SUBSURFACE DRIP AND FURROW IRRIGATION COMPARISON WITH ALFALFA IN THE IMPERIAL VALLEY

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ABSTRACT

A subsurface drip irrigation (SDI) and furrow irrigation study was installed in a silty clay loam soil at the USDA-ARS Irrigated Desert Research Station near Brawley, CA in early 1991 to evaluate the potential for water savings and yield improvements with subsurface drip irrigation of forage alfalfa as compared to furrow irrigation. In bed-planted alfalfa, subsurface drip lateral spacings of 1.02 m (40 inch) and 2.04 m (80 inch) installed at an average depth of 40 cm below bed centers were investigated beginning in 1991. During the first one and one-half year operation, approximately 20 percent higher yields were achieved in the drip plots with 94 percent of the water application amounts used in the furrow irrigated plots. Problems with surface soil wetting were noted in all drip treatments during the 1991-1992 phase (Phase I) of the experiment. These problems resulted in the decision to reduce water applications during a "dry-down" period during each harvest cycle to allow for harvest equipment traffic while limiting potential for soil compaction and plant damage from equipment. To provide an alternative method to deal with the surface soil wetting, the alfalfa crop was terminated in late 1992, the drip system replaced at 63 to 70 cm (25 to 28 inch) depth, alfalfa replanted in 1993, and the system operated in subsequent years. During this second phase (Phase II), applied water and evapotranspiration were similar (within 5 percent) in drip and furrow irrigated plots, while yields averaged between 19 and 35 percent higher in subsurface drip irrigated plots during the 1993 through 1996 period. Problems with surface soil wet areas were nearly eliminated with the deeper drip lateral placement during the 1993 through 1996 period. Additional work was conducted to determine long-term impacts of long-term drip system operation on patterns of salt accumulation using Colorado River water.

Key Words: alfalfa, drip irrigation, furrow irrigation, lysimeter, evapotranspiration, subsurface drip irrigation, water conservation, salinity

INTRODUCTION

In the arid and semi-arid western U.S., irrigation is required to achieve economic alfalfa yields, and as a perennial crop with a potentially long growing season, alfalfa can use a large quantity of irrigation water. Alfalfa production in Imperial County, CA alone was valued at in excess of $170 million in the early 1990's, with over 100,000 ha in production at that time. Increasing

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competition for limited water supplies during droughts in CA have focused concern on crops that are commonly perceived to be "high water users". Alfalfa certainly has attributes that can put it into this water use category, with numerous reports available which have estimated annual evapotranspiration in desert regions at or in excess of 6.5 feet (1900 mm) (Donovan and Meek, 1983; LeMert, 1972; Joy and Dobrenz, 1971; Erie et al., 1969; Lehman et al, 1968).

Studies of the early 1990's at a number of location have indicated the potential for drip irrigation to conserve water while maintaining or enhancing yields (Phene et al, 1991; 1992a; 1992b). Surface installation of drip laterals are impractical in a crop such as forage alfalfa due to dense plantings and repeated harvesting operations. For these reasons, interest developed for evaluation of permanently-installed subsurface drip irrigation systems for use in alfalfa. As of the initiation of the experiment in 1990, the authors were only aware of one previous research effort to evaluate subsurface drip irrigation in alfalfa, and that was in Israel (Gideon Oron, personal communication). Since that time, several field demonstrations and grower installations have been put in place and operated in several western U.S. states. The project reported on here covers the field data collection from the 1991 through 1996 period in a project conducted in the Imperial Valley of California. This experiment focused on the comparison of crop responses, irrigation water requirements and salt accumulation as affected by subsurface drip versus furrow irrigation. In addition, the influence of two drip tubing types and two lateral spacings (40 inch versus 80 inch) were evaluated.

PROCEDURES

Descriptions of the experiment will be divided into two phases, with both phases conducted at the same experimental site near Brawley, CA: (1) Phase I – planting in April, 1991 through termination of the first planting in December, 1992; and (2) Phase II – replacement of drip tubing at a deeper installation depth in spring of 1993, followed by Sudangrass as an intermediate crop, replanting of alfalfa in November, 1993 and production seasons in 1994 through 1996.

