AN IMPLEMENT TO INSTALL AND RETRIEVE SURFACE DRIP IRRIGATION LATERALS

H. Zhu, C. L. Butts, M. C. Lamb, P. D. Blankenship

ABSTRACT. *A surface drip irrigation tape installer/retriever was developed for small fields. One operator can install drip tapes on or just beneath the soil surface to precisely irrigate crops after planting and retrieve the drip tapes after irrigation is no longer needed for the season. The implement is mounted to the tractor using a three-point hitch and performs both functions of installation and retrieval of drip tapes in one unit. The retriever mainly consists of a speed reducer, a power transmission line, a drip tape distributor, drip tape spool supporters, water extractors, tensioners, and drip tape guides. The installer mainly consists of a chisel, a press wheel, a tape depth adjustment screw, a tension spring, two soil cover plates, and a tangling prevention ring holder. During the installation process, drip tapes are placed in shallow trenches cut by the 5-cm wide chisel and are covered with soil by 6.5-cm wide pneumatic wheels. The depth of drip tapes can be adjusted from 0 to 5 cm beneath the soil surface. During the drip tape retrieval process, drip tapes are distributed evenly across rotating spools while any water in the tapes is squeezed out. The retrieval speed is adjusted by changing the tractor PTO speed. To retrieve excess disposable drip tapes, a special spool was developed to quickly remove the tapes from the unit. No tools are needed for either installing or removing drip tape spools. Mathematical models were developed to calculate drip tape length, retrieving time, and spool sizes. Speeds of both retrieval and installation increased as the total number of laterals per ha decreased, or as the field length increased.*

Keywords. *Drip irrigation, Drip tapes, Handling implement, Farm equipment.*

The development of a method to effectively irrigate row crops at low capital investment will improve the economic feasibility of irrigation. In peanut production over an 8-year period, variable costs accounted for approximately 25% of irrigation costs, while fixed costs accounted for 75% (Lamb et al., 1997). At average peanut prices, returns over variable cost of irrigation were positive in all years; however, returns over total cost (variable + fixed cost) were positive in only 5 of 8 years supporting the need for a more cost-effective method of irrigation.

Drip irrigation has advantages over other irrigation methods. It has been widely used in many applications throughout the world, resulting in crop yield increases and improved water conservation. Declining water supplies and environmental concerns have stimulated the development of drip irrigation technology (Bucks et al., 1974; Sammis, 1980; Hodgson et al., 1990; Camp et al., 1993; Hanson et al., 1997; Lamm et al., 1997).

The use of surface drip irrigation has increased rapidly in the United States and other countries. A recent survey indicated that surface drip irrigation systems were installed on 394,000 ha for field crops in the United States in 2000, a 10% increase over similar irrigation systems installed in 1999 (Anonymous, 2001). This trend is expected to continue as drip tape manufacturers improve the manufacturing technology. With the surface drip irrigation, drip tapes can be laid out to irrigate crops after planting and then be retrieved after irrigation is no longer needed. It can be installed simply with low initial investment and provide flexible irrigation schedules without using large pumps and wells.

Another advantage of using this method of irrigation is that it provides flexible field arrangement for farm managers to move the irrigation system to other fields for reuse. The improvement of commercial drip tape quality has made it possible to retrieve drip tapes for reuse (Burt and Barreras, 2001). However, the disadvantage of using surface drip irrigation is that drip tape laterals must be installed and retrieved every year, thus increasing labor cost. The handling equipment to install and retrieve drip tape is crucial to the successful application of surface drip irrigation to row crops. Drip tapes currently manufactured are reliable, inexpensive, and applicable to a variety of farming operations. Very few drip tape-handling implements are available to support this irrigation technique for the growing market demand. Little information on drip-tape retrieval process and management has been published (Barreras, 2000) until a recent report by Burt and Barreras (2001) who extensively evaluated procedures and requirements for the equipment to install and retrieve drip tapes used to irrigate vegetable crops.

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The authors are **Heping Zhu, ASAE Member Engineer,** Agricultural Engineer, USDA-ARS, Application Technology Research Unit, Wooster, Ohio; **Christopher L. Butts, ASAE Member Engineer,** Agricultural Engineer, **Marshall C. Lamb,** Agricultural Economist, and **Paul D. Blankenship, ASAE Member Engineer,** Agricultural Engineer, USDA-ARS, National Peanut Research Laboratory, Dawson, Georgia. **Corresponding author:** Heping Zhu, USDA-ARS, Application Technology Research Unit, Ag. Eng. Bldg., OARDC, 1680 Madison Ave., Wooster, OH 44691; phone: 330-263-3871; fax: 330-263-3670; e-mail: zhu.16@osu.edu.

