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Evaluation of Retrievable Drip Tape Irrigation Systems

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BACKGROUND

California growers of lettuce, broccoli, celery, and cauliflower have long been leaders in drip tape applications. Starting in the early 1990s, large acreages of buried, subsurface drip irrigation (SDI) were installed with the intent of leaving the tape in the ground for up to 10 years (Burt and Styles, 1999). Tape burial depths were typically 20 - 25 cm below the soil surface. Although yields and irrigation efficiencies typically increased, there were numerous challenges with SDI. Since the tape was buried, such issues occurred as gopher damage, problems with root intrusion, soil back-siphonage when the system was shut off, damage during harvesting during wet weather, and difficulties in developing uniform wetting patterns for germination. In addition, because the location of the buried tape was permanently fixed, any shifting of the beds that took place during cultivation operations would result in vertical or lateral displacement from the tape. The fixed position also made crop rotations inherently inflexible since crop bed widths could not be varied.

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Surface drip tape has none of these problems. However, it can only be used on crops that can withstand a wet soil surface. But even with applicable crops it was not used, in part because it was so difficult to retrieve. The tape was also difficult to reuse. The number of reuses was generally limited by the number of splices put into the tape each time. The splices were large and made rewinding the tape difficult. In many cases the grower would have to modify the retrieving equipment to accommodate the bulky splices.

Recently, through trial and error experiments, growers have made technological improvements which make the use of surface tape much more feasible. The development of special equipment to retrieve the tape from the end of the furrows has finally made the reuse of tape possible. Tape polymers themselves have also been improved to be tougher and less likely to stretch when being retrieved. With the additional availability of good commercial drip tape splicing machines, the use of tape for multiple seasons has expanded quickly. The splicing machines enable growers to splice the tape in the field or in the shop (out of the weather and in cleaner conditions) and the new splices do not hinder the rewinding of the tape into compact rolls as did the old couplings and wire ties.

These developments have allowed most growers to cut their annual cost by reusing tape for many seasons. Reuse is not possible with all crops, but this does not preclude the use of surface drip tape (Minetti, 1999; and Yokota, 1999). For instance, strawberry farmers still dispose of their tape annually, but can keep their annual cost low by buying 4 mil tape (note: mil is a common term used to refer to the tape wall thickness, where 1 mil = 1 thousandths of an inch). Since 1997, most of the California central coast's new drip applications on lettuce, cauliflower, broccoli, and celery have used surface retrievable tape rather than SDI. Although not documented in this study, farmers have consistently reported to the authors that they noticed substantial yield increases when they converted from furrow/sprinkler irrigation to SDI, and further increases when they shifted from SDI to retrievable tape systems.

The authors have observed that farmers are most concerned with apparent rips in the tape, leaks, and other physical damage when they talk about how many times they can reuse tape. Few growers have considered whether the tape flow rates change (either up or down) with increased reuse.

This paper reports on research conducted at the Irrigation Training and Research Center (ITRC) of Cal Poly to determine (1) typical design and management procedures for retrievable drip tape systems, and (2) how the discharge characteristics of reusable tape changes with time.

Typical Practices and Layouts

Interviews were conducted with 15 growers in the Salinas and Santa Maria Valleys to determine their procedures for drip tape layout and extraction (retrieval), maintenance and management practices. About a third of the interviewed growers were using SDI prior to switching over to surface drip tape retrieval. The rest of the growers interviewed made the switch from conventional irrigation (sprinklers and furrows) to a retrieval system.

Mainlines and Submains

Growers use numerous materials and methods to convey the water from the pump to the field. Many use completely portable systems, with above ground Yellowmine™ pipe or layflat hose as mainlines and submains. However, many growers use buried PVC pipe as mainlines and submains; some of the growers had the buried pipelines with previous SDI systems, and others prefer the buried pipelines because they are easier to farm around than surface pipelines. In general, leased land is supplied by above ground mainlines and submains.

Manifolds

The manifolds (the pipe that directly supplies the tape) are generally above ground, and are either layflat hose or oval polyethylene (PE) hose. The layflat hose connections tend to leak more than those with the PE hose, but large diameter PE hose manifolds are bulky, difficult to roll up, and hard to store. Portable systems tend to have large (15 cm or larger) diameter manifolds that are long (100 meters or more in length), with pressure regulation at the head of the manifold. Systems that are supplied by buried PVC pipeline submains sometimes have smaller diameter (5 cm - 10 cm) PE manifolds and pressure regulation at the beginning of each manifold. Smaller manifolds provide two advantages over the completely portable systems: (1) the pressure regulation is better, which provides better, more uniform water distribution, and (2) the smaller lengths and diameters are easier to remove and store.

