DRIP IRRIGATION OF ROW CROPS: WHAT IS THE STATE OF THE ART?

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ABSTRACT

Drip irrigation of row crops is increasing throughout the United States. This irrigation method has the advantage of precisely applying irrigation water in both location and amount, thus offering the potential of increased profit due to reduced water, fertilizer, and cultural costs and increased revenue due to increased yield. This paper is a report on the state of the art of drip irrigation of row crops in California, Texas, and Arizona.
Keywords. Drip irrigation, Row crops.

DRIP TAPES

Many drip tapes are now on the market. They offer a range of tape diameters, wall thickness, emitter spacings, and emitter flow rates. Initially, a tape diameter of 16 mm only was available; however, diameters ranging from 10 mm to 35 mm now exist. The larger diameter tapes make lateral lengths of 400 m to 800 m possible while maintaining acceptable emissions uniformity

Table 1. Drip tapes.

Manufacturer (Drip Tape Name)	Diameter (mm)	Wall Thickness (mil)	Emitter Spacings (mm)	Emitter Flow Rates (l/h)
T-Systems International (T-Tape)	10, 16, 22, 35	4, 6, 8, 10, 15	102, 203, 305, 406, 456, 610	0.53,0.76, 1.02, 1.29, 1.51
Netafim (Streamline, Typhoon)	16, 22, 25	6, 8, 10, 13, 15	203, 305, 406, 610, 762	0.61, 0.79, 1.25
Rainbird (Raintape TPC)	16, 22	6, 9, 14	203, 305, 406, 610	0.98. 1.14, 1.32
Roberts Irrigation Products (RO-DRIP)	16, 22	5, 6, 8, 10, 13, 15	102, 203, 305, 406, 610	0.41, 0.91, 1.29
ToroAg (Aqua-Traxx)	16, 22	4, 6, 8, 10, 12, 15	102, 203, 305, 406, 610	0.49, 0.76, 1.02
Chapin Watermatics (Twin-Wall)	16, 22	4, 6, 8, 10, 15, 20, 25	51, 102, 203, 229, 305, 406, 610	0.57-2.27
Nelson Irrigation Corp. (Pathfinder)	16, 22, 35	8, 10, 15	203, 305, 406, 610	0.51, 1.02, 1.41
Queen-Gil	12.5, 16.5, 20.5	6, 8, 12, 16	100, 200, 300, Variable	0.2, 0.4, 0.8, 1.0, 1.2, 1.6, 1.8, 2.7
Eurodrip	16, 22		Customized	1.2, 1.55, 2.45
Drip Tape Manufacturers and Engineers, Inc.	16, 22	5, 6 , 7-8, 10, 15	108, 216, 317, 438	0.57, 0.79, 1.06

(Tiger Tape)

along the lateral length. Wall thicknesses generally range from 4 mil to 15 mil, and emitter spacings of 51 mm to 762 mm are available. Emitter discharge rates range from 0.53 l/h to 2.27 l/h depending on manufacturer. The range of emitter spacings and discharge rates offer a wide range in tape discharge rates. Table 1 shows these characteristics of tapes by manufacturer.

The quality of the drip tapes generally is excellent as shown in Table 2. Coefficients of manufacturing variation generally are less than 0.05. Emitter discharge exponents generally are between 0.50 and 0.60, although one tape has an exponent of about 0.40. A filtration requirement of 200 mesh is recommended for most of the drip tapes, although some manufacturers recommend a lesser degree of filtration.

Table 2. Performance characteristics of drip tapes.

Manufacturer (Drip Tape Name)	CVa	x[b]
T-Systems International (T-Tape)	0.03[c]	0.50-0.52[c]
Netafim (Streamline, Typhoon)	0.03[d]	0.44-0.48[d]
Rainbird (Raintape TPC)	0.02[c]	0.40[3c]
Roberts Irrigation Products (RO-DRIP)	0.03[d]	0.52, 0.57[d]
ToroAg (Aqua-Traxx)	0.02-0.04[d]	0.50, 0.54[d]
Chapin Watermatics (Twin-Wall)	0.01-0.03[c]	0.51-0.58[c]
Nelson Irrigation Corp. (Pathfinder)	0.025[d]	0.48[d]
Queen-Gil	<0.05[d]	0.56[d]
Eurodrip	0.01-0.02[c]	0.53-0.60[c]
Drip Tape Manufacturers and Engineers, Inc. (Tiger) Tape)	0.049[d]	0.52[d]