Several manufacturers have produced commercially available drip tape retrievers and installers. However, no existing equipment combines retriever and installer into one unit. Most drip tape installers use an injection head to place the drip tape above or beneath the soil surface. There are four types of drip tape retriever typically used in the field. The drip tape retriever from Wroot Water Systems (Doncaster, England) can automatically pick up the ends of drip tape and feed it into reels for winding. Arizona Drip Systems Inc. (Coolidge, Ariz.) provides a drip tape retriever that can wind one or two rows of drip tape on tapered drums with the tractor hydraulic power supply. Buckeye Tractor Co. (Columbus Grove, Ohio) developed a hydraulic motor-driven retriever to wind drip tapes for either disposal or reuse for small field applications. Andros Engineering Co. (Santa Margarita, Calif.) manufactures a retriever mounted on a specially designed trailer to retrieve tape on up to 8 ha per day with four workers (McGill, 2002). Commercial implements have been improved considerably in the last 10 years; however, they are still expensive, difficult to operate, and labor intensive. They are subject to mechanical problems. A single implement to install and retrieve drip tapes is preferred to reduce the capital investment (Coates, 1985, 1986).

Therefore, development of a simple, inexpensive, and combined tape installer/retriever would greatly benefit farmers using surface drip irrigation technology to increase their crop yield and reduce production cost. The objective of this research was to develop an implement that provides both functions of drip tape installation and retrieval and can be operated by one person, in an effort to increase the feasibility of farmers to better utilize this type of irrigation technology.

Installer/Retriever Description

Development of Retriever

Power Transmission

Figure 1 shows a schematic of the drip tape retriever developed in this research. The retriever uses the tractor PTO as a power source to wind the drip tapes from the field onto a spool. The PTO drives a right angle gearbox with speed reduction ratio of 3 to 1. A pulley is mounted on the gearbox output shaft from which power is transmitted to the spool shaft pulley via a drive belt. The distance between the two pulleys is 1.5 m. The 3-cm diameter spool shaft is 1.5 m long and set 1 m above the ground. The final speed ratio from tractor PTO to the spool is 3.5:1.

The unit is mounted with a three-point hitch behind the tractor. A hardwood platform, which is 1 m wide, 1.8 m long, and 0.6 m above the ground, is a part of the unit and is used to store rolls of drip tape.

Drip Tape Distributor

During the retrieval operation, it is necessary for the drip tape to be evenly distributed across the spool width. To achieve this requirement, the drip tape travel speed across the spool width should automatically match the multiplication of drip tape width by spool rotation speed. An 18-cm diameter wheel is eccentrically mounted on the driving shaft to produce reciprocating motion. The eccentricity was adjustable up to 3.5 cm. The reciprocating motion is conveyed by a 6.5-cm nylon roller to a 1.3-cm reversible ratchet

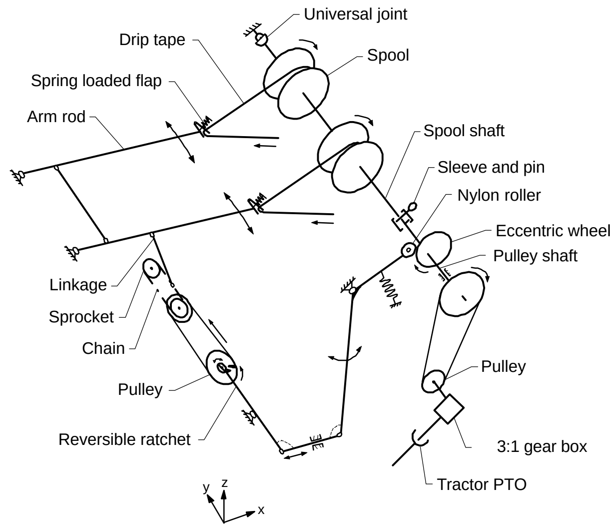

Figure 1. Thee-dimensional schematic of the drip tape retriever.

containing 45 teeth. The ratchet drives a pulley to transfer the motion to two, 12-tooth, 4-cm O.D. sprockets with a single strand chain. The ratchet converts the reciprocating motion to the 90° one-way motion of the chain. The speed of the chain is adjustable. Two arms that hold two drip tapes 0.61-m under the two spools are connected with a linkage to the chain. The motion of the arms serves to distribute the drip tape evenly across the spool width. The adjustable arm length ensures even drip tape distribution across the spool width. Once the chain has completed a circle, the drip tape also completes a trip across the spool width, back and forth.

