Using Subsurface Drip Irrigation in Alfalfa in Western Colorado

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Summary

Increasing competition for water resources and demands for irrigation practices that are environmentally friendly are ongoing motivations to use irrigation water more efficiently. The objective of this study was to compare irrigation performance, forage yields, and forage quality of subsurface drip irrigation (SDI) with traditional furrow irrigation at the Colorado State University, Agricultural Experiment Station, Western Colorado Research Center at Fruita during the 2013 growing season. Based on data obtained from soil moisture sensors, soil moisture was concentrated in the soil profile where alfalfa roots can readily obtain soil moisture without water losses occurring to evaporation or deep percolation. There were no significant differences in alfalfa forage yields between irrigation treatments in the first, third, fourth, and total 2013 forage yields. The forage yield of the furrow irrigation treatment in the second cutting was significantly lower that SDI treatments. Forage quality of the alfalfa grown under the irrigation treatments was excellent for all four cuttings in 2013. There were no significant differences among irrigation treatments for any of the forage quality factors evaluated. In 2013, 18.6 inches of water were applied to SDI, and under furrow irrigation 71.0 inches of water was applied to the field with 39.8 inches of tailwater (runoff) and 31.2 inches of infiltration water. Compared to furrow irrigation, 12.6 inches less water was required under SDI to produce the same amount of alfalfa hay.

Introduction

Increasing competition for water resources and demands for irrigation practices that are environmentally friendly are motivating factors to use agricultural irrigation water more efficiently. Additionally, sustainable crop production systems require more efficient irrigation water applications. This dictates the use of improved management by irrigators to avoid overwatering to reduce deep percolation and salt and selenium loading and other contaminants into water supplies that affect downstream users.

When irrigation water is cheap, plentiful, readily accessible, and is a major factor to achieve high crop yields, overwatering is likely (Sadler and Turner, 1994). Good management along with proven technology is essential to apply irrigation water in an optimum manner. The use of good management and proven technology would likely result in a reduction in the amount of water needed to meet crop water requirements (Clegg and Francis, 1994).

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In Colorado, nearly 660,000 acres (6,578 farms) are furrow irrigated (USDA, 2008). Furrow irrigation is a partial surface flooding method of irrigation where water is applied in furrows at the top of a sloping field and gravity moves the water to the end of the field. Numerous conditions influence the amount of water that infiltrates into the soil along the length of the field and the amount of water that drains off the end of the field as runoff or tailwater (Pearson et al., 1998).

Subsurface drip irrigation (SDI) is a low pressure, high efficiency irrigation system that uses buried drip lines (tube or tape) to meet crop water needs. SDI technology has been commercialized since the 1960s, but in recent times has gained in popularity primarily because of increasing scarcity of water resources and advancements in SDI technologies (Reich, 2009).

With SDI, water is applied below the soil surface at a depth to meet crop water needs while allowing for crop production using mechanization. Optimum management and performance of SDI systems can reduce soil crusting, use less water, eliminate surface water and evaporation, eliminate deep percolation, eliminate irrigation water runoff, and reduce weeds and diseases. Furthermore, high fertilizer application efficiencies are possible when fertilizers are applied through SDI systems.

Purchase and installation costs of SDI systems are higher than those for furrow irrigation. The cost of the SDI equipment and associated installation costs vary from $1,000 to $2,000 per acre depending on various factors specific to the farm and field situation. The life of an SDI system is expected to range from 12 to 15 years (Reich, 2009).

The objective of this study was to compare irrigation performance, forage yields, and forage quality of SDI with traditional furrow irrigation at the Colorado State University, Agricultural Experiment Station, Western Colorado Research Center at Fruita. SDI drip lines were installed at 8-inch and 16-inch depths to compare the performance of these two drip lines. Drip lines at a 16-inch depth are preferred in many cases over 8-inch deep drip lines to allow tillage operations without damaging the buried drip lines. This report describes results obtained during the 2013 growing season.

Mater ials and Methods

Fig. 1. Installing drip tape on May 11, 2012 at the Colorado State University Western Colorado Research Center at Fruita.

The refurbishing of the existing irrigation water filtration system was completed on May 10, 2012. Subsurface drip tape was installed in a 1.5 acre field on May 11, 2012. The drip tape was installed two lines at a time using a heavy duty drip tape applicator pulled by a John Deere 2955 tractor (Fig. 1). The drip tape was installed at two depths (8 and 16-inch depths 30-inches apart. The two drip line depths were separated into two irrigation zones (Fig. 2).

