NRCS

6200 Jefferson NE
Albuquerque, New Mexico 87109
Phone: (505) 761-4400 **Fax**: (505) 761-4402
Web site: www.nm.nrcs.usda.gov

September 8, 2003

NEW MEXICO AGRONOMY TECHNICAL NOTE NO.66

SUBJECT: ECS – Water Conservation Through Drip Irrigated Alfalfa Cropping Systems

Purpose: To distribute Agronomy Technical Note No. 66.

Effective Date: When contents have been noted.

Filing Instructions: Filed on web site at: http://www.nm.nrcs.usda.gov/technical/TechNotes/agro.html

KENNETH B. LEITING
State Resource Conservationist

Attachment

Dist:
Electronic

Water Conservation through Drip Irrigated Alfalfa Cropping Systems
Final Report

EXECUTIVE SUMMARY

Alfalfa continues to be the number one crop for irrigated agricultural acreage in New Mexico and accounts for almost 50 percent of the water used for irrigated agriculture. The state has mandated that no more than 15 acre-feet of water over a 5-year period be used for irrigated crop production. This 4.8-acre project started with encouragement from the farming community to demonstrate potential water savings through subsurface drip irrigation (SDI). Declining water tables and increased political and environmental demands for water resources were the major reasons this has become an interest to the farming community. Approximately 43 acre-inches less water were applied to drip irrigated alfalfa as compared to the sprinkler irrigated field during the course of the demonstration project. Each acre-inch of applied water from drip irrigation produced approximately 349 pounds of alfalfa. Major events in water supply coupled with root intrusion made this demonstration perform poorly in the first and third years. Drip irrigated alfalfa produced 4,500 pounds per acre less total alfalfa than the sprinkler irrigated alfalfa and 560 pounds less than the furrow irrigated field. Alfalfa cultivars performed the same across all years with significant yield variability in the third year after many of the drip lines failed. We believe that recent advances in herbicide treated emitters in the drip tape will prevent root intrusion in future applications. This project ultimately demonstrated the validity, practicality, and pitfalls of using drip irrigation. The project highlighted concerns over uniformity, system hygiene, longevity, fertility, maintenance, crop performance, and rotations into other crops. Rotation from alfalfa to another crop was investigated with a review of available literature. Subsurface drip irrigation has been shown to have an impact on tomatoes by increasing yield by an average of 14% with a 25% water savings. Unfortunately, cotton (a favored rotation in the arid southwest) and lettuce was not a favorable crop for drip irrigation. Literature results did show that SDI is better than furrow irrigation systems in most cases. The potential for water conservation with SDI is still possible and has begun to be adopted several farms in the southwestern United States. The economics of the system still remains to be determined.

Figure 1. Water ponding from sprinkler irrigation.

INTRODUCTION

Alfalfa dominates irrigated land in the region where this demonstration project was located. There were approximately 69,500 acres of irrigated land in Chaves and Eddy counties in 1997. Alfalfa accounted for approximate 62 percent of this irrigated land. The water production function presented by Sammis (1981) suggests that 48 percent of all the water withdrawal for agricultural purposes (Wilson 1995) was used to produce alfalfa. Water use for agriculture, however, has declined due to a number of factors including water shortages, increased environmental regulations, and political obligations to downstream users. The water that is left should be used as efficiently as possible.

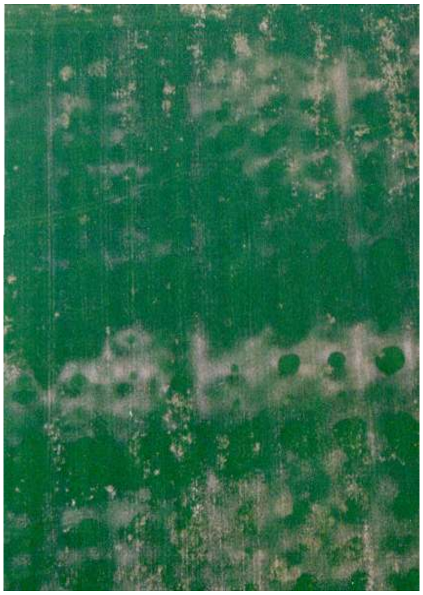

Figure 2. Poor water uniformity due to worn nozzles in sideroll sprinkler system.

Current irrigation systems are often subject to poor water application efficiency. Sprinklers can often apply more water at one time than the soil can absorb (Figure 1). Worn nozzles or insufficient pressures to run the sprinkler systems (Figure 2) as well as poor engineering of nozzling packages on center pivots (Figure 3) reduce the efficiency of how water is used for crop production. Many regions of the southwest are known for high wind conditions during the spring which severely limits the efficiency of these types of irrigation systems (Figure 4).

Subsurface drip irrigation (SDI) could improve many of the limitations experienced by other irrigation systems but may also help to reduce the quantity of water used to produce similar yields currently produced in the region. SDI has become more popular in the last 20 years, but SDI systems have existed in the USA for the last 40 years. Although initially applied in California and Hawaii, currently Israel may well be using and developing the most advanced technology. In areas where water is the scarcest and has the greatest potential of producing high incomes, new water conservation policies have emerged and indeed new irrigation systems have been developed, tested and applied.

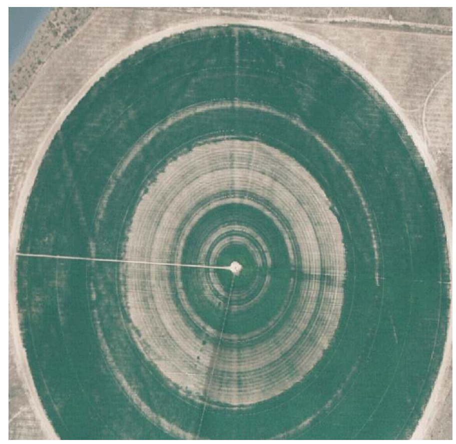

Figure 3. Poor alfalfa uniformity in center pivot system due to poor nozzling.

