SUBSURFACE DRIP IRRIGATION OF 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 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 alfalfa versus furrow irrigation. This is part of several long-term experiments at the Brawley USDA station to investigate water use, crop response, and salinity management criteria for using subsurface drip irrigation with Colorado River water. During the first one and one-half years of operation, with 94 percent of the water application given to the furrow plots, approximately 20 percent higher yields have been obtained in the drip plots. Problems with surface soil wetting have been noted in all drip treatments, even with the drip laterals placed at a 16 inch depth. This has resulted in the need to reduce drip water applications during a "dry-down" period during each harvest cycle in order to allow for harvest equipment traffic while limiting soil compaction and plant damage. Additional work is underway to assess alternate installation depths to eliminate wetting of the soil surface and to determine the influence of long-term drip system operation on patterns of salt accumulation.

Keywords: alfalfa, furrow irrigation, salinity, water conservation, water requirement, evapotranspiration.

INTRODUCTION

Forage alfalfa is a major crop in many areas of the western U.S, including the Imperial Valley. In the arid and semi-arid west, irrigation is required to achieve economic alfalfa yields. As a perennial crop with a potentially long growing season, alfalfa can use a substantial amount of irrigation water. Alfalfa production in Imperial County alone has been valued at in excess of $170 million for the past several years, with over 100,000 ha in production. Increasing competition for limited water supplies during the current California drought have focused concern on crops that are commonly perceived to be "high water users". Numerous reports are available which estimate annual alfalfa evapotranspiration (ET) 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).

Considering the continuing need for forage alfalfa production in California and the large amount of water used in the Imperial and Palo Verde Valley areas (1.5 million acre-feet) and in California (estimated 4 million acre-feet), there is incentive for investigating improvements in water use efficiency.

Recent studies in a number of locations have indicated the potential for drip irrigation to conserve water while maintaining or enhancing yields (Phene et al., 1991; 1992a; 1992b). Surface installations of drip laterals are impractical with forage alfalfa due to dense plantings and repeated harvesting operations. For

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these reasons there is interest in evaluating a permanently-installed subsurface drip irrigation system for use in alfalfa. We are aware of only one previous research effort to evaluate the use of subsurface drip irrigation in alfalfa (in Israel, Gideon Oron, personal communication).

This project is a five-year evaluation of alfalfa water requirements and the long-term influence of irrigation management on soil accumulations of salts and potentially yield-limiting specific ions. This experiment focuses on: (1) the comparison of crop responses, irrigation water requirements, and salinity accumulations as affected by subsurface drip versus furrow irrigation; and (2) the influence of two drip lateral spacings on the above characteristics.

MATERIALS AND METHODS

The five-year study is being conducted in Brawley, CA in cooperation with the USDA-ARS Salinity Laboratory (USSSL), Riverside, CA; the USDA-ARS Irrigated Desert Research Station (IDRS), Brawley, CA; the Imperial Valley Conservation Research Center Committee (IVCRC), Brawley, CA; the Imperial Irrigation District (IID); and the Metropolitan Water District of Southern California (MWD).

The experimental site is located at the USDA-ARS Irrigated Desert Research Station near Brawley, CA, in a 7 acre field with Holtville silty clay soil. Five irrigation treatments, replicated three times, are under investigation in this experiment. There are two drip lateral spacing treatments, 40 inch (1.02 m) and 80 inch (2.04 m). The drip laterals are placed 41 cm below the center of each bed, with 1.02 m and 2.04 m beds, respectively. Two different types of drip tubing are used within each lateral spacing treatment: (a) pressure-compensating in-line turbulent flow emitters on 20 mm tubing (designated as type "a" emitter); and (b) in-line turbulent-flow emitters made out of herbicide-impregnated plastic on 20 mm tubing (type "b" emitters). Both emitter types have a nominal flow of 2 L h⁻¹ at 18 to 20 psi and are spaced 40 inches (1.02 m) apart.

Treatments are designated as follows: T₁ = 1.02 m lateral spacing with type (a) emitters; T₂ = 1.02 m spacing with type (b) emitters; T₃ = 2.04 m spacing with type (a) emitters; T₄ = 2.04 m spacing with type (b) emitters; and T₅ = furrow irrigation with 40 inch (1.02 m) beds. Plot size for treatments T₁ and T₂ are 8 beds in width by 525 feet (160 m), while 80 inch (2.04 m) bed-width treatments were 4 beds in width by 525 feet (160 m) in length. To avoid potential scalding problems, a common concern associated with the high Imperial Valley summer temperatures, alfalfa was planted on 40 inch beds. Individual furrow plot size was 16 beds in width by 525 feet (160 m) in length.