Spool Design

Two types of spools (fig. 2) were developed for two different purposes: one to retrieve reusable drip tape and another to retrieve disposable drip tape. To retrieve reusable drip tapes, a regular spool consisting of two flanges and a barrel is used. The inside and outside diameters of the spool barrel are 3.8 cm (for easy passage over the shaft) and 14 cm, respectively. The retriever is designed to use spools up to 25 cm wide and 61 cm in diameter (fig. 2a). The weight of the spool with a full load of drip tape is about 22 kg, which is ideal for one person to transport.

To retrieve disposable drip tape, another spool was designed to easily remove the drip tape from the spool. The spool barrel is a truncated cone shape, which is 20 cm wide, 14 cm in diameter at the smaller side and 20 cm in diameter at the larger side. The barrel is permanently attached to the flange on the larger diameter side. The flange at the smaller side is removable from the barrel for unloading the disposable tapes from the spool (fig. 2b).

Spool Support Design

Two spools can be simultaneously mounted on the spool shaft. The shaft is 3.8 cm in diameter, 15 cm long, and 1 m above the ground. The left end of the shaft is inserted into a sleeve with a ring pin. The sleeve contains two U-shape slots, which lock to the pulley shaft. The right end of the spool shaft is connected to a solid D-type universal joint. With the sleeve and the universal joint, the shaft can be disconnected in any direction without using tools. Two collapsible brackets are mounted on both sides of the spool to permit easy removal of