[a] Coefficient of Manufacturing Variation

[b] Emitter Discharge Exponent

[c] Obtained from CATI Publication 990102, *Irrigation Equipment Performance Report – Drip Emitters and Microsprinklers*, Center for Irrigation Technology, California State University, Fresno

[d] Supplied by manufacturer

Drip tape can be buried or installed on the surface. Installation equipment is now available for installing drip tape at depths down to about 0.45 m. Equipment is also available for extraction of both buried and surface drip tape. Several manufacturers offer a method of heat-welding tape to repair leaks and to couple tape as it is extracted from the field.

ARIZONA

Drip irrigation has been used in Arizona for several decades. Originally, drip irrigation was used in landscapes, as a means to reduce water costs for homeowners and commercial sites. In agriculture, drip was first used to irrigate specialty crops like grapes and tree crops. Surface drip systems were used to maximize yield and quality by taking advantage of the management control provided by drip irrigation.

Only recently has drip irrigation been used in Arizona in row crop production. Increased water costs, reduced groundwater reserves and public pressure have forced growers to look for more efficient alternatives to the traditional surface irrigation systems.

Tape Spacing and Configurations

Although there are several system types used, there are two basic types of field layouts most growers use: 1 m (40 in.) and 2 m (80 in.) spacings. The reason for these spacings is that cotton, the major crop grown in Arizona, is planted on 1 m spacing. In addition, most vegetable crops in Arizona are grown on beds spaced 1 m apart. However, melons are normally grown on beds spaced 2 m apart. The 1-m spacing gives growers more options in what type of crop can be grown. Unfortunately, 1 m spacing also means more tape, more connections, and higher costs.

In recent years, variations of the 2 m spacing have begun to show up. To avoid the higher costs of a 1 m spacing, growers have opted for 1.8 m (70 in.) spacing. On the 1.8 m spacing, the options for melons still exist. However, using the 1.8 m spacing will also allow the grower to plant two rows of cotton per tape. Planting on either side of the tape, growers are able to put the cotton at 89 cm (35 in.) spacing, and still use conventional field equipment.

The depth at which the drip tape is injected into the soil varies quite a bit. For the most part, drip tape is buried about 20-30 cm. (8-12 in.) below the soil surface. Depending on soil type and past experiences, growers may vary this depth. Recently, the trend has been to inject the tape at a shallower depth. If the tape is buried too deep, the amount of water required to germinate the seed may be prohibitive.

The tape used covers the entire spectrum of companies and types. Thickness of the tape varies with the expected duration of the system. Growers who plan to keep the tape in the ground for several years use thicker tape, opting for 10 or 15 mil tape. Emitter spacing has also varied over the years. Growers have traditionally used 22.5 cm (9 in.) spacing but have also used 30 cm (12 in.) and 45 cm (18 in.) spacings. Again, these decisions are based on the soil type and the crops to be grown.

Water Supply

The water supply in Arizona comes mainly from Irrigation Districts that are operated throughout the state. A few growers have retained use of their own wells. The switch to drip for these growers is easier. They have control of their water source, which is, for the most part, relatively clean. However, other growers must pump out of a ditch or reservoir that is primarily fed via a surface water system. To assure a relatively clean water supply for the drip system, surface water often requires additional filtration. In almost all cases, sand filters are used for filtration. However, other filter types such as disc filters are occasionally used. To use a surface water supply, normally a reservoir or settling pond is needed to avoid flushing the filters excessively. In one case, it was estimated that a grower pumping out of a farm ditch to irrigate

130 ha (320 ac) of cotton used almost 6.2 ha-m (50 ac-ft) of water for back-flushing his sand filters. Another 3.7 ha-m (30 ac-ft) were lost by manually flushing the intake water, without allowing it to pass through the filters. This manual flush was done because at the initiation of irrigation, the water delivered by the district was often heavy with sediment from the surface system. At $291/ha-m ($36/ac-ft), this was a cost of $2880 per year. He has since decided to install a holding pond to help settle out some of the organic and larger materials in the water.