Phase I: A 7 acre field in a Holtville silty clay loam was the experiment site at the USDA-ARS Irrigated Desert Research Station. There were two drip lateral spacing treatments, with 1.02 m (40 inch) and 2.04 m (80 inch) bed widths, with subsurface drip laterals placed 40 cm below each bed center. Two different types of drip tubing were used within each lateral spacing treatment: (a) pressure-compensating in-line emitters on 20 mm tubing ("RAM" in Table 1); and (b) turbulent-flow in-line emitters made out of herbicide-impregnated plastic ("Rootguard" in Table 1). Both emitter types had a nominal flow of 2 L/hr at 18 to 20 lb/in^2, with emitters spaced 1.02 m apart on the laterals. Initial phosphorus and potassium fertilizer applications were made (450 kg K20/ha and 90 kg P205/ha) prior to planting to assure these nutrients as non-limiting. Similar applications were also made prior to the second phase (Phase II) of the experiment.

Treatments were designated as shown in Table 1. Plot size in the 1.02 m bed width treatments was 8 beds in width by 160 m (525 feet), while 2.04 m bed width treatments were 4 beds in width by 160 m length. Scalding problems are a common concern associated with high summer temperatures and aeration problems during flood irrigation in alfalfa in some soils in desert regions such as the Imperial Valley. To reduce potential for scalding problems and stand losses, alfalfa was planted on beds in the furrow irrigated treatments. To maintain uniform evaluation conditions for comparison purposes, subsurface drip plots were also planted on beds.

Table 1. Subsurface drip and furrow irrigation treatments – phase I of alfalfa experiment.

Treatment Number	Subsurface Drip Lateral Spacing And / or furrow spacing (inches / meters)	Type of Drip Emitters used
T1	40 inch / 1.02 m	Ram
T2	40 inch / 1.02 m	Rootguard
T3	80 inch / 2.04 m	Ram
T4	80 inch / 2.04 m	Rootguard
T5	Furrow irrigated – 40 inch	N / A

Drip system installation was completed in March, 1991 and the crop planted April 2. About 230 mm of post-plant irrigation was applied to all treatments using sprinklers in order to achieve acceptable germination and establish the crop. Drip irrigation was initiated and the first furrow irrigation applied in late-May of that year. The water supply was Colorado River water, collected in an on-site reservoir. The irrigation water used in the study had an average electrical conductivity of 1.15 dS m^{-1}, boron = 0.13 to 0.31 mg/L; pH of 7.4 to 7.7, bicarbonate concentration of 2.2 to 2.7 mmol L^{-1}, Ca = 80 to 125 mg/L; Mg = 30 to 37 mg/L; and chloride concentrations of 2.5 to 3.6 meq L^{-1}. For use in the drip system, water was filtered through an intake screen, dual sand media filter with automatic backflush and a 200-mesh screen filter. Media filters were flushed daily, and main lines and laterals were flushed weekly. Phosphoric acid was injected continuously to achieve a final concentration of 15 mg P/liter in applied water. Chlorine treatments were administered on approximately a weekly basis by applying chlorine during injection of N-phuric acid during the injection period. Treatment applications were designed to lower water pH below 5.5 during the chlorine injection period of about 1 hour per week, resulting in free chlorine concentrations ranging from 14 to 18 mg /L during injections.

Analog water meters and pressure gauges were read periodically on all treatments, and drip treatments were operated at pressures of 16-21 lb/in^2. All furrow and drip water applications are measured using calibrated water meters, and sprinkler water application estimates are based on operating pressure, sprinkler output and operating time. A 3 m by 3 m by 1.5 m deep weighing lysimeter irrigated via subsurface drip irrigation was located in the center of the field. The lysimeter was planted with alfalfa, and served as both an evapotranspiration (ET) measuring device and as an irrigation controller, with a 1 mm irrigation initiated in the lysimeter and in treatments T1 through T4 following each 1 mm of measured lysimeter crop evapotranspiration. This high-frequency, low-volume application was used in all SDI plots, with multiple water applications per day on typical warm or hot irrigation days.

The original intent with SDI system management was to supply water to the main field to fully match evapotranspiration as measured using the lysimeter, and this approach was followed through 1991. Surface wet areas were noticed in limited parts of the plots (estimated at 2 to 3 percent of total bed area). For this reason, irrigation water applications in SDI plots were scaled back to 25 to 50 percent of crop Etc during the period 4 to 6 days prior to each harvest through bale removal period to facilitate surface soil drying and limit problems with harvest operations and soil compaction.

