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Installation, Repair, Retrieval and Economic Returns of S3DI Systems in Corn and Cotton Rotations

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Abstract

The use of shallow subsurface drip irrigation (S3DI) systems in row crops can be economically favorable provided the system can remain in the field without major repairs for a substantial amount of time. This research documents installation, repairs, retrieval, and partial economic returns of S3DI systems in-service for 4, 5, 6, and 8 years. Irrigation systems were installed on five different fields for specific agronomic research projects. Either corn or cotton were grown in each field over the life of the systems. Crop yields were documented across years and systems. At the end of the project, drip laterals were retrieved and the number of repairs in each field were documented. Installation costs across all irrigation systems ranged from \$174 to \$212 ha-1 yr-1 averaged over the life of the system. Repair costs ranged from \$3 to \$45 ha-1 yr-1 depending on the length of service and amount of biological or mechanical damage to the drip tubing. Overall, it would take between 10 to 20 years for the cost to repair exceeded the cost to replace depending on labor cost and/or level of biological or mechanical damage to the drip tubing.

Keywords: Corn yield; Cotton Yield; Drip Irrigation; Drip Irrigation Repair; Drip Tubing Retrieval; Partial Net Revenue

Introduction

Shallow subsurface drip irrigation (S3DI) is a technique of burying drip tubing 4 to 5 cm below the soil surface. This irrigation system is especially useful in small, irregularly shaped fields that are common in the southeast USA. Sorensen et al. [1,2] showed that using a shallow soil covering over drip tubing can significantly reduce rodent damage. In addition, yield potential of irrigated peanut (*Arachis hypogaea* L.), cotton (*Gossypium hirsutum* L.), and corn (*Zea mays* L.) was over 2, 3, and 7 times greater, respectively, than associated dryland crops depending on yearly precipitation timing and amount [2]. This increased yield and gross revenues were enough to cover the cost of the in-field portion of the irrigation system compared with the dryland revenue [2].

Even though drip tubing is covered with soil, there were still problems with rodent damage to the tubing. This became apparent when drip tubing in peanut needed major repairs compared with corn or cotton crops. Explanation for more tubing damage in peanut compared with corn or cotton is the amount of foliage cover. In corn and cotton, open canopy crops, rodent pressure was minimized by predators being able to see and capture rodents. In dense canopy crops, such as peanuts, rodents were protected [1]. In this same research, they found the expense to repair, and the number of repairs made to project tube replacement was estimated at \$0.67 $repair^{-1}$ and about 494 holes ha^{-1}, respectively [1].

In research by Sorensen and Lamb [3], drip tubing was subjected to conventional tillage, strip tillage, or no-tillage to determine crop yield and drip tube longevity. The conventional tillage drip tubing was retrieved and installed (same tubing) yearly while the strip and no-tillage drip tubing was not retrieved. Corn, cotton, and peanut crops were grown, and the tubing was evaluated at the end of the project. It was estimated that conventional tilled drip tubing that was removed and re-installed had a life span of over 8 years while the strip and no-tillage systems had life spans of 3.6 and 4.2 years, respectively [3].

Sorensen [4] cut peanut vines at 20 and 40 cm gaps over drip tubing as a possible technique to reduce rodent damage in peanut. Vine cutting removed foliage adjacent the drip tubing, opening the dense crop cover, provide less cover for rodents and possibly allow predators to control rodent population. Cutting peanut vines did not reduce yield compared with non-cut peanut plants. The 40 cm gap reduced the number of rodent damage repairs or holes by half. However, the number of holes per unit area in the 40 cm gap was large enough to be a burden on farm labor.