The irrigation water supply in this experiment is Colorado River Water supplied through the Imperial Irrigation District canals. The water is collected in a lined on-site reservoir, filtered through an intake screen at the pump, filtered through a dual sand media filter system with automated backflush, and finally run through a 200-mesh screen filter. Due to the high silt load, the sand media filters are automatically flushed at least once per day. All main lines and lateral flush ends are manually flushed once per week. All drip and furrow irrigation treatments are instrumented with electronic flow meters. The drip system is also instrumented with pressure transducers which are connected to the USDA-ARS Water Management Research Laboratory in Fresno, CA via a datalogger/computer system. Analog water meters and pressure gauges are also read periodically on all treatments. The drip treatments are operated at pressures of 16 to 21 psi.

A weighing lysimeter 3 m by 3 m by 1.5 m deep, which is also irrigated via subsurface drip, is located in the central part of the field. The lysimeter serves both as a crop evapotranspiration (ETₜ) measuring instrument and as an irrigation controller. A 1 mm irrigation is initiated in both the lysimeter and in treatments T₁ through T₄ following each 1 mm of measured lysimeter ETₜ. A schematic of the lysimeter/irrigation control system is shown in Figure 1. This system operates in a feedback mode to provide a high frequency, low volume water application in all SDI plots.
Phosphoric acid was injected continuously in the lysimeter and all drip plots to achieve a concentration of 15 mg P/liter in the irrigation water. An initial broadcast P application was made in all plots and side-dress P applications were made in furrow-irrigated plots in amounts equivalent to applications in drip-irrigated plots.

The design of the irrigation system was finalized and construction of the irrigation system components began in December of 1990. Drip system installation was completed in March, 1991 and the crop was planted on April 2 through 4. Approximately 164 mm of post-plant irrigation was applied to all treatments using sprinklers. Both drip and furrow irrigation treatments were initiated in late May.

Furrow irrigation is accomplished through a gated-pipe system; water is supplied by an irrigation canal on the southern edge of the field; flows through a water meter on each field replicate, and out to the field through 8 inch diameter gated pipe. Irrigation water is applied without tailwater, and flow rates are 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 each irrigation. Following each harvest, a shank was pulled through each furrow at a shallow depth (2 to 3 inches) to break up the surface soil and improve water infiltration. In June of 1992, a consultant began to assist the project in determining irrigation scheduling in the furrow treatments to match furrow irrigation management in the project with typical farming practices in the Imperial Valley.

Water samples were collected at least monthly to determine any major seasonal changes in quality. Long-term average irrigation water quality components were as follows:

Electrical conductivity (EC) at 25 C: 1.15 dS/m
Boron: 0.13 to 0.25 mg B/L
Chloride: 2.5 to 3.5 meq Cl/L
Calcium: 80 to 120 mg Ca/L
Magnesium: 30 to 35 mg Mg/L

The timing of alfalfa harvests was determined based on 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 the variability in the degree of flowering which corresponded with the initiation of regrowth. Therefore, a combination of these morphological observations was used to determine timing of harvests. Alfalfa harvest in all plots was accomplished using commercial harvesting equipment (swather, rake, wire baler) on two central beds per plot in the 80 inch bed-width plots and on all eight beds in the 40 inch bed-width plots. The entire plot length (525 feet) was included in the harvest. The first harvest was in late June, 1991.

Initially, a commercial operator and truck were used to pick up the baled alfalfa in the field, but following repeated problems in: (1) coordinating schedules for timely bale pickup, and (2) compaction problems associated with wheel-traffic on wet beds, an alternative method was devised for bale pickup. Bales are individually picked up and weighed and placed on a trailer for removal from the field. Reported forage yields are based on actual bale weights. Yields are corrected to a constant water content. Samples for determination of forage yield quality components are collected from random bales from each plot using a core sampler.

Plant water status was monitored using infrared thermometry and the Crop Water Stress Index (CWSI) as described by Idso et al. (1982). An automated, aspirated psychrometer was used to determine wet and dry bulb temperatures required for determination of vapor pressure deficit (VPD) in the CWSI procedure.

Access tubes are installed in the southern and northern sectors of each plot, three to six replications per treatment, with soil water content monitored by neutron attenuation. Three access tubes were placed at approximately 200 foot intervals in each furrow-irrigation plot to measure water application uniformity.
and depth of wetting across the field. Soil samples are collected to a depth of 2.2 to 2.5 m in all plots once per year (in October/November) to assess the long-term impact of irrigation practices on accumulation of salts and other chemical constituents. Periodic soil samples were collected to evaluate developing patterns of surface soil (upper 0.75 m of the profile) salt accumulation as a function of irrigation treatment and location within the plant beds.