Subsurface Drip Irrigation is defined by ASAE S526.1 "Soil and Water Terminology" as "application of water below the soil surface through emitters, with discharge rates generally in the same range as drip irrigation" (as cited in Camp et al. 2000). Current systems are quite different from the ones used in the past. Well-designed modern systems, use water filtration, air vacuums, check valves, pressure regulation, flow measurement, chemical injectors, and a system of distribution tapes (Camp et al. 2000). The main two functions of a SDI system are to dissipate the water pressure in the distribution system and to discharge a limited, nearly constant flow rate whether located in high- or low-pressure positions (CAST, 1988, p. 33).

Figure 4. Wind drift very common in the spring of every year during crop establishment and results in poor stand uniformity and poor water efficiency.

Most SDI systems irrigate tree, fruit, vine, agronomic, pasture, landscape, and turf crops. SDI has been successfully used for vegetable crops such as tomatoes, lettuce, potatoes, sweet corn, apples, asparagus, bananas, broccoli, cabbage, melons, carrots, okra, onions, and squash among others. For agronomic crops, it is used primarily on cotton and sweet corn. Other crop applications have included alfalfa, grain sorghum, peanuts, pearl millet and wheat (Camp et al. 2000). Several horticultural and agronomic studies using SDI indicate a yield enhancing effect but there are both pro and con sides to the adoption and benefit of using SDI.

One of those disadvantages to SDI is that there is a learning curve that could make growers resist developing and using SDI. SDI systems demand good management. Maintenance of drip tapes, emitters, leaks, and row and emitter spacing must be planned effectively in order to maintain the initial investment for long periods of time. Properly maintained, all components of SDI systems could last up to 10 years, and more for some parts of the system. Soil salinity issues must also be addressed as well as the effects of excess calcium carbonate dissolved in the irrigation waters. SDI requires a heavy initial investment, especially relative to an already established furrow or sprinkler irrigation system. An operational SDI system involves a pressurized water distribution system and includes a variety of components such as pumps, valves, filters, chemical injectors and a distribution system of solid pipes and flexible tape or tubes. Because of the initial investment, there might be a reduction or loss of profits for the first couple of years. After the system is adapted and well managed it is quite possible that it will be profitable due to yield increases and operation cost savings.

MATERIALS AND METHODS

The location of the field is known as Bench 14 at the NMSU Agricultural Science Center, Township 18S, Range 26E, Section 16 (NW1/4, NE 1/4). The field was surveyed prior to drip installation to comply with the National Environmental Policy Act (NEPA). The report concluded that there was no evidence of historical significance in the proposed study area. The soil series was a Reagan clay loam series (fine, carbonatic, Thermic, Typic Calciorthid) (USDA, 1981).

Figure 5. Tape installation with modified “Ox” ripper implement.

T-Tape International supplied the drip tape (81,500 feet, 5/8" diameter tape, 24-inch emitter spacing that delivered 0.28 gallons per minute per 100 feet of row at 8 psi). The tape was placed 30" apart in lines running east to west to a depth of 14-inches (Figure 5).

The tape was connected to PVC pipe (1,080 feet, 2-inch, 200#) at the head and foot of the field in four stations. A supply line (1,680 feet of 8-inch, 100#

PVC) had to be installed from the irrigation water reservoir to the field. Trenching was done with a ditch-witch (rented) to a depth of twenty-four inches to hold the 8-inch pipe and 2-inch pipe (Figure 6).

One flow sensor and six pressure gauges were installed to track water application and insure optimum system performance. Pressure combined with flow measurements assisted farm personnel in tracking system performance.

Figure 6. Delivery line installation.

An electronic controller for four valves was used to deliver water to each of four zones in the system. The pumping plant could not be sized to irrigated the entire 4.8 acres at one time due to budget constraints which necessitated four stations that would run in succession. The controller was equipped with a lightning arrester to protect the system from damage during electrical storms. The pump station (Grundfos, 5HP) was purchased (August, 1999) for pressurizing and delivering water to the demonstration site. Three phase electricity also had to be connected to the pump. The pump station was protected from the elements with a shelter to prevent over-heating and freezing damage. The controller was also protected from the weather and farm operations.

Figure 7. Pump with pressure tank and cycle-stop valve to maintain pressure on delivery line.

Electricity was delivered to the southeast corner of bench 14 to supply the power requirement of the controller and injector pump used to deliver fertilizer and water treatments through the drip irrigation system. Additionally, the pump station was connected to the pumping station power supply located near the irrigation reservoir after new transformers were installed by Southwestern Public Service.

The site was planted September 13, 1999. All system components were not in place, however, it was critical to plant alfalfa for evaluation in the year 2000. Alfalfa (variety Rio) was planted in a north/south direction. A demonstration of fifteen possible varieties to use in southeastern New Mexico was planted in the middle of the bench. Each drip irrigation system station included all 15 varieties for a total of four replications (Table 1). These varieties included Amerigraze, Arriba, Signal 8000, Dona Ana, Conquista, Rio Penasco, Signal 7000, Salado, Rio, WL 525HQ, WL 414, Magna 901, New Mexico Common, Rio Grande, and Tahoe. Salado is resistant to high salinity conditions and may do better than others if soil salinity increases under drip irrigation.

Table 1. Plot map for varieties planted to the drip irrigated field.