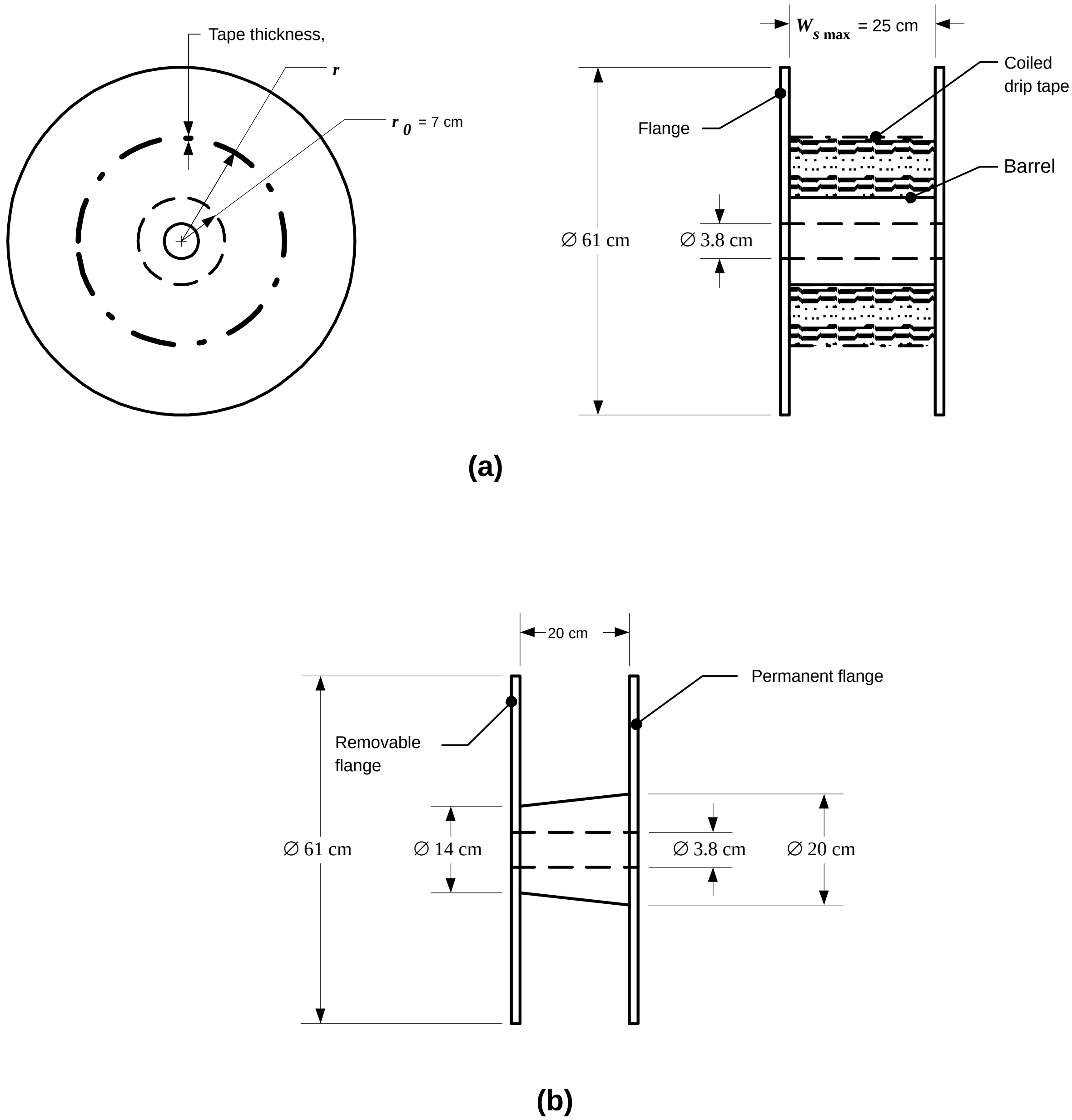

Figure 2. Schematics of spools used to retrieve (a) reusable and (b) disposable drip tape.

the spools loaded with drip tape from the implement. A tapered pin in the bracket is inserted into a notch in the spool flange to lock the spool to the bracket. Two cylindrical sleeves with wing bolts are attached to each bracket. One sleeve prevents horizontal movement of the spool on the bracket. The other sleeve is used to tighten the bracket on the spool shaft. The nominal distance between two spools was 0.91 m, which is adjustable. The spool shaft can be possibly extended to support four spools at one time; however, this function was not completed at this design stage.

Water Extractor/Tensioner

A spring-loaded water extractor and tensioner mounted at the end of the arm hold and gently squeezed the drip tape before it is wound on the spool. This apparatus consists of an adjustable compression spring and a strap hinge with two flaps. When the drip tape is pulled between the two flaps, water is extracted and the tension between the flaps is provided for a more tightly wound spool of tape.

Drip Tape Length, Retrieving Time, Spool Width, and Diameter

When the drip tape is wound over the spool barrel, its trajectory is assumed to follow an Archimedean spiral, given by a polar equation as,

$$r = k\theta \quad (1)$$

where

$$k = \frac{\delta}{2\pi} \quad (2)$$

and r is the coiling radius (cm) of drip tape to the center of spool, θ is the rotation angle (degree), and δ is the thickness (cm) of drip tape. The initial coiling radius is the spool barrel radius (r_0), and the final coiling radius is to the value that is sufficient to coil the entire length (L_T) of drip tapes. The initial angular rotation (θ_0) can be determined by substituting equation 2 into equation 1 and rearranging for θ,

$$\theta_0 = \frac{2\pi r_0}{\delta} \tag{3}$$

Similarly, the angular rotation (θ) at any radius during the retrieval process can be determined by,

$$\theta = \frac{2\pi r}{\delta} \tag{4}$$

Since the spool winds drip tape with a constant speed n (rpm), the actual initial and final values of θ should be $\theta_0 = \pi n t_0$ and $\theta = \pi n t$, respectively. Here, t_0 is the initial time (min), and t is the final time (min). Therefore, the time to wind a drip tape over the spool from radius r_0 to r in a single roll would be,

$$\Delta t = t - t_0 = \frac{60}{n\delta}(r - r_0) \tag{5}$$

If the spool width is W_s (cm) and drip tape width is W_t (cm), total rolls of drip tape wound in a spool is,

$$q = \frac{W_s}{W_t} \tag{6}$$

that yields the total time, T (min), to retrieve the tape as,

$$T = \frac{W_s}{W_t}\Delta t = \frac{60}{n\delta}\frac{W_s}{W_t}(r - r_0) \tag{7}$$