Some Standard Setups

Although drip irrigation of row crops is relatively new to Arizona, growers in the state have been using this technology for several years with much success. In one case, the grower has set up several drip stations throughout his farm. Each station contains a set of filters, chemical injectors for fertilizers and acid, and a holding tank. The holding tank gives the grower some extra flexibility in water delivery. Utilizing wells on the farm, he is able to pump to the holding tanks at his convenience. The elevated tanks then deliver the water to the fields under pressure. In this way, water hammers and other problems associated with turning large well pumps on and off can be avoided. Also, he can take advantage of non-peak power costs by pumping during off hours.

This farm also delivers water to both ends of a field (head and tail). The main lateral to the field is a 15 cm (6 in.) supply line. The buried drip tape is connected to the line under the ground. At the other end, a 10 cm (4 in.) line is installed and connected to the drip line. When irrigating under normal circumstances, water enters from both ends. The allows for relatively long runs (up to 183 m - 600 ft) using 1.3 cm (0.5 in.) tape. This also helps avoid problems when a break occurs in the drip tape. By supplying water from both ends, the point at which the break occurs does not get filled with soil because the water is entering from both sides. This also makes it easy to find the break, as the soil quickly becomes saturated. When flushing is required, the water supply to the 4-in. lateral is turned off and the lateral is used as a manifold flush line. Finally, the use of two supply lines allows for flexibility when repairing laterals lines or the main supply line. At the very least, it is hoped that irrigation water can be supplied by at least one line.

Another farm uses a similar system but utilizes reservoirs to buffer their irrigation system supply. Additionally, the reservoirs are used to grow fish. This gives added value to the irrigation water.

Mobile Power Plants

In an effort to make drip more economical, growers are opting for mobile pumping plants that are moved from field to field. These self-contained, power plants come with a pump, a filter, and all of the connections for injection. Growers simply tow the system to the field, hook it up, and then pump out of their farm ditches. Once the irrigation is complete, they move to the next field. The one drawback is that the timing of the irrigation schedule is rigid. The grower must be careful not to commit his power plant to too many hectares, or he will not be able to keep up with crop demand.

Some New Ideas

As the implementation of drip irrigation grows in Arizona, the technology often struggles to keep up with grower's demands and innovations. Often, their farms are divided into 366 m (1200 ft.) field lengths. To divide these fields into more reasonable lengths for drip tape would require a relatively large investment. However, instead of dividing fields, growers have opted to use larger diameter tape. Instead of using the more common 1.3 cm (0.5 in.) diameter tape, they are using 1.9 cm (0.75 in.) or 2.2 cm (0.875 in.) tape. This larger tape reduces friction losses and gives a more uniform application down the length of the field. They have also done away with the lateral at the end of the field. So, on some fields, crops are being irrigated from one end, running 366 m using 2.2 cm tape. Although no studies have been completed in Arizona yet, growers are not seeing significant differences in yield down the field. Also, they are saving water over the traditional surface systems.

Buried Drip Tape… Not just for irrigation anymore

With global economies and the opening of borders for trade, it is becoming increasingly difficult to find "niche" crops and markets that make it profitable to irrigate with $291/ha-m ($36/acre-ft). water. Vegetable crops may hold some promise, but quite often, everyone is harvesting at the same time, driving prices down. For one local grower, drip is being used to speed up the growing season of vegetables to help meet a niche market need. Originally designed to raise cut flowers, a 4 ha (10 ac) shade house was constructed in Central Arizona. After the flower company moved out, the shade house was taken over by a grower who now uses the shade house for vegetable crops. Under each bed, there are four drip lines. Two lines are used to deliver irrigation water and the other two are used to warm the soil. There is a thermal well on site that is used to pump heated water through these two lines (without emitters). They heat up the soil and help the vegetables emerge and grow quicker than in the field.