Tape Connections

Hoses are connected to the manifolds in numerous ways. Even a single manufacturer of drip fittings, such as Agricultural Products, Inc.©, provides several dozen types and sizes of fittings for connection between PE hose, layflat hose, and PVC pipe to the tape. Figures 1 - 3 show some connections.

Figure 1. Manifold connection with "quick release" fitting directly connecting PE oval hose manifold to the tape.

Figure 2. Manifold connection with layflat hose, a short (30 cm) section of PE hose, and "quick release" fittings on both ends of the PE hose section.

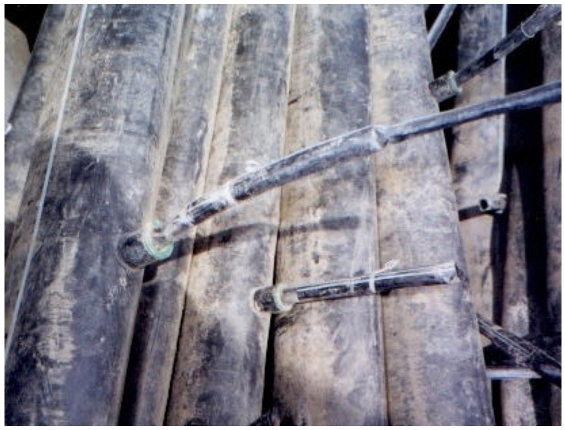

Figure 3. Manifold connection with punched socket fitting, a short section of polyethylene hose and wire ties to the tape.

Tape Installation

Several commercial manufacturers provide tape installation equipment that will place the tape above or below ground. They sell it in a variety of configurations (Figure 4).

Figure 4. Three point hitch commercially available injection system.

The majority of the growers interviewed purchased a whole unit when they began. However, if they wanted more layout units later, they would just buy the injection heads and make the units themselves. Some growers make their whole layout unit from scratch (Figures 5 and 6), although they may use commercially available tape reels.

Figure 5. Tape injection unit manufactured by farmer with many commercially available parts.

Figure 6. Homemade injector heads.

An important aspect of retrievable tape installation is to secure it against the wind. One option is to shelter it in a groove. The groove is a V-shaped soil impression on the top middle of the bed. It is made by a shoe that has been manually attached by the growers on the front of the injection head. Some growers do not use a shoe, but instead just attach an extra piece of steel onto the front of the injection shank. There are many variations of this, including pressing the injection shank into the soil a few centimeters which allows loose soil from the sides of the groove to fall onto the tape, thereby shielding it from the wind and minimizing temperature expansion/contraction problems. If tape is not sheltered from the sun, temperature expansion of the tape can lift sections of it above the soil surface, where it may be exposed to wind. Contraction due to low night temperatures can also cause excessive stress on couplings and fittings.

A second option is to "stitch" the tape into the soil at the heads and tail-ends of the rows by covering a 3 m section of the tape at each end of the drip line. When installing several rows of tape simultaneously, the ends of the tape are tied to a temporary bar that holds the ends in place as the tractor moves down the field (Figure 7).

Figure 7. Use of a temporary bar to secure the ends of tape while a 4-row injector moves down the field.

A third option is to have a worker follow the layout tractor and scoop a shovel-full of soil onto the tape every 15 - 20 ft. This is extremely labor-intensive, and is disappearing as a practice.

The last option to prevent the wind from carrying the tape away is to "permanently" secure, or staple, the tail-ends of the tape to a stake at the end of the bed, so that there is no slack in the line. The upstream end of the tape is secured by the manifold connections. A problem with stapling the tape is that the tape will be tightly stretched during daytime installation, but will contract at night time, possibly pulling the manifold pipe into the field (Figure 8).

Figure 8. The affect of a cold night on drip tape that has been stapled into the tail-end.

Tape Extraction and Retrieval

Tape extraction must be executed with care, otherwise there is a risk of stretching the tape, especially if it is retrieved in the hot mid-afternoon. Extraction machines are available from companies such as Andros Engineering, although some growers will construct their own machines using commercially available components. A hydraulically driven reel is mounted to the side of a trailer and an operator must manually overlook the operation (Figures 9 and 10). The trailer can have up to four reels and remains at the location of the manifold while retrieving.

