

Analysis of the Impact of Alfalfa Forage Production under Summer Water- Limiting Circumstances on Productivity, Agricultural and Growers Returns and Plant Stand

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With one figure and 3 tables

Received January 25, 2001; accepted March 20, 2001

Abstract

The trade-off between summer water conservation from alfalfa production and the effects on plant growth, agricultural crop value, and grower returns in the low desert area (Imperial, Palo Verde, Parker and Yuma Valleys of California and Arizona) was analyzed using an experimental plot in the Palo Verde Valley. The purpose was to provide a basis for evaluating water conservation decisions and policies. Four summer dry-down periods (withdrawing water for a predetermined period) of 0 days (control), 35 days, 70 days, and 105 days were analyzed. Our results show that whereas the various dry-down periods would provide water conservation ranging from 254 to 944 million m³, the region would experience agricultural income decline by US \$16 to US \$73 million. For growers, benefits of dry-down would be effective only if the water price exceeds US \$0.045 m⁻³ in California and US \$0.036 m⁻³ in Arizona. Also dry-down would have possible adverse effects in the following areas including declines in plant stand density, long-term productivity, service industry sales, employment and biological benefits of soil fertility and organic matter that is attributed by the alfalfa plant in which case agriculture's and growers monetary losses could increase.

Key words: agricultural and grower returns - alfalfa -plant stand -productivity -summer dry-down

Introduction

Irrigation water use for alfalfa production in the low desert is estimated at 2.08-2.2 billion m³ annually. This is because alfalfa acreage in the Valley, which averaged about 119233 ha during 1992-97, is greater than any other single crop in the desert. Furthermore, it uses more water than any other crop commonly grown in the desert because its production is year round, which results in continuous water consumption. It requires 1727- 2032 mm ha⁻¹ of irrigation water annually. This is approximately 45 % more water than cotton, 65 % more than wheat, 66 % more than sorghum, 89 % more than lettuce, and 75 % more than cantaloupe. Efforts to conserve water in the desert must therefore focus on reducing alfalfa acreage or practicing deficit irrigation, or both of these factors.

Of particular interest has been water use of alfalfa in the summer months. It is estimated that 45 % of annual water use of alfalfa occurs during late June to September. During that same time, only 29 % of the annual yield is produced. In order to evaluate the possibility of conserving water by maintaining alfalfa forage production under water- limiting circumstances, several agencies, municipalities, and environmental groups have been interested in evaluating the economics of summer- time alfalfa production along with its water use.

This paper analyses the effects of summer dry-down (withdrawing water for selected periods during the summer) on yield, crop value and grower costs and returns and industry water savings. It also discusses potential problems such as poor persistence of the alfalfa plant stand, possible yield decline from subsequent harvests and the potential loss of biological benefits from dry-down in crop rotation.

Materials and Methods

The experiment consisted of four treatments: three in the duration of summer dry-down and a control of no dry-down. The dry-down periods included 35 days (8 July to 12 August), 70 days (8 July to 16 September), and 105 days (8 July to 21 October). The control no dry-down treatment was watered at 100 % evapotranspiration (ET) throughout the experiment. After each dry-down period, irrigation at 100 % ET was resumed for the rest of the growing season.

The alfalfa field was seeded in October 1995 with 28 kg ha⁻¹ of 'UC Cibola' variety. The field was managed under uniform irrigation and harvest conditions until the beginning of this study. Previous crops included alfalfa hay from 1991 to 1993 and sudangrass hay in 1994.

The soil type at this location is a Ripley silty clay loam (coarse-silt over sandy or sandy-skeletal, mixed (calcareous) hyperthermic Typic Torrifuvents). Results from prestudy soil analysis show Olsen P (extractable P) = 9 mg kg⁻¹, K=117mgkg⁻¹, Ca=74mgI-I, Mg=26.7mgI-I, pH = 7.8, and ECe (electrical conductivity of saturated soil extract) = 1.14 mS cm⁻¹. Soil fertility was maintained in accordance with laboratory recommendations.