RESULTS AND DISCUSSION

System Operation:

The drip irrigation and irrigation control system in this experiment has worked well to date. The most persistent problems with the drip plots have been related to the development of "wet" and "dry" areas within the field. Although the areas affected are relatively limited, they warrant attention due to their influence on the way irrigation and harvesting operations must be managed. Our preliminary conclusions are that wet areas are a result of both too shallow placement of the drip laterals (at 16 inches) and a limited number of malfunctioning emitters. Dry areas are largely thought to be associated with both a limited number of malfunctioning or missing emitters and some emitter plugging associated with silt entering the system during the early phases of installation and operation of the drip system. Root intrusion has not been observed to date in any emitters in the dry areas. Work will be conducted during the winter of 1992-1993 to determine the cause of dry areas noted in the field. Details of the "wet area" problems are discussed below.

Even with the drip laterals buried 16 inches (41 cm) below the soil surface and high frequency, low volume irrigation, water was repeatedly observed at the surface at a number of locations in all drip irrigation treatments. In several field surveys to assess the extent of the field area affected, it was determined that less than 3% of the field had areas with wet soil or standing water at the surface. Any wet surface areas, however, often cause problems in harvest equipment traffic in the field. The most consistent problem areas were those in which heavy equipment was driven over beds with sporadic wet surface soils. After the initial soil compaction and damage to the plant crowns in these locations, problems with water movement to the surface became a recurrent situation. In order to limit compaction, irrigation in the drip plots was scaled down to 25% to 50% of lysimeter-application amounts during the last 4 to 5 days prior to harvest through bale removal. This resulted in a localized drying of wet surface areas and reduced further plant damage, compaction, and vehicle traffic problems. However, any plant stress associated with this "drying" period may result in yield losses, so it is important to try to develop strategies for drip tubing operation and installation depths that will not restrict yields.

Work is underway at the time of this report to determine the degree to which improper depth of drip tubing installation (too shallow) versus malfunctioning equipment (emitters) are the source of the wet soil surface areas. Measurements to date indicate that the 16 inch (41 cm) drip tubing installation depth is not sufficiently deep to prevent some wet surface areas even with high frequency drip irrigation with the emitter output and spacing used in this study. A deeper lateral installation is under consideration as a potential remedy to this problem, but a number of soil and plant factors (salinity management, surface soil cracking, plant survival in dry surface soils) will also be considered in determining best management practices for subsurface drip irrigation of alfalfa in heavy soils.

Water Applications and Patterns of Water Use:

Total applied water, including sprinkler irrigation for crop establishment and drip or furrow irrigation during April through December of 1991 and January through September of 1992 are shown in Figures 2 and 3. A sprinkler application averaging 164 mm was applied to all treatments during the crop establishment in 1991. Applied water in 1991, not including sprinkling for crop establishment, was similar across drip treatments with an average of 1174 mm compared with 1310 mm in the furrow irrigation treatment. Total applied water for 1992 (through the eighth harvest cycle ending in late September, 1992) was similar across drip
treatments with an average of 1108 mm versus 1102 mm in the furrow treatment. The lower water applications in the furrow treatment in 1992 largely resulted from inadequate irrigations during winter and early spring.

In the lysimeter, frequent irrigation could be maintained throughout the harvest cycle to sustain a high soil water content, which resulted in extremely high forage yields and rapid regrowth following each harvest. In the furrow plots, typical practices for the Imperial Valley were followed, which included application of the last irrigation 5 to 7 days prior to each harvest followed by harvest and the next irrigation immediately after harvested bale removal.

In all plots, neutron-probe determined soil water contents were used in conjunction with gravimetric soil sampling to determine the depth of penetration of applied water. Preliminary estimates of stored soil water use from the 3 to 8 foot zone in the soil profile from planting (April 1991) through December of 1991 range from 110 to 140 mm (4.5 to 5.6 inches). Preliminary estimates show an additional 150 to 190 mm (6 to 7.5 inches) of soil water depletion in the 3 to 8 foot zone of the profile during the January through September period of 1992. Effective rain measured at the field site was less than 110 mm in both years. Rain and applied irrigation water were inadequate to replenish stored soil water at depths greater than 3 feet in any irrigation treatment, resulting in a gradual depletion of stored soil water in the 3 through 8 foot zone during the two year study. Soil water data to date suggests little or no potential for deep percolation losses, and observations in piezometers in several locations indicated no shallow groundwater to a depth of 12 feet.

