NITRATE MANAGEMENT OF WASTEWATER WITH SUBSURFACE DRIP IRRIGATION

C. J. Phene, Consultant in Soil and Irrigation Sciences, SDI+ R. Ruskin, Geoflow Inc.* *Geoflow Inc., 200 Gate Five Road, #101, Sausalito, CA 94966 **ABSTRACT** The use of treated wastewater (WW) for irrigation is subject to concern because of the possible nitrate contamination of domestic water supplies and health hazards from the pathogens in WW. The staff of the Water Management Research Laboratory (USDA-ARS-Fresno) developed a highly efficient irrigation and management method which minimized and sometimes even eliminated the downward movement of soluble nitrate-N below the root zone of field crops. This high frequency subsurface drip irrigation (SDI) system should be ideal for applying WW with minimal potential leaching of nitrate-N, because the nitrification process will be minimized and most NH4+ molecules will be either fixed or adsorbed by the soil or taken up by the deep roots.

The objectives of this paper are to present and discuss the operation of SDI systems, their physical characteristics, and research results defining soil water, nitrate-N and deep rootzone profiles obtained when SDI systems are used specifically related to the management of nitrate in irrigation water or recycled wastewater. Three physical characteristics, unique to SDI, contribute to its advantages and to minimizing nitrate-N leaching: (1). Reduced evaporation; (2) Larger wetted soil volume and surface area than surface drip irrigation (DI); and (3). Deeper rooting. Characteristics 2 and 3 will be addressed here.

The research discussed in this paper demonstrates that SDI shows unique potential for safely using and disposing of WW. In addition to the controlled movement of NO3-N to the ground water (GW), the mere fact that the treated WW does not come to the soil surface adds another safety dimension to the handling of a potentially hazardous material. Key words: Irrigation, nitrate, effluent, wastewater, subsurface, drip, reuse.

INTRODUCTION

Annual increases of food demand forecasts for various regions range from 2.3% (East and South Asia) to 3.8% (West Asia and North Africa). Even when taking account of the potential production of rain-fed agriculture, the irrigated agricultural production sector will need to increase its productivity by 3 to 4% per annum. Presently, in view of the fact that 20-30 Mha of existing irrigated agriculture is facing severe salinity problems, the 3-4% targeted increase will be an almost impossible goal to achieve without significant increases in water conservation, including steps such as reuse of agricultural and urban effluents (Hennessy, 1993).

Secondary and tertiary treated domestic wastewaters (WW) are being used more and more for irrigation of field crops, landscape, groundwater recharge and other applications (Nellor et al.,1985; Brown, 1987; Bureau et al., 1987 and Kirkpatrick and Asano, 1986). Secondary treated WW has even been considered for irrigation of raw-eaten vegetable crops (Kirkpatrick and Asano, 1986; Sheikh et al., 1986). However, the use of treated WW for irrigation is subject to major concerns because of the possible nitrate contamination of domestic water supplies and the occurrence of methemoglobinemia (blue baby disease), as well as health hazards from the pathogens in WW (Broadbent and Reisenauer, 1990).

Health, safety, economics and environmental concerns also play important roles in limiting widespread use of WW (Pettygrove, 1990).

WW usually contains three major forms of N: (1) Ammonium; (2) Organic N; and (3) Nitrate/nitrite. Ammonium (NH4 +)represents the principal form of N in WW (5-40 mg N/L), but in most soil containing significant clay, 4 + can be either fixed by clay particles or temporarily adsorbed by negatively-charged clay and organic colloids. Organic N is readily converted to NH + by the mineralization transformation process resulting from aerobic and anaerobic bacteria activity. A two-step nitrification 4+ to nitrite-N and then nitrite-N to nitrate-N, involving respectively Nitrosomonas and Nitrobacter bacteria. Although these bacteria are present in most soils, their population may be quite low in subsoils and dry sandy soils and their activity may be restricted if the soil temperatures are low (Broadbent and Reisenauer, 1990).