Field	Border				Border	Field
		11 - WL414	9 - Rio	12 - Magna 901		
		15 - Tahoe	13 - NM Common	2 - Arriba		
	REP 4	10 - WL525HQ	8 - Salado	14 - Rio Grande		
		6 - Rio Penasco	4 - Dona Ana	5 - Conquista		
		3 - Signal 8000	1 - Amerigraze	7 - Signal 7000		
		5 - Conquista	11 - WL414	10 - WL525HQ		
		1 - Amerigraze	2 - Arriba	15 - Tahoe		
	REP 3	13 - NM Common	14 - Rio Grande	12 - Magna 901		
		8 - Salado	3 - Signal 8000	4 - Dona Ana		
		9 - Rio	6 - Rio Penasco	7 - Signal 7000		
		10 - WL525HQ	11 - WL414	14 - Rio Grande		
		7 - Signal 7000	4 - Dona Ana	12 - Magna 901		
	REP 2	3 - Signal 8000	6 - Rio Penasco	13 - NM Common		
		9 - Rio	15 - Tahoe	8 - Salado		
		2 - Arriba	1 - Amerigraze	5 - Conquista		
		13 - NM Common	15 - Tahoe	14 - Rio Grande		
		10 - WL525HQ	12 - Magna 901	11 - WL414		
	REP 1	7 - Signal 7000	9 - Rio	8 - Salado		
		4 - Dona Ana	6 - Rio Penasco	5 - Conquista		
		1 - Amerigraze	3 - Signal 8000	2 - Arriba		
			North Edge of Bench 14			

Irrigation Water Quality

There was a frequent occurrence of bacterial growth on the screens that control the electric pump to the cycle stop valve. An evaluation of the type of bacteria and what sanitation procedures needed to occur prior to the cycle stop valve revealed little. The overall water quality is given in Table 2. This changed drastically in 2000 and prevented its use in the drip system for most of the first summer.

Additionally, the water level in the reservoir had be maintained at a level of 12-inches above the pump assembly. The irrigation reservoir was also not allowed to drop below 1-foot from the freeboard space in order to prevent the pump from going dry. A lo/hi switch was installed on the reservoir to prevent damage to the drip pump.

Table 2. Irrigation water suitability test results for water used in drip irrigation demonstration.

		Degree of Restriction on Use								
Potential Problem	**Units**	**None**			**Slight to Moderate**			**Severe**		
pH: 8.0				<7.0	7.0		8.0	>8.0		
							✖			
SALINITY										
EC w	dS/m			**<0.7**	**0.7**	✖	**3.0**	**>3.0**		
						(1.77)				
TDS	mg/L			**<450**	**450**	✖	**2000**	**>2000**		
						(1418)				
INFILTRATION (SAR = 0.19)	No Problems									
SAR = 0-3 *and* ECw		**>0.7**	✖		**0.7**		**0.2**	**<0.2**		
SAR = 3-6 *and* ECw		**>1.2**			**1.2**		**0.3**	**<0.3**		
SAR = 6-12 *and* ECw		**>1.9**			**1.9**		**0.5**	**<0.5**		
SAR = 12-20 *and* ECw		**>2.9**			**2.9**		**1.3**	**<1.3**		
SAR = 20-40 *and* ECw		**>5.0**			**5.0**		**2.9**	**<2.9**		
SPECIFIC ION EFFECTS										
Sodium† (14.5 mg/L = 0.19 meq/L)										
Flood irrigation	SAR	✖		**<3**	**3**		**9**	**>9**		
Sprinkler	meq/L		✖	**<3**	**>3**					
Chloride (24 mg/L = 0.7 meq/L)										
Flood irrigation	meq/L	✖		**<4**	**4**		**10**	**>10**		
Sprinkler	meq/L	✖		**<3**	**>3**					
Boron (0.01 mg/L)	mg/L	✖		**<0.7**	**0.7**		**3.0**	**>3.0**		
Bicarbonate‡ (228 mg/L)	meq/L			**<1.5**	**1.5**	✖	**8.5**	**>8.5**		
Iron (0.02)	mg/L	✖		**<0.1**	**0.1**		**1.5**	**>1.5**		

† For surface irrigation, most tree crops and woody plants are sensitive to sodium and chloride; use the values shown. Most annual crops are not sensitive; use salinity tolerance tables. With overhead sprinkler irrigation and low humidity (<30 percent), sodium and chloride may be absorbed through the leaves of sensitive crops.

‡ Overhead irrigation only.

Cropping Systems

Horticultural and agronomic studies of SDI systems were primarily identified through different online databases available at the New Mexico State University Library, as well as through NMSU researchers. The authors of each identified article were then contacted to obtain further information. Unfortunately, not much additional data could be obtained since some of the studies were conducted several years ago and the information was either not available or some studies were still in the research process.

Studies that compared SDI to furrow irrigation systems were the focus of the literature search. A total of 16 studies were identified, but not all included a direct SDI vs. furrow yield comparison. From these 15 papers, 118 distinct data points were gathered. These data points, include SDI and furrow crop yield variables such as soil type, farm location, whether the experiment was located at an experimental farm or a commercial farm, year of publication/study and soil condition.

Even though SDI systems have been used for several years, not much information has been written directly comparing yield potential with other systems making the data collection process a difficult task. Wilson et al. (1984) cautioned about this problem: "because drip irrigation on cotton is so new, much of the information about drip is tentative. Only a few carefully controlled and monitored drip experiments have been done at State or Federal agricultural experiment stations". That observation could still be made today and could be applied to most, if not all, of the crops analyzed for this study.

