Deficit Irrigation of Alfalfa as a Strategy for "Saving" Water

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ABSTRACT

Alfalfa is California's single largest agricultural water user due to its large acreage and long growing season, using 4 to 5.5 million acre feet of water each year. Because of this water use, the California Department of Water Resources is interested in deficit irrigation of alfalfa for providing water for transfer elsewhere. One strategy is to terminate irrigation during July and August when alfalfa yields are relatively small and use the "saved" water for nonagricultural uses. The amount of transferable water would be the difference in the evapotranspiration (ET_c) of a fully-irrigated field and that of a deficit-irrigated field; however, no information exists on the potential ET_c differences.

Evapotranspiration was determined in a commercial field using the eddy covariance and surface renewal energy balance methods in a fully irrigated part of the field, and the surface renewal method in the deficit irrigated part of the field. In addition, alfalfa yield, applied water, canopy coverage and plant height measurements were made in both parts of the field.

Deficit irrigation greatly reduce alfalfa yield in 2003, 2004, and 2005. Yield reductions due to deficit irrigation generally ranged from 41 to 88% of the fully-irrigated treatments. Cumulative ET_c in 2005 was 48.1 inches for the fully-irrigated treatment. Deficit irrigation (no irrigation) started on July 25. Cumulative ET_c between July 25 and December 6 (end of measurement period) was 20.8 inches for the fully irrigated treatment and 11.4 inches for the deficit irrigated treatment for a difference of 9.4 inches.

INTRODUCTION

Water transfers from the water-rich agricultural areas of northern California are

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being used by the California Department of Water Resources to supply water to areas with limited water supplies. The strategy is to fallow land and then transfer an amount of water equal to the seasonal evapotranspiration (ET_c) of the crop that would normally be grown in the fallowed fields. It is assumed that no ET_c occurs in the fallow fields.

Alfalfa is California's single largest water user due to the amount grown, typically about one million acres, and its long growing season. Seasonal alfalfa water use generally ranges from 4 to 5.5 million acre-feet per year. Because of this large water use, the Department of Water Resources is interested in transferring water from alfalfa production to other uses during periods of water shortage. A possible strategy is to deficit irrigate the flood-irrigated alfalfa fields during July and August, a period of time during which both alfalfa yield and water use efficiency (ratio of yield to ET_c) are relatively small. Deficit irrigation consists of terminating flood irrigations during those months.

Unlike a fallow field, deficit irrigated alfalfa can continue to transpire. The difference in ET_c between fully-irrigated and deficit-irrigated alfalfa is unknown because of this transpiration. Also unknown is the effect of deficit irrigation on subsequent yields of the following year. Thus, an experiment was conducted to determine the effect of deficit irrigation in the summer on the yield and ET_c of alfalfa and to determine the effect of the deficit irrigation on yield of the next year.

METHOD

A commercial field located near Davis, CA was selected for the fully-irrigated and deficit-irrigated treatments. The fully-irrigated alfalfa was irrigated according to the irrigator's normal practices. In 2003, 2004, 2005, and 2006, the deficit-irrigated treatments consisted of no irrigation during July and August with no fall irrigation. Deficit irrigation started at about the end of June in 2003, 2004, and 2006, and at the end of July in 2005. In 2003 and 2005, a second deficit irrigation water treatment consisted of applying a September irrigation after the deficit irrigation. Each treatment consisted of three alfalfa checks with border checks between the irrigated and deficit irrigated treatments. The border checks were necessary to prevent water flow through cracks in the soil from the irrigated treatments into the deficit irrigated treatments. The field scale approach was used to obtain the field-wide conditions experienced by commercial agriculture. A randomized replicated experimental design was not feasible because of the constraints caused by the use of a commercial field. The same field was used in 2003, 2004, and 2005. A new site was selected for the 2006 experiment.