In the Future

Drip irrigation is here to stay in Arizona. Our clayey soils and year-round growing season make Arizona an ideal location for this technology. Furthermore, the development of buried drip tape has helped many growers in Arizona avoid the problems generated by our 49°C (120°F) daytime temperatures and the seemingly perpetual UV degradation of plastic and other materials exposed to sunlight. The biggest obstacle for the widespread implementation of drip irrigation is capital. Although growers may be able to recover their costs in a few years, with favorable yields and market conditions, many growers simply cannot put their hands on enough capital. However, piece-by-piece, Arizona is converting to more efficient irrigation systems, including sprinkler, improved surface systems, and subsurface buried drip.

CALIFORNIA

A variety of drip irrigation practices is used depending on crop and location. Strawberry growers in the coastal valleys use 16 mm diameter tape with an emitter spacing of 203 mm. The tape is removed and discarded after each crop. Plastic mulch is used with the drip tape installed at about 25 to 75 mm deep. In some locations, a bed spacing of 1.01 m is used with a bed width of 0.61 m containing two plant rows and one drip lateral per bed. At other locations, a 1.52 m bed spacing is used with a 1.01 bed width containing four plant rows and two drip laterals per bed.

Cool-weather vegetables (lettuce, cauliflower, celery, broccoli, artichoke) are also grown in the coastal valleys of California. Currently, about 10 percent of the irrigated acreage in Salinas Valley use drip irrigation. Initially, subsurface drip irrigation was used, but now most growers use surface drip irrigation and extract the drip tape after each crop for reuse later. This transition is the result of buried drip tape being damaged during the crop harvest. Because these crops were irrigated up to the time of harvest, the harvesting equipment would create deep ruts in the soil down to depths deeper than the installation depth. This would severely damage the buried drip tape, and thus conversion to surface drip irrigation eventually occurred. A bed spacing of 1.01 m is commonly used, but some growers are using a 1.5 m spacing with six plant rows and three drip laterals. A tape diameter of 16 mm, wall thickness of 8 to 10 mil, and an emitter spacing of 305 mm are normally used for these crops.

Along the westside of the San Joaquin Valley, drip irrigation of cotton, processing tomato, peppers, and melon has been practiced. Initially, a tape diameter of 16 mm was used with lateral lengths of 180 m to 245 m, but newer systems used a 22 mm tape diameter with lateral lengths up to about 400 m. The larger diameter drip tapes are more conducive for the larger fields used along the westside compared to the field sizes used in the coastal valleys, which generally are relatively small. Interest now exists in the largest tape diameters which are promoted as being appropriate for lateral lengths of about 800 m. Subsurface drip irrigation is normally used with tape depths of 200 mm to 305 mm, although some growers have experimented with deeper depths. Common emitter spacings are 305 mm to 457 mm using low-flow drip tape with an 8 to 10 mil wall thickness.

Studies comparing drip irrigation with other irrigation methods have shown mixed economic results. Earlier studies of drip irrigation of row crops focused on cotton production, however, the economics of drip irrigation cotton is questionable. Cotton yields for drip irrigation tend to be generally higher compared with furrow irrigation while less water was used for drip irrigation. However, no trend in profit occurred, thus indicating that it is difficult to predict that cotton production under drip irrigation was always be more profitable compared with furrow irrigation. Currently, drip irrigation is being used for processing tomato, fresh-market tomato, and pepper. Conditions best suited for drip irrigation are fields with relatively steep slopes, sandy soil, fields with extreme variation in soil texture, and salt affected fields.

Several case studies of the successful use of drip irrigation of row crops have been conducted over the past years. Buried drip irrigation of pepper was compared with historical sprinkler irrigation at two locations (Irrigation Training and Research Center, 1996a,b). Both sites experienced increased yields (30 % and 37 %, respectively), reduced water use (19 % and 2 %), and increased energy use (18 % and 21 %). However, the energy use efficiency, defined as the ratio of crop yield to BTU's of energy use increased (18 % and 13 %). For both sites, net returns increased by $4,288/ha and $2,265/ha.