Furrow irrigation was through a gated pipe system, with water applications measured using a water meter on each field replicate. Irrigation water was applied without tailwater, and flow rates were adjusted during irrigation as necessary to keep applied water within the harvest area for each plot. Typical water applications during each individual irrigation in the furrow-irrigated plots ranged from 2.5 to 4.2 inches (37 to 55 mm), with the amount varying due to prevailing soil water status and infiltration during different parts of each season. Mr. Dean Currie of Stephen Elmore Farms cooperated by assisting with recommendations for furrow irrigated plots (soil water balance calculations and hand soil sampling) to better match furrow plot irrigation scheduling with typical Imperial Valley alfalfa water management practices on similar soils. Following each harvest, a shank was pulled through each irrigation furrow at a shallow depth (2 to 3 inches / 5 to 8 cm) to break up surface soil and improve water infiltration.

Alfalfa harvests were done using commercial-type swather, rake and baler. Harvest results are based on the total plot area, with all bales counted, individually weighed in the field and corrected to equivalent water content. The timing of alfalfa harvests was determined based upon observation of crown regrowth and flowering. Percent flowering was found to be difficult to use for determining harvest schedules during some parts of the season due to variability in the degree of flowering which corresponded with initiation of regrowth. Therefore, a combination of morphological observations was used to determine harvest timing.

Access tubes were installed in two locations per plot, three to six replications per treatment with soil water content measured by neutron attenuation. Soil samples were collected to a depth of 2.5 m in all plots once per year (in October / November) to assess the long-term impacts of irrigation practices on accumulation of salts and other chemical constituents. Additional soil samples were collected multiple times per year to a depth of 0.75 m to assess salt accumulation in the upper parts of the plant root zone.

Phase II: The basic reasons for the system modifications in 1993 were problems with development of "wet' and "dry" soil surface areas in beds within the field (about 2 to 3 percent of the total bed area affected. The lateral installation depth in Phase II was 63 to 70 cm (25 to 28 inches) below the average soil surface. Laterals were placed below the center of each bed, on beds 1.02 or 2.04 m width, as in Phase I. The same two types of drip tubing were used as described for treatments in Table 1, and the same treatment numbering was used as described for Phase I. The second alfalfa crop was also established using sprinkler irrigation of about 135 mm. The lysimeter was modified, with the subsurface drip system re-installed at the deeper depth. Unlike Phase I, during Phase II all drip irrigation treatments received water at the same time as the lysimeter throughout each harvest cycle. Unlike Phase I, there was no reduction in applied water during the period prior to harvest through bale removal. This resulted in treatment water applications which were much closer to lysimeter applications.

RESULTS AND DISCUSSION

Phase I:

System Operation. The most persistent problems with the subsurface drip treatments were the development of “wet” and “dry” areas within the field, with the total area affected between 2 and

3 percent of the bed area during this phase. It was determined that the "wet" areas resulted from the high capillary movement of water within this clay soil in combination with too shallow (40 cm / 16 inch) drip lateral placement. After the initial soil wetting in these areas, any heavy equipment traffic resulted in compaction and damage to plant crowns and water movement in these areas tended to be a recurrent problem. To limit compaction, irrigation in the drip plots was scaled down to 25 to 50 percent of lysimeter application amounts during the last 4 to 6 days prior to harvest, and kept at reduced levels through bale removal. This irrigation at reduced quantities resulted in localized drying of the wet surface areas and reduced further problems. However, plant water stress associated with this "drying" period was routinely measured during this dry-down phase (using infrared thermometer and the Crop Water Stress Index (CWSI) approach) as exceeding 0.16 to 0.25 compared with 0 to 0.05 in the lysimeter (data not shown), indicating mild but significant water stress with this approach.

In addition, some malfunctioning emitters (20 to 35 in the field) with excessive flow rates contributed to the problem. The excessive flow rate problems were quite limited but were all found in the "Ram" drip tubing. The "dry" areas were extremely limited in the amount of area affected (less than 0.5 percent of the bed area). Evaluations indicated the causes of "dry" areas were missing emitters (in about 20 percent of the "dry" problem areas in the "Ram" drip line) and fine silt deposition caused by filtration problems in the remaining areas. Root intrusion was not a significant cause of emitter plugging in either type of tubing.

<u>Water Applications during Phase I.</u> Applied water in 1991, including sprinkler irrigation for crop establishment, was similar across drip treatments (average of 1404 mm) compared with 1540 mm in the furrow irrigation treatment. Total applied water for 1992 (through the eighth harvest cycle ending in September, after which the crop was terminated) was similar across drip treatments (average 1389 mm) versus 1462 with the furrow treatment. Relatively low water applications in the furrow treatment in 1992 resulted from inadequate irrigations during winter and early spring which would otherwise have stored more soil water for later use. Estimates of stored soil water use from the 0.9 to 2.4 m zone in the soil profile during the period from planting (April) through December of 1991 range from 110 to 140 mm (4.5 to 5.6 inches) across treatments. Estimates show an additional 38 to 53 mm (1.5 to 2.1 inches) of soil water depletion in the same part of the soil profile during the January through September period of 1992. Effective rainfall measured on-site were less than 110 mm (4.5 inches) both years.