Along with the SDI field another 1.5 acre field, with the same soil type and located nearby, was concurrently planted with the same alfalfa variety. The difference between the two fields was the second field was furrow-irrigated with gated pipe. Seedbed preparation, planting date and commencement of irrigation was the same for both the SDI plot and the furrow-irrigated plot.

Round-up Ready® alfalfa variety "Denali" was planted at a ¼ to ½ inch depth at a rate of 20 pounds/acre in furrow irrigated plots on May 14, 2012 and then in the SDI irrigated plots (at the same rate) on May 15, 2012.

Fig. 2. Two subsurface drip zones with flush valves and drip lines exiting the main lines at the Colorado State University Western Colorado Research Center at Fruita.

We began applying water through the SDI system on May 16, 2013 (Fig. 3). The soil near the soil surface was challenging to wet. To completely wet the soil surface and the seed a short surface irrigation with gated pipe was required.

Water use was monitored at a CoAgMet weather station located on station at the Western Colorado Research Center near the study site. Water use was also monitored using an atmometer (ETgage Company, Loveland, CO). Irrigation water application was determined with a gated pipe flow meter (McCrometer Model MO300 flow meter, Hemet, CA installed in gated pipe section, MCCrometer Great Plains, Model MD306, Aurora, NE) and tailwater was determined using a broad-crested flume fitted with a water level sensor (Global Water, Model WL16U-03,25ft, College Station, TX).

Soil moisture was monitored using data loggers (M. K. Hanson, model no. AM400-02A, Wenatchee, WA). Soil moisture sensors (Watermark, model no. 200SS, Irrometer Co., Riverside, CA) were buried at 8, 16, and 32-inch depths. Sensors were installed approximately 30 feet from the top and bottom of the field, at approximately the middle of the 16-inch and 8-inch zones. In the furrow irrigation field, soil moisture sensors were installed in the middle of the field from side to side and at approximately ¼ of the way down from the top and at approximately ¼ of the distance up from the bottom of the field.

Irrigation water with the SDI system was applied at 0.11 inch per hour. We irrigated 6 hrs/zone on April 12, 13, 14, and 15, 2013. We irrigated 4 hrs/zone on May 9, 15, 23, and 27, 2013. After first cutting we applied at 4 hrs/zone twice a week. The SDI irrigation system was shut down on June 24, 2013 for second cutting. The SDI system was restarted on June 27, 2013 at 4 hrs/zone 3 days/week. The SDI system was shut off on July 26, 2013 because of rain and for third cutting. The SDI system was turned back on three times per week at 4 hrs/zone until a rainy period occurred in September. The SDI irrigation system did not run much in September and October 2013 because of third and fourth cutting harvests and the considerable rain we experienced during this period.

Results and Discussion

The alfalfa plant stands in the SDI treatments and the furrow irrigation block in 2013 were thick, uniform, and vigorous. All alfalfa was free of weeds (Fig. 4).

On September 26, 2012 the CoAgMet weather station at the Experiment Station logged the cumulative evapotranspiration (ET) for a full stand of alfalfa at 32.05 inches. The seasonal average ET according to the Colorado Irrigation Guide (1988) for alfalfa grown in the Fruita area is 36.22 inches. Water applied by the SDI was calculated at 45.0 inches for the same period as the CoAgMet weather station in 2012.

Fig. 3. Pumping and filter station for the subsurface drip irrigation system at the Colorado State University Western Colorado Research Center at Fruita.

Seasonal efficiency was estimated at 71 percent or better (Note that 2012 was the establishment year for alfalfa and to become experienced with the operation of the SDI system).

Precipitation in western Colorado is sporadic and only provides a small contribution to crop production (Fig. 5). During May, July, August, and September 2013 there were 5, 8, 10, and 11 rain events, respectively (Fig. 5). No rain occurred during June 2013. The total amount of precipitation that occurred from May through September was 5.23 inches.

In 2013, there was excellent agreement in the seasonal ET derived from the CoAgMet weather station and the atmometer that was located at the top of the SDI alfalfa field. The seasonal ET from the weather station was 41.3 inches while the seasonal ET determined by the atmometer during the same time period was 41.1 inches (Fig. 6).

The cumulative irrigation water applied using the SDI system along with the four cutting dates are shown in Fig. 7. During the 2013 growing season 18.5 inches of water was applied using SDI to produce the alfalfa crop. Certainly, some of the 5.23 inches of precipitation that occurred during May through September would have contributed to crop production. Also, the antecedent moisture that occurred during winter 2012-13 would have also been available for crop growth.