Buried drip irrigation of processing tomato was compared with furrow irrigation on a sandy loam soil along the eastside of the San Joaquin Valley using tape depths of 250 mm and 500 mm

(Fulton, 1996). Yield of the shallower installation depth was 10.3 Mg/ha higher compared with the furrow system, while the yield of the deeper installation depth was 20.2 Mg/ha higher. Drip irrigation production costs (system cost, installation costs, energy costs, maintenance costs) were $568/ha/year more compared to the furrow costs. A conclusion of this study was that higher cash value crops must be grown with drip irrigation to recover the drip system costs. Lower cash value crops may not generate sufficient revenue to offset these costs, although higher yields occur under drip irrigation. For this situation, the increase in revenue for the deeper tape would be $1,222/ha assuming a unit crop price of $60.5/Mg.

An ongoing study is comparing subsurface drip irrigation of processing tomato with sprinkler irrigation at two locations along the westside of the San Joaquin Valley in salt affected soils occurred where processing tomato is normally not grown. Results thus far show yields of the drip irrigation to be 13.4 Mg/ha and 22.4 Mg/ha higher than those of the sprinkler irrigation for the same amount of applied water (B. Hanson and D. May. Unpublished data). This study is discussed in more detail in these proceedings.

TEXAS

Cotton

The most well known adoption of drip irrigation in Texas is the St Lawrence area of West Texas, which began in 1984. Rainfall in the region averages between about 254-381 mm (10-15 inches) in good years, and water well yields are very low, typically 2.2 l/s (35 gpm). Growers usually tie about 6 wells together with a goal of being able to provide a daily irrigation volume capability of 2.5 mm (0.1 inch). Not surprising, the conversion from furrow to drip irrigation with its frequent application of small amounts of water had a dramatic impact on the region's cotton yield and quality. For the most part, growers use the lease expensive drip tubing/tape product available.

Along with drip irrigation, these farmers also started practicing alternate row irrigation of cotton. Alternate row irrigation of cotton has received much attention by Texas researchers since it improves yields under all forms of irrigation throughout West Texas. Enciso and Unruh (1999) are continuing this work and are determining the optimal row and plant spacings which will produce the maximum cotton yield under deficit drip irrigation. Preliminary results of their work are shown in Figure 1. The closer row spacings of 0.38 m (15 inches) and 0.76 m (30 inches) produce higher yields than the conventional 1.02 m (40 inch spacing).

High frequency irrigation of cotton under both drip and sprinkler systems has also received much attention from Texas researchers. For example, Bordovsky, et al (1992) found that deficit LEPA center pivot irrigation of cotton every 3 days produced greater yields than those obtained with larger irrigation volumes. LEPA, like subsurface drip, can have very high efficiencies, but which is better?

Bordovsky (2000) has been investigating the relationship between deficit irrigation and the effectiveness of both drip and LEPA. Some of his results are summarized in Table 1. Under full irrigation, there is little difference in yield between daily drip irrigation and three variations of high frequent LEPA irrigation (irrigating every day, every other day, and every three days). However, under deficit irrigation, cotton yields are higher with drip, with the difference becoming greater as irrigation amounts are lowered. Of course, the costs of drip are much higher than a LEPA center pivot. For Texas High Plans conditions, drip costs would have to be no more than $1,482/ha ($600/ac) under deficit irrigation for the economic return of drip to exceed that of LEPA (Figure 2).

<u>Drip and Plastic Mulch</u>

In 1986, drip irrigation and plasticulture for melon production was first adopted by growers in the Lower Rio Grande Valley of Texas and quickly spread to other melon production areas of the state. "Drip under plastic" now accounts for 95% of all melon production in the state. The reason is that, in most years, melons ripen quicker on the plastic mulch and harvest can begin 7 to 10 days earlier, when prices are the highest. Thin-walled drip tapes are used for one or two seasons, then disposed of, along with the plastic mulch. Drip under plastic out performs furrow

