USA: Subsurface drip irrigation of row crops: a review of 15 years of research at the Water Management Research Laboratory, University of California

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Ayars, J. E., Phene, C .J., Hutmacher, R. B., Davis, K. R., Schoneman, R. A., Vail. S. S. & Mead, R.M.
Water Management Research Laboratory, Fresno, University of California, Shafter Research Station, and United Agri Products Fresno, California

Micro-irrigation has developed rapidly since the mid-1960s. Presently there are over 3 million hectares of micro-irrigation in the world representing about 2% of the total irrigated land. The trend is for increased adoption of the system. One approach of using drip irrigation in field crops is to bury the driplines in the soil in order not to hamper soil cultivation. The present paper describes 15 years of research in subsurface drip irrigation (SDI) at the Water management Research Laboratory (WMRL) dealing with problems of crop yield and water use, water distribution, root intrusion and damage to the system by rodents and cultivation.

The studies were conducted at three locations in California: 1. California State University, Fresno Research Farm; 2. The University of California West Side Research and Extension Center; 3. Britz Commercial Farm near Modesto, CA.
Following are three summaries of the field results of the three locations mentioned above, followed by a general overview of SDI as presented in the review paper - which summarizes the main points of the review.

1. California State University, Fresno Research Farm

The crop used was **tomato**, variety UC82B. The drip system used was Agrifim in-line 2 L/h emitters spaced 61 cm along the line. The lines were shanked in at a depth of 0.46 m and 1.52 m apart directly under the beds. The crop was seeded in April and germinated by sprinkler irrigation as is the accepted practice in San Joaquin Valley of California. Irrigation quantities were determined using corrected (van Bavel's evapotranspiration model) open pan evaporation and crop coefficient. Electronic soil moisture sensors were used to automatically control irrigation timing. The treatments included furrow irrigation and seven SDI treatments based on either pan evaporation or soil sensors. Furrow irrigation was once in 6 days at peak evapotranspiration (E_t) while the SDI treatments were irrigated several times a day (2 to 6). Nitrogen fertilizer was applied half by pre-plant broadcasting and half by fertigation.

All SDI treatments produced more marketable **tomato** yield than the furrow irrigated treatment. The SDI plot irrigated on the basis of open pan evaporation produced the highest yield (132 t/ha) while the furrow irrigated plot produced the lowest yield (90 t/ha). The total soluble solids percentage (Brix), on the other hand, was lower for the SDI pan evaporation controlled treatment (4.0 %) than for the apparently drier furrow irrigated treatment (5.3 %). The quantity of irrigation water applied to the two treatments was very similar (627 vs. 648 mm, respectively).

As part of this study overview, the research conducted at the California State University, Fresno Research Farm, one location out of three, showed that the water use efficiency (WUE) of SDI was 30% higher than the furrow irrigation (20.4 vs. 14.3 kg/mm).

2. University of California, West Side Research and Extension Center

A series of experiments were conducted at the West Side Field Station (WSFS) from 1984 to 1990. The crops used in the rotation were: **processing tomatoes**, **cantaloupe** and **sweet corn**. The drip irrigation laterals consisted of in-line turbulent flow 4 L/h emitters spaced 91 cm apart. The SDI laterals were installed in the center of each bed spaced 1.63 m apart at a depth of 0.45 m. An end-of-line manifold connected the drip laterals to a single riser for flushing. The laterals for the surface drip were installed after planting and removed prior to harvest. A weighing lysimeter was used to schedule irrigation automatically.

Tomatoes (cv UC82B) were planted in February - March and harvested manually in July - August. The treatments were high frequency SDI; high frequency surface drip (HFSD) and low frequency surface drip (LFSD). In 1987 three phosphors (P) fertilizer treatments were added (0, 67 and 134 kg/ha) by daily injection of phosphoric acid in the irrigation water. In 1990 three fertilizer treatments were added in a split plot arrangement as follows: (i) N 448 kg/ha (ii) N 448 kg/ha & P 101 kg/ha (iii) NPK 591, 101 & 442 kg/ha, accordingly. Pre-plant fertilizer was applied at planting directly below the seeds and the remaining fertilizer was applied by fertigation. Sprinkler irrigation was used to germinate and establish the crop. **Cantaloupe** (var. PMR 45) was planted in May and harvested every three days during August (a total of 6 harvests). Fertilizer application and germination irrigation was the same as for **tomatoes. Sweet corn** (cv Supersweet Jubilee) was sown in May and harvested in late June. The sub-treatments were three phosphorus levels (same as for **tomatoes**).

The SDI treatment produced significantly greater red **tomato** yield than the surface drip irrigation treatments only when phosphors was injected with the irrigation water. The maximum yield (220 t/ha) was obtained with SDI and the middle level of phosphors, while the yield of the surface drip treatments was about 190 t/ha. With no phosphors added the yield was about 180 t/ha. The water use efficiency of the SDI treatment was 16% greater than the low frequency surface drip. Phosphors injection through the drip lines resulted in greater response in the SDI than the other treatments. Crop evapotranspiration was similar (approximately 700 mm) for all treatments. The number of non-marketable **cantaloupes** in the SDI treatment was significantly lower by about 40% than in the surface drip irrigation treatments, but there was no difference in total yield between the treatments (mean of 877 t/ha). The reason for the quality advantage of the SDI treatment was the significantly lower number of damaged fruit due to the soil surface being dry under the SDI treatment. There were no differences in the yield of **sweet corn** among the irrigation of phosphors fertilizer levels with mean yield of 29 t/ha.