Installation costs, especially labor, of any irrigation system has been increasing over time. The longer an irrigation system can function with the least maintenance cost, the more value to a landowner. Additionally, the landowner would need to plant the greatest acreage of the crop with the highest net return. In southwest GA, depending on the price of the three major row crops typically grown, peanut is more economically beneficial compared with corn or cotton. Unfortunately, if the landowner uses S3DI, peanut would not be advantageous due to rodent damage and high maintenance costs. Therefore, the objective of this research was to document partial net revenue of corn and cotton rotations when using S3DI. Drip tubing was evaluated at 4, 5, 6, and 8 years after installation following various crop rotations of corn and cotton.

Materials and Methods

Tubing installation. Drip tubing was installed at two locations and at multiple sites within each location. Location 1 was at Dawson, GA (USA) (31o47'02"N by 84o29'16"W) installed on a Tifton loamy sand (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults). There were two irrigation systems installed at this location. Site 1 (D4) was installed in 2016 on a 1% slope with an east to west row direction. Site 2 (D5) had drip system installed in 2017 on a 2% slope with a north to south row direction.

Location 2 was at the Shellman Multi-crop Irrigation Research Farm (Shellman, GA: USA; 31o 44' 44" N by 84o 36' 30"W) on a Greenville sandy loam (Fine, kaolinitic, thermic Rhodic Kandiudult) with 1% slope and a south to north row direction. There were three individual systems installed, two in 2019 (S1, S2) and the last in 2020 (S3).

Drip tubing, at all locations and sites, was installed using a three row "home-made" injector that buried the drip tubing approximately 5 cm below the soil surface using 15 cm covering disks at 1.86 m spacing in alternate crop row middles. Irrigation water was supplied through a series of 5 cm (Dawson) and 10 cm (Shellman) diameter flexible hose with drip tube laterals connected using plastic adapters (Flexnet, Netafim USA, Fresno, CA). At the Dawson site, drip tubing was installed with the equipment described above and connected to the flexible mainline with appropriate plastic connectors. Drip tubing wall thickness was 0.2 mm with emitters spaced at 30 cm (Streamline 630: Netafim USA, Fresno, CA) and a flow rate of 0.91 L h^{-1} per emitter. At Shellman, the drip tubing had 0.25-mm wall thickness (S3 had wall thickness of 0.20 mm) with emitters spaced at 40 cm (Typhoon 875, Netafim USA, Fresno, CA) and a flow rate of 0.84 L h^{-1} per emitter. Different drip tubing characteristics were used at the various sites due to field length (Dawson, 91 m; Shellman, 335 m). Operating pressure at all sites was regulated between 70 to 100 kPa at the laterals (200 kPa at the pump) and water flow and irrigation depths were determined using mechanical water meters. Each irrigation treatment had its own mainline and water meter. At the end of each growing season, the flexible mainline was retrieved and stored to prevent biological or mechanical damage.

Land and crop management. Land preparation was the same for all locations the first year. Before drip tubing was installed, the area was disk harrowed and deep ripped in the fall. In the spring, lime was applied at rates determined by soil testing and incorporated using a field cultivator. All pre-plant herbicides and fertilizers were applied and incorporated using a field cultivator. After planting and crop emergence, drip tubing was installed with the equipment described above. Following drip tubing installation, tillage consisted of a 2-row strip till unit (KMC manufacturing, Tifton, GA) used to prepare the seed bed so as not to disturb the existing drip tubing. Strip tillage depth ranged between 30 and 45 cm depending on soil conditions. Crop management for each individual crop was similar across locations depending on rainfall patterns, manpower, and equipment availability. All crop rows were planted in single rows 0.91 m apart using a commercial six-row vacuum type planter. All preplant soil amendments and fertilizers were applied prior to strip tillage operation. All crops were managed for maximum crop yield with applied fertility and pesticides (herbicides, insecticides, and fungicides) as required by crop scouting and manufacturers' recommendations.