The experiment was initiated in 2003, but no ET_c measurements were made at that time. In 2004, the Bowen ratio energy balance method (Todd et al., 2000) was used to determine ET_c. However, the results from this method were unsatisfactory due to problems with the instruments used by this method. In 2005, ET_c was calculated from data measured by the eddy covariance (EC) energy balance method (Tanner et al., 1985) and the surface renewal (SR) energy balance method (Spano et al., 1997). The EC method was used in the fully-irrigated treatment and the SR method was used in the deficit-irrigated treatment with no fall irrigation. Calibration of the SR method was achieved by installing an SR system near the EC system in the fully-irrigated treatment and using the EC data to calibrate the SR method for alfalfa. SR calibration coefficients generally ranged between 0.3 (just before harvest) to 0.4 (just after harvest).

Yield and yield quality were determined by sampling at nine locations in each treatment. In addition, canopy coverage, plant height, and soil water tension were also measured. Canopy coverage was measured with a digital infrared camera (Dycam, Inc., Woodland Hills, CA); soil water tension was measured with Watermark® electrical resistance blocks (Irrometer, Inc., Riverside, CA).

RESULTS/DISCUSSION

Alfalfa Yields

Alfalfa yields of the different treatments are shown in Tables 1, 2, and 3 for 2003, 2004, and 2005, respectively. The yields of 2006 are being analyzed. In 2003, yields of the fully irrigated treatment decreased over time during the period of deficit irrigation (Table 1). Deficit irrigation was imposed starting in July. Yields of the deficit irrigation treatments were substantially smaller than those of the full irrigation, particularly for the 4^{th} and 5^{th} harvests of both deficit treatments. For the 6^{th} harvest, yield of the deficit treatment with a September irrigation was higher than those of the earlier harvests under deficit irrigation. Yield of the 6^{th} harvest of the deficit treatment with no September irrigation also was higher than the earlier yields of that treatment, reasons for which are unclear. However, yields of less than 0.5 tons/acre are uneconomical to harvest, therefore, in reality, the yields of the deficit irrigated treatments were zero except for the 6^{th} harvest of the deficit (September irrigation) treatment.

Table 1. Treatment yields of 2003. The 4th, 5th, and 6th harvests occurred on August 6, September 8, and October 23, respectively. The numbers in the parenthesis are the yield reductions in percent of the full yield.

	Yield (tons/acre)				
	4th Harvest	5th Harvest	6th Harvest	Total	Yield Reduction
Full	1.56	1.35	0.58	3.49	
Deficit (no Sep. irrig.)	0.35 (78)	0.25 (82)	0.43 (26)	1.03	2.46
Deficit (Sep. irrig.)	0.28 (82)	0.16 (88)	0.96	1.40	2.09

Yields of 2004 also decreased over time during the measurement period for the fully irrigated treatment (Table 2). Deficit irrigation, which started at the end of June, resulted in a substantial yield reduction for the 6th and 7th harvests. The practical yield of these harvests was zero since yields less than 0.5 tons/acre are uneconomical to harvest. The September irrigation was omitted this year.

Table 2. Treatment yields of 2004. The 5th, 6th, and 7th harvests occurred on July 16, August 16, and September 24, respectively. The numbers in the parenthesis are the yield reduction in percent of the full yield.

	Yield (tons/acre)				
	5th Harvest	6th Harvest	7th Harvest	Total	Yield Reduction
Full	2.21	1.56	1.14	4.90	
Deficit (no Sep. irrig.)	1.96 (11)	0.25 (84)	0.19 (83)	2.21	2.69

The yields of 2005 of the fully irrigated treatment decreased over time (Table 3). Deficit irrigation started on July 25. Yields of the deficit irrigation were considerably smaller than those of the full treatment. The September irrigation increased the yield of the 7th harvest compared to the deficit (no September irrigation) treatment.

Table 3. Treatment yields of 2005. The 6th and 7th harvests occurred on August 23 and October 6, respectively. The numbers in the parenthesis are the yield reduction in percent of the full yield.

	Yield (tons/acre)			
	6th Harvest	7th Harvest	Total	Yield Reduction
Full	0.65	0.44	1.08	
Deficit (no Sep. irrig.)	0.23 (65)	0.26 (41)	0.61	0.47
Deficit (Sep. irrig.)	0.32 (51)	0.52	0.85	0.23

Crop Evapotranspiration

ET_c increased over time during the first part of 2005 as the climate became warmer (Fig. 1). However, considerable variability existed in the data as a result of day-to-day climate variability. The first harvest occurred on or about April 14 and the last harvest on or about September 30. Just after harvest, daily ET_c decreased to values between 0.08 inches/day to 0.15 inches/day. However, the day-to-day variability sometimes masked the harvest effect, particularly early in the year. Maximum daily ET_c between harvests was about 0.30 to 0.35 inches/day during the summer months. After September 15, ET_c decreased over time.