The experimental design was a randomized complete block with three replications. Each plot was 6.1 m wide by 15.24 m long. A 0.91-m deep trench was cut along the border of each plot and a 10 mil plastic sheet installed to prevent (or at least limit) lateral movement of water. Additionally, a 1.02-m wide soil dike was erected between plots to prevent lateral run-off of water between treatments.

Flood irrigations were scheduled using the California Irrigation Management Information System (CIMIS) ET model. Irrigation was applied when 50 % of the available moisture was depleted. Flow meters were installed into a gated pipe to measure the amount of water applied in each irrigation.

Irrigation flow rates were monitored closely to prevent standing tail water at the end of each plot. Soil temperatures were measured using temperature data loggers placed at 152 mm depth in each plot. Also, bi-weekly neutron probe readings were made at 0.30, 0.61, 0.91, and 1.22 m depths in each plot. Neutron probe measurements provided additional data on lateral and vertical volumetric moisture distribution.

Treatment measurements included forage yield and stand persistence during and after the treatment period. The use of data after the treatment period allows us to analyze the long-term effects of dry-down on productivity and plant health. Plots were harvested to a 51-mm stubble height when the plants in the control treatment reached I/10th bloom. Dry matter was determined by drying a sub sample at 49°C. Stand persistence was measured by counting plants in two 0.1 m² quadrants in each plot, once at the beginning of the study and twice at the end.

Yield and plant stand variations and separation of means among treatments were analyzed using Fisher's protected least significant difference (LSD) at P = 0.05 (Steel and Torrie 1980) both before the beginning of the treatments and at selected times during and after the treatment applications.

A partial budgeting analysis was used to estimate and compare agricultural income (crop value) and growers' partial net returns (PNR) among treatments. Partial analysis includes only those items of income and expense that change by treatment. All other costs that apply to all treatments were held constant.

We estimated crop values as production times average prices for the summer seasons in California and Arizona. We used average market prices for five years (1992-97) to normalize the effects of price fluctuations from year to year. Growers' PNR were calculated as crop values less costs of production that vary by treatment.

Costs of production in the PNR analysis included water, irrigation labor, weed control, and harvest applied during the time of study. Water applications were 7918 m³ ha⁻¹ in the control, 5786 m³ ha⁻¹ in 35 days, 1523 m³ ha⁻¹ in 70 days and 0 m³ ha⁻¹ in 105 days dry-down. Water costs vary by location and sources of water. For this reason we evaluated PNR at several water prices and determined the break-even price level that equates the PNR of the control and the dry-down treatments. Beyond the break-even water prices, PNR from dry-down were higher than the control.

Labor hours were estimated at 1.38 h ha⁻¹ per irrigation as provided in the Palo Verde Alfalfa Cost study. Irrigation was applied twice between cuttings. Therefore irrigation labor hours by treatment included 8.30 h ha⁻¹ in the control (3 cuttings), 5.53 h ha⁻¹ in 35 days (2 cuttings), 2.77 h ha⁻¹ in 70 days (1 cutting) and 0 h ha⁻¹ in 105 days (0 cutting) dry-down periods. Irrigation labor cost was estimated at US \$7.00 h⁻¹ wage rate including fringe benefits.

Weed control treatments were applied as needed. Harvest costs were estimated at US \$29.64^{ha-1} for each swathing and raking, US \$29.64 t-1 for baling and US \$4.40 t-1 for hauling and stacking. Harvesting rates were obtained from the alfalfa cost study developed for the Palo Verde Valley in 1997.

Total industry savings of water in dry-down was estimated by multiplying the differences in the amount of water use between the control and dry-down treatments by the total alfalfa acreage in the Valley.

Results

We analyzed yield variation just before the experiment began. As expected, there were not significant yield differences among treatments before the experiment began. After 35 days of dry-down, plots in all of the dry-down treatments showed significant (about 50 %) yield decline. Yield decline continued as the length of the dry-down period increased (Table I). In fact, no yield was obtained as the dry-down continued until irrigation resumed again. Using the control as a reference, the total yield declined 16 % (1.20 t ha⁻¹), 52 % (4.0 t ha⁻¹), and 72 % (5.48 t ha⁻¹) if water was withheld for 35, 70, and 105 days, respectively.