The irrigation data presented in Fig. 8 indicate the irrigation efficiency that can be achieved with SDI at the 8-inch drip line depth over an entire cropping season the year following alfalfa stand establishment and with the SDI system operating under field conditions. The soil surface was not wetted during the growing season and thus evaporation from the soil surface was minimized. Additionally, the response of Sensor #3 positioned at a 32-inch depth indicate that the soil is quite dry at the deeper depths and thus deep percolation did not occur. Low Watermark sensor readings indicate greater soil water contents while high readings indicate low soil water contents. The response of Sensor #2 shows that irrigation water was being concentrated at the 16-inch depth at a location that was readily available to the alfalfa root system, thus, providing irrigation water to the alfalfa plant without applying water that is lost to evaporation or deep percolation. We had considerable rain events during the month of September and this response is indicated by the data from Sensors #1 and #2 and as shown in Fig. 8.

The data presented in Fig. 9 also indicate the irrigation efficiency that can be achieved with SDI when the drip lines were installed at 16-inch depths. More of the upper portion of the soil profile was drier during the growing season than at the 8-inch depth; thus, evaporation at the soil surface was further limited compared to SDI at the 8-inch depth. The response of all three sensors was quite similar at the 16-inch depth and

Fig. 4. Alfalfa field grown with the subsurface drip irrigation system in 2013 at the Colorado State University Western Colorado Research Center at Fruita.

was closer to each other than those in the 8-inch depth. This readily indicates that soil moisture is being concentrated in the soil profile where alfalfa roots can readily obtain soil moisture without losses occurring to evaporation or deep percolation. Again, we had considerable rain events during the month of September and this is indicated by the response shown from Sensors #1 and #2. The response of the 16-inch depth was similar to the 8-inch depth, except the soil moisture among the three depths were similar but concentrated lower down in the soil profile compared to the 8-inch depth.

The data in Figs. 8 and 9 illustrate there are a range of soil moistures that are acceptable to obtain high efficiency irrigations using SDI that result in the production of high alfalfa yields without causing soil moisture losses to evaporation or deep percolation.

The responses of the sensors located at the three soil depths at the top end of the furrow-irrigated alfalfa field readily show the variations that occur under furrow irrigation (Fig. 10). Furrow irrigation wets the entire soil profile increasing the potential for deep percolation and increasing evaporation at the soil surface. Thus, more irrigation water is needed to accommodate significant water losses to evaporation and deep percolation in order to maintain high crop yields.

The response of the sensors at the three soil depths of alfalfa grown under furrow irrigation at the bottom end of the field (Fig. 11) is quite similar to the responses at the top end of the field (Fig. 10).

The first year of alfalfa is an establishment period. Two cuttings were obtained from both SDI and furrow plots during 2012. The two alfalfa cuttings were obtained on July 27, 2012 and September 23, 2012 with the SDI plots averaging 3.35 and 3.58 tons/acre of total annual dry matter for the 8-inch deep and 16-inch deep tape treatments, respectively. The furrow-irrigated alfalfa averaged an annual total of 3.62 tons/acre of dry matter in 2012.

In 2013, detailed yield data were obtained from four cuttings (Tables 1, 2), with water applied per ton of dry matter produced presented in Table 3.

There were no significant differences in alfalfa forage yields between irrigation treatments in the first, third, fourth, and total 2013 forage yields (Table 1). The forage yield of the furrow irrigation treatment in the second cutting was significantly lower that the SDI treatments.

Moisture concentrations of alfalfa were determined at harvest. There were no significant differences in harvested alfalfa moisture concentrations between irrigation treatments in the first, third, fourth, and total 2013 forage yields (Table 2). The harvested moisture concentration of alfalfa at the 16-inch depth was significantly higher than the 8-inch depth or the furrow irrigation treatment in the second cutting.

In 2013, 18.6 inches of water were applied to both SDI treatments, and under furrow irrigation 71.0 inches of water was applied to the field with 39.8 inches of tailwater (runoff) and 31.2 inches of infiltration water. Thus, the furrow irrigation used 1.68 times more water than the SDI to produce the same amount of alfalfa hay. In other words, compared to furrow irrigation, 12.6 inches less water was required under SDI to produce the same amount of alfalfa hay. When the total amount of applied irrigation water (71.0 inches) is considered, furrow irrigation used 3.8 times more water than the SDI to produce the same amount of alfalfa hay. However, much of the tailwater eventually flows back into the Colorado River for use by downstream users.