Figure 9. Commercially available tape extraction machine.

Figure 10. Example of a homemade retrieval trailer, powered by an old tractor engine.

The procedures for retrieving drip tape from the field vary from grower to grower. But before retrieving the tape, the grower must make certain that there is no crop interference, and that the tapes have no water in them.

To ensure that the tapes are clear of water, they may be blown out with air. During this procedure, the retrieval team hooks up a hose from the trailer to the block manifold, with all the lines still connected, and blows air through the lines to flush the water out. The action of blowing the lines is important to reduce the risk of algae build-up if the tape is stored for any amount of time. Since the tape is not filled with water, it also reduces the load on the retrieving head, and allows the tape to be coiled tightly onto a reel.

Depending on the size of the air compressor, it can flush up to a 20 acre block. A common practice is to flush 4 - 10 tapes in advance of the trailer, while the retrieval trailer extracts 4 other tapes at a time. Growers use a rule of thumb -- if irrigation has taken place within 2 days prior to retrieval, they will flush water from the lines.

Before the tape is retrieved, it is often "lifted." This is a procedure in which the tape is lifted over the crop and laid on top of the crop prior to retrieval. Lifting can be done by hand, by sending a worker down the rows to manually lift the tape over the crop; or it can be done mechanically using a tractor with pipes extended from it laterally (Figure 11). If a tractor is used, the team must first disconnect the tape from the manifold, blow out the lines with air, if necessary, and then stake the lines to the ground at the end of the rows.

Figure 11. A typical lifting tool on the back of a tractor.

Tape will be retrieved either before or after harvest, although broccoli is the primary crop with tape removal after harvest. If it is retrieved after harvest, there is generally less labor required but there is a risk that the harvesting crew may damage the tape. All celery growers remove tape prior to harvest because the harvesting procedure of celery will destroy the tape.

INITIAL ANALYTICAL PROCEDURES

Testing of Discharge Characteristics

Fourteen growers provided a total of forty-one 100' sections of tapes of 8 different brands, with various numbers of reuses (1 - 16). The hose samples were tested at the Water Delivery Facility of the Cal Poly ITRC in San Luis Obispo, California. Flow rates from 50 emitters/sample were measured (5 minute sample time) using a domestic water source to eliminate further plugging. The inlet pressure to each hose was controlled by a pressure regulator that was adjusted to 10.1 psi. There was a negligible pressure difference between the inlet and end of the tape samples due to the short length of tape and the low flow rates. Tapes were flushed for 1 minute prior to stabilization of the pressure, to remove any loose material that might be inside the hose.

Small pieces of cut radiator hose were inserted on both sides of each emitter to ensure that all water from one emitter did not move sideways along the hose, but fell into the appropriate catch can. Volumes were measured with 100, 250, or 1000 ml graduated cylinders depending upon the volume to be measured.

Maintenance Rating

During the interviews, all farmers described their maintenance practices. A rating table (Table 1) was developed to categorize their maintenance programs, based upon 2 practices: (1) frequency of hose flushing, and (2) frequency of chemical injection for maintenance purposes. The rating of 1 - 5 (poor - excellent) is based upon the lower value received; that is, if the chemical injection was excellent but the flushing was average, the tape was given an "average" rating overall.

Table 1. Maintenance Categorization.

Rating	Flushing per season	Chemical injection per season
Excellent (5)	9+	11+
Good (4)	6 - 8	8 - 10
Average (3)	3 - 5	5 - 7
Fair (2)	1 - 2	3 - 4
Poor (1)	0	0 - 2

Adjustment of Published Flow Rates

The emitter flow rates were measured at a pressure of 10.1 psi. Manufacturers may list their nominal flow rates at a different pressure, such as 8 psi. The published manufacturer flow rates were adjusted to expected flow rates at 10.1 psi by assuming a discharge exponent of 0.55.

Coefficients of Variation (cv)

Manufacturers publish a coefficient of variation (defined as the standard deviation divided by the mean) of flow rates due to manufacturing variability. A manufacturing cv value of 0.03 was assumed for all products except T-Systems, which publishes a value of 0.02. An "actual" cv was computed based on the actual measured 50 flow rates per sample tape. The "actual" cv is impacted by plugging, wear, and leaks, as well as by manufacturing variation. It does not include pressure differences, as there was a negligible pressure difference between the 50 emitters within a sample tape.

RESULTS

Overall Results

The overall results of the 41 hose samples are shown in Table 2.

Table 2. Overall results of emitter testing.