Rain and applied irrigation water were inadequate to replenish stored soil water at depths greater than 3 feet in any irrigation treatments, resulting in a gradual depletion of stored soil water in the upper 1.2 to 2 m of the soil profile during the first two years of the study. Observation wells and monitoring of two drain lines under the plots indicated no shallow groundwater to a depth of 3.5 m and no deep percolation resulting in drainage during the experiment.

Long-term (1964 to 1873) yearly class A pan evaporation at the Brawley USDA-ARS weather station averaged 2933 mm. The four-year average alfalfa ET measured in a prior alfalfa study at Brawley totaled 1924 mm (76 inches) (LeMert, 1971). Neither year of Phase I in this experiment covers a full 12-month period, so one way to put water use in perspective is to compare field treatment ET with lysimeter ET. Lysimeter ET for January through September, 1992 totaled

1605 mm, while drip and furrow plots averaged estimated ET ranging from 1432 to 1510 mm (including estimated soil water use and applied water) while the four-year average lysimeter ET for the January to September period in the study of LeMert (1971) was 1711 mm. Since the lysimeter ET represents a non-stressed alfalfa crop and it was irrigated and harvested at the same time as the field plots, the lower ET in field plots indicates the level of water stress imposed.

Alfalfa Yields – Phase I Although the possibility of differential harvest dates was considered across treatments, harvests across all irrigation treatments have not varied by more than 5 days and the number of hay harvests have been identical across treatments. Silverleaf whitefly infestations were a problem particularly in the late summer/early fall months each year, with forage quality reductions and some fungal growth occurring particularly in August or September harvests. No differential whitefly infestations were noted in association with irrigation treatments.

Forage yields in June through December in the crop establishment year (1991) in the 2.04 m (80 inch) drip lateral spacings (treatments T3, T4) averaged 17% lower than in the 1.02 m (40 inch) treatments (T1, T2), while the furrow irrigation treatment (T5) averaged 32% lower than T1 and T2. In 1991, T1 and T2 treatments averaged 6.3 T/acre at 6% moisture content versus 4.3 T/acre in the furrow irrigated plots. In 1991 and 1992, no significant yield differences existed between treatments where the only difference was in types of drip tubing (T1 versus T2, or T3 versus T4). Yields in the 2.04 m (80 inch) drip lateral treatments (T3, T4) in January through September, 1992 averaged 102% of yields in the 1.02 m (40 inch) drip lateral treatments (T1, T2) with an average of 11.7 T / acre at 6% moisture. The furrow treatment (T5) during the same period averaged yields 14% lower (10.0 T/acre) than T1 and T2.

Phase II (Deeper Drip Lateral Placement):

The first crop grown following the drip lateral installation was sudangrass in the summer and fall of 1993. The sudan crop was used to firm up the beds and reestablish the plots following placement of the new drip laterals. Alfalfa was replanted during November of 1993 and established using 135 mm (5.4 inches) of sprinkler irrigation for germination and crop establishment.

Irrigation Scheduling, Plant Water Status and Evapotranspiration. During Phase II with the deeper drip tubing installation depth, it was not necessary to scale back irrigations in the drip plots during the harvest cycle to avoid surface soil wet areas. The deeper lateral depth largely eliminated surface "wet soil" areas and harvest equipment trafficability problems. Even during high water application periods in the summer in which as much as 14 mm (0.6 inches) of water per day was applied per day, surface wet areas did not develop. Water applications for all drip treatments and furrow plots were nearly identical during 1994 and 1995 (averaging about 1886 mm for SDI in 1994 versus 1910 mm for furrow; and 1843 mm for SDI in 1995 versus 1881 for furrow), and 1970 mm (SDI) versus 1928 mm (furrow) in 1996. These amounts were actually about 100 mm (1994), 75 mm (1995) and 61 mm (1996) more than in the lysimeter-grown alfalfa (which was irrigated to replace 100 percent of ET). The extra water was applied in excess of estimated lysimeter ET in the late winter and spring of each year to build up stored soil water.