Forage quality of alfalfa is important to producers and buyers. Forage quality of the alfalfa grown under the three irrigation treatments was excellent for all four cuttings in 2013. There were no significant differences among the three irrigation treatments for any of the forage quality factors evaluated (Table 4).

Clearly, SDI uses irrigation water more efficiently than furrow irrigation and the data in this report indicate SDI can significantly reduce the amount of water needed to produce high alfalfa yields and high quality hay. Subsurface drip irrigation has been used successfully to produce alfalfa at other locations (Alam et al., 2002).

SDI offers advantages over furrow irrigation including increased efficiency, potentially fewer weeds, less disease, improved downstream water flow and quality, and more flexibility for field operations because the soil surface is not wetted. However, SDI has some disadvantages. It is expensive to install and maintenance costs may be higher. Irrigation water must be clean and thus water with sediment must be filtered. Pumps may be needed to provide the pressure required to operate an SDI system, thus, operating costs may be higher than furrow irrigation. Germinating shallow-planted seeds with SDI can be problematic and an additional irrigation system may be needed to provide surface moisture for a germination irrigation.

Acknowledgments

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References

Alam, M. T.P. Trooien, T.J. Dumler, and D.H. Rogers. 2002. Using subsurface drip irrigation for alfalfa. J. American Water Resources Assoc. 38:1715-1721.

Clegg, M.D. and C.A. Francis. 1994. Crop management. Pp. 135-156. *In*: Sustainable Agriculture Systems (J.L. Hatfield and D.L. Karlen, eds.). Lewis Publishers, CRC Press. Boca Raton, FL.

Pearson, Calvin H., Karl E. White, and Aubrey L. Brinkworth. 1998. Surface residue and soil clods during furrow irrigation under simulated conditions. J. Sustain. Agric. 12:5-21.

Reich, D., R. Godin, J.L. Chavez, and I. Broner. 2009. Subsurface drip irrigation. Colorado State University Extension. Fact Sheet No. 4.716. Fort Collins, CO.

Sadler, E.J. and N.C. Turner. 1994. Water relationship in a sustainable agriculture system. Pp. 21-46. *In*: Sustainable Agriculture Systems (J.L. Hatfield and D.L. Karlen, eds.). Lewis Publishers, CRC Press. Boca Raton, FL.

USDA, National Agricultural Statistics Service. 2008. 2007 Census of agriculture. General Data, Table 7. Pps. 13-16.

Table 1. Alfalfa forage yields in the subsurface drip irrigation study at Colorado State University, Western Colorado Research Center, Fruita, CO during 2013.

Treatment	First cutting May 21	Second cutting June 25	Third cutting Aug. 13	Fourth cutting Sept. 28	Total 2013 forage yield
	Dry matter (tons/acre)				
16-inch drip line depth	3.32	2.72 A	2.39	1.44	9.88
8-inch drip line depth	3.61	2.82 A	2.15	1.46	10.04
Furrow irrigation comparison	3.64	2.44 B	2.45	1.34	9.87
Ave	3.52	2.66	2.33	1.41	9.93
CV (%)	6.4	5.8	7.8	6.4	5.2
LSD (0.05)	NS	0.27	NS	NS	NS

*Numbers in the same column followed by different letters are significantly different at the 5% level of probability.

Table 2. Moisture concentration of harvested alfalfa hay in the subsurface drip irrigation study at Colorado State University, Western Colorado Research Center, Fruita, CO during 2013.

Treatment	First cutting	Second cutting	Third cutting	Fourth cutting
	Moisture content (%)			
16-inch drip line depth	23.6	26.1 A	24.7	22.3
8-inch drip line depth	23.1	24.8 B	25.6	21.7
Furrow irrigation comparison	22.9	24.3 B	24.5	22.6
Ave	23.2	25.0	25.0	22.2
CV (%)	4.4	2.9	3.2	2.8
LSD (0.05)	NS	1.2	NS	NS

Table 3. Subsurface drip irrigation demonstration: water applied per dry ton of alfalfa at the Western Colorado Research Center, Fruita, CO.

Treatment	Inches of irrigation water applied per dry ton of alfalfa
16-inch drip line depth	1.88
8-inch drip line depth	1.85
Furrow irrigation	3.16

Table 4. Forage quality analysis for dry matter, crude protein, acid detergent fiber (ADF), neutral detergent fiber (NDF), dNDF48, ash, fat, lignin, and calcium in subsurface drip and furrow-irrigation alfalfa at the Colorado State University, Western Colorado Research Center at Fruita during the 2013 growing season.