With an assumption that the tape has the same diameter in each individual layer in a roll and total number of layers of the tape in a roll is m, the length of the first layer is,

$$l_1 = 2\pi\left(r_0 + \frac{\delta}{2}\right) \tag{8}$$

The length of the i^{th} layer is,

$$l_i = 2\pi\left[r_0 + \frac{\delta}{2} + (i-1)\delta\right] \tag{9}$$

From the series summation, the total tape length of a roll, L (cm) is obtained as,

$$L = \sum_{i=1}^{m} l_i = 2\pi m\left(r_0 + \frac{m\delta}{2}\right) \tag{10}$$

The total length of drip tape with q rolls in the spool, L_T (cm) is,

$$L_T = \frac{W_s}{W_t}L \tag{11}$$

The number of layers, m, is derived from the equation 10 as,

$$m = \sqrt{\frac{L}{\pi\delta} + \left(\frac{r_0}{\delta}\right)^2} - \frac{r_0}{\delta} \tag{12}$$

The coiling radius of last layer of tape in a single roll is,

$$r = m\delta + r_0 \tag{13}$$

Equation 13 can be written as,

$$m = \frac{r - r_0}{\delta} \tag{14}$$

Substituting equations 10 and 14 to equation 11 results in,

$$L_T = \frac{\pi W_s}{\delta W_t}\left(r^2 - r_0^2\right) \tag{15}$$

or the final diameter, d (cm), of the drip tape coiled on the spool barrel is,

$$d = 2r = \sqrt{\frac{4\delta W_t}{\pi W_s}L_T + d_0^2} \tag{16}$$

where $d_0 = 2r_0$ is the spool barrel diameter (cm).

The total time to completely retrieve the entire drip tape with length L_T in minutes is obtained from the combination of equations 7 and 16 as,

$$T = \frac{1}{2n\delta}\frac{W_s}{W_t}\left(\sqrt{\frac{4\delta W_t}{\pi W_s}L_T + d_0^2} - d_0\right) \tag{17}$$

Therefore, the total retrieving time could be calculated from equations 17 if the total drip tape length and spool sizes are known. With equation 15, total drip tape length could be determined from a given size spool. Spool size can also be determined from the drip tape length, using equation 16.

Development of Installer

The drip tape installer is attached to the same frame as the drip tape retriever. The installer primarily consists of a chisel, a press wheel, a tape depth adjustment screw, a tension spring, two soil cover plates, and a tangling prevention ring holder (fig. 3).

The 5-cm wide chisel can penetrate the soil to a depth ranging from 0 to 5 cm. The press wheel (4 cm wide and 20 cm in diameter) is mounted behind the chisel. The tape depth adjustment screw is used to adjust the chisel height relative to the press wheel to achieve the desired depth. The tension spring adjusts pressure from the press wheel on the soil surface depending on the soil hardness. Two soil cover plates mounted behind the press wheel cover the drip tapes with soil, if desired.

The tangling prevention ring holder is mounted behind the spool, about 0.6 m away from the shaft, and is centered on the roll of drip tape. The ring holder is used to keep the drip tape in the midway of the reel width so as to prevent the drip tapes from tangling during installation. The drip tape travels through a slot in front of the press wheel during installation.A

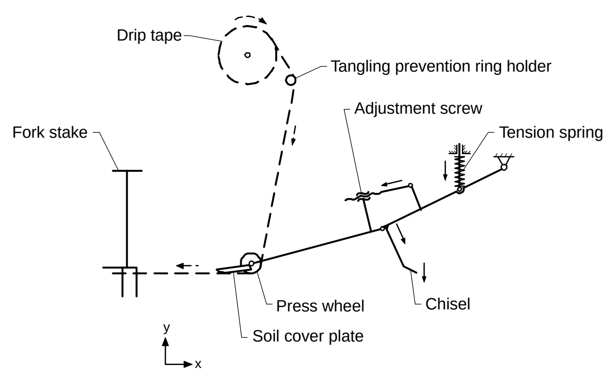

Figure 3. Two-dimensional schematic of the drip tape installer.

fork-shaped stake temporarily anchors the end of the drip tape at the beginning of each bed.

The same shafts and collapsible brackets used for retrieval spools are used for supporting the rolls of tape. The drip tape reels are not locked to the bracket during the installation process. Two sidewalls of the bracket provide friction to keep the reel from freewheeling when the tractor stops. Two rolls of drip tapes can be mounted on the unit. The unit may be expanded to have four rolls of drip tapes at one time; however, this expansion was not practiced in this study.