The staff of the Water Management Research Laboratory (USDA-ARS-Fresno) developed a highly water and fertilizer efficient irrigation and management method which minimized and sometimes even eliminated the downward movement of soluble nitrate-N below the root zone of field crops. The method known as deep (0.45 m below the soil surface or deeper) high frequency subsurface drip irrigation (SDI) can achieve minimum leaching if four conditions are satisfied: (1) Irrigation events are short and frequent and designed to replace crop water uptake as closely as possible (no leaching fraction); (2) Nitrogen is applied with the water through the SDI system at a rate equivalent to the uptake rate of the crop less the amount mineralized from the soil; (3) The crop is deep rooted; and (4) the shallow water table is at least 2.0 m from the soil surface. Hence, a SDI system should be ideal for applying treated WW with minimal potential leaching of nitrate-N, because the nitrification process will be minimized and most NH4+ molecules will be either fixed or adsorbed by the soil or taken up by the deep roots

The objectives of this paper are to present and discuss the design and operation of SDI systems, their physical characteristics, and research results defining soil water, nitrate-N and deep rootzone profiles obtained when deep SDI systems are used. The authors will relate how this method can be adapted for irrigation with treated WW.

RESEARCH APPLICATIONS OF SDI FOR MINIMIZING DRAINAGE AND NITRATE LEACHING UNDER INTENSIVE FIELD CROPPING SYSTEMS.

In 1984, a SDI system was installed by the USDA-ARS-WMRL at Five Points, CA (Univ. of California, West Side Field Station). The soil is a Panoche clay loam (*Typic Torriorthents*) with excellent water retention and a depth exceeding 2 m. This SDI system has been in use ever since and is the system used in all the research reported herein.

The experimental design is a randomized block, consisting of three irrigation treatments, replicated four times. Each plot (see Figure 1) contains 10 beds, spaced 1.63 m from center to center and 91 m long. Early in 1984, SDI laterals were installed in one of the three field treatments and in the lysimeter and the other two treatments consisted of surface drip at high frequency and at low frequency and these laterals were installed yearly after the crop was germinated. SDI laterals were trenched at the center of each SDI bed and at a depth of 0.45 m from the soil surface. The laterals are spaced 1.63 m apart and consist of in-line turbulent flow emitters, spaced 1.0 m apart along the laterals and with a discharge rate of 4 L/h (Davis et al., 1985). A large precision weighing lysimeter measured the crop evapotranspiration (ETc) and was used in a feedback mode to schedule irrigation automatically in the SDI treatments after 1 mm of ETc had occurred (Phene et al., 1989).

Each year at planting, N and P fertilizer (11-48-0) was applied at a rate of 112 kg/ha, directly below the seeds. All remaining fertilizers were injected daily through the SDI and surface drip systems with the injection rate of N, P, and K designed to match the crop uptake of each nutrient. Weekly, tissue analyses were used to adjust the injection rates to maintain a sufficient nutrient level for each nutrient (Phene, 1993).

Table 1. Yearly values (12 months) of reference and crop evapotranspiration, precipitation, irrigation, drainage and water use efficiency (WUE) for several crops irrigated by SDI from 1984 to 1990, at Five Points, California.

Crop/year	ET 0mm	Crop ETC& Soil E mm	Precipitation mm	Irrigation Application mm	Drainage mm	WUE*kg/m3

Tomato 1984	1,823	959	104	692	0**	2.20
Tomato 1985	1,720	855	127	792	59	2.41
Cantaloupe1986	1,701	863	167	552	90	1.81
Tomato 1987	1,657	793	187	658	36	3.88
Cotton 1988	1,583	979	205	694	83	3.13
Sweet Corn 1989	1,514	693	86	667	2	2.92
Tomato 1990	1,618	875	145	773	38	2.41
MEANS '84 - '90	1,659	860	146	689	44	2.68

* WUE defined as total above-ground dry matter irrigation water applied ** In 1984 the initial water content of the lysimeter was relativley low due to drying down by the previous crop.

During the ten year period from1984 to 1993, this SDI system was used intensively to grow many field crops, often achieving extremely high water use efficiency. The same experimental design was used until the end of the 1990 cropping season. Basic ET, precipitation, irrigation, drainage and water use efficiency data are shown in Table 1. In 1991, the field was fallow; in 1992, the two surface drip irrigated treatments (HFDI and LFDI) were converted to two SDI treatments, installed at 0.30 m and 0.60 m depths and the original SDI system installed at 0.45 m in 1984 was maintained as the original treatment. Wheat was grown in 1992 and cotton in 1993.

A. General SDI design characteristics and operation criteria.

The design and operation of subsurface drip irrigation systems differs only slightly from that of standard drip systems except for three important criteria: (1) Backflow preventers and vacuum relief valves must be installed at several locations, principally at the highest elevation points of the system; and (2) SDI systems require frequent flushing of the mains, submains and laterals, especially during their first 6 months of operation; and (3) Because the root systems of crops irrigated via SDI are usually located deeper in the soil profile than for crops irrigated by surface drip systems, fertility management becomes more critical since the rootzone will extend into soil lacking many nutrients.