Item	Value of item	Coefficient of variation of the item values	Average of minimum 4 values	Average of maximum 4 values
Percentage change in flow from published values	-4.7	2.25	-20.5	17.0
Average "actual" cv value of the 41 samples	0.10	1.20	0.01	0.40

The data in Table 2 show that on the average, the flow rates declined somewhat. However, much of the decline (assumed to be due to plugging) was offset by increases in flow that were found in 6 samples. Some of the increases were due to leaks (very large holes were excluded from the data) and other increases are unexplained. Possible explanations include inaccurate published flow rates, widening of the flow paths due to tape stretching from temperature changes or retrieval, or an error in the assumed discharge exponent.

The actual cv values are certainly lower, on the average, than values published by manufacturers. In a few cases, the actual cv values were higher than those published, indicating that it is possible to measure flows from tape samples that are made with a higher-than-published uniformity. The overall lower cv values, however, indicate a general decline in performance over time.

Performance as a Function of Number of Uses

Figure 12 shows that there is no correlation between the number of uses of tape and the actual cv. This result is similar to that found by Barricarte (1999) in a comparison of 15 drip and microsprayer systems on trees and vines. Barricarte found that some irrigation systems deteriorated rapidly and other, older systems had very high uniformities (low cv's). Certainly, Figure 12 shows that is possible to maintain very high emitter uniformities even with repeated uses of tape.

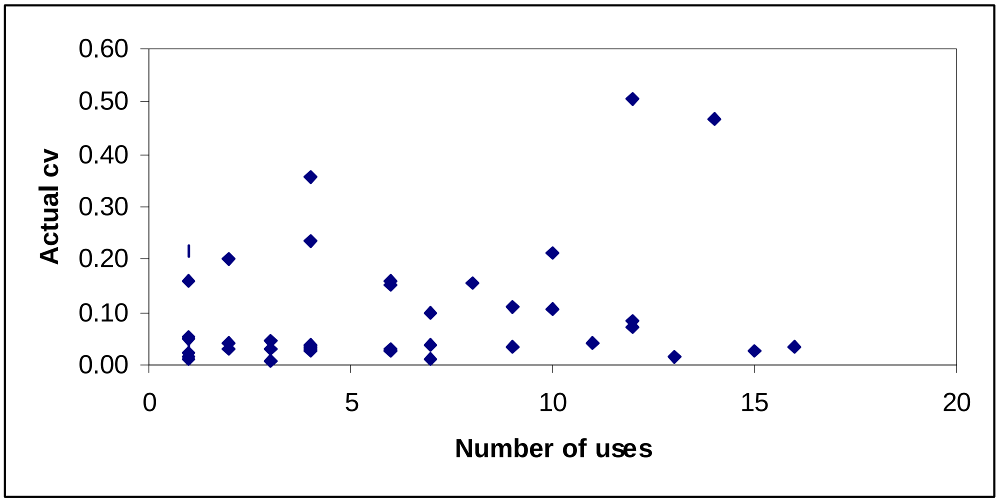

Figure 12. Relationship between number of uses and actual cv of emitters.

Maintenance vs. Performance

Figure 13 arranges the data to compare the maintenance rating (1 = poor; 5 = excellent) against the change in cv (assuming an initial cv of 0.03 for all tapes except T-Systems, which claims an initial cv of 0.02). The asterisk represents an outlier in the data set, which was not used in the analysis. The "whiskers", or lines extending to either side, indicate the general extent of the data. Tukey's pair-wise comparison showed that there is only a significant difference between maintenance ratings 3 and 4.

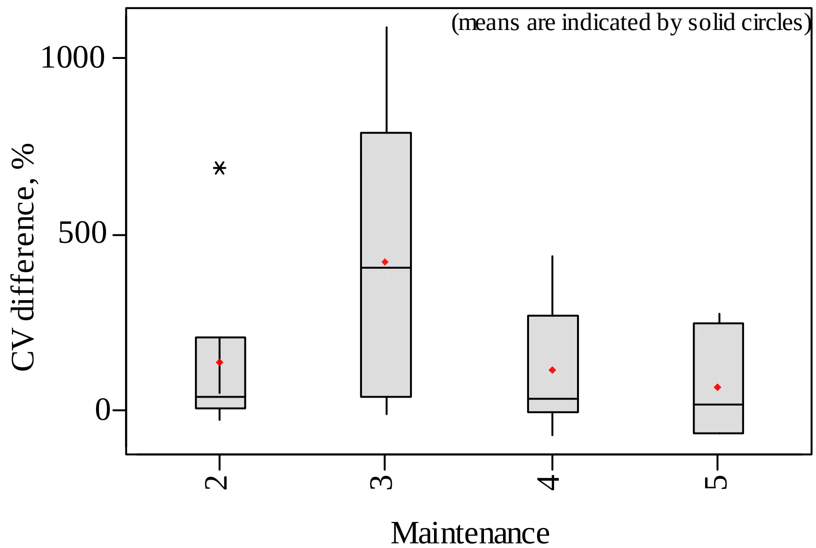

Figure 13. Relationship between maintenance index and CV differences.