Correspondingly, crop values were lower in the dry-down treatments compared to the control (Table 2a, b). The magnitude of decline in crop

Table 1: Alfalfa hay yield by treatment and harvesting date

Dry-down days	Yield (t ha ⁻¹)					Total (12/8/97-13/1/98)
	Harvesting days					
	7/7/97	12/8/97	16/9/97	21/10/97	13/1/98	
0 (control)	2.45	2.69	1.89	2.45	0.63	7.66
35	2.07	1.41	2.27	2.15	0.63	6.46
70	2.40	1.46	0.00	1.62	0.58	3.66
105	2.47	1.44	0.00	0.00	0.74	2.18
LSD (0.05) ¹	NS	0.33	0.12	0.20	0.03	0.47
CV (%)	8.10	21.20	12.80	14.30	5.30	10.50

LSD, least significance; NS, not significant; CV, coefficient of variation.

¹ Any two differences of means in the column greater than the LSD value is significant.

values would depend on the price of alfalfa hay. Using five-year average prices for the summer seasons in California and Arizona, crop value declines were estimated at US \$138 ha⁻¹ in 35 days, US \$462 ha⁻¹ in 70 days, and US \$633 ha⁻¹ in 105 days dry-down for California. For Arizona the crop value decline estimates per hectare were US \$118 in 35 days, US \$396 in 70 days, and US \$542 in 105 days. The combined crop value decline for the low desert alfalfa hectares of California and Arizona therefore were approximated at US \$15.88 million, US \$53.19 million, and US \$72.86 million in the 35 days, 70 days and 105 days dry-down, respectively.

Table 2a: California Low Desert-Imperial and Blythe: gross returns, costs of production, and partial net returns per hectare of summer dry-down in alfalfa production

Dry-down days	Crop value ¹ (US\$ ha ⁻¹)	Costs of treatments (US\$ ha ⁻¹)	Cost of water at various prices (US\$ ha ⁻¹)			Partial net returns ³ at various water prices (US\$ ha ⁻¹)		
			US\$	US\$	US\$	US\$	US\$	US\$
			0.032m ⁻³	0.045m ⁻³	0.050 m ⁻³	0.032 m ⁻³	0.045 m ⁻³	0.050 m ⁻³
0 (control)	885	311	257	360	398	317	214	176
35	747	271	188	262	291	288	214	185
70	423	173	49	69	77	201	181	173
105	252	98	0	0	0	154	154	154

¹ Based on US \$ 115.50t⁻¹ (five years average price for California desert alfalfa hay).

² Costs include irrigation labor, harvest, and weed control.

³ Partial net returns = gross returns - costs of treatments (irrigation labor, harvest, weed control, and water).

Table 2b: Arizona Low Desert-Yuma and Parker Valley: gross returns, costs of production, and partial net returns per hectare of summer dry-down in alfalfa production

Dry-down days	Crop value ¹ (US\$ ha ⁻¹)	Costs of treatments (US\$ ha ⁻¹)	Cost of water at various prices (US\$ ha ⁻¹)			Partial net returns ³ at various water prices (US\$ ha ⁻¹)		
			US\$	US\$	US\$	US\$	US\$	US\$
			0.032m ⁻³	0.045m ⁻³	0.050 m ⁻³	0.032 m ⁻³	0.045 m ⁻³	0.050 m ⁻³
0 (control)	758	311	257	289	328	190	158	119
35	640	271	188	211	239	181	158	130
70	362	173	49	56	63	140	133	126
105	216	98	0	0	0	118	118	118

¹ Based on US \$99 t⁻¹ (five years average price for Arizona desert alfalfa hay). ² Costs include irrigation labor, harvest, and weed control.

³ Partial net returns = gross returns - costs of treatments (irrigation labor, harvest, weed control, and water).