No irrigation occurred after July 25 for the deficit-irrigated treatment (no September irrigation). ET_c of this treatment continued to decrease over time until about August 25 (Fig. 1). Thereafter, a trend of relatively constant ET_c was found over time. Values of the deficit treatment were similar to those of the full treatment after September 30.

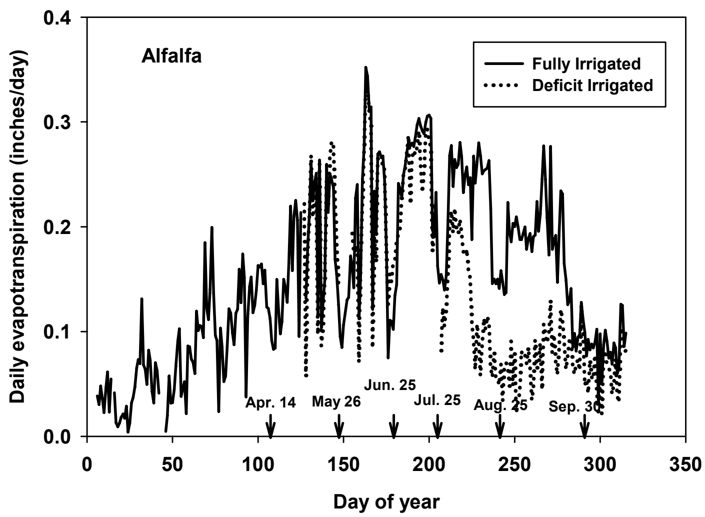

Figure 1. Crop evapotranspiration of fully-and deficit-irrigated alfalfa. The arrows are the harvest dates.

The day-to-day variability in the ET_c data makes it difficult to identify trends in the data. Thus, the data were smoothed using a 3-term moving average (Fig. 2). While the smoothing distorted the data to some degree, the effect of harvest on ET_c is clearly shown. During each harvest, ET_c decreased substantially even though the reference crop evapotranpiration (ET_o) remained high. After September 30, values of ET_c and ET_o were similar.

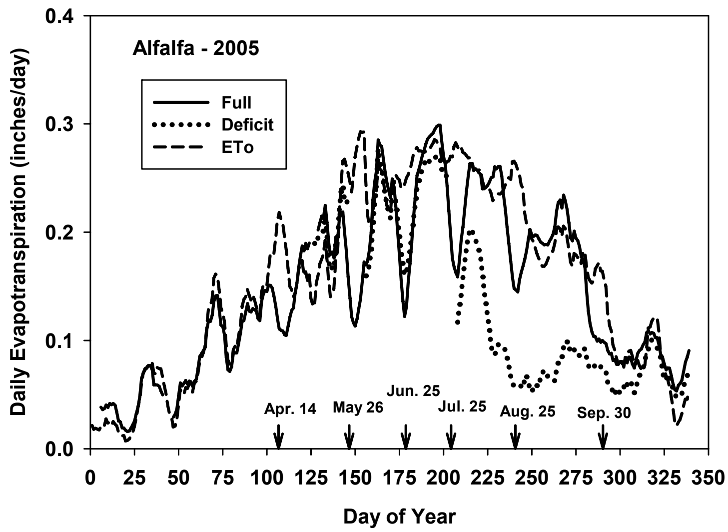

Figure 2. Smoothed crop evapotranspiration using a three term moving average. The arrows are the harvest dates.

Seasonal 2005 ET_c of the full treatment was 48.1 inches. Between July 25 and December 6 (end of measurement period), ET_c of the full treatment was 20.8 inches and that of the deficit treatment was 11.4 inches. The difference was 9.4 inches.

Cumulative ETc at the end of July 2006 was 32.2 inches. The difference in ET_c between the fully-irrigated and deficit-irrigated treatments for July 2006 was 2.6 inches.