The SDI systems also need to be irrigated very frequently but that is also true of surface drip systems. However, for SDI systems which are not using trifluralin-impregnated emitters, the frequent irrigation with simultaneous continuous injection of phosphoric acid and yearly injection of fumigant (sodium Metham) has been shown to be necessary to prevent emitter plugging and root intrusion of field crops for up to ten years. Perennial crops should use the trifluralin-impregnated emitters or other herbicide application techniques since fumigant injection is not possible.

B. Unique Physical Characteristics of SDI Systems.

Three physical characteristics, unique to SDI, contribute to the advantages of this method and to minimizing nitrate-N leaching: (1). Reduced evaporation component of ETc; (2) Larger wetted soil volume and surface area than surface drip; and (3). Deeper crop rooting patterns than surface drip. For the purpose of treated WW reuse, characteristics 2 and 3 are extremely important and therefore, they will be addressed here.

1. Large Wetted Soil Volume

One of the most obvious physical advantages of SDI over surface drip (DI) is the wetted soil pattern generated in the soil profile. Phene et al. (1989, 1990), Ben-Asher and Phene (1993), and Phene (1993), have shown that for a given discharge rate of water, (1) the spherical volume of a wetted clay loam soil is approximately 46% larger for the SDI system than the hemispherical volume wetted with a DI system (2) the corresponding wetted surface area available for root uptake is 62% larger in the SDI system than in the DI system (excluding the soil surface in the surface drip pattern) and (3) the wetted radius is 10% shorter in the SDI than in the DI system (see Figure 2). The implications are that under similar irrigation conditions: (1) the wetted soil volume in the SDI system will be at a lower water content than in the DI system and the leaching potential will be lowered, (2) the surface area of soil available for root uptake of water and nutrients will be increased greatly in the SDI system and (3) the shorter wetted radius in the SDI system will allow closer emitter spacing than in the DI system, resulting in improved wetted uniformity.

2. Deep Rooting Pattern

Hybrid sweet corn (*Zea mays L.*, cv. Supersweet Jubilee) was grown during 1989 in the field plots described above. Figure 3 shows the covariance curves plotted to show differences in root length densities (RLD = the root length per unit volume of dry soil) between high frequency DI (HFDI) and SDI (RLD*HFDI* - RLD *SDI*)(Phene et al., 1990). The solid line represents the treatment differences in RLD and the dashed lines represent the 95% confidence band about the treatment differences. From the soil surface to a depth of 0.2 m the RLD of the Figure 1 and Figure 2sweet corn grown under HFDI was greater than that in the SDI treatments. However, the RLD of sweet corn grown with the SDI system was greater than that grown under the HFDI treatment from a depth of approximately 0.2 m below the soil surface to nearly 1.9 m depth. Similar rooting patterns have been characterized for cotton and tomato and in general it was found that the maximum RLD occurs at the depth of the water source, at least down to 0.60 m.

C. Minimizing Deep Percolation And Nitrate-Nitrogen Leaching

In 1987, Phene et al,. used the weighing lysimeter to measure evapotranspiration of a SDI irrigated tomato crop (Phene et al., 1998). In this experiment, the water supply rate (I) was equal to the sum of soil evaporation (E), plant transpiration (T) and deep percolation (D) less precipitation (P) and water was applied as often as 1.0 mm/h as measured by the mass change of the weighing lysimeter. In this study, a shallow water table was maintained at a depth of two meters. This caused a slight upward hydraulic gradient from the water table. The soil matric potential (SMP) of the Panoche clay loam soil was measured hourly at depths of 0.15, 0.30, 0.70, 1.00, 1.55 and 2.00 m and the crop lysimeter was irrigated by an SDI system with the drip lateral installed 0.45 m deep. Figure 4 shows the hourly SMP for a 24-hour period in the lysimeter with a mature tomato crop. Irrigations (1.0 mm/h) are shown by the arrows located on the horizontal time axis. Figure 5 shows the calculated mean daily SMP from hourly measurements for a period of 30 days. These data indicate that the SDI system maintained a nearly constant daily and seasonal SMP profile and a net upward hydraulic gradient (_H/_Z); where _H is the hydraulic head and _Z is the vertical distance between measurement points.