After each crop harvest, crop debris was mulched using either flail mower or bush hog type equipment depending on manpower and equipment availability. Fall tillage consisted of strip tillage (described above) and herbicide applications to keep winter weeds at a minimum. Spring tillage consisted of the same strip till unit or a special "homemade" equipment that tilled only the crop row (no deep ripping). All farming practices used GPS-guided assistance tractor with attached equipment. All field personnel were directed to not use any equipment or perform any farm practices within the fields that did not have GPS guidance. Only self-propelled corn and cotton harvesters moved through the field that did not have GPS capability.

Tubing retrieval. Drip tube removal was accomplished using a "homemade" tubing lifter that pulled the tubing out of the soil and laid it back down on the soil surface. This equipment needed some mechanism to hold the end of the tubing once it come out of the soil to provide resistance. For the Dawson location, manpower was used for resistance. However, at the Shellman location, another tractor was used to follow the retriever with the front wheel of the second tractor driving over the retrieved tubing. Once the tubing was on the soil surface, another "homemade" equipment was used to roll up the tubing using a hydraulic motor attached to a spooled wheel that collected the tubing into a roll. Once the tubing was rolled onto the spool, the center part of the spool was manually collapsed, and the tubing removed for disposal. At the Dawson location, the land area at each site (D4, D5) was small enough that all tubing repairs (Netafim 630 TWD coupling, Netafim USA, Fresno, CA) were counted manually by walking adjacent each lateral. In Shellman, as each lateral was being retrieved the hydraulic motor was stopped and the repair connector (Netafim 870 TWD coupling, Netafim USA, Fresno, CA) was removed and counted. At both sites the number of repair connectors were

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counted per lateral and then totaled per land area.

During the irrigation season the supply and discharge ends of the tubing were exposed for connection (supply) and visual inspection (discharge) to determine if each lateral would pressurize. At the end of each crop year, after the mainline was retrieved, both the supply and discharge end would be lightly covered with soil to protect the ends. In the spring, the tubing would be uncovered, the supply end would be connected to the mainline and the line pressurized. If a drip lateral did not pressurize, inspection was performed the length of the lateral to identify the cause. With the supply and discharge ends exposed during the growing season, they were subject to biological and mechanical damage. Therefore, repairs made at either end were counted but not considered “infield damage” but were considered normal annual maintenance. All repairs made in the first and last 2 m of each lateral were considered normal maintenance.

Installation/Retrieval expenses. Not all expenses to install, repair, and retrieve drip tubing were recorded. For instance, the time it took for tubing installation was not recorded. Labor costs described by Sorensen et al. [3] was \$8 h^{-1} but has risen to a minimum of \$18 h^{-1} (local area) which was used for the labor costs for this research.

The following discussion is a good estimate of the time and costs to install drip tubing. A minimum of three people were required to install the drip tubing. One tractor driver and an individual at each end of the field to make turn arounds i.e., cut the tubing and to stake the tubing down on the return trip, with an approximate 3-min turn-around time. The tractor can safely install drip tubing at 3.5 km h^{-1}. At the Dawson site for field D4, it took about 1.0 h to drive the actual rows with an added 0.5 h for turns. Labor cost for this field was three people for 1.5 hours for a total of \$81 $field^{-1}$, \$155 ha^{-1}, and about \$20/ha^{-1} yr^{-1} over the life of the system (8 yr). Shellman field S1 is more like a real field situation. Total row length to install the tubing for S1 was 3.73 km which could be driven in 1.06 hr plus 0.56 hr for turn time, for a total of 1.56 hr. The labor results for S1 were \$81 $field^{-1}$, \$37 ha^{-1}, and \$7.36 ha^{-1} yr^{-1} for the life of the system (5 yr).