Though costs of production were less in the dry-down treatments (Table 2a,b), our estimate showed that PNR of the control were still higher compared to the 35-day dry-down until water prices reached US \$0.045 m⁻³, the break-even price that equates PNR of the control and dry-down. PNR of the control would be higher than 70-day dry-down treatment until water prices reached US \$0.050 m⁻³ and would be higher than the 105-day dry-down period until water prices reached us \$0.052 m⁻³. For Arizona, PNR of the control treatment was higher than the 35-day dry-down treatment until water prices reached us \$0.036 m⁻³. PNR of the control would be higher than the 70-day dry-down treatment until water price reached us \$0.038 m⁻³ and than the 105-day dry-down period until water prices reached \$0.041 m⁻³. Beyond the break-even prices, the dry-down treatments began to show higher PNR. Of course, changes in prices of alfalfa hay would change the analysis. Higher alfalfa prices would increase the break -even water prices and lower prices would reduce them. Generally, it can be approximated that a 10 % change in the price of alfalfa hay would cause the break-even water price change by at least 10 %.

At the start of the experiment, plant stand densities (counted on 30 June 1997) were equal between treatments, averaging 99.6 plants m⁻². When re-evaluated on 21 October 1997, plant stand density in all treatments was reduced compared to the 30 June 1997 sampling, but the reduction was greatest in the 105 days dry-down treatment (Fig1). At that time, stands in the 105 days dry- down treatment averaged 16.7 plants m⁻², 60 % fewer plants than in the control. Although the stand counts taken in October showed that the 70 days dry-down treatment had stands equal to

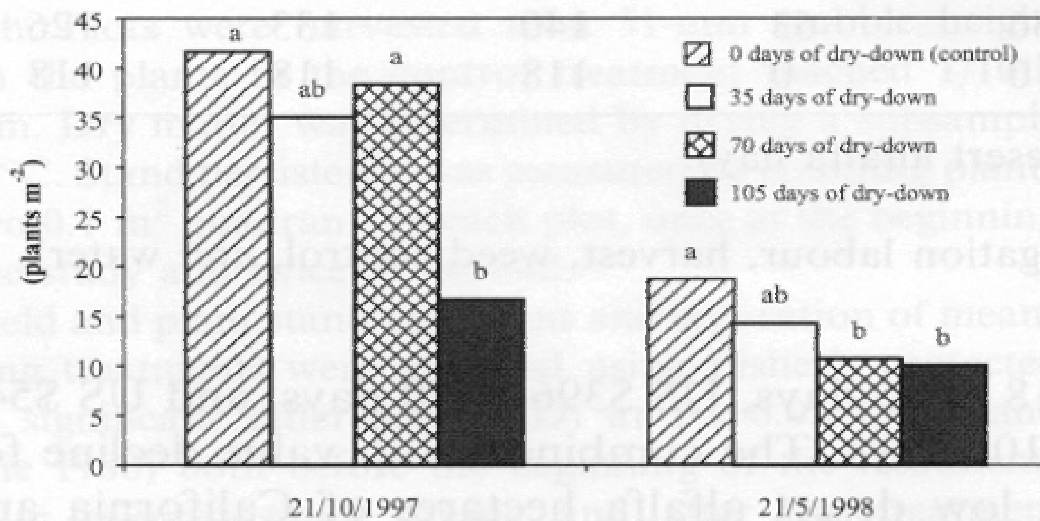


Fig. 1: Stand density of the control (0 days of dry-down) compared to three dry-down periods. Within date, bars with the same letter are not significantly different (LSD = 0.05)

those in the control, stand in this treatment declined over the winter of 1997-98. At the final stand count on 21 May 1998, stand in the 70 and 105-day treatments averaged 10.3 plants m⁻², which were approximately 50 % of the control (Fig. 1).

Water saving estimates from the various dry-down periods for the 119 233 ha in the low desert were about 254 million m³ in 35 days, 763 million m³ in 70 days, and 944 million m³ in 105 days (Table 3a, b).

Discussion

Our study quantified several factors that would be useful in evaluating the impact of alfalfa production under water limiting conditions. We showed water savings due to dry-down and evaluated the consequential crop and return losses both to the economy of the region and to growers. We also determined water prices that would make water-limiting conditions cost effective.

In the August harvest (35 days after the last irrigation), all dry-down treatments produced about 50 % less alfalfa compared to the control. Undoubtedly, the deep-rooted alfalfa plants were able to exploit soil water for several days after irrigation was terminated. Continuation of growth for a short period after irrigation is terminated was also reported by Ottman et al. (1996) and Metochis and Orphanos (1981). After the 12th August cutting, growth ceased in the 70 or 105-day dry-down treatments until irrigation was resumed.