Treatment	Dry matter	Crude protein	ADF	NDF	dNDF48†	Ash	Fat	Lignin	Ca
	%	%	%	%	%	%	%	%	%
First cutting									
16-inch depth	96.9	20.4	31.4	38.0	18.0	9.6	1.80	7.30	1.29
8-inch depth	97.1	21.8	30.0	37.0	18.0	9.3	1.78	6.60	1.20
Furrow	97.0	21.6	31.0	37.9	18.2	8.8	1.78	6.88	1.14
Second cutting									
16-inch depth	96.6	21.6	35.7	42.3	17.8	8.9	1.58	6.70	1.20
8-inch depth	96.6	22.6	34.0	40.1	17.7	9.2	1.58	6.25	1.25
Furrow	96.8	21.4	35.4	42.4	18.3	9.4	1.68	6.80	1.27
Third cutting									
16-inch depth	97.2	20.2	35.0	41.9	18.8	8.4	1.88	6.92	1.39
8-inch depth	97.2	21.3	32.8	39.7	17.7	8.6	1.95	9.42	1.47
Furrow	97.2	18.8	36.2	44.0	19.4	8.4	1.85	7.40	1.28
Fourth cutting									
16-inch depth	95.4	22.4	30.8	36.6	16.4	10.9	1.72	6.80	1.54
8-inch depth	94.9	21.6	32.5	39.2	17.4	11.0	1.62	7.00	1.47
Furrow	94.6	21.8	32.4	39.0	17.4	11.0	1.58	7.05	1.46

†Denotes digestible NDF at 48 hours of incubation.

Table 4 (continued). Forage quality analysis for phosphorus, potassium, and magnesium in subsurface drip and furrow-irrigation alfalfa at the Colorado State University, Western Colorado Research Center at Fruita during the 2013 growing season.

Treatment	P	K	Mg
	%	%	%
First cutting			
16-inch depth	0.32	2.82	0.26
8-inch depth	0.32	2.68	0.28
Furrow	0.32	2.53	0.27
Second cutting			
16-inch depth	0.30	2.46	0.25
8-inch depth	0.31	2.52	0.28
Furrow	0.32	2.37	0.27
Third cutting			
16-inch depth	0.30	2.12	0.25
8-inch depth	0.30	1.96	0.28
Furrow	0.28	1.98	0.24
Fourth cutting			
16-inch depth	0.32	2.62	0.30
8-inch depth	0.33	2.60	0.30
Furrow	0.33	2.70	0.30

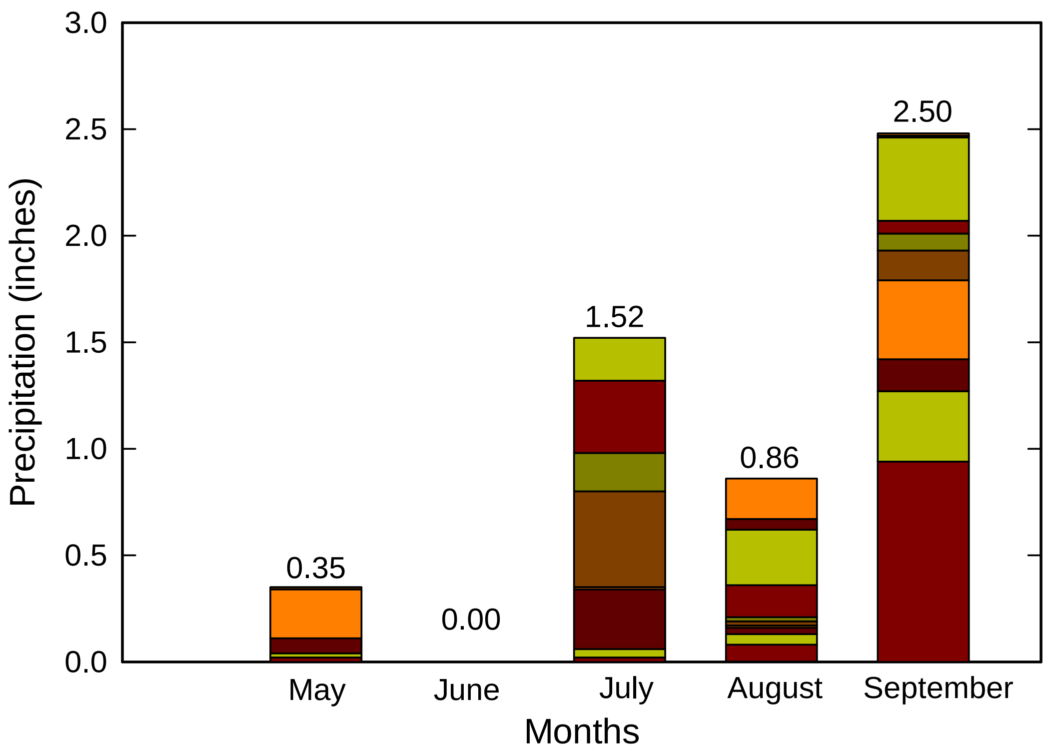

Fig. 5. Monthly precipitation at the Western Colorado Research Center at Fruita that occurred during the 2013 growing season. Rain events that occurred during the month are shown by the stacked bars.

