UCRTRAC Accumulative Research Summary
Section A: Irrigation Water Use Efficiency Including Utilization of Effluent Water
Project 8

Title: The Development of Irrigation and Nitrogen Fertilization Programs on Tall Fescue to Facilitate Irrigation-Water Savings and Fertilizer-Use Efficiency.

Objective:

1. Test irrigating tall fescue at a defined annual amount (80% historical ET_o plus rain) with increased irrigation during the warm season to improve grass performance, and then proportionally adjusting the cool-season irrigation amount downward to make up for the additional warm-season irrigation. These treatments are being compared to irrigating tall fescue at a constant rate of 1) 80% historical ET_o plus rain and 2) 80% ET_o (real time) plus rain.

2. In conjunction with irrigation treatments, test the influence of the annual nitrogen-fertility rate on the performance of tall fescue.

3. Quantify the effects of irrigation and nitrogen-fertility treatments on tall fescue visual appearance and drought stress tolerance, growth (clipping yield), and nitrogen uptake, along with treatment effects on soil water content and soil nitrogen status.

4. Develop BMPs for tall fescue relating to turfgrass water conservation and nitrogen-fertilizer use efficiency, which provide for optimal performance in terms of visual quality and drought stress tolerance, growth (clipping yields), and nitrogen uptake.

5. Conduct outreach activities, including trade journal publications and oral presentations, emphasizing the importance of turfgrass BMPs, and how to properly carry out these practices for turfgrass irrigation and nitrogen fertilization.

- This study was conducted concurrently with a second, “Irrigation Water Banking on Tall Fescue in the Inland Climatic Conditions of Riverside”, Chapter Two, Project VI. The latter study was conducted on 10.0- x 20.0-ft plots of Jaguar III tall fescue in each 20.0- x 20.0-ft irrigation cell.

- Irrigation treatments were applied from April 1998 to December 2000 in 20.0- x 20.0-ft irrigation cells. Each cell contained a 10.0- x 20.0-ft main plot of Shortstop tall fescue, established from seed in January 1994 (Fig. 1).

- Nitrogen fertility treatments were applied to three 6.7- x 10.0-ft subplots within each main plot of Shortstop tall fescue during the 3-year study (Fig. 1).

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- For the constant 80% historical irrigation treatment (treatment A) and the two irrigation water banking treatments (treatments B and C), quarterly historical ET_o quantities were calculated from monthly historical tables. This quantity was multiplied by the irrigation treatment percentage for the quarter to yield irrigation treatment quantity for a 3-month period (Tables 3 to 5). Treatments A, B, and C required that the controller be programmed four times per year.

- For the 80% ET_o (real time) irrigation treatment (treatment D), amount of irrigation was programmed into the controller each week, based on the previous 7-day ET_o from a CIMIS station located 169 ft from the research plot (Tables 3 and 4).

- Annual summary of ET_o, historical ET_o, rainfall, and applied irrigation is presented in Tables 8 to 10.

- Rainfall was not subtracted from either the 3-month (treatments A, B, and C) or weekly (treatment D) allotment, but may have resulted in cancellation of an irrigation event if rainfall > 0.5 inches (Tables 8 to 10). This occurred in 1988 but not in 1999 and 2000.

- Nitrogen fertility treatments were made by applying three different N rates on the same four application dates (Tables 3 and 4).

Annual N rates (lb/1000 ft^2):

1998	3.0, 4.5, 6.0
1999-2000	4.0, 6.0, 7.7

- More information about methods and measurements of this study are listed in Tables 6 and 7.

Location: Established precision irrigation plot located at the UCR Turfgrass Field Research Facility.

Duration: 3 years

Funding Source: California Department of Food and Agriculture, Fertilizer Research and Education Program (CDFA-FREP)

Findings:

- Visual turfgrass quality ratings for all treatments were relatively low (Tables 1 and 2). This was primarily caused by a lack of irrigation.

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- Irrigation water banking treatments (treatments B and C) had a higher percentage of rating dates on which visual turfgrass quality ≥ 5.0 than other irrigation treatments during the critical July to September quarter (Table 2).

- Annual overall visual turfgrass quality ratings were significantly affected by N-fertility rate treatments, unlike irrigation-level treatments (Table 1). Greater amounts of slow-release N fertilizer improved visual turfgrass quality and color of tall fescue. These data may suggest that under water-limiting conditions, additional amounts of slow-release N may help maintain growth activity, which is important (see BMPs listed in Executive Summary).