All available data was tabulated and codes were used to identify recurring events and make data manipulation easier (Saenz, 2002). Thirteen regions were identified among the papers. Table 3 represents the codes given to each region. However, regions were later categorized into four groups: Arizona, California, New Mexico, and Texas.

Table 3. Study locations used for literature review of SDI in row crops.

1	Shafter, CA	7	Weslaco, TX
2	Arizona	8	Fort Collins, CO
3	Salinas Valley, CA	9	Bushland, TX
4	Las Cruces, NM	10	Stratford, CA
5	San Joaquin and Imperial Valley, CA	11	Lower Rio Grande Basin, NM
6	Fresno, CA	12	Estancia Basin, NM
		13	Roswell/Hagerman, NM

This analysis was originally planned to study only alfalfa, but once lack of information available was realized, the study was expanded to 24 different crops that were identified through the papers obtained and suggestions made by faculty at New Mexico State University (Table 4). Some of the crops were later eliminated from the table since insufficient information was found through the search process.

Because this study includes more than one crop and crop yields are measured in different ways, a meta-analysis was deemed appropriate to determine whether and to what extent a yield advantage could be associated with either an SDI or a furrow system. Meta-analysis is nothing more than individual analysis grouped as a large collection of studies with the only objective to obtain an equilibrated answer from their results (as cited in Wolf, 1986, p. 11). Agriculture is an area where results might vary constantly from a series of different plots which necessitates a modern statistical method such as meta-analysis.

Table 4. Potential crops for consideration in rotation with alfalfa.

1	Cotton	13	Potatoes
2	Sweet corn	14	Barley
3	Tomatoes	15	Asparagus
4	Alfalfa	16	Cantaloupes
5	Green chile	17	Cucumber
6	Red chile	18	Mid-season yellow onion
7	Onions	19	Sweet Spanish onions
8	Cabbage	20	Bell peppers
9	Carrot	21	Jalapeño peppers
10	Lettuce	22	Fall spinach
11	Corn	23	Broccoli
12	Wheat	24	Cauliflower

RESULTS

Progression of SDI demonstration project. Figures 9 through 13 depict the progression of the demonstration plot from 1999 to 2002. The major obstacle that developed was root intrusion (Figure 14). The variety trial reflects the decreased performance with an increased coefficient of variation (Table 5).

Variety Trial Results

The variety trial within the drip irrigated field showed no difference among the evaluated varieties. The three year average yield was 7.67 tons/acre with the largest decline in the third year due to clogged tape. Despite the graphic loss of irrigation uniformity third year variety trial yield was still over 6 tons/acre. The relative feed value average a score of 160 with a crude protein of 19 percent and neutral detergent fiber content of 37 percent.

Figure 8. Plots after tape ripped in, 1999.

Figure 10. Herbicide affected area (light green) filled in after treatment with manure, water, and time.

Figure 12. Field in 2002 showing further degradation of emitters due to root intrusion.

Figure 9. Field in 2000 showing no growth in herbicide carryover area.

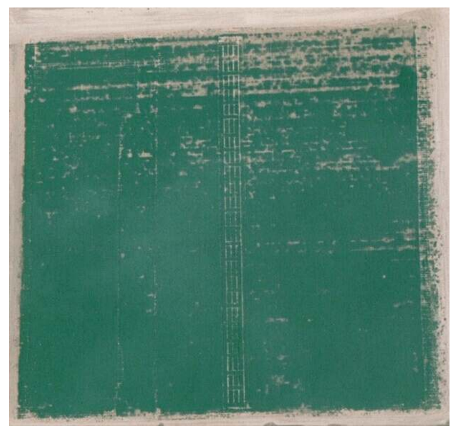

Figure 11. Field showing failed drip tape on north (top) due to root intrusion.

Figure 13. Root mass recovered in 2002 after treatment and purge.

Table 5. Dry matter yields (tons/acre) of alfalfa varieties sown September 13, 1999, at NMSU's Agricultural Science Center at Artesia and drip-irrigated.

	Total annual yields			
Variety	2000	2001	2002	3-yr Average
Rio Penasco	8.30*	8.73*	7.74**	8.25**
Rio Grande	8.47*	8.76**	7.18*	8.14*
WL525HQ	8.13*	8.60*	7.26*	8.00*
Signal 8000	8.25*	8.32*	6.97*	7.85*
Dona Ana	8.49**	8.18*	6.57*	7.74*
WL414	8.22*	7.81*	7.06*	7.70*
NM Common	7.90*	8.36*	6.62*	7.62*
Arriba	8.11*	7.47*	7.29*	7.62*
Signal 7000	8.01*	7.70*	6.84*	7.52*
Tahoe	8.27*	7.79*	6.21*	7.42*
Magna901	7.93*	8.05*	6.18*	7.38*
Salado	8.38*	7.89*	5.80*	7.36*
AmeriGraze 702	7.51*	7.81*	6.70*	7.34*
Rio	7.56*	7.17*	6.47*	7.07*
Mean	8.06	8.16	6.78	7.67
CV, %	7.91	11.81	20.30	10.82
DMRT (0.05)	NS	NS	NS	NS

2000 Harvest dates: 5-May, 13-Jun, 20-Jul, 18-Aug, and 13-Sep.
2001 Harvest dates: 19-Apr, 24-May, 20-Jun, 16-Jul, 17-Aug, and 28-Sep.
2002 Harvest dates: 14-May, 17-Jun, 12-Jul, 15-Aug, and 23-Sep.
**Highest numerical value in the column.
*Not significantly different from the highest numerical value in the column based on the 5% DMRT.
DMRT (0.05) stands for Duncan's Multiple Range Test for differences among all entries at the 5% level. If the difference between two numbers within a column is equal to or greater than the DMRT, it is 95% certain that they are truly different.
NS means that there were no significant differences between varieties within that column at the 5% level.

