Subsurface Drip Irrigation

Increased Yield, Quality and Water Use Efficiency of Alfalfa

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Research Overview

Forage alfalfa is a major crop in many Western States of the USA, including the Imperial Valley of California where about 100,000 ha of alfalfa is currently grown. In Imperial County alone, the alfalfa economic value often exceeds US$170 million per year. In arid and semi-arid areas with a long growing season where alfalfa can be grown as a perennial crop, alfalfa requires a large amount of irrigation water. The annual evapotranspiration of desert-grown alfalfa has been estimated to be in excess of 1,900 mm/year.

Experiments to investigate practices and problems with long-term management of alfalfa with subsurface drip irrigation (SDI) were initiated at the Irrigated Desert Research Station in the Imperial Valley of California in 1991 by the USDA-ARS Water Management Research Laboratory, Fresno, California. This research project was partially funded by the Imperial Valley Conservation Research Center Committee (IVCRCC), the Imperial Irrigation District (IID) and the Metropolitan Water District of Southern California (MWD). The objectives of this project were to develop crop-specific guidelines for Best Management Practices (BMPs) of SDI systems for alfalfa, including system design criteria, identifying optimal irrigation and fertigation practices, crop water use and soil salinity patterns under SDI systems and developing crop coefficients (Kc) for use with standard state-provided reference evapotranspiration

Research Site and Methodology

1991-1992 Systems - The experiment was located on a 2.83 ha field at the USDA-ARS, Irrigated Desert Research Station (IDRS) in Brawley, CA. The soil was a Holtville silty clay; the irrigation treatments were statistically selected and replicated three times and the numbers and widths of beds in each plots are defined in ***Table 1***.

All SDI laterals were installed at 0.41 m depth, directly below the center of each bed, they used turbulent flow type emitters with discharge rates of 2 L/h at 1.41 kg/cm2 and 20 mm wall thickness; RAM-40 and RAM-80 emitters were pressure compensated. All beds were 160 m long.

1993-1995 Systems - These SDI systems used identical laterals as used in the 1991-1992 systems, except that they were installed at about 0.70 m depth. The furrow system was identical to the 1991-1992 furrow system.

The irrigation water came from the Colorado River with the following water quality:

- Electrical conductivity (ECw) at 25C: 1.15 dS/m.
- pH: 7.4 - 7.7.
- Boron: 0.13 - 0.25 mg/L.
- SAR: 5-7.

TABLE 1 *Irrigation treatment identification and specifics.*

Irrigation Treatments	Number of Beds	Bed Width (m)
SDI – Ram-40 (Netafim)	8	1.02
SDI – RG-40	8	1.02
SDI – Ram-80 (Netafim)	4	2.04
SDI – RG-80	4	2.04
Furrow	16	1.02

The water was delivered to a reservoir, pumped and filtered through a dual sand media filter with an automated backflush and an in-line screen filter (200 mesh). The water was acidified to a pH of 6.5 by injection of N-pHURIC and phosphoric acid at 15 mg P/L. The injections were performed with a flow proportioning injection pump to maintain constant pH or concentration of phosphoric acid. Flowrates and pressures were monitored continuously with electronic flowmeters and pressure transducers which were connected to a datalogger/computer system and monitored remotely in Fresno via telephone modem.

A gated pipe system was used to supply the furrow irrigation system. Water to each plot was metered through a totalizing flowmeter and applied through a 200 mm gated pipe system. Flowrates were adjusted to avoid tailwater and to keep applied water within the harvest area. After each harvest, the soil in each furrow was shanked to a depth of 50-75 mm to break up the soil crust and improve infiltration.

In all the plots, alfalfa was germinated in April 1991 with uniform sprinkler irrigations totaling 164 mm of water. Harvest timing was scheduled based on flowering and crown regrowth. The harvest was performed with commercial harvest equipment such as a swather, rake and wire baler on the two middle beds in the RAM-80 and RG-80 to insure that the bed borders were not influenced by the other treatments. All beds were harvested in all the other treatments and all 160 m of beds were harvested in all plots. First harvest in 1991 was in late June. All yields were adjusted to constant water content.

TABLE 2 *Water applied in 1991, 1992 and 1994 to all treatments and the weighing lysimeter.*

Irrigation Treatments	Water Applied (mm)			
	1991 April to November	1992 January to November	1994 January to December	Totals*
Mean of All SDI Treatments	1174	1365	1900	4603
Furrow Treatments	1310	1491	1900	4865
Lysimeter	1305	1744	1800	4849

*Includes 164mm of sprinkler irrigation in 1991.