Figure 6 shows the SMP profile and the direction of _H/_Z for day 195 of 1987. These data indicate that except directly below the drip lateral, between soil depths of 0.45 and 0.70 m, _H/_Z is upward everywhere else. Therefore the net flux of water and salts is upward and deep percolation losses can either be prevented or controlled. By using this high frequency SDI management approach with salt-tolerant crops we can also force the plant to utilize a significant volume of water from the water table and thus help temporarily and locally control the water table level without drainage outflow.

Figure 7 shows the soil NO3-N concentration profile, before and after a cotton crop in 1988. These data indicate that deep rooted crops, such as cotton, tomato and corn, can actually extract NO3-N from the deep soil profile during the season (Phene, et al., 1990). In 1988, most of the drainage from the lysimeter occurred early in the season, following the unusually high rainfall for this location (205.7 mm, the long term mean is 150 mm), and before the application of NO3-N to the irrigation water. At the end of the season, a large increase in NO3-N concentration also occurred near the soil surface resulting from the extremely large amount of dry matter which decomposed in the top 0.30 m (Phene, 1993). Calculations of N uptake by the crop indicated that approximately 80 kg/ha of N was taken up from the soil in addition to the 250 kg/ha applied N.

The research referred to in this paper was done on Panoche Clay Loam soils. Other research not discussed here and commercial experiences on lighter texture soil (such as Hanford Fine Sandy soil) indicate that with closer emitter and lateral spacings, similar results can be achieved.

D. Economics and Capital Costs

Total permanent SDI installation costs (including in-field filtration) range between $2,000 and $4,000 per hectare. A typical SDI system is also expected to last at least ten

Figure 3 and Figure 4

Figure 5 and Figure 6

years when managed properly. In addition to the precise control of nitrate movement, SDI also provides a substantial reduction of potential health risks, both to the grower and to the consumer of edible crops. With SDI, it is practical to use filtered secondary treated water (Oron et al., 1991). With sophisticated real time monitoring and control of the field equipment, it may even be practical to use filtered primary treated effluent. Thus, the savings in capital cost of water treatment plants may be several times the cost of the sophisticated SDI system.

FUTURE RESEARCH PROJECTS

California State University at Chico is installing a 2 ha. plot to use the treated effluent from a swine feed lot to grow alfalfa. The second stage will be to extend the experiment to 10 ha. using additional effluent from a dairy.

California State University at Chico is also installing a SDI system using treated human effluent on turf with the purpose of testing the percolation of nitrates into the ground water.

Geoflow and Woodward-Clyde International, Asia-Pacific Office have developed a technique to use primary treated effluent (Geoflow, 1994). The whole system is monitored and controlled by a Programmable Logic Controller (PLC) with real time communication to the engineer's office. When a flow reduction is sensed, the system is automatically flushed and pressure increased by bypassing the pressure regulator. In the event of any flow decrease due to bacterial slime, fresh water and chlorine are automatically injected into the system, allowed to remain in the line for 40 minutes of contact time and then flushed out with either fresh water or WW and acid.

The authors anticipate reporting on the first results of these trials at WEFTEC 1997.

CONCLUSION

These combined results demonstrate the potential of the SDI method for minimizing non-point source agricultural pollution with NO3-N. Although drainage outflow can be reduced greatly and the soil ECe in the root zone is tolerable for most field crops, this practice may not completely eliminate the need for drainage to sustain the long term salt balance of irrigated agriculture in arid regions (van Schilfgaarde, 1990).

The SDI method shows some unique and economical potential for safely irrigating field crops with treated WW. In addition to the controlled movement of NO3-N to the ground water, the mere fact that the treated WW does not come to the soil surface adds another safety dimension to the handling of a potentially hazardous material. In locations where year around cropping is possible, continuous dispersal could be carried out without requiring major storage facilities.

However, during the winter months when ET is low, some reservoir might be required to store the excess WW not evapotranspired by the crop. Because of the relatively low N concentration, this dispersal method could be used with a deep rooted crop such as alfalfa, using a SDI system installed at 0.60 m or deeper. When the active root system of alfalfa is 0.5 m deep, the nitrogen fixation process may be impaired and the frequent injection of N is needed to produce good quality alfalfa and high yields. USDA-ARS-WMRL research results with SDI for alfalfa have shown that this method is indeed feasible, conservative and sustainable.Figure 7 and Figure 8

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