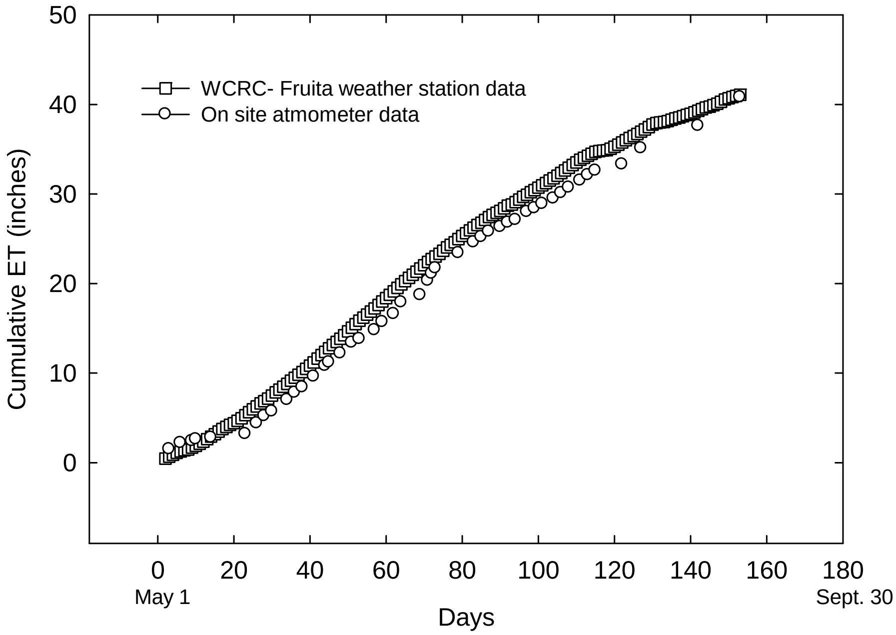

Fig. 6. Seasonal ET estimated by the research center CoAgMet station and with an atmometer located at the top of the SDI field. Note the agreement in ET between the automated weather station and the data from the atmometer.

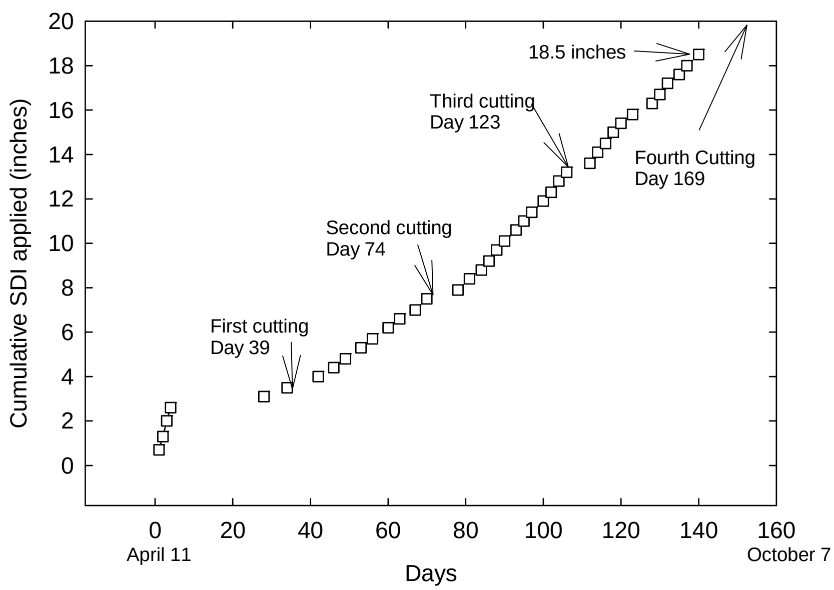

Fig. 7. Calculated cumulative irrigation water applied to alfalfa using a subsurface drip system Colorado State University, Western Colorado Research Center at Fruita during 2013.