Canopy Coverage and Plant Height

Canopy coverage of the 2005 fully irrigated treatment varied from between 20 and 40 % just after harvest to between 90 and 100 % just before harvest except after the last harvest (Fig. 3). During the period of deficit irrigation, maximum canopy coverage between harvests was between 55 and 65 %. After the last harvest, canopy coverage of the fully-irrigated alfalfa was about 70% and that of the deficit irrigated area was between 45 and 55 %.

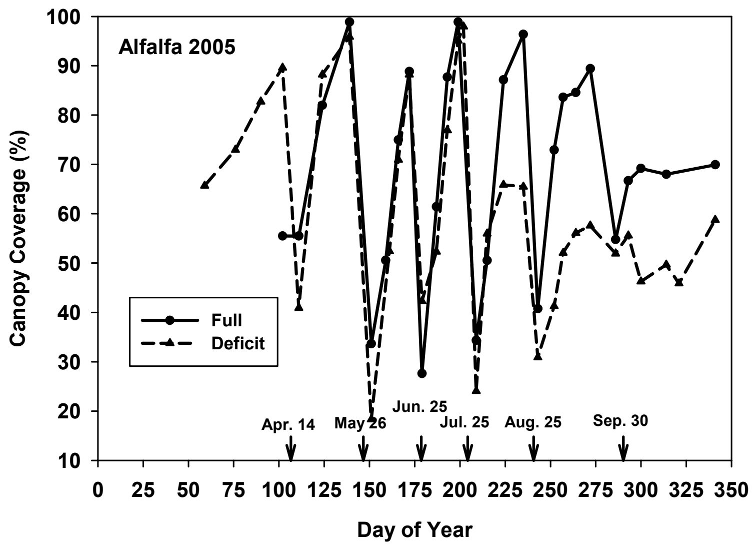

Figure 3. Canopy coverage of the 2005 fully-and deficit-irrigated alfalfa.

Plant height (Fig. 4) showed a behavior similar to that of the canopy coverage with values ranging from less than 5 inches just after harvest to generally between 18 and 23 inches just before harvest (data not shown). During the period of deficit irrigation, maximum plant height was less than 12 inches.

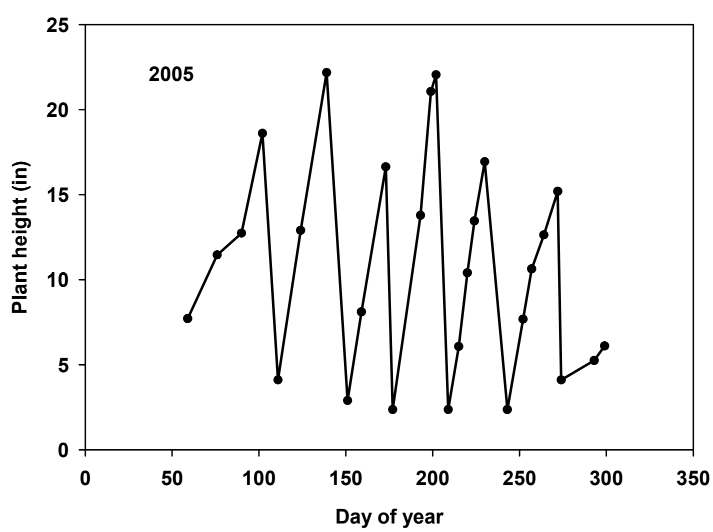

Figure 4. Plant height in 2005.

Crop Coefficients

Substantial fluctuation in the 2005 crop coefficients occurred up to the 100th day of the year (DOY100) with many values exceeding two (Fig. 5). Substantial fluctuations also occurred near the end of the measurement period. The average crop coefficient prior to DOY100 was 1.00. Values exceeding 1.5 were eliminated. After DOY100, the harvest schedule affected the crop coefficients over time. Just after harvests, crop coefficients ranged from about 0.3 to 0.5. Maximum coefficients between harvests were about 1.2 (excluding extreme values).