As part of this study overview, the research conducted at The University of California West Side Research and Extension Center, one location out of three, proved that subsurface drip irrigation resulted in better yields than surface drip irrigation as long as sufficient phosphorus fertilizer was applied.

3. Field studies at the Britz Commercial Farms

In 1991 an SDI system was installed on five 2.4 ha plots on two adjacent fields at the Britz Commercial Farms located on the west side of San Joachim Valley - south of Mendota, California. The following types of drip tubing were installed in each group of five plots: Ram (0.05 l/min/m, 1 m emitter spacing), T-system (0.025 l/min/m, 0.3 m emitter spacing), Chapin (0.37 l/min/m, 0/3 m emitter spacing), Typhoon (0.25 l/min/m, 1 m emitter spacing), Roberts (0.025 l/min/m, 0.6 m emitter spacing). The depth of placement was 0.45 m. The crops grown were **cotton** and **tomato**. Line spacing was 2 m corresponded to every other bed of **cotton** and 1.7 m for every bed of 2 rows of **tomato**. In addition there was a furrow irrigated field. An automated evaporation pan (multiplied by pan factor and crop factor) was used for irrigation scheduling of the SDI fields, while irrigation scheduling of the furrow field was done by the grower. **Cotton** (var. SJ-2 or Acala MAXXA) was planted in April into moist soil and machine harvested in October. **Tomato for processing** (var. Apex 1000 or Hunt 427) was planted in March and manually harvested in August.

The study was conducted for three years. While the yield of **cotton** under furrow irrigation, the method used in the field prior to the study, stayed stable at a level of 1.5 t/ha, the mean yield under the SDI treatments increased during the three years of the study by 47% - from 1.39 to 2.04 t/ha. **Tomato** yield under furrow irrigation was approximately 106 t/ha while the average **tomato** yield under the five SDI treatment was 127 t/ha with little difference among the years. The water balance data showed that over 35% of the water used consumptively - crop evapotranspiration (E_{tc}) - by the **cotton** crop under SDI came from the shallow ground water at a depth of 2 m, having electrical conductivity (EC) of 7 dS/m, while under furrow irrigation there was 17% deep seepage. The amount of water applied under furrow irrigation was 475 mm, (E_{tc} of 437 mm) compared to a mean of 365 mm (E_{tc} of 549 mm) under SDI. The drip laterals suffered some damage from rodents and cuts during bed preparation. The tubing with the smallest wall thickness (e.g. Chapin) suffered from extensive damage while Ram tubing had the smallest damage. Also tubing not placed directly under the bed suffered more damage from field machinery.

Application uniformity of an irrigation system is a critical issue. Drip irrigation, especially SDI can potentially achieve high application uniformity. The uniformity studies (using the 18-point method) in the Britz Farms showed that the Typhoon and Ram systems had the highest uniformity coefficient (UC) (UC = 97.0 and 95.5, respectively) and lowest coefficient of variability (CV) (CV = 3.9 and 5.8, respectively), while the Chapin had the smallest UC (76.3) and highest CV (10.4). The application of phosphoric acid in the irrigation water was beneficial in preventing root penetration and chemical deposits in the system.

As part of this study overview, the research conducted at the Britz Commercial Farms, one location out of three, showed that SDI resulted in 17% higher yield

of tomato and 27% higher yield of cotton than furrow irrigation. Further findings in favor of SDI proved lower level of water application thus a substantial increase in water use efficiency of cotton (from 3.15 kg /mm to 5.59 kg/mm).

General Overview

Five issues of concern dealt with in the subsurface drip irrigation (SDI) studies, conducted by the Water Management Research Laboratory of the USDA-ARS; Fresno, California, may be identified.

1. *Depth of placement* – A drip lateral placement at a depth of 0.45 m was successfully used in the studies. The clay loam soils have good water transmitting properties enabling good water distribution. Additionally, as is the common practice in the San Joaquin Valley of California even under furrow irrigation, germination is achieved by post seeding sprinkler irrigation or pre-plant wetting of the soil to leach salts, resulting in wet soil for seed germination and establishment. In lighter soils the depth of placement has to be reduced to shorten the distance the water has to move to the root system.

2. *Bed placement* – Placement of drip laterals between every other **cotton** row and centered between **tomato** and **corn** rows proved to be very effective and minimized the cost of installation. Ignoring this point may result in sever damage to the SDI system and to yield. It may result in salt accumulation within the root zone rather than on the periphery.

3. *Useful life* – Both hard hoses or tapes (e.g. Typhoon and Ram) are suitable for use in SDI systems. In the study the drip tubing was in excellent shape after 10 years of use when phosphoric was applied through the system.

4. *Yield and applied water* – Large yield increases of **tomato**, **corn** and **cantaloupe**, and moderate increases in **cotton** yield were obtained under SDI. The increase was a result of improved water and fertilizer management. Any reduction in applied water was a result of switching from an inefficient system to very effective SDI system, which also utilizes shallow ground water.

5. *Irrigation frequency* – Irrigation frequency is not a critical issue as long as the soil is kept at reasonably high moisture content and deep percolation is avoided.

Main crops mentioned: Cantaloupe, corn (incl. sweet), cotton & tomato (incl. processing)

Key words: Bed placement, coefficient of variability (CV), crop coefficient, crop yield, depth of placement, drip irrigation, drip laterals, driplines, evapotranspiration, fertigation, furrow irrigation, irrigation frequency, irrigation scheduling, irrigation timing, micro-irrigation, pan evaporation, root intrusion, soil sensors, sprinkler

irrigation, subsurface drip irrigation (SDI), uniformity coefficient (UC), water use, water use efficiency, water distribution

Geographic terms: California, Modesto