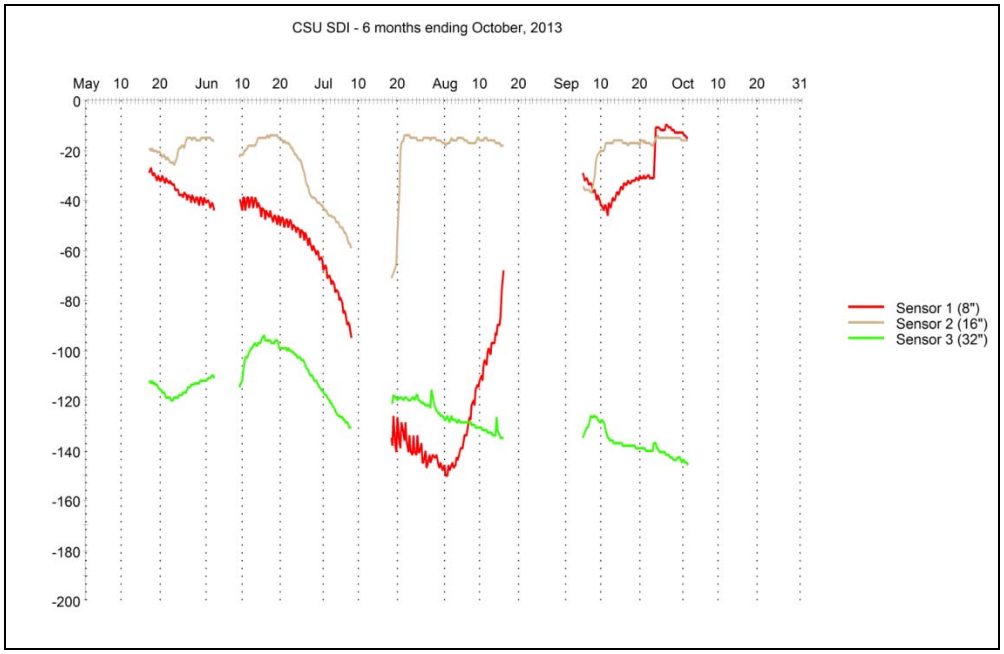

Fig. 8. Watermark sensor readings, which correlate with soil moisture contents, of alfalfa grown with subsurface drip irrigation (SDI) with drip lines installed at an 8-inch depth. Calendar date is the x-axis and the units on the y-axis are centibars.

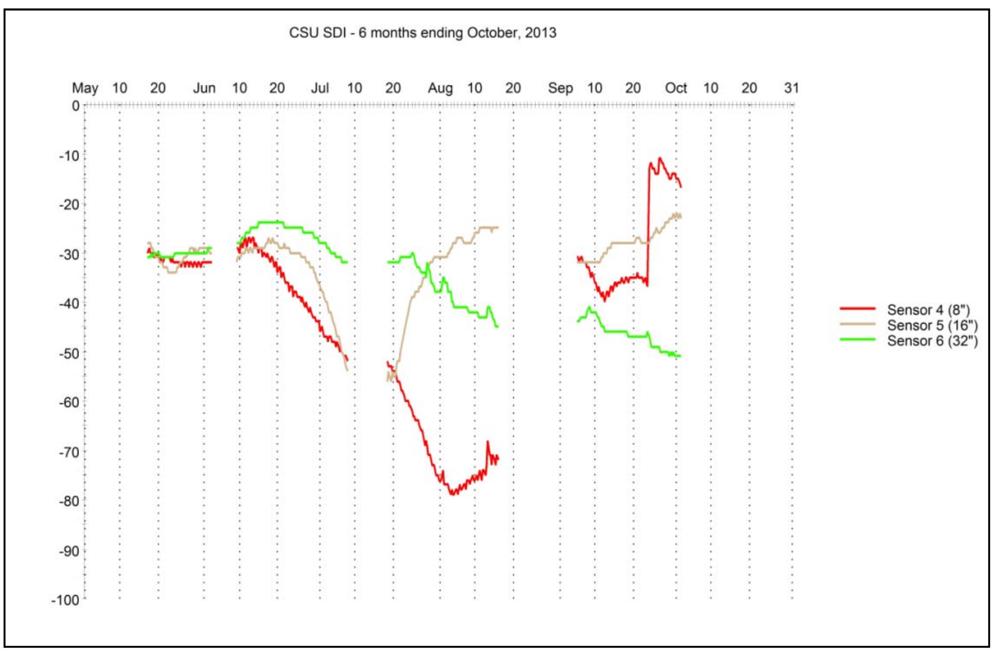

Fig. 9. Watermark sensor readings, which correlate with soil moisture contents, of alfalfa grown with subsurface drip irrigation (SDI) with drip lines installed at a 16-inch depth. Calendar date is the x-axis and the units on the y-axis are centibars.