Drip tubing retrieval methods were different for the two locations due to soil type. The Dawson site was easier to retrieve due to lighter soil texture compared with Shellman which had a heaver soil texture. At the Dawson site, retrieval consisted of a tractor operator and a person at each end of the field. Retrieval equipment could only lift one line at a time. At Dawson, each line was held manually while the tractor moved though the field. Retrieval speed was similar to installation speed at 3.5 km hr^{-1}; therefore, it took three times as long to lift but turnaround time was much faster at about two minutes per turn. After lifting the tubing and laying on the soil surface, rolling the tubing took about 30 min for the whole field as four lines could be rolled at a time because of short row length. Retrieval cost for D4 and D5 were similar at \$109 and \$105 $field^{-1}$, respectively.

Shellman fields required two tractor operators to lift the tubing. The lead tractor lifted the tubing out of the soil. The second tractor followed the first with the front tractor tire running on the drip tubing providing friction so the tubing would pull out of the soil. Both tractors traveled at about 2.5 km h^{-1}. Turnaround time was less than a minute. Two people were required to retrieve the tubing into rolls, retrieving one lateral at a time at about 5 min/lateral. Total retrieval cost for S1, S2, and S3 were \$159, \$154, and \$154 ha^{-1}, respectively.

The equipment used to lift the tubing out of the soil and to roll the tubing into rolls has no commercial value because they are “homemade” so the major cost would be tractor power and fuel. When spreading costs over the life of the irrigation system, the cost of fuel to install, repair, and retrieve the drip tubing will be minimal compared with other costs, and was not included.

Partial net income. Corn and cotton were the only crops used in this research. Individual fields were part of ongoing research so not all fields had the same rotation across years. Each crop year used individual crop price for that year to determine yearly gross revenue. The average price received for corn across all years was \$0.19 kg^{-1}. The average price for cotton lint across all years was \$1.78 kg^{-1}. These average crop prices were used to determine the average gross revenue across years, locations, and fields. Gross revenue per unit area across years was averaged for each field. Total expenses for each system were subtracted from the average gross revenue for the partial net revenue.

Results and Discussion

Installation expense. Expenses that were recorded were physical equipment that could be counted or totaled, i.e., drip tubing, mainline, appurtenances, repair couplings, and labor cost to repair holes [1]. Table 1 documents physical irrigation system parts and appurtenances required for installation and repair with associated costs.

The installation costs at both Dawson and Shellman locations and individual fields are documented in Table 2. Installation costs on a per area basis are greater at Dawson (D4, D5) than at the Shellman sites. The higher expenses at these sites attributed to the short field length (less tubing) and long field width (more mainline; D4). The mainline (Flexnet, Netafim USA, Fresno, CA) was 60 (5 cm diameter) to 85 (10 cm diameter) times more expensive than field drip tubing. When installation costs are spread over the life of the system, Dawson had higher costs (\$205 yr^{-1}) than Shellman (\$183 yr^{-1}) except for Shellman S3 field. Higher costs at Dawson can be attributed to the longer mainline and shorter field runs and for Shellman S3 the shorter life span by one year. Therefore, growers would need to maximize their field length to width ratio to reduce the cost of the mainline to tubing ratio. Shellman farm fields have a much larger field length to width ratio resulting in less expensive system to install.

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Table 1: Installation and repair values for drip tubing, mainline, appurtenances, repair couplings and labor (2023 values).

Installation Inputs	$ unit^{-1}		Repair Inputs	$ unit^{-1}	
	Cost	Unit		Cost	Unit
Streamline 630[a]	0.086	m	labor	18	hour
Typhoon 875	0.1	m	time/repair	5	min
Flexnet to tubing	0.85	each	Repair coupling	0.63	each
Flexnet (5 cm)	5.11	m	Repair coupling	0.87	each
Flexnet (10 cm)	8.42	m			

[a]Streamline, Typhoon, Flexnet are products of Netafim USA, Fresno, CA.

Table 2: Shallow subsurface drip irrigation system installation date, total area, mainline, tubing, appurtenances, and installation expenses for systems installed at Dawson and Shellman, GA.