Commercial Demonstration - Recently, a commercial SDI system was tested using Netafim's Typhoon thinwall dripperline, 13 mil wall thickness, with emitters spaced 0.60 m and with a flowrate of 1.51 L/h. These laterals were installed in two blocks, each of 8 ha in area, at 0.3 m depth in one block and at 0.6-m depth and with laterals respectively spaced 1.0 and 1.5 m. SDI laterals were 345 m long and connected to input manifolds at the top end of the field and to flushing manifolds at the bottom end of the field. The alfalfa was planted on the flat (no bed) early in 1997 in the 0.3-m depth block and early in 1998 in the 0.6-m depth block and in both cases, flood irrigation was used to germinate the seeds. Each of these two separate systems was used to irrigate 4 ha of forage and 4 ha of seed alfalfa in the high desert of Nevada where three or four forage cuttings are usually possible. These SDI systems were monitored and controlled by a commercial, real time irrigation monitoring and control system, using evapotranspiration inputs based on an automated evaporation pan and electronic soil moisture sensors. Irrigations were automatically scheduled every time one mm of evapotranspiration was calculated using a crop coefficient (Kc) and the evaporation from the screened evaporation pan. Flows, pressures, pH and ECw were monitored continuously during irrigation. The pH of the water was automatically maintained at 6.5 by injecting sulfuric acid first, then phosphoric acid and potassium nitrate with a flow proportioning injection pump.

TABLE 3 *Mean SDI alfalfa forage yields, furrow yields and percentage SDI yield increases over furrow yields for 1991, 1992 and 1994.*

Irrigation Treatments	Yields (ton/ha)			
	1991 April to November	1992 January to November	1994 January to December	Totals*
Mean of All SDI Treatments	11.10	23.38	16.81	51.29
Furrow Treatments	8.05	19.82	12.10	39.97
SDI Percent Yield Increase	37.89	17.96	38.93	28.32

Results

Irrigation Scheduling, Water Applied and Evapotranspiration

Irrigation Scheduling, Water Applied and Evapotranspiration - A precision weighing lysimeter, 3 m x 3 m in surface area and 1.5 m deep was irrigated by three SDI laterals with similar design as the RG-40 SDI system in the field. The lysimeter was used to measure the actual evapotranspiration (Etc) of the alfalfa and to provide the Etc variable for the control system. Every time one mm of Etc was measured by the lysimeter, the control system initiated, on the hour, a one mm irrigation in each of the SDI systems in the field and in the lysimeter (the irrigation period for the RG & RAM-80 was twice as long as those for the RG & RAM-40 treatments). The furrow irrigation was irrigated based on neutron probe determination of a soil water balance, with a typical application ranging from 37 to 55 mm, depending on the soil water status, the infiltration rate and the time within the cutting cycle. Most of the time, the furrow irrigation was limited either by the low water infiltration or the forage-cutting schedule. ***Table 2*** shows the total water applied for partial years in 1991 and 1992 and for a full year in 1994. Since there was no runoff, no deep drainage and no increase in soil water content, all the water was used in the evapotranspiration process and all systems were operated at a very high efficiency. This could be achieved with the furrow irrigation system because of the relative flat and short furrows and the very low infiltration rate, which limited the amount of infiltrated water to that of evapotranspiration or less.

TABLE 4 *1994 forage alfalfa yield responses of SDI (brands and lateral spacings) versus furrow treatments and respective percentage yield increases.*

SDI Yield (ton/ha)	Furrow Yield (ton/ha)	% Yield Increase Over Furrow
All SDI 16.81	12.10	38.93
All Geoflow 16.43	12.10	41.98
All 1.02m SDI 15.86	12.10	35.79
All 2.04m SDI 16.81	12.10	31.07
All SDI 17.78	12.10	45.94

Yields - Mean SDI yields and furrow yields for 1991, 1992 and 1994 are shown in ***Table 3.*** In 1991, although not statistically different, the RAM-40 and RG-40 yielded 17% more than the RAM-80 and RG-80 and 33% significantly more than the furrow plots. However in 1992, during the second year, the RAM-80 and RG-80 treatments yielded 2% more than the RAM-40 and RG-40 and 19% more than the furrow plots. Similarly in 1994, the same trend continued ***Table 4.*** Since there was no significant difference between the 40 and 80 treatments, all SDI treatments were averaged together. In 1991, 1992 and 1994, their mean yields were respectively 37.89, 17.96 and 38.93% greater than the furrow plots.

TABLE 5 *Alfalfa quality factors for 100% dry alfalfa, obtained after the May 1994 harvest.*

	SDI - 40	SDI - 80	Furrow
Crude Protein (%)	36.92	21.85	18.37
Crude Fiber (%)	19.65	30.14	29.55
Mod. Crude Fiber (%)	20.18	33.21	33.46
Total Digestible Nutrient (%)	60.50	52.70	51.90
Estimated Net Energy (Kcal/lb)	510	435	422

Effects of Brands of Drip Tubes and Lateral Spacings in 1994 - The effects of brands of drip tubing and lateral spacings on yields are shown in ***Table 4*** for 1994. This data show that there was no significant difference between the two brands of drip tubing. However the considerable trends of yield increases for the RAM-80 and the RG-80 over the corresponding RAM-40 and RG-40 were not always significant but averaged 12.11% for the whole season.