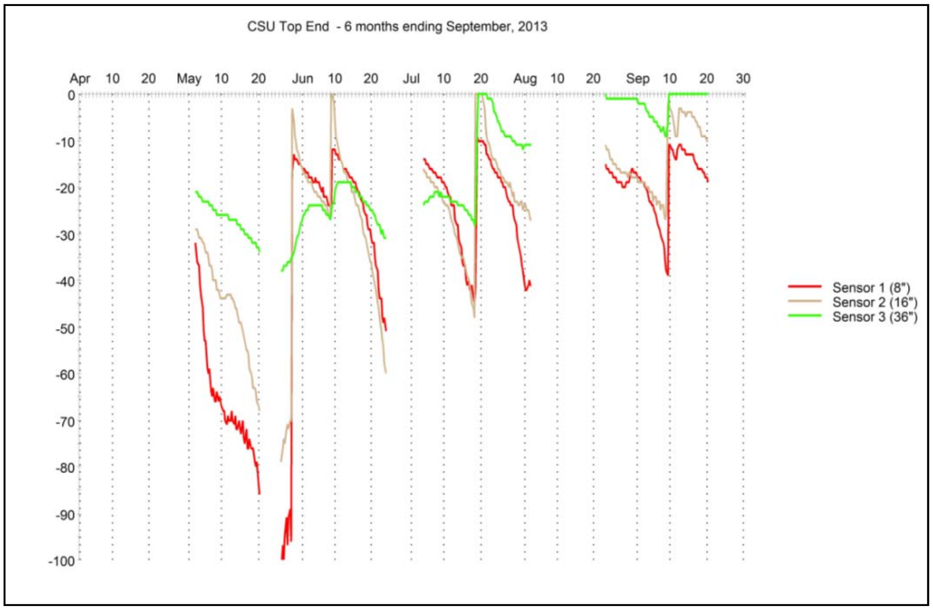

Fig. 10. Watermark sensor readings, which correlate with soil moisture contents, at the top end of the field in alfalfa grown with furrow irrigation. Calendar date is the x-axis and the units on the y-axis are centibars.

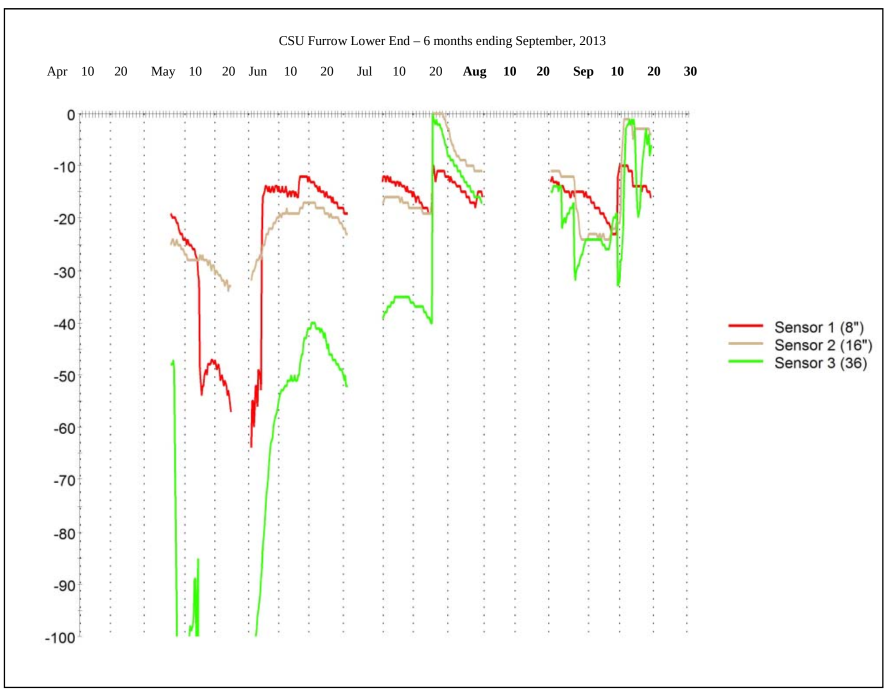

Fig. 11. Watermark sensor readings, which correlate with soil moisture contents, towards the bottom end of the field in alfalfa grown with furrow irrigation. Calendar date is the x-axis and the units on the y-axis are centibars.