- Additional Findings are discussed in the Executive Summary.

Status: A 3-year study was completed and Progress, Annual, and Final Reports were prepared. Information associated with the study was presented at the UCR Turfgrass Research Conference and Field Day, SCTC Institute and Expo, and at an annual meeting of CDFA-FREP. Information associated with this study was published in abstracts from the presentations, *Turf Tales Magazine,* and *Better Turf Thru Agronomics*.

Executive Summary

This project involved the study and development of best management practices (BMPs) for landscape water conservation and nitrogen- (N-) fertility efficiency on tall fescue, currently the most widely-planted turfgrass species in California. We believe this subject was worthy of investigation because water use is the most important environmental issue in California and it was consistent with CDFA/FREP goals of improving crop-water management and fertilizer-use efficiency. The objectives of this 3-year project were to: 1) test irrigating tall fescue at a defined annual amount (80% historical ET_o plus rain) with increased irrigation during the warm season to improve turfgrass performance, and then proportionally adjusting the cool-season irrigation amount downward to make up for the addition of warm-season irrigation (water banking treatments) as compared to irrigating tall fescue at a constant rate of 80% historical ET_o plus rain and 80% ET_o plus rain (80% real-time ET_o plus rain); 2) in conjunction with irrigation treatments, test the influence of the annual N-fertility rate on the performance of tall fescue; 3) quantify the effects of irrigation and N-fertility treatments on tall fescue visual appearance and drought stress tolerance, growth (clipping yield) and N uptake, along with treatment effects on soil-water content and soil N status; 4) develop BMPs for tall fescue relating to turfgrass water conservation and N-fertilizer use efficiency, which provide optimal performance in terms of visual quality and drought stress tolerance, growth (clipping yields), and N uptake; 5) conduct outreach activities, including trade journal publications and oral presentations, emphasizing the importance of turfgrass BMPs, and how to properly carry out these practices for turfgrass irrigation and N fertilization.

Field Study Protocol and Weather Information

Treatment, measurement, and research plot management protocols proceeded well during the 3-year study. It should be noted that the 80% historical ET_o plus rain and the 80% ET_o plus rain irrigation treatments were basically equivalent to 100% historical ET_o plus rain and 100% ET_o plus rain, respectively, for typical landscape irrigation systems. As might be expected, the irrigation system distribution uniformity (DU) for the research plot (average DU for the 12 irrigation cells = 83%) was basically 20% higher than for typical landscapes. Thus, the amount of irrigation applied according to our irrigation-level treatments was representative of current landscape irrigation water budgets which allocate 80% to 100% ET_o per unit surface area of landscape. However, unlike our turfgrass experimental plots, most landscape surface area is not covered with 100% turfgrass. Many landscapes are covered with a combination of trees, shrubs, groundcovers, turfgrasses, and non-plant materials.

In 1998, annual ET_o was 5% below historical ET_o, with an abundance of rainfall during the January to March quarter and a lack of rainfall during the October to December quarter. Both 1999 and 2000 were close to normal for ET_o, although annual rainfall totals were considerably lower than historical totals. As might be expected, such fluctuations in rainfall affected our data and interpretations concerning irrigation-level and N-fertility treatments.

Field Study Results

From 3 Apr. 1998 to 15 Dec. 2000, there were 66 rating dates for visual turfgrass quality and color. The N treatments significantly affected these ratings more than the irrigation treatments. The irrigation x N treatment interaction basically was not significant. The majority of the ratings were between 5.0 and 5.5, which would be considered relatively low on a 1 to 9 scale. These ratings were relatively low due to a lack of irrigation versus a lack of N fertilizer. This is surprising because our irrigation treatments were equivalent to 100% historical ET_o plus rain and 100% ET_o plus rain (typical irrigation budgets are between 80% and 100% ET_o). These data show that when developing BMPs for tall fescue, the first priority is allocating sufficient irrigation (not too little nor too much). To achieve this may involve matching the area of tall fescue maintained to the area the water budget can support.

Greater amounts of slow-release N fertilizer improved visual turfgrass quality and color. These data suggest that under water-limiting conditions, additional amounts of slow-release N may help maintain growth activity which results in higher visual turfgrass quality and color.

