 mm effluent	457	399	14.9	22.4	770	0.0193
LSD P=0.05			1.4	NS	NS	0.0023
Mean of both years 2000- 01						
SDI, Control			16.2	24.9	744	0.0218
SDI, 25.4 mm effluent			16.4	26.7	734	0.0223
SDI, 50.8 mm effluent			16.5	25.1	732	0.0226
LEPA, 15.2 mm effluent			14.1	22.2	780	0.0181
LEPA, 25.4 mm effluent			15.8	23.8	782	0.0201
LEPA, 50.8 mm effluent			15.1	23.3	805	0.0188
LSD P=0.05			1.3	NS	25	0.0015

[1] Total applied N-P-K from the three sources: starter treatment at planting (34 kg N/ha + 50 kg/ha P_20_5), wastewater application, and the amount naturally occurring in the water (0.033 kg N/ha-mm).

[2] Total of seasonal change of soil water storage in the 2.4 m profile plus irrigation and precipitation.

[3] Water use efficiency (WUE) is defined as grain yield in Mg/ha divided by total water use in mm.

Grain yields were similar with commercial fertilizer or effluent for the SDI treatments at approximately 16.0 Mg/ha. The smaller 15.2 mm effluent amount applied with LEPA had an appreciably lower grain yield (14.9 Mg/ha), perhaps indicating some crop nutrient stress. In 2001, grain yield averaged approximately 16.8 Mg/ha for the two SDI effluent treatments (25.4 and 50.8 mm effluent applications) and approximately 15.3 Mg/ha for similar LEPA treatments. The LEPA treatment with the smaller 15.2 mm effluent application had significantly lower yields, which was further indication of the apparent combination of increased nutrient and water stress for the LEPA treatments compared to SDI. There were no statistically significant differences in biomass at physiological maturity as affected by irrigation method or effluent application in either year, although SDI tended to have greater biomass in 2001 (Tab. 2).

Water use and Water Use Efficiency

Water use was significantly higher (P=0.05) for the LEPA sprinkler irrigation plots as compared to the SDI plots in 2000, averaging approximately 85 additional mm of use (Tab. 2) In 2001, there were no significant differences in water use between irrigation systems. When averaged over the two years, water use for LEPA treatments had approximately 50 mm greater water use than SDI which was statistically significant (P=0.05). As discussed earlier, SDI yields tended higher and LEPA water use tended higher, so it was not surprising that water use efficiency was higher with SDI in both years (Tab. 2). Averaged over the two years of the study, SDI produced approximately 3 kg more grain for each mm of water use. This is probably a combination of better nutrient utilization and less crop water stress for SDI.

Nutrient Utilization and Soil Residual N

There were no significant differences in plant nitrogen uptake in 2000 related to irrigation method or applied effluent but there was a slight trend for higher uptake with SDI and for increasing effluent rates with the LEPA treatments (Tab. 3).

Table 3. Applied nitrogen, plant uptake and change in residual soil nitrogen in a biological effluent study, KSU Northwest Research-Extension Center, Colby, Kansas, 2000-2001.

Irrigation System & Effluent Amount	Irrigation mm	Applied Nitrogen kg N/a	Plant Uptake kg N/a	Change in Residual Soil N (8 ft)			Nitrogen Balance[1] kg N/ha
				NH4-N kg N/ha	NO3-N kg N/ha	NH4-N plus NO3-N kg N/ha	
Year 2000				**Spring 2000 to Fall 2000**			
SDI, Control	495	275	262	24	-19	4	8
SDI, 25.4 mm effluent	495	256	276	26	24	2	-22
SDI, 50.8m effluent	495	434	265	6	83	89	81
LEPA, 15.2 mm effluent	508	174	231	15	-126	-112	55
LEPA, 25.4 mm effluent	508	257	252	1	-82	-81	85
LEPA, 50.8 mm effluent	508	435	259	4	-55	-50	226

LSD P=0.05			NS	NS	NS	NS	
Year 2001				**Fall 2000 to Fall 2001**			
SDI, Control	457	273	310	-44	-28	-72	35
SDI, 25.4 mm effluent	457	234	309	-37	-39	-76	1
SDI, 50.8 mm effluent	457	398	307	-9	102	93	-2
LEPA, 15.2 mm effluent	457	160	168	-41	-35	-75	67
LEPA, 25.4 mm effluent	457	234	244	-30	-52	-82	71
LEPA, 50.8 mm effluent	457	399	297	-36	72	35	67
LSD P=0.05			89	NS	NS	NS	
Sum of both years 2000-01				**Spring 2000 to Fall 2001**			
SDI, Control		547	573	-20	-47	-67	41
SDI, 25.4 mm effluent		490	585	-11	-16	-74	-21
SDI, 50.8 mm effluent		833	572	-3	185	182	80
LEPA, 15.2 mm effluent		333	399	-27	-160	-187	122
LEPA, 25.4 mm effluent		490	497	-29	-133	-163	156
LEPA, 50.8 mm effluent		857	556	-31	17	-16	317

[1] Nitrogen balance as defined here is the total applied nitrogen minus the total of the quantity, above-ground biomass N uptake plus the soil residual nitrogen in the upper 2.4 m soil profile. Positive values indicate losses primarily through volatilization or leaching, while negative values indicate increase in recovered nitrogen, probably due to mineralization that was not accounted for in the analysis.

In 2001, there was a stronger trend towards higher crop N uptake with SDI and the lower 0.6 inch effluent LEPA application had significantly lower crop N uptake. There were no differences in plant uptake for the SDI treatments, probably a good indicator of N sufficiency in the soil profile, but plant uptake increased with higher rates of effluent for the LEPA treatments, probably indicating some N losses due to volatilization or possibly leaching. The principal source of nitrogen in the swine effluent at application time is ammonium nitrogen, which is subject to rapid volatilization losses when applied to the soil surface under hot weather conditions. The application of the effluent subsurface with the SDI system would have reduced or eliminated such losses.

There were no statistically significant differences in the change in residual soil N levels between any of the sampling periods, but there was a trend towards slightly lower losses of both ammonium nitrogen (NH4-N) and nitrate nitrogen (NO3-N) with SDI than with LEPA (Tab. 3). As effluent application increased to the highest level, soil residual N actually increased in storage for the SDI treatment (181 kg N/ha) and was only a small loss (16 kg N/ha) for the LEPA treatment when compared over the entire study period.

A comparison of the nitrogen balance of applied minus recovered nitrogen (Tab. 3) indicates that SDI recovered more nitrogen in plant uptake and the residual N than LEPA. When examining the total study period, the 25.4 mm effluent application with SDI resulted in 21 kg/ha additional N being recovered than was applied while the same effluent application on the LEPA treatment resulted in losses of 156 kg N/ha. This further supports the statements about increased volatilization or leaching losses with LEPA.

Conclusions

These results from the engineering feasibility emitter discharge study show that the drip irrigation laterals used with SDI have potential for use with beef lagoon effluent. However, the smaller emitter sizes normally used with groundwater sources to maximize zone size and length of run may be risky for use with lagoon effluent. Emitter discharge in the range of 1.5 to 2.3 L/hr-emitter performed well over the course of four seasons and resulted in little clogging.

The results from the swine effluent agronomic study indicate that SDI can result in better corn production with less water, less nitrogen volatilization and less leaching than LEPA sprinkler irrigation.

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