The applied water was not much different between drip and furrow irrigated treatments in Phase II for two basic reasons: (1) the lack of a cut-back period in drip irrigation around harvest time resulted in higher yields, faster regrowth and therefore higher plant transpiration; and (2) the upper limit on irrigation amounts in furrow irrigated plots is restricted by low soil infiltration rates (see discussion below). Under conditions of minimal crop water stress in the crop lysimeter, the monthly crop ET compares closely with the monthly ET values determined in prior furrow-irrigated alfalfa lysimeter studies by Donovan and Meek (1983) and LeMert (1972) at the Brawley site. Lower soil evaporation under subsurface drip irrigation explains lower monthly ET values during several summer and fall months. Despite shallow (<10 cm) shanking of each furrow following each harvest, water infiltration and furrow applications typically declined significantly with each subsequent irrigation following each shanking. Low infiltration rates, which prevailed in the second and third irrigations following harvest in furrow irrigated plots, continued to set the upper limit on furrow plot water applications. While nearly 3.5 to 4.2 inches of water could be applied in the first irrigation after harvest, the second and third post-harvest irrigations routinely would only allow 2.4 to 3.1 inches application. It is difficult to apply water in amounts greater than about 95 percent of the lysimeter-measured ETc without risking scalding injury due to the prolonged presence of surface water. Efforts were made to counter this deficit irrigation by applying more water during the winter months, and storing it for root water uptake in high evaporative demand periods.

Limited infrared thermometer data was collected to evaluate plant water status during several periods each year. This data, collected to determine "Crop Water Stress Index" values, indicated that after drip system replacment in 1993, plant water stress was significantly less in subsurface drip irrigated plants than in furrow irrigated plants during the 5 to 7 days prior to harvest and early re-growth period (data not shown). In addition, water stress levels were also significantly less than during comparable pre- and post-harvest periods during the 1992 alfalfa season (when irrigation had to be cut back during the harvest period to avoid surface soil wet areas). Plant regrowth (measured as canopy width and height) following cutting was 34 to 60 percent faster during the first 10 days following cutting in the subsurface drip irrigated plants than in furrow-irrigated plants (data not shown).

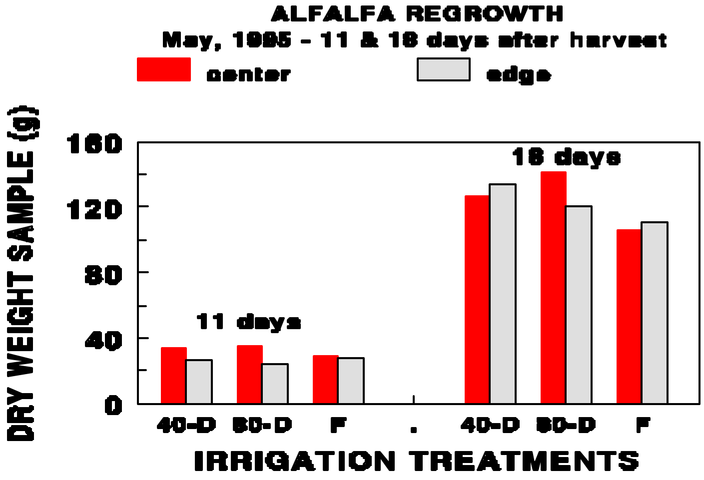

Figure 1. Regrowth of alfalfa at 11 and 18 days after cutting for harvest in May of 1995. Regrowth was measured as dry weights of samples collected at the center row(s) of the beds or in outer rows (edge) of the bed in 40 inch drip (40-D), 80 inch drip (80-D) and furrow (F) plots.

During Phase I of this experiment, downward water movement with furrow and drip irrigation was largely confined to the upper 75 to 90 cm (2.5 to 3 feet) of the soil, and root densities reflected this, with most of the root system confined to the upper 90 cm (data not shown). During Phase II, the same pattern of water use was evident in furrow irrigated plots. With the deeper drip installation depth in Phase II, however, soil water use and root activity was shifted somewhat deeper in the drip plots, with more water use in the 0.9 to 1.2 m depth and a much drier upper soil zone (0.15 to 0.25 m depth) (data not shown).