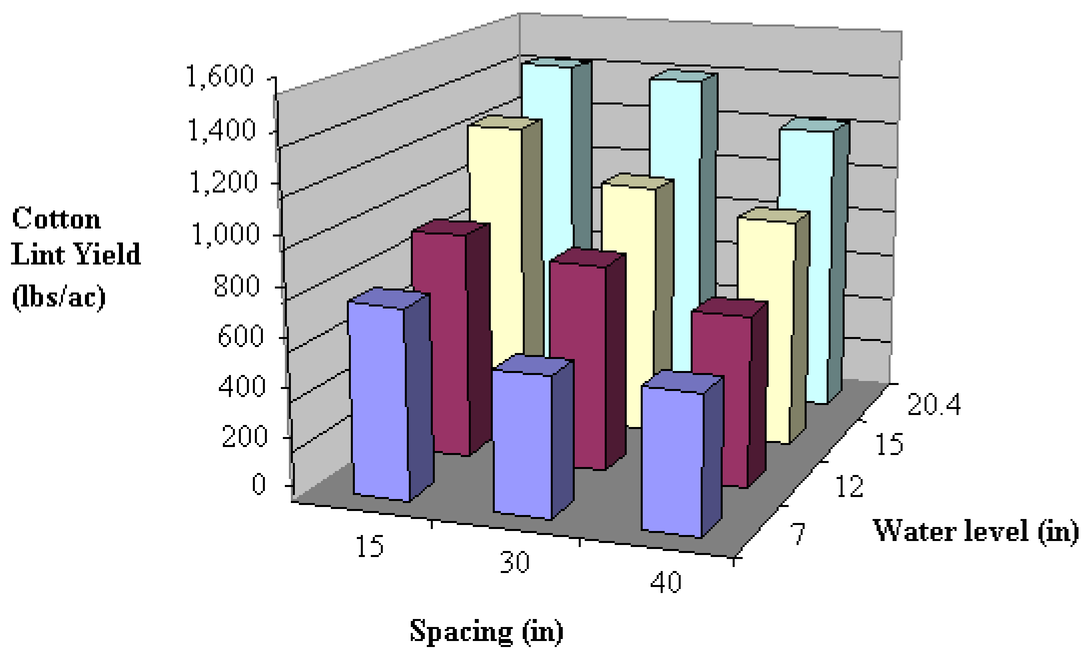

Figure 1. Relation between row spacing, irrigation volume, and yield, St. Lawrence Farms, TX, 1997-1999 (source: Enciso and Unruh, 1999).

Table 3. Average annual cotton lint yield resulting from irrigation with LEPA and SDI, TAES, Halfway, 1995-1998 (Source: Bordovsky, 2000)

Irr. Cap. (mm/day)	Seasonal Irr. (mm/year)	Cotton Lint Yield (Mg/ha)			
		SDI	LEPA		
		1 day	1 day	2 day	3 day
2.5	132	1.24 a[a]	1.01 c	1.10 b	1.02 c
5.0	180	1.34 a	1.22 b	1.21 b	1.22 b
7.6	185	1.36 a	1.25 bc	1.24 c	1.30 b
Avg.	165	1.31 A	1.16 B	1.18 B	1.18 B

[a] Values in a row followed by the same letter are not statistically different (0.05 Tukey)

Figure 2. Comparison of net return to management of LEPA and drip irrigation systems based on production costs and yields at irrigation volumes of 0.1, 0.2 and 0.3 inches/day, at a pumping depth of 300 feet and at 20 year irrigation system life based on small plot yields (source: Bordovsky, 2000).

irrigation, not only by reducing irrigation amounts, but by improving fertilizer use efficiency (with injection) and producing better yields and quality. For example, Table 2 shows a comparison between melon production under typical drip/plastic versus furrow irrigation.

Texas researchers have improved drip/plastic mulch systems by incorporating water harvesting or “rainfall capture.” Water harvesting is not a new concept; evidence is that water harvesting was practiced in the Negev Desert in 2100 B.C. (Evenari et al, 1961). As related to plasticulture, rainfall capture involves the formation of depressions in the bed (Figure 3). Once covered with plastic mulch, holes are punched in each depression to allow rainfall that is caught in the depressions to infiltrate directly into the bed. The purpose is to take advantage of early spring rains in situations where drip irrigation and plastic culture are installed in advance of planting. This practice seems to be particularly suitable for the Winter Garden area of Texas (roughly south and west of San Antonio, extending to Laredo). Dainello et al. (1999) have shown that use of rainfall capture in the Winter Garden will reduce the required number of irrigations by one or two.