Water Application Quantities

Water and yield from three alfalfa fields including the drip project were recorded for the entire 2001 year and partially from 2000 and 2002. Problems with irrigation water supply and root intrusion in 2000 and 2002 necessitated a shorter time frame for evaluation. Drip irrigation did allow for more alfalfa production with less water (Table 6). Rain for the reported period totaled 5.48 inches and was used with irrigation water to calculate pounds of alfalfa per acre-inch of applied water. The flood field used a total of 97.6 acre-inches while the sprinkler system used 93.3 and the drip system used 50.2. The sprinkler system, however, produced the most alfalfa.

Table 6. Alfalfa yield and water application totals over time for the SDI demonstration project in Artesia. Alfalfa produced per acre-inch of applied water and rain is calculated on the last line.

Flood (variety Rio planted 9.4.1997)				Sprinkler (var. Rio, 9/4/1997)			Drip (var. Rio, 9/13/1999)		
Day	Irrig.	Rain	lb/A	Day	Irrig.	lb/A	Day†	Irrig.	lb/A
2000-09-13	7.25			2000-08-07		1610	2001-10-01	3.00	
2000-09-27	6.83			2000-08-07	7.00		2001-04-19		3071
2001-04-16			2076	2000-08-19	5.00		2001-04-27	1.68	
2001-04-24	7.50			2000-09-12		2060	2001-05-14	4.04	
2001-05-10	6.67			2000-09-13	7.00		2001-05-24	1.49	2726
2001-05-14		1.31		2000-09-29	7.52		2001-06-11	2.57	
2001-05-23			3233	2001-04-23		919	2001-06-18	1.83	
2001-06-06	8.00			2001-04-30	7.00		2001-06-20		2457
2001-06-15			2119	2001-05-14	2.64		2001-07-16	6.03	2248
2001-06-20	7.41			2001-05-25		2669	2001-07-28		
2001-07-13			2642	2001-06-01	7.00		2001-08-17		1920
2001-07-19	7.34			2001-06-12	7.00		2001-09-04	2.88	
2001-07-28		0.26		2001-06-21		2833	2001-09-10	1.31	
2001-07-31	6.10			2001-06-26	7.00		2001-09-16		
2001-08-13			2713	2001-07-23		3255	2001-09-17	0.76	
2001-08-22	6.85			2001-07-28			2001-09-22		
2001-09-04	8.33			2001-08-01	7.00		2001-09-24		
2001-09-16		0.57		2001-08-13	3.50		2001-09-28		1924
2001-09-18			1980	2001-08-21		1978	2001-10-30		
2001-09-22		0.56		2001-08-28	7.00		2001-11-08	9.15	
2001-09-24		0.47		2001-09-10	4.60		2001-11-19	3.10	
2001-10-17	9.04			2001-09-16			2001-12-06		420.3
2001-10-30		0.33		2001-09-22			2002-01-01		
2001-11-13			1167	2001-09-24			2002-01-07	1.01	
2002-01-01		0.22		2001-10-01		2462	2002-01-31		
2002-01-31		0.20		2001-10-30			2002-02-13	1.28	
2002-03-19		0.61		2001-12-07		684	2002-03-19		
2002-03-30		0.70		2001-12-17	0.88		2002-03-26	1.04	
2002-04-16	7.86			2002-04-01	5.28		2002-03-30		
2002-04-26		0.25		2002-04-18	2.64		2002-04-26		
2002-05-10			1970	2002-05-16		3214	2002-05-14		2705
2002-05-20	8.46			2002-05-21	5.28		2002-06-14	9.01	
2002-06-09			2083	2002-06-16		2265	2002-06-24		1952
Total	97.63	5.48	19983	Total	93.34	23950	Total	50.18	19423
pounds/acre-inch			194	pounds/acre-inch		242	pounds/acre-inch		349

Cropping System Analysis

The literature was surprisingly sparse for this type of analysis (Table 7). However, data used to construct Table 8 was based on those records where information was available for crop yield and water used for both SDI and furrow systems. Only barley, lettuce, cantaloupes, onions, carrots, potatoes, cotton and tomatoes fulfilled this requirement. These data were taken from just 14 of 16 studies. The scatter graph (Figure 14) was constructed based on each crop record and let us identify one more time those crops that would be used to construct a valid model (Saenz, 2002). Crops that were used in the final analysis were chosen from those records summarized in Table 8 Lettuce, cotton, and tomatoes were the only crops with enough data to perform a meta-analysis.

Table 7. Literature talley for evaluated under drip and/or furrow irrigation systems from which metadata analysis could be conducted.

	Favorable Response to		Information Available from		Inconclusive	No Data
Crop	Drip	Furrow	Drip Only	Furrow Only		
Alfalfa	0	0	0	0	0	0
Asparagus	0	0	0	2	0	0
Barley	1	0	0	0	0	0
Broccoli	0	0	0	2	0	0
Cabbage	0	0	0	2	0	0
Cantaloupes	6	6	0	1	0	0
Carrot	0	0	0	6	0	0
Cauliflower	0	0	0	2	0	0
Corn	0	0	12	0	0	0
Cotton	10	3	3	0	1	2
Cucumber	0	0	0	1	0	0
Green chile	0	0	0	1	0	0
Lettuce	1	4	1	2	0	0
Onion, Sweet Spanish	0	0	0	1	0	0
Onion, Mid-season yellow	0	0	0	1	0	0
Onions	2	2	6	2	0	0
Peppers, bell	0	0	0	3	0	0
Peppers, jalapeño	0	0	0	2	0	0
Potatoes	1	0	0	5	0	0
Red chile	0	0	0	1	0	0
Spinach, fall	0	0	0	1	0	0
Sweet corn	0	0	0	2	0	0
Tomatoes	19	1	0	1	0	0
Wheat	0	0	1	0	0	0
Total	40	16	29	32	1	2