When one examines maintenance versus changes in flow rate (Figure 14), there is a borderline significance (P-value = 0.031). Therefore, a Tukey test was performed, which showed that there was a significant difference between maintenance ratings 3 and 4.

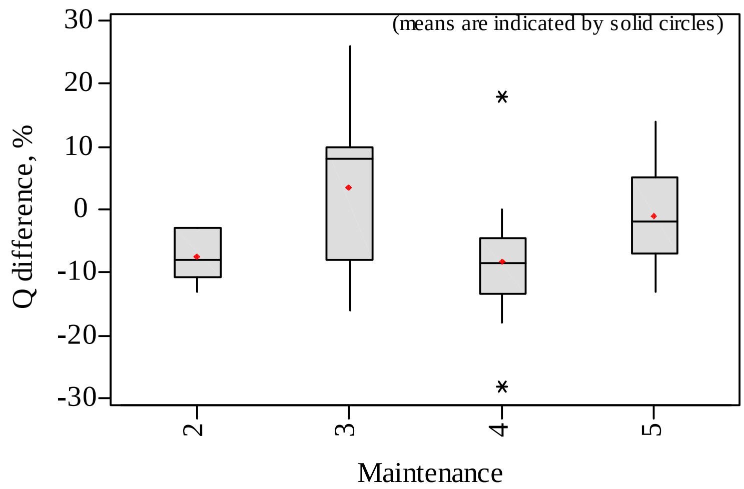

Figure 14. Maintenance relationship to Q differences, %.

Brand Versus Changes in Flow Rate

The P-value for brand vs. flow rate difference is 0.001, which shows a significant difference. Brand 3 was removed from the analysis because there was only one sample of that brand. Figure 15 shows that there is a large amount of overlap between brands, but there are also noticeable trends. However, one must be cautious when interpreting the results because the sample size was small, and the maintenance and number of uses were not the same for all brands. For that reason, tape brand names are not included in this paper.

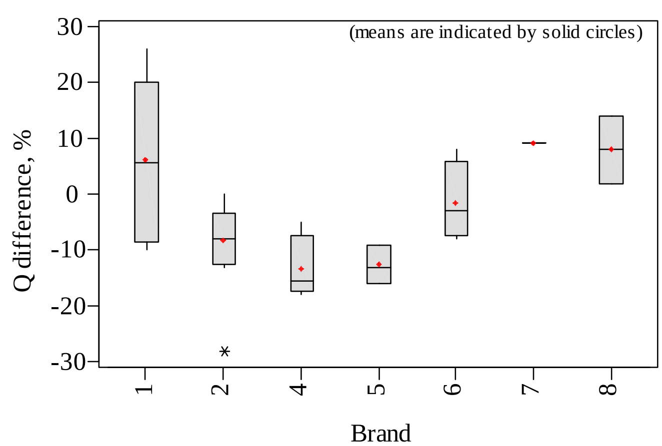

Figure 15. Box plot of brand to Q differences, %.

DISCUSSION AND CONCLUSIONS

Retrievable drip tape systems lack most of the disadvantages of SDI, and have advantages over conventional irrigation systems for certain crops. Successful implementation of retrievable systems requires special equipment for tape installation and retrieval, and has been achieved with a wide assortment of hardware to deliver the water to the tape.

Some farmers have repeatedly used the same drip tape with virtually no decline in discharge uniformity between emitters, as evidenced by tape used 15 and 16 times still maintaining a cv of 0.03. Other farmers use drip tape for only one or 2 uses and the discharge characteristics of their tape suffer greatly.

The researchers were not able to clearly isolate the reasons for difference in performance, although a wide range of operation and management practices was documented among farmers. Isolation of specific causes for decline, such as maintenance, could be done if the research was restricted to only a few growers who use consistent practices and equipment over long periods of time with the same type of tape.

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