Operating Drip Tape Installer

During drip tape installation, the subsequent steps are followed. Only one operator is required for the installation process.

1. Mount the drip tape installers on the frame and adjust them to the proper positions, depending on the drip tape spacing and crop row location.
2. Adjust chisel depth to obtain desired drip tape depth. Lift soil cover plates above the soil surface if drip tapes are to be installed only on the soil surface.
3. Mount one roll of drip tape on the shaft for the 0.91-m nominal lateral spacing, or two rows of drip tape on the shaft for the 1.83-m nominal lateral spacing.
4. Use the collapsible brackets to keep the tape reels on the shaft.
5. Adjust the position of the tangling prevention ring to the midway of the reel width.
6. Pass the end of drip tape through the tangling prevention ring and under the press wheel.
7. Use the fork stake to anchor the end of tape to the soil (fig. 3).
8. Start the tractor to install drip tapes on or beneath the soil surface.
9. At the end of the field, stop the tractor and cut the tapes to the desired length.
10. If this end of tape is not connected to the water supply line, fold the end of tape twice with 5 cm length, and then cut a piece of 6 cm long drip tape and slide it on the folded section. This step performs the same function as inserting a plug to the end of drip tape.
11. Turn the tractor to the adjacent bed, and repeat steps 6 to 10.

Operating Retriever

Retrieve Reusable Drip Tapes

The drip tape retriever remains at the field edge during operation. Drip tapes can be retrieved before or after harvesting, depending on the crop type and operation schedules. Only one operator is required for the retrieval process. To operate the installer properly, the following steps are suggested.

1. Select spools with proper size according to equation 16.
2. Disconnect all drip tape from couplers on water supply lines.
3. Move the implement to the other edge of the field where drip tapes stop.
4. Install two empty spools on the shaft at a time, and tighten the spools on the shaft with wing bolts.
5. Coil the end of tapes on the spool barrels twice, insert the end of tapes under the first coil, and stretch the tapes to the spring-loaded flaps.
6. Start tractor engine and adjust PTO speed to wind drip tapes. Since the other end of drip tape is open, water in the drip tapes is squeezed by the flap and extracted from the tape. At the same time, the spring-loaded tensioner provides tension to the drip tape to tightly coil over the spool barrel.
7. After drip tapes are retrieved, secure the exposed tape end on the roll and then move the retriever to next beds and repeat steps 2 to 5.
8. After spools are full, disconnect the sleeve from the pulley shaft, and set the spool shaft end on the ground.
9. Remove the full spools from the shaft and store them on the platform, then repeat steps 1 to 8.

Retrieve Disposable Drip Tapes

Steps to retrieve disposable drip tapes are almost the same as the steps to retrieve reusable tapes except for using the specially designed spools. Once the spools are full, remove the spools from the shaft and discharge the drip tapes from the spools, and then install the spools back to the shaft. Use the end of drip tapes to tighten the roll of tapes after they are discharged.

Field Tests

The implement was used to install and retrieve drip tapes in the fields with peanut, corn, and cotton crops during their growing seasons in the year 2002 (figs. 4 and 5). The field size for each crop was 0.25 ha with 15 beds. Each bed was 91 m long and 1.83 m wide, and contained two laterals with 0.91-m spacing. One operator installed all the tape in approximately 18 min at a 6.4-km/h travel speed. Installation time included anchoring the ends of two tapes at the beginning of each bed, laying two 0.91-m spacing drip tapes on the soil surface, cutting the tapes at the end of each bed, and driving the tractor and turning the tractor to the adjacent beds. It took another 1.5 min to replace two spools on the shaft. For such a design of the field, the drip tape installation speed with one operator was approximately 72 min/ha. The installation time can be reduced as total number of tapes per ha decreased or as the field length increased. Longer fields

Figure 4. The implement used to install drip tapes in a field with 0.91-m lateral spacing.

Figure 5. The implement used to retrieve drip tapes in a field with 0.91-m lateral spacing.

reduce the total number of laterals installed per ha, resulting in less time for cutting, anchoring and turning.