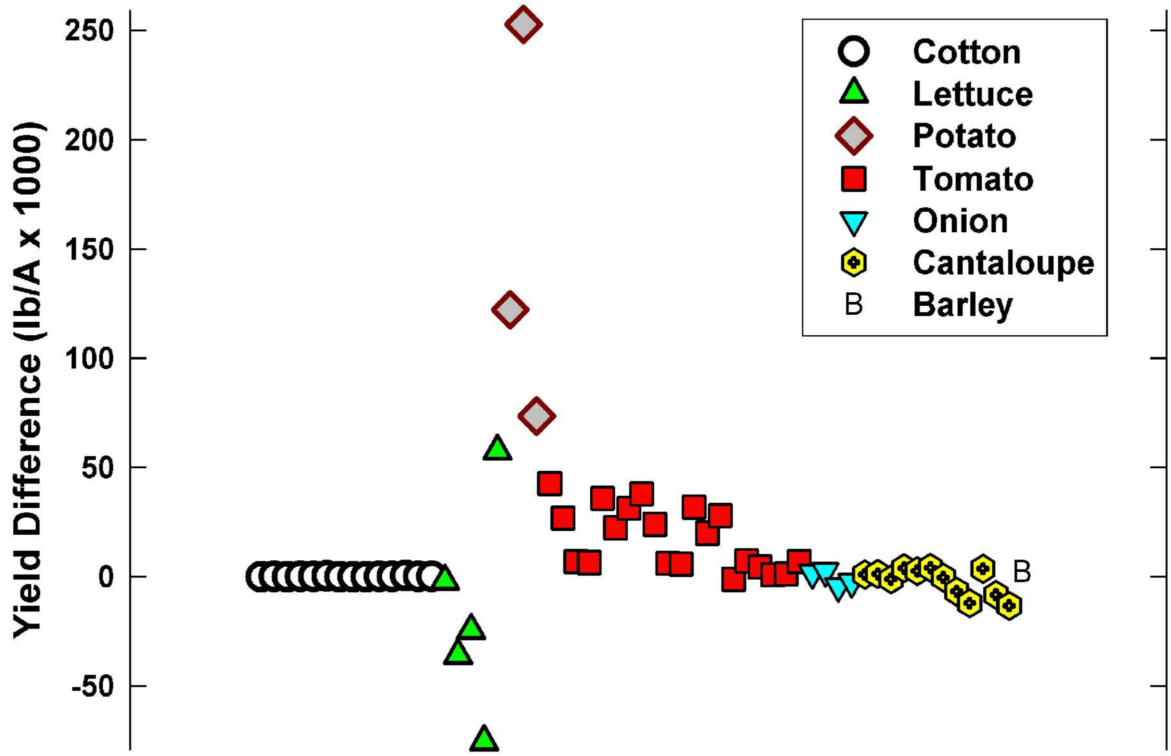

Figure 14. Yield advantage (+) or yield decline (-) as a result of using drip irrigation over furrow irrigation.

Cotton was found in 6 of 14 studies but only four of them favored SDI while the remaining studies were inconclusive. Lettuce was found in only two studies and both papers were inconclusive as shown in Table 8. Tomatoes were the only crop that really showed significant results from a series of three studies and they all favored an SDI system.

Crops such as potatoes could lead us to favor SDI since this crop shows a significant response to SDI systems (Figure 14). Unfortunately, all records were obtained from the same paper; barley had only one record from one single paper that favored SDI system but was not enough to be included on our study. The same thing happened for carrots and cantaloupes as several records were developed within one single experiment.

Crop yields affected by drip irrigation over furrow methods could significantly improve and can also reduce the amount of water used for it (Table 8). The findings in this analysis show that for tomatoes SDI helped to improve yield by 14 percent with 25% less water. Analysis on cotton and lettuce indicated that there was no improvement, however, some would argue that the apparent yield increase of 19% could indicate potential for SDI. Lettuce appeared to require 18 percent less water when SDI was used and resulted in a 22 percent yield increase when compared to furrow irrigation.

Table 8. Crop yield from furrow and drip irrigated experiments with yield differences calculated to show negative numbers as a yield decrease when drip irrigation was used. Authors either favored SDI or offered no opinion (inconclusive).

Crop	Author	Furrow Yield	Drip Yield	Yield Difference	Favor SDI	Inconclusive
			lb/A			
Cotton	DeTar et al., 1992	1738	1704	-34	X	
		1445	1637	192		
		1608	1613	4		
		1325	1516	192		
	Wilson and Ayer, 1985	1968	2208	240	X	
		2016	2280	264		
	Wilson et al., 1984	1440	1320	-120		X
		912	912	0		
		1728	1728	0		
	DeTar et al., 1994	1636	1677	41		X
	Wuertz, 2001	1355	1574	219	X	
	Fulton et al., 1991	1350	1890	541	X	
		1290	1439	149		
		1290	1439	149		
Lettuce	Hanson et al., 1997	39474	37515	-1959		X
		835200	799339	-35861		
	Sammis, 1980	384452	359922	-24530		X
		220324	144950	-75374		
		79388	136922	57534		
Potato	Sammis, 1980	206052	328256	122204	X	
		51379	304172	252793		
		372856	446446	73590		
Tomato	Ayars et al., 1999	89672	132264	42592	X	
		89672	116573	26901		
		89672	96622	6950		
		89672	96173	6501		
		89672	125543	35871		
		89672	112093	22421		
		89672	121053	31381		
	Rose et al., 1982	79986	117976	37990	X	
		79986	103980	23995		
		79986	86185	6199		
		79986	85784	5798		
		79986	111982	31996		
		79986	99984	19999		
		79986	107977	27991		
	Bogle et al., 1989	28187	27117	-1070	X	
		28187	35412	7225		
		24708	29168	4460		

Table 8. Crop yield from furrow and drip irrigated experiments with yield differences calculated to show negative numbers as a yield decrease when drip irrigation was used. Authors either favored SDI or offered no opinion (inconclusive).