Soil Salinity Profiles Developing under Drip versus Furrow Irrigation. Accumulations of salt within the root zone of alfalfa can be a significant problem, since alfalfa has a threshold salinity level of 2.0 dS m^{-1} (rootzone soil saturation extract salinity level associated with the beginning of yield reductions). In the first phase of the study, concentrations of salinity in the 15 cm to 90 cm (2 to 3 feet) of the soil profile largely remained in the range of 1.7 to 2.6 dS m^{-1} even after the first 18 months of irrigation. However, in some parts of the beds, salinity levels exceeded 4 to 4.5 dS m^{-1}, largely in areas of the field or parts of the profile where soil water movement was always in one direction and leaching was limited. Larger areas of the beds and outer root zone were found to be exceeding 4 dS m^{-1} EC_{se} within the upper 2.5 feet (75 cm) of the profile according to hand soil samples collected in July, 1995.

In some areas of the surface 15 cm (6 inches) of soil in the drip plots had salinity levels in excess of 3 to 3.5 dS m^{-1}, presumably due to movement of water and salts up to the soil surface layers. Even these high concentrations of salts did not result in stunted plants, perhaps due to limited root activity in the upper parts of the soil profile. However, these surface concentrations of salt do represent a potential threat if flushed down into the active root zone by rain or too small an amount of water applied for leaching. In general, locations and amounts of salt accumulation across the beds in phase I and phase II of this study depended on lateral spacing and whether or not the wetted patterns of lateral water movement from adjacent beds met.

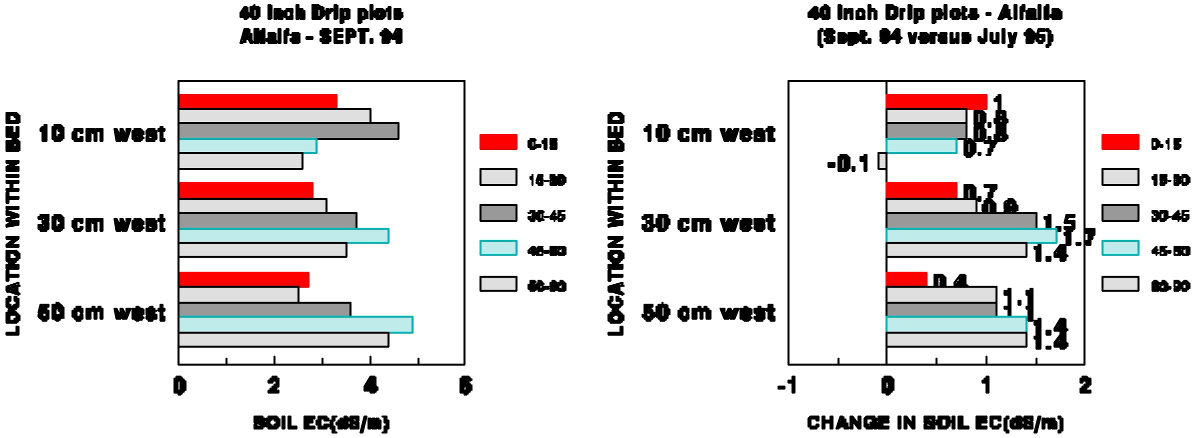

Figure 2. For 40-inch beds SDI plots: (left) Soil salinity (EC, electrical conductivity) as a function of location within planted bed (10, 30 or 50 cm from lateral) and depth in the soil profile (0-15, 15-30, 30-45, 45-60, 60-75 cm); and (right) change in soil EC between Sept., 1994 and July, 1995 (positive numbers indicate net increase in salinity during the period).

In the 1.02 m (40 inch) drip lateral spacing treatments, the highest salt accumulations were under the furrows, with lateral water movement from drip laterals on adjacent beds meeting at the furrows and depositing the most salt in that location. In the 1.02 m furrow plot beds, the highest salt accumulations were found in the center of the beds due to lateral movement of water and salts from furrows on both sides of the beds. In the 2.04 m (80 inch) drip lateral spacing treatments, the highest salt accumulations were about 15 to 45 cm deep and under the outer plant rows at the edge of the beds. At the wide drip lateral spacing, the lateral movement of water and salts out from the emitter did not consistently extend beyond the edge of the bed, resulting in the a higher accumulation of salts near the outer edge of the wide bed. The patterns can be seen in Figures 2 through 4.