Retrieval tests were conducted in corn, cotton, and peanut fields. Drip tapes were retrieved on reusable tape spools from the corn prior to harvest and from cotton field after harvest. Peanuts were dug and inverted in windrows. The tapes in peanuts were retrieved from the inverted windrows prior to combining with disposable tape spools due to some rodent damage. The tractor engine speed was 1100 rpm during the retrieval. One operator retrieved thirty 91-m drip tapes in approximately 20 min. The time required to remove two full spools and replace them with two empty spools was 2.5 min. At this retrieval rate, 91-m laterals spaced 0.91 m apart could be removed from 1 ha in approximately 90 min. With the same lateral arrangement, the retrieval time for disposable tapes was 88 min/ha. Similar to the installation, the actual retrieving time per ha decreased as the number of laterals per ha decreased or as the field length increased. The limitation of the retriever is that it requires drip tapes to be above the soil surface. Drip tapes must be lifted above the ground before retrieval if the tapes are buried beneath soil or covered by roots.

VALIDATION OF EQUATIONS

Equations 15, 16, and 17 were validated with the same fields used to test the implement to retrieve the drip tapes. The parameters of spools and drip tapes are listed in table 1. The tractor engine speed was 1100 rpm. The actual thickness of flat drip tapes with 0.2-mm wall thickness was 1.32 mm after the tapes were used for the entire growing season. A digital stopwatch was used to measure the retrieving time.

Table 1. Parameters of spools and drip tapes used in the test and calculation

Spool flange diameter (cm)	61
Spool width, W_s (cm)	18.4
Spool barrel diameter, d_0 (cm)	14
Spool speed, n (rpm)	80
Nominal drip tape ID (cm)	1.6
Flat drip tape width, W_t (cm)	2.5
Drip tape wall thickness (cm)	0.020
Actual drip tape thickness, δ (cm)	0.13

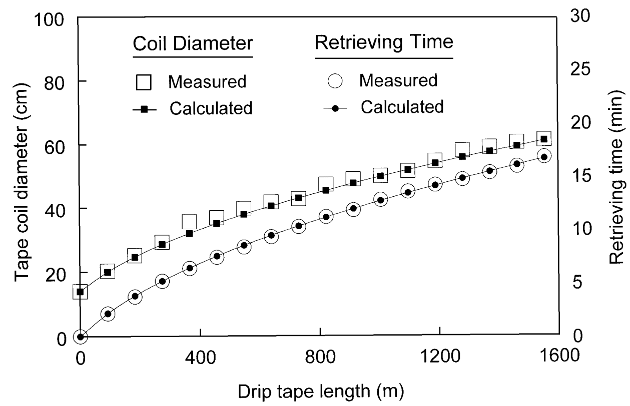

Figure 6. Comparison of the calculated and measured tape coil diameters and retrieval times for various drip tape lengths.

Figure 6 compares the measured and calculated retrieval times, and tape coiling diameter for various drip tape lengths. The curves represent the best fits for the drip tape-coiling diameter and retrieving time calculated with equations 16 and 17. Correlations between measured and calculated retrieving time and coiled tape diameter were 0.995 and 0.997, respectively. For the 61-cm diameter spool, the calculated drip tape length from equation 15 was 1565.4 m while the measured length was 1554.5 m.

Equation 17 indicates that retrieving time is inversely proportional to the spool speed. For example, with the parameters listed in table 1, the calculated time required to retrieve 1554.5-m drip tape is 16.6 min when the spool speed is 80 rpm while it is 8.9 min when the spool speed is 150 rpm. Equation 17 also illustrates that retrieving time increases as the square root of the drip tape length.

CONCLUSIONS

- A simple and inexpensive implement, which consolidates a drip tape installer and retriever in the same unit was developed for surface drip irrigation applications. No tools are needed for either mounting or removing drip tape spools. However, the retriever requires drip tapes to be above the ground before winding.
- Only one operator is required to operate the unit. For a field containing fifteen 91-m long beds with 0.91-m lateral spacing, the speed to install drip tapes was 72 min/ha when the tractor travel speed is 6.4 km/h, and the speed to retrieve drip tapes was 90 min/ha when the spool speed was 80 rpm. The speeds of installation and retrieval can be increased by increasing field length or by decreasing total number of drip tapes per ha. Further investigation on the implement performance, durability, and economical feasibility in large fields should be conducted in the future study.
- The drip tape distributor developed in the implement evenly distributes drip tape across the spool width.
- The simple spring-loaded water extractor and tensioner extracts water from drip tape and provides tension to tightly wind tapes to spool barrels.
- Equations developed to calculate drip tape length, retrieving time, and spool flange diameter agreed very well with measured data.

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