Crop	Author	Furrow Yield	Drip Yield	Yield Difference	Favor SDI	Inconclusive
		24708	25600	892		
		37999	39337	1338		
		37999	44868	6868		
Onions	Ellis et al., 1986	27920	29525	1606		X
		27920	30596	2676		
		18464	14094	-4371		
		18464	15967	-2498		
Cantaloupe	Bucks et al., 1981	50922	51922	1000	X	
		50922	52161	1240		
		50922	49721	-1201		
		50922	54842	3920		
		50922	53562	2640		
		50922	55042	4120		
		37681	37281	-400		
		37681	30960	-6720		
		37681	25561	-12120		
		37681	41361	3680		
		37681	29401	-8280		
		37681	24401	-13280		
Barley	Tollefson, 1985	4319	6479	2160	X	

Published horticultural/agronomic research papers indicated SDI systems increased yields 16% for barley, for example, while saving 33% of the water application. Although not all of these crops could be included in the meta-analysis, Table 9 indicates a water savings and some potential for yield improvement.

Table 9. Selected crop yield and water savings reported by authors used in Table 8.

Crop	Yield		Water Savings
	Difference (lb/A)	Improvement (%)	%
Asparagus	-	-	33
Barley	22	16	33
Broccoli			33
Cabbage			33
Cantaloupes	-2117		33
Cauliflower			36
Cotton	172	10	34
Cucumber			34

Table 9. Selected crop yield and water savings reported by authors used in Table 8.

Green chile			33
Lettuce	-16038	5	17
Onion, Mid-season yellow			33
Onions	-153	5	31
Peppers, bell			33
Peppers, jalapeño			67
Potatoes	149529	190	8
Red chile			33
Spinach, fall			33
Sweet corn			33
Tomatoes	17315	23	13

Among the potential problems recognized during the data gathering process was that this process was done under selective inclusion based on personal feeling about data relevance. Also, several papers were found but not many included a drip vs. furrow comparison analysis, making our data range not as wide as it should have been. As a consequence, we were forced to use multiple results from the same study which biased the meta-analysis. Another caveat is that standard deviation estimates could not be obtained from the published yield comparison studies. The published data could have and should have been weighted in the meta-analysis by dispersion estimates. Poorly designed studies could have been used as well as good studies. Dispersion estimates (only one paper reported a standard error estimate) could have helped rank study quality and interpret findings. Finally, we were unable to determine explanatory variables among the papers that would help to interpret results. Soil type and soil condition and other variables were rarely reported.

The meta-analysis should be replicated in an extensive way by collecting more information for the crops included or alternative ones. Additionally, tests should be conducted on experimental or commercial farms in alliance with producers in order to measure the desired variables in a consistent manner to determine their influence on crop yield and water savings.

When this project was undertaken, it was widely believed that subsurface drip irrigation systems clearly and consistently produced higher crop yields. Certainly every farmer testimonial we found and heard indicated that this is true. However, while this may actually be true, few well-designed horticultural/agronomic research studies are available to verify or refute this belief.

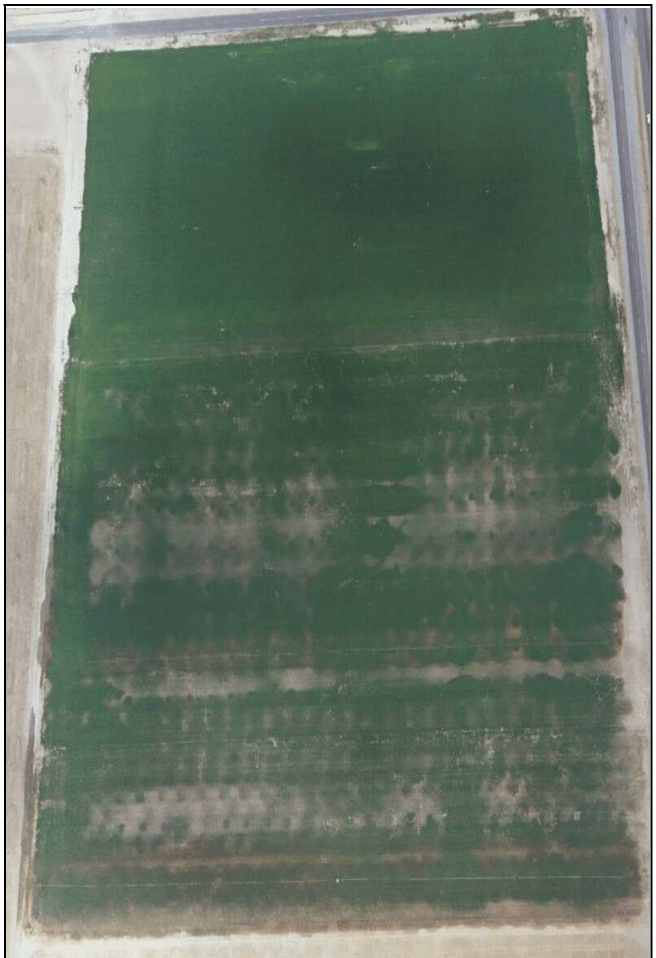

Figure 15. Aerial view of drip irrigated alfalfa field on the north (top) next to a sprinkler irrigated field on the south (bottom) near Artesia, NM.