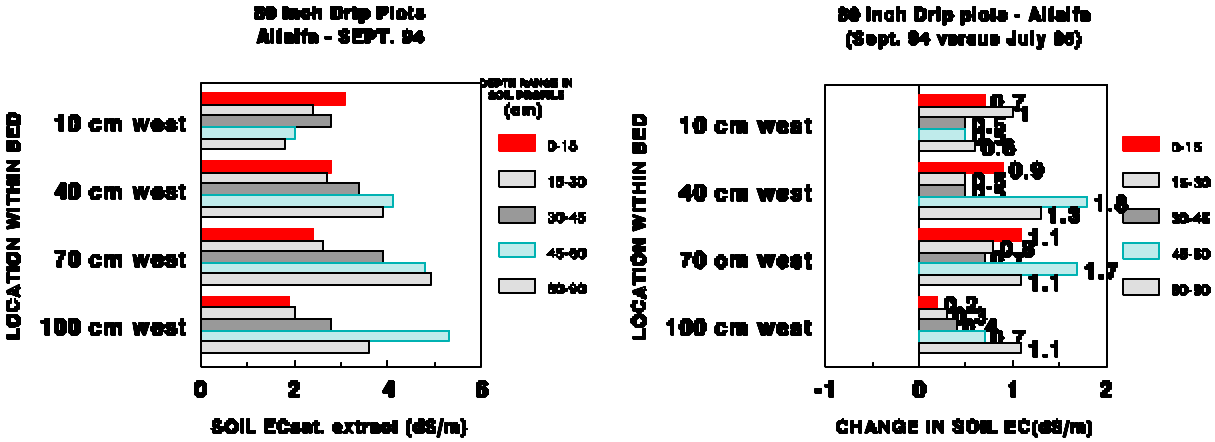

Figure 3. For 80-inch beds SDI plots: (left) Soil salinity (EC, electrical conductivity) as a function of location within planted bed (10, 30 or 50 cm from lateral) and depth in the soil profile (0-15, 15-30, 30-45, 45-60, 60-75 cm); and (right) change in soil EC between Sept., 1994 and July, 1995 (positive numbers indicate net increase in salinity during the period).

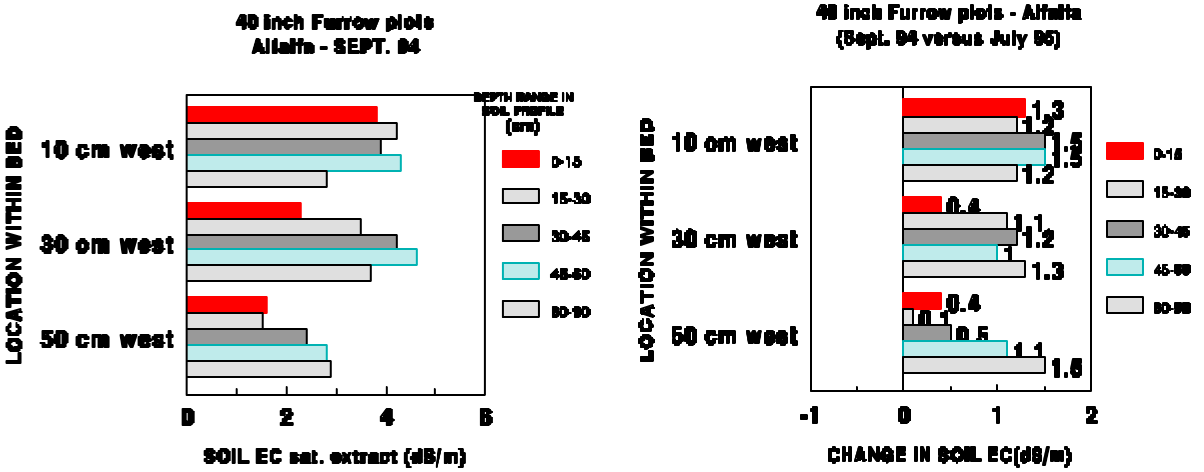

Figure 4. For 40-inch Furrow-irrigated plots: (left) Soil salinity (EC, electrical conductivity) as a function of location within planted bed (10, 30 or 50 cm from lateral) and depth in the soil profile (0-15, 15-30, 30-45, 45-60, 60-75 cm); and (right) change in soil EC between Sept., 1994 and July, 1995 (positive numbers indicate net increase in salinity during the period).

Much of this within-bed variation and stratification in salinity levels developed during Phase I of the study was eliminated with the large pre-plant water application (8 to 10 inches of water) made in late-spring of 1993 (after installation of the new drip tubing and prior to sudangrass planting), but the patterns soon re-emerged with irrigations during Phase II.