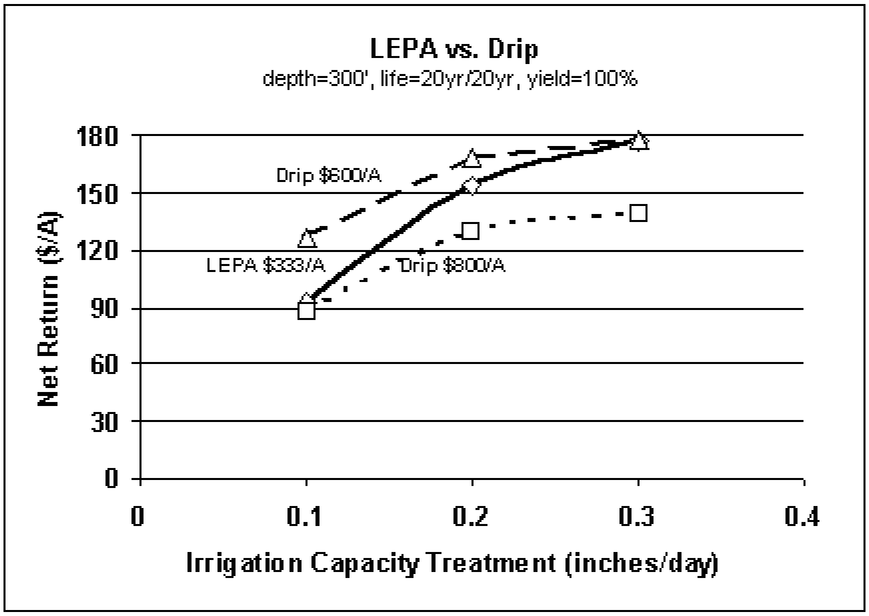

Table 3. Comparison melon production with well-managed furrow irrigation and drip tape/plastic mulch systems in Starr County, Texas (source: Fipps and Perez, 1995).

Production indicator	drip/plastic mulch system	furrow irrigation
Precipitation	66 mm (2.6 in)	66mm (2.6 in)
Irrigation water volume	112 mm (4.4 in)	333 mm (13.1 in)
Number of irrigations	8	7
Nitrogen (as N)	68 kg/ha (61 lb/ac)	177 kg/ha (158 lb/ac)
Yield , boxes (1 box = 0.14 m3)	1235/ha (500/ac)	741/ha (300/ac)

Figure 3. Plasticulture with rainfall capture.

Drip and Turf

As with cotton, the first drip irrigation systems for turf were installed in West Texas. In the 1980's, EcoDrip of Garden City pioneered turf drip systems for athletic fields using "twin-wall' tubing. When properly maintained, these systems have performed and produced excellent turf quality. One field has been continuously irrigated with drip for over 15 years. The effectiveness of turf drip systems is expected to improve with modern drip products that are available today.

In the last few years, a new drip product has been pioneered in Texas, vector flow. Drip tape is manufacture to include a v-shaped strip is attached to and runs along the underside of the tubing. The purpose of the v-shaped strip is to reduce deep seepage and help spread the water horizontally. Indeed, Brown (1999) found that in sand tank experiments, vector flow tape performs as advertised with the benefits more pronounced in sandy soils. Difficulties with patents and business establishment have so far prevented the widespread introduction of this technology for drip irrigation.

General Status

The amount of drip irrigation is increasing in Texas, and on a percentage basis, doubles about every 4 years. However, the total acreage of about 30,360 ha (75,000 acres) is only a small fraction of the 2.55 ha (6.3 million acres) under irrigation. Researchers and growers have demonstrated that most crops respond well to drip irrigation. The only problems are economics, and the proper design and management of systems.

However, the future looks very bright for drip irrigation. Texas is a water short state, and competition between irrigation and other sectors will increase over time. Drip is seen as one way of doing more with less. At Texas A&M, for example, the experiment station located at Weslaco recently converted all of its irrigation to drip due to the drought, continued water shortage in the border region, and the fear that the station was going to be accused of wasting water.

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