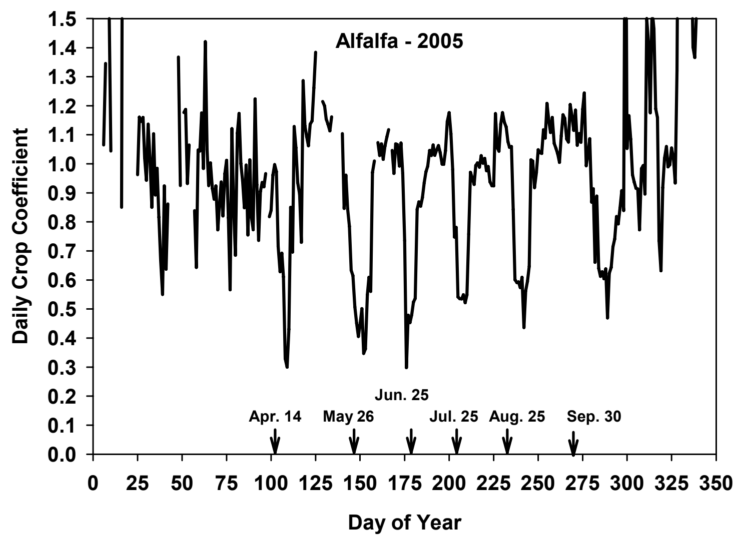

Figure 5. Daily crop coefficients of fully irrigated alfalfa in 2005.

Soil Moisture Tension

Soil moisture tension was less than about 50 centibars for the fully irrigated alfalfa until the end of September (Fig. 6). Soil moisture tension then increased with time because the last irrigation occurred near the end of September. Soil moisture tension in the deficit irrigated treatment increased with time during August, followed by a slight decrease at the end of August (reasons for which are not clear). Thereafter, soil moisture tension increased over time; however, the tension levels were greater than those of the fully irrigated treatment.

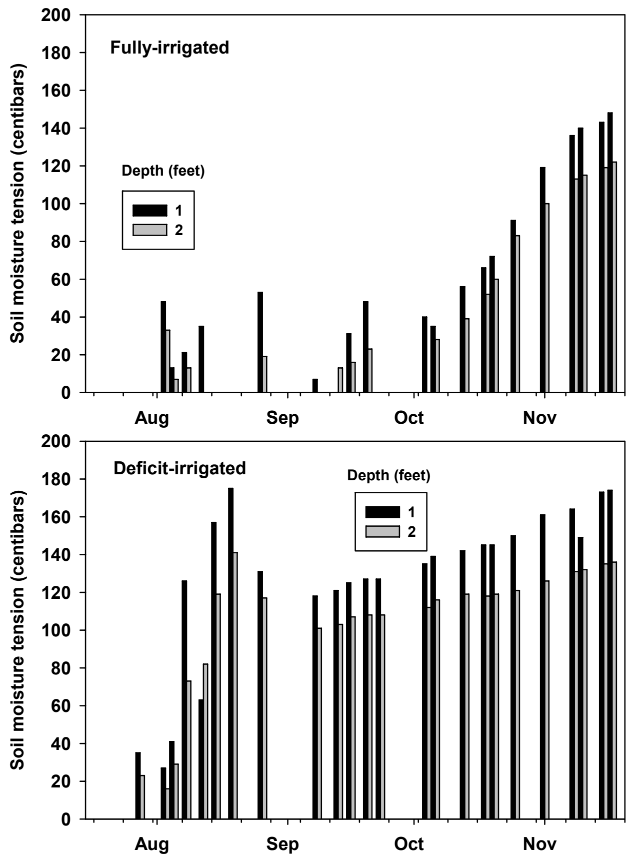

Figure 6. Soil moisture tension of fully and deficit irrigated alfalfa.

CONCLUSIONS

Deficit irrigation of alfalfa during July and August greatly reduced crop yield. Yields reductions of the deficit-irrigated treatments ranged from 41 to 88 % of the fully-irrigated alfalfa yields. In some cases, the yield was uneconomical to harvest. Deficit irrigation imposed at the end of July 2005 reduced the seasonal crop evapotranspiration by 9.4 inches. Deficit irrigation also reduced the maximum canopy coverage and plant height. Based on visual observations, deficit irrigation in a given year did not adversely affect the following year's yield.

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