Location	Field	Install[a]	Total	Main	Fittings	Tubing[b]	Install	Total	Total	System
	name	date	area	line	cost	cost	labor	costs	area cost	Cost
		year	ha	$ field-field^{-1}	$ fieldfield^{-1}	$ fieldfield^{-1}	$ field-field^{-1}	$ field-field^{-1}	$ ha^{-1}	$ha^{-1} yr^{-1}
Dawson	D4	2016	0.52	511	46	245	81	883	1697	212
	D5	2017	0.31	168	15	146	40	369	1191	199
Shellman	S1	2019	2.2	603	31	1203	81	1918	872	174
	S2	2019	1.7	462	23	930	70	1485	873	175
	S3	2020	1.7	462	23	800	70	1355	797	199

[a]Retrieval date = fall 2023.

[b]Thin-wall drip tubing = 5470 m ha^{-1}

Repair expenses. During the life of each irrigation system, repairs were needed due to biological and mechanical damage. Table 3 documents the extent of repairs in each irrigation system at Dawson and Shellman locations. Biological damage was consistent with previous research documented by Sorensen et al. [1] with major damage from rodents. On a per area basis, Dawson D4 and Shellman S3 had the most drip tube damage. At Dawson, there was a situation in D4 where it was documented that white tailed deer (Odocoileus virginianus) had bedded down for an extended period during the 2022 growing season causing damage in a small area. Field D4 was farthest away from any human traffic and close to large production fields. Contrary to D4, D5 had a very low amount of damage probably associated with human traffic. There was a major paved road on one side and a field road on another. The amount of human traffic may have helped reduce biological damage.

At Shellman, S1 and S2 had much lower number of repairs across the life of the system compared with S3. At Shellman S3, major repairs were needed due to mechanical damage. During a strip till operation, the tractor GPS was not corrected by the operator with a recent software update and the guidance system was off-track causing damage throughout the irrigation system. Almost all S3 was tilled before the error was recognized and a correction applied to the GPS unit. This occurred in spring 2021 and repairs were made till 2023 as these damaged areas were slowly corrected. After this GPS mishap, a calibration area was set up and GPS testing and corrections were made before entering the actual field and operations started. The yearly cost to repair for Dawson was much lower than for Shellman (Table 3) probably attributed to the smaller field size and human traffic (D5).

The total number of repairs for any site, across the life of the irrigation system, with a corn and cotton rotation, was less than those described by Sorensen et al. [3]. Their crop rotation also consisted of peanut and suggested without peanut, drip tubing life span would be about 8 years for a conventionally tilled field where the drip tubing would be retrieved and installed each year. For a strip till, field, they suggested a life span of 3.6 years. This research documents drip tubing is viable for 8 years in a corn/cotton rotation (Dawson D4). Total cost to repair per unit area for Dawson averaged $9 yr^{-1} for the life of the system while Shellman averaged $27 yr^{-1}. The average cost to install divided by the average cost to repair implies that the Dawson system would take 22 years before the repair costs exceed the replacement costs. At Shellman, due to the GPS system mistake on S3, the cost to repair would exceed the cost to replace in only 7 years. If we removed S3, then the time to replace increased to 10.5 years.

The average total cost of the irrigation system to install plus the total repair cost over the life of the system was $214 yr^{-1} and $209 yr^{-1} for Dawson and Shellman, respectively (Table 2 & Table 3). Sorensen et al. [3] showed that total cost for strip till, no-till and

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conventional tillage areas had an installation and repair cost of \$150 yr^{-1}. The increased costs for this research were probably due to inflationary costs of irrigation components and labor expenses. The major expense for tubing retrieval was labor. Tractor and fuel costs were minimal when spread over the life of the irrigation system and was not included in overall expenses.

Table 3: Dawson and Shellman irrigation system repairs made over the life of the system consisting of number of couplings used, repair time, cost of couplings, hourly and area labor expenses, yearly cost, total system cost per area per year.