Crop Establishment and Forage Yields. Excellent plant stands achieved in all plots. Although water applications and crop water use were quite similar in the furrow and drip-irrigated plots in 1994, 1995 and 1996, yields were significantly higher in the drip irrigated plots than in furrow-irrigated plots. In 1994, forage yields averaged across all SDI treatments totaled 9.3 T/acre versus 7.2 T/acre in furrow plots, or 23 percent higher with SDI. Harvests did not start until March in 1994, since it was an establishment year for the new crop. In 1995, yields averaged across SDI treatments totaled 9.9 T/acre versus 8.1 T/acre in furrow plots, or 18 percent higher with SDI. In 1996, yields declined in all treatments, with 8.8 T/acre average yields in SDI plots versus 7.3 T/acre in furrow plots, or 17 percent higher with SDI. These values for 1995 are higher than in earlier reports on this project since one harvest was left out of earlier calculations. All yields were corrected to 6% moisture content. Forage yields were not significantly affected by type of drip tubing. There was a trend toward higher forage yields in the 2.04 m (80 inch) lateral spacing treatments when compared with 1.02 m (40 inch) spacing, but the differences were usually less than 4% and not significant.

During both Phase I and Phase II of this experiment, the yield advantage under drip was greater in the first year than in subsequent years. Although the possibility of differential harvest dates across irrigation treatments would have been allowed if necessary, in practice, harvest dates across all irrigation treatments did not vary by more than 3 to 4 days, and the total number of harvests was identical in all treatments.

Hay was sampled from representative bales in all treatments during selected harvests at different times of the year, with samples sent to a commercial laboratory for analysis of components of forage quality. None of these results have been compiled and fully analyzed at the time of preparation of this report.

Insect Problems and Relationship to Irrigation Method. During the late-summer of 1994, a significant problem with cutworms developed which resulted in severe damage to regrowth during the hot late-summer months. Since the damage occurred over a long time period and affected the subsurface drip plots much more seriously than the furrow irrigated plots, efforts were made to determine an explanation for the difference as well as to control the problem. Discussions with University of CA and pesticide industry representatives suggested that use of furrow irrigation results in a routine flooding of soil cracks which the cutworms retreat to during the warmest parts of the day in alfalfa fields. This flooding both drowns out some of the cutworms and floats them up to the soil surface where afternoon conditions are not good for their survival. Because this flooding does not occur in subsurface drip irrigated plots, it was thought that worm populations could increase to the point where they were a threat to both regrowth and stand survival. In order to limit cutworm damage, two spray pesticide applications were made about 7 days apart after sunset, when the worms come up above the soil surface and can be reached using pesticide sprays directed onto the beds.

There have been repeated other problems with insects such as flea beetles, aphids and some white fly damage during the fall months (mostly related to secondary fungus development on honeydew). Some of these infestations have required pesticide applications. In these other insect infestations, problems have not appeared to be significantly influenced by irrigation method.

System Operation and Problems. No problems with excessive emitter flow rates have been detected to date in this second phase of the experiment. No evidence of root intrusion into the drip lines has been found during Phase II operation. As in previous reports, we should note that the lack of root intrusion problems in this study was achieved under the following operating conditions: (1) use of "Ram" drip tubing or "Rootguard" drip tubing, both of which have turbulent-flow emitters and thick walls when compared with tapes; (2) continuous injection of a 5 to 7 percent phosphoric acid solution to maintain a concentration of 10 to 20 mg/L; and (3) weekly injection of chlorine (free chlorine level of 5 to 10 mg/L) and N-phuric acid (to bring the pH down to about 3.5) for a duration of about 1 to 2 hours per week. There is no firm evidence that root intrusion would occur if the chemical treatments were not used, but from the standpoint of prevention of chemical precipitate clogging, acid treatments of one type or another are most likely a necessity.

CONCLUSIONS

Increases in water use efficiency (expressed as forage yield per mm of crop water use) with SDI in this experiment were over 20 percent higher than with furrow irrigation averaged across all years. These higher water use efficiencies largely came from increases in yield, not from large reductions in applied water or ET. Particularly in the Phase II portion of the experiment, SDI allowed continued water applications during the harvest period (cutting through baling), resulting in faster regrowth and larger yields than in furrow-irrigated plots. Short run lengths (600 feet) also resulted in relatively high water application uniformity in the furrow plots compared with what would typically be expected in agricultural fields with longer runs. In many soils and cultural conditions less conducive to uniform water applications, there may be greater opportunities to also save water with SDI systems through reductions in deep percolation losses. In forage market areas where land values and water costs are low, even 20 percent potential yield increases may not warrant conversion costs to SDI. However, where water costs are increasing or total water or land availability are serious limitations, SDI has promise as a viable alternative to other irrigation methods.

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