Once irrigation resumed, yield for the 35-day dry-down treatment was equal to or greater than that for the control at subsequent harvests. For the 70-day dry-down treatment, yield was approximately 34 % less than the control at the first harvest following the resumption of irrigation (21 October) but was equal thereafter. Yield for the 105-day dry-down treatment was 0.11-0.16 t ha⁻¹ greater than that for all other treatments on 13 January 1998. However, yields for this harvest were low for all treatments due to the cool weather and relatively short days typical in this region during November and December.

Several examples in the literature show similar responses of alfalfa to irrigation termination or deficit irrigation (Metochis and Orphanos 1981, Prate et al. 1988, Rice et al. 1989, and Guitjens 1993). Most of these studies show that alfalfa yields recover once normal irrigation resumes. One exception, is the work of Ottman et al. (1996)

Table 3a: California Low Desert-Imperial and Blythe: water savings and crop value estimates for summer dry-down alfalfa production

Dry-down days	Amount of water saving ¹ (million m ³)	Crop value (US\$ ha ⁻¹)	Crop value difference	
			(US\$ ha ⁻¹)	(million US\$) ²
0 (control)	0	885	0	0
35	193	747	138	12.49
70	579	423	462	41.82
105	717	252	633	57.30

¹ Water savings and crop value differences for the various dry-down periods calculated in reference to no dry-down.

² For an average of 90522 ha in California low desert during 1992-97.

Table 3b: Arizona-Yuma and Parker Valley: water savings and crop value estimates for summer dry-down alfalfa production

Dry-down days	Amount of water saving ¹ (million m ³)	Crop value (US\$ ha ⁻¹)	Crop value difference	
			(US\$ ha ⁻¹)	(million US\$) ²
0 (control)	0	758	0	0
35	61	640	118	3.39
70	184	362	396	11.37
105	227	216	542	15.56

¹ Water savings and crop value differences for the various dry-down periods calculated in reference to no dry-down.

² For an average of 28 711 ha in Arizona low desert during 1992-97.

who showed permanent yield reductions for alfalfa if irrigation was withheld during the hottest part of the summer in central and southern Arizona.

The losses in yield and plant in dry-down led to losses in agricultural income and growers revenue. To the economy of the region, the losses in agricultural income would also induce adverse impacts in employment and service industry activities. To individual growers, losses in revenue would depend on prices of the alfalfa hay and cost of production savings. Using the five years average summer hay prices the control showed higher PNR until water price reached US \$0.045 m⁻³ in California and US \$0.036 m⁻³ in Arizona. That means higher water prices would result in cost effectiveness of dry-down.

The impact of dry-down, however, is not limited to yield and return losses. Long-term impacts in plant stand density following dry-down as well as the loss of benefits by other crops in rotation might be of interest to growers.

Regarding stand densities we found the following. It is not unusual, even for well-watered alfalfa, to show a substantial reduction as plants mature and develop larger crowns (Morris et al. 1992), however, our data shows that stands decline more rapidly when water is withheld for periods greater than 35 days in the summer. The delayed stand loss in the 70 day treatment compared to no dry-down might be explained by the 'accumulated stress load' theory proposed by Leath (1989). In essence, Leath proposed that individual plants are able to withstand only so much stress whether it is from biotic or abiotic factors. While plants in the 70-day treatment obviously did not die during the dry-down period, perhaps the stress of the summer dry-down predisposed these plants to diseases or other stress factors over the winter of 1997-98. Consequently, while immediate yield losses can be determined shortly after a dry-down period, the loss in stand and thus subsequent long-term yield losses may not be fully realized until several months after irrigation is resumed.

Also, potential biological benefits (N left in the soil, lower incidence of plant diseases, increased number of beneficial insects, increased soil microbial activity and organic matter) that other crops are expected to gain in rotation with alfalfa may not be fully realized with dry-down in which case agriculture and growers' monetary losses could increase.

Acknowledgement

We would like to thank Mr. Walter Graves, Farm Advisor Emeritus for participating in this project and Dr Dan Putnam in administrating the project.

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