	Repairs Counted	Total Area	Couplings Counted	Repair Time	Labor Cost	Labor Cost	Coupling Cost	Total Cost	System Cost
Dawson	number	ha	Number ha^{-1}	min ha^{-1}	\$ h^{-1}	\$ ha^{-1}	\$ ha^{-1}	\$ ha^{-1}	\$$ha^{-1}$ yr^{-1}
D4	17	0.52	33	163	49	94	21	115	14
D5	1	0.31	3	16	5	16	2	18	3
Shellman									
S1	71	2.2	32	355	107	48	62	110	22
S2	38	1.7	22	190	57	34	33	67	13
S3	103	1.7	61	515	155	91	90	180	45

Partial net revenue. Crop rotation for each field is shown in Table 4. Each field was part of other research projects across years. Average gross revenue and eventual partial net revenue are shown in Table 5. The cost to retrieve tubing was calculated and averaged \$14 and \$17 yr^{-1} at the Dawson location, field D4 and D5, respectively. Tubing retrieval cost at the Shellman location averaged \$34 yr^{-1} or just over double the cost at the Dawson location probably due the slower travel speed required to remove the tubing from the heaver soil which increased labor costs. Total cost to install and repair ranged between \$219 ha^{-1} yr^{-1} to \$283 ha^{-1} yr^{-1} depending on length of service for the system and damage to the drip laterals. The net partial revenue ranged from \$2017 to \$2486 ha^{-1} yr^{-1} depending on location (Table 4). Across both locations, the total yearly total cost for system installation, repair, and retrieval was about 11% of the gross revenue.

Table 4: Crop rotation for each individual field across years.

Year	Dawson		Shellman		
	D4	D5	S1	S2	S3
2016	cotton				
2017	cotton	cotton			
2018	cotton	corn			
2019	corn	cotton	corn	cotton	
2020	corn	corn	corn	corn	corn
2021	corn	corn	corn	corn	corn
2022	corn	corn	corn	corn	corn
2023	corn		corn	corn	corn

Table 5: Average yearly gross revenue, yearly installation cost, yearly repair expense, yearly retrieval cost, and partial net revenue for Dawson and Shellman.

Location	Install date	Total system life	Total gross revenue	Average gross revenue	Total system cost	Partial net revenue
Dawson	yr	yr	\$	\$$ha^{-1}$ yr^{-1}	\$$ha^{-1}$ yr^{-1}	\$$ha^{-1}$ yr^{-1}
D4	2016	8	18422	2303	240	2063
D5	2017	6	16228	2705	219	2486
Shellman						
S1	2019	5	12062	2412	228	2184
S2	2019	5	11342	2268	219	2050
S3	2020	4	9201	2300	283	2017

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Conclusion

The use of shallow subsurface drip irrigation systems in row crops can be economically favorable provided the system can remain in the field without major repairs. This research documented the installation, repair, and retrieval expenses of various S3DI systems. The economic returns of five S3DI systems were monitored over the lifespan of 4, 5, 6, and 8 years. Irrigation systems were installed at five different fields for specific agronomic research projects where rotations of corn or cotton were grown in each field over the life of the S3DI system. Crop yields across years were documented with each system. At the end of the life span of each system, drip laterals were retrieved and the number of repairs in each field were documented. Installation costs across all irrigation systems ranged from \$174 to \$212 ha^{-1} $year^{-1}$ averaged over the life of each individual system. Repair costs ranged from \$3 to \$45 ha^{-1} yr^{-1} depending on the length of service and amount of biological or mechanical damage to the drip tubing. Average gross revenue from corn and/or cotton ranged from \$2300 to \$2700 ha^{-1} yr^{-1} with a net partial revenue (subtracting the average irrigation system cost) ranging from \$2017 to \$2486. Overall, it would take between 10 to 20 years for the cumulative repair costs to exceed the cost to replace depending on labor cost and/or level of damage to the drip tubing.

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