CONCLUSIONS

We found that alfalfa can be produced with subsurface drip irrigation. Recent inclusion of herbicides into the buried tape would undoubtedly eliminate root intrusion that developed in the third year. We experienced a 46 percent reduction in water use with SDI and produced 19 percent less alfalfa than sprinkler irrigated alfalfa. The SDI field produced only 3 percent less alfalfa than the flood irrigated field we tracked. Some local producers have planted alfalfa over SDI next to sprinkler irrigated alfalfa in late 2002 (Figure 15). Visual observations from the ground and the air suggest that drip irrigation should do better than the sprinkler system just south of the SDI field. Time will tell if similar problems will arise that were experienced in this demonstration.

What should follow the alfalfa will eventually become a question that needs to be answered in this area. We found that tomatoes were the only crop with a significant crop yield increase due to irrigation method and water used in all three tests applied by Saenz (2002). Independent variables for cotton and lettuce showed no significant impact on crop yield in any of the tests. However, infrastructure, price, water availability, and experience will need to be considered before a rotation can be decided on.

References

Ayars, J.E., C.J. Phene, R.B. Hutmacher, K.R. Davis, R.A. Schoneman, S.S. Vail, and R.M. Mead. 1999. Subsurface Drip Irrigation of Row Crops: a Review of 15 Years of Research at the Water Management Research Laboratory. Agricultural Water Management 42, 1-27.

Bogle, C. R., T. K. Hartz, and C. Nunez. 1989. Comparison of Subsurface Trickle and Furrow Irrigation on Plastic-mulched and Bare Soil for Tomato Production. American Society of Horticultural Science 114 (1) 40-43.

Bucks, D.A., L.J. Erie, O.F. French, F.S. Nakayama, and W.D. Pew. 1981. Subsurface Trickle Irrigation Management with Multiple Cropping. (Abstract). Transactions of the ASAE.

Camp, C.R., F.R. Lamm, R.G. Evans, and C.J. Phene. 2000. Subsurface Drip Irrigation -Past, Present, and Future. Proceedings of the 4th Decennial National Irrigation Symposium.

Council for Agricultural Science and Technology: Effective Use of Water in Irrigated Agriculture. 1988. CAST. Task Force Report 113.

DeTar, W. R., C. J. Phene and A. Clark. 1992. Subsurface Drip Irrigation Compared to Furrow Irrigation of Cotton. Extracted from Cotton Engineering-systems Beltwide Cotton Conferences. 494-495.

DeTar, W. R., C. J. Phene, and A. Clark. 1994. Subsurface Drip Vs. Furrow Irrigation: 4 Years of Continuous Cotton on Sandy Soil. Extracted from Engineering-Systems Beltwide Cotton Conferences. 542-545.

Ellis, J.E., E.G. Kruse, A.E. McSay, C.M.U. Neale, and R.A. Horn. 1986. A Comparison of Five Irrigation Methods on Onions. HortScience 21 (6) 1349-1351.

Fulton, A. E., J.D. Oster, B.R. Hanson, C. J. Phene, and D. A. Goldhamer. 1991. Can Farmers Use Water More Effectively? : Two On Farm Demonstrations Compare Irrigation Methods. California Agriculture 45, (2) 4-8.

Hanson, B.R., L. J. Schwankl, K. F. Schulback and G.S. Pettygrove. 1997. A Comparision of Furrow, Surface Drip, and Subsurface Drip Irrigation on Lettuce Yield and Applied Water. Agricultural Water Management 33, 139-157.

Rose, J.L., R. L. Chavez, C. J. Phene, M. M. S. Hile and D. J. Robb. 1982. Subsurface Drip Irrigation of Processing Tomatoes. Proceedings of the Specialty Conference on Environmentally Sound Water and Soil Management. 369-376.

Sammis, T.W. 1980. Comparison of Sprinkler, Trickle, Subsurface, and Furrow Irrigation Methods for Row Crops. Agronomy Journal 72, (5) 701-704.

Saenz, Luis F. 2002. Crop yield under drip irrigation systems compared to furrow irrigation systems. Masters Thesis, New Mexico State University, Las Cruces, NM.

Sammis T. W. 1981. Yield of Alfalfa and Cotton as Influenced by Irrigation. Agronomy Journal 73:323-329

Tollefson, S. 1985. Subsurface Drip Irrigation of Cotton and Small Grains. Extracted from Drip/Trickle Irrigation in Action: Proceedings of the Third International Drip/Trickle Irrigation Congress. 887-895.

United States Department of Agriculture. 1981. Soil Survey of Eddy County, NM.

Wilson, Brian C., P.E., 1997,"Water Use by Categoriesin New Mexico Countiesand River Basins, and Irrigated Acreage in 1995", New Mexico State Engineer Office, Technical Report (in press), Santa Fe, NM.

Wilson, P., H. Ayer and G. Snider. 1984. Drip Irrigation for Cotton: Implications for Farm Profits. Economic Research Report 517. Economic Research Service, U.S. Department of Agriculture, Washington D.C., 1984

Wolf, F. M. 1986. Meta Analysis: Quantitative Methods for Research Synthesis. Quantitative Applications in the Social Sciences, 59, 11. Newbury Park, CA.: Sage Publications.

Wuertz, H. 2001. Subsurface Drip Irrigation: On-Farm Responses and Technical Advances. Drip Irrigation for Row Crops. NMSU. College of Agriculture and Home Economics. Cooperative Extension Service Circular 573.