In 1994, the RAM-80 and RG-80 plots greatly out-yielded the furrow plots from the beginning ***(Table 4).*** Since this was the crop's first year,

continued on reverse

harvests did not start until the end of March and in the subsequent year, one could expect at least one or perhaps two additional harvests. Although all plots were harvested on the same dates, there were some cases were the SDI plots could have been harvested from 3-5 days earlier than the furrow plots, indicating a potential for an extra harvest each year. Because the deeper SDI system does not require stopping irrigation before and during harvest, the alfalfa regrowth can be speeded up. Data for 1995 are not available for analysis at this time. However, as shown in the quality data presented in *Table 5* and discussed in that section, there is a loss in quality associated with the wider spacing, which may affect the economics significantly.

Alfalfa Quality - Alfalfa was sampled for quality from representative and replicated bales, at different times of the year, starting in 1994. The samples were sent to a commercial laboratory for analysis of percentage of crude protein, crude fiber, modified crude fiber, total digestible nutrients (TDN) and estimated net energy (ENE), based on 100% dry matter. *Table 5* gives results for one set of representative samples obtained one day after harvest in May 1994. These data indicate that the SDI-40 has 101% increase in crude protein over the furrow plots and 68.97% over the SDI-80. For the TDN and ENE, the SDI-40 percentage increases were respectively 16.57 and 20.85% over the furrow samples and 14.80 and 17.24% over the SDI-80. Economically, the gain achieved by using the 2.04-m lateral spacing over the 1.02-m spacing may have been lost because of lower alfalfa quality.

Water Use Efficiency - Water use efficiency can be increased by either increasing the yield, reducing the water evapotranspired, or both. *Table 6* gives the calculated WUE for the mean of all SDI plots and the furrow plots for 1991, 1992 and 1994 and the percentage increases for the WUE of the SDI plots over the furrow plots. The overall increase in WUE for the three seasons was 35.52% and very significant. The implication is that by achieving a combination of yield increase and reduced water use, a 35% water use reduction can be obtained without loss in yield or quality.

Commercial Applications - In the commercial application described above, the forage yield increase generated by the SDI system planted in 1997, was approximately 20% compared to similar flood irrigated alfalfa. However, the seed yield was nearly doubled (93.75%). It is difficult to calculate accurate water savings since the water applied to the flood irrigated plots is not metered. However, based on coarse time estimates, the water applied to the SDI block was decreased by approximately 50% from the amount applied to the flood block. The alfalfa was re-planted late in the 1998 block and germination was difficult so that no realistic yield data were obtained in 1998. Towards the end of this short season, the 1998 alfalfa was growing well and the stand was very uniform. Presently, the seed alfalfa in both blocks is starting to bloom and the seed yield should be impressive again. So far gophers have caused one of the major problems and the problem is much worse in the shallow SDI block than in the deep SDI block. Over 100 leaks had to be repaired in the shallow laterals versus 3 leaks in the deep SDI laterals.

TABLE 6 *Mean SDI alfalfa water use efficiencies (WUE), furrow WUE and percentage SDI WUE increases over furrow WUE for 1991, 1992 and 1994.*

Irrigation Treatments	Water Use Efficiency (kg/m³)			
	1991 April to November	1992 January to November	1994 January to December	Totals*
Mean of All SDI Treatments	0.945	1.713	0.885	1.114
Furrow Treatments	0.615	1.329	0.637	0.822
SDI Percent WUE Increase	53.66	28.89	38.93	35.52

Conclusions

Several years of research and demonstration on the use of SDI for irrigating alfalfa have provided some knowledge on the potential for achieving large increases in WUE for this crop without reducing yield or quality. The increase in WUE resulted from the combination of yield increase (28.32%) and a small decrease in water application (6%) when compared to short furrow irrigation in a soil with a very low infiltration rate. Under less ideal furrow or flood irrigated conditions, the decrease in water application would be more significant, as demonstrated with the commercial system. There does not seem to be any yield decrease by using 2.04 m lateral spacing compared to 1.02 spacing but the quality factors seem to be lower in the wide spacing than in the 1.02 m spacing, at least during the first year. Therefore, the economic gain achieved by reducing the cost of the SDI system may be offset by the loss in quality. Based on the research and commercial results, installing the SDI laterals as deep as possible, seems to be an important management practice to minimize the wetting near the soil surface, to minimize soil compaction by the harvesting equipment and to minimize the potential rodent damages in light soil. In order to achieve the stated benefits, SDI requires the use of high frequency irrigation and accurate management of fertility. In addition, seed germination and management of soil salinity will also require the use of sprinkler or flood irrigation systems. The always-great potential for emitter plugging from particulate matter, biological slimes, chemical precipitation and/or root intrusion must be carefully considered starting with adequate system design, proper installation and continuous and preventive management of the water and chemicals.

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