Long-term (1964 to 1973) yearly average Class A pan evaporation at the Brawley USDA-ARS field station has been measured previously as 2933 mm. The four-year average alfalfa ET measured in a previous study at Brawley totalled 76 inches (1924 mm) (LeMert, 1971). Since neither year of the current study covers a 12-month period, the January through September, 1992 ET was calculated for both the lysimeter-grown alfalfa and treatments. Lysimeter ET for this period totalled 1605 mm, drip and furrow plots averaged less than 1350 mm (including estimated soil water depletion and applied water), while the four-year average alfalfa ET (LeMert, 1971) using the USDA-ARS lysimeter at Brawley for January through September was 1711 mm. The lysimeter alfalfa represents a non-water-stressed alfalfa crop. Since the lysimeter alfalfa was harvested at the same time as the adjacent field plots, the lower ET in the field plots indicates the level of water stress imposed on the field plots. This water stress largely occurred during the "dry-down" period associated with preparing the field for each harvest. Crop water stress index measurements in drip and furrow-irrigated plots (data not shown) indicated that CWSI values of 0.15 to 0.20 (indicating mild water stress) were quite common during the "dry-down" periods preceding harvest.

Alfalfa Yields and Quality

Although the possibility of differential harvest dates across treatments would have been allowed if necessary, harvest dates across all irrigation treatments have not varied by more than 5 days. The number of total hay harvests have been identical across all treatments. Whitefly infestations were a problem particularly in the late summer/early fall months of both years, with forage quality reductions and some fungal growth problems particularly in the September harvests of both years. Although whitefly counts were not done in any plots, no differential whitefly infestations were visually noted in association with the irrigation treatments.

Forage yields in June through December in the crop establishment year (1991) in the 30 inch drip lateral spacing treatments (T3, T4) averaged 17% lower than in the 40 inch lateral spacing treatments (T1, T2), while the furrow irrigation treatment (T5) averaged 33% lower than T1 and T2 (Figure 4). In 1991 and 1992, no significant yield differences existed between treatments representing types of drip tubing (T1 versus T2 or T3 versus T4).

Yields in the 30 inch drip lateral treatments (T3, T4) in January through September of 1992 averaged 102% of yields in 40 inch lateral treatments (T1, T2), while the furrow treatment (T5) averaged 14% lower than T1 and T2 (Figure 5).
Hay samples have been collected from representative bales in all treatments during selected harvests in order to characterize any treatment effects on components of hay quality. Analyses of this data have not been completed.

Soil Salinity

Comparisons of soil samples collected at the initiation of the experiment with those collected in November of 1991 and November of 1992 will be used to determine patterns of salt accumulation across beds in each of the irrigation treatments. Analyses of these data sets were not completed at the time of this report. This information will be used to predict any need for periodic leaching in SDI or furrow-irrigated plots. The amount, frequency, and cost of leaching required for salinity management will be factored in when determining the overall utility of these irrigation systems. This concept will be discussed in future reports as the data become available.

CONCLUSIONS

Two different types of drip irrigation emitters/tubing and two different drip lateral spacings (1 meter (40 inch) and 2 meter (80 inches)) were compared with furrow-irrigated alfalfa. Major objectives were to compare alfalfa yield responses, evapotranspiration, and patterns of salt accumulation under subsurface drip irrigation versus furrow irrigation. After one and one-half years of operation, total alfalfa yields were approximately 22% higher in SDI plots than in furrow plots, with 8% lower water applications. Forage yields in plots with 40 inch lateral spacing were 7% higher (1991) and 2% lower (1992) than in 80 inch lateral spacing plots, while yields were not significantly affected by drip emitter/tubing type. High frequency irrigations with SDI installed at 41 cm (16 inch) depth did not prevent water from reaching the soil surface in some field locations during irrigation. For this reason, water applications had to be reduced during the alfalfa harvest operations to reduce surface soil wetting and avoid compaction and harvest equipment traffic problems. Future efforts will consider: (1) methods to better replenish deep stored soil water using irrigation during low evapotranspiration periods of the year; and (2) deeper drip tubing installation depths to avoid problems of water moving to the soil surface.
REFERENCES


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Figure 2. Applied water (mm and inches) during the period from April through December in 1991 alfalfa irrigation treatments and for the lysimeter (not including sprinkler irrigation for crop establishment) at Brawley, CA.

Figure 3. Applied water (mm and inches) during the period from January through September in 1992 alfalfa irrigation treatments and for the lysimeter at Brawley, CA.

Figure 4. Total alfalfa yield (corrected to constant water content) from June through December of 1991 in alfalfa irrigation treatments at Brawley, CA.

Figure 5. Total alfalfa yield (corrected to constant water content) from January through September of 1992 in alfalfa irrigation treatments at Brawley, CA.
9 kg (19.8 lbs.) Weight Loss
Equals
1 mm (0.04 inch) of Water Lost
Through Evapotranspiration
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