Clipping yield and N uptake measurements are a direct measurement of growth activity which can be affected by irrigation and N treatments, temperatures, and other factors. Cooler temperatures during November and December dramatically reduced growth activity during all 3 years of the study. The influence of N treatments was significant and straightforward during all 3 years of the study: more N fertilizer resulted in more growth activity. The influence of irrigation treatments on clipping yield and N uptake (growth activity) was significant and caused by drought conditions of selected irrigation treatments and growth periods. The irrigation x N interaction basically was not significant.

Leaves rolling and wilting and turning brown, which were due to drought stress, were rather common during the study, especially from June through January. These data show that drought stress was an important factor during this study. However, there were very few significant differences among irrigation or N treatments. There basically were no significant irrigation x N treatment interactions.

Irrigation and N treatments generally did not affect soil concentration of TKN, NH_4-N, and NO_3-N when soil was sampled in October of each year of the study. It is possible that soil N concentrations would have been significantly different among N treatments during different periods of the year.

Another fairly consistent trend during the 3-year study for soil water levels was that the water banking irrigation treatments had a higher volumetric soil water content (wetter) and lower soil water tension (wetter) than the 80% historical ET_o and 80% ET_o irrigation treatments during the July to September quarter. These data would be expected since more irrigation water was applied for the former irrigation treatments.

Conclusions of the Field Research

These data show that when tall fescue is maintained in Riverside, Calif. (inland area between marine and desert climates), under an irrigation water budget that is similar to 100% historical ET_o plus rain or 100% ET_o plus rain, per unit landscape area, drought stress occurs which results in relatively low visual turfgrass quality and color. Also, growth activity (clipping yield and N uptake) are reduced. Basically, this condition was due to a lack of water versus the lack of N fertilizer and illustrates the need for the maintenance of shoot growth and plant vigor by providing a good plan for an irrigation water budget and a good N-fertility program. A good plan for an irrigation water budget for tall fescue includes not planting 100% of the landscape area in tall fescue, maintaining the best possible irrigation system, and irrigation water banking. A good N-fertility program for tall fescue includes enough N to promote growth to endure and recover from drought stress and the use of fertilizers with a higher percentage of slow-release nutrients.

Best Management Practices for Tall Fescue Irrigation and Nitrogen Fertilization

1. Provide adequate irrigation for the maintenance of growth activity (shoot growth and N uptake) and visual appearance. This is the first priority in the maintenance of tall fescue.
    - 1.1 Match the area of tall fescue maintained to the area the water budget can support for all 12 months of the year.
    - 1.2 As often as possible, adjust irrigation amount to actual tall fescue water needs.
    - 1.3 Maintain the most efficient irrigation system as possible.
    - 1.4 Practice water banking.
    - 1.5 Promote good growth activity, especially N uptake, for a good defense against NO_3-N leaching below the rootzone and contributing to groundwater contamination.
    - 1.6 Comments 1.1 to 1.4 are important practices leading to water conservation.
2. Provide adequate N for the maintenance of growth activity (shoot growth and N uptake) and visual appearance.
    - 2.1 Nitrogen has a dramatic affect on growth activity (shoot growth and N uptake) and visual appearance, especially when adequate water is provided.
    - 2.2 Growth activity is helpful during times of plant stress and recovery. However, this growth activity should not be minimal nor excessive.
    - 2.3 Use larger amounts of slow-release N fertilizers to improve visual appearance and growth activity of tall fescue subjected to drought stress.

2.4 In California, it is optimal to fertilize in the fall, followed by the spring, and then in the summer. Fertilization during the winter is not recommended. These comments are based on the air and soil temperatures required to support growth activity. As the season becomes less desirable for N fertilization, use smaller amounts of N and/or use N fertilizers with a higher percentage of slow-release N.

Outreach Activities

In terms of our outreach activities, we identified professional turfgrass managers, personnel involved in the fertilizer industries, educators, and consultants as the primary audience for the outreach activities, and home-lawn owners as the secondary audience. These are the people who would either be directly implementing BMPs or would be recommending appropriate BMPs to others. In order to reach both our primary and secondary audiences, we submitted articles to trade journals that summarized the background and objectives of the research project, including special emphasis on irrigation and fertility-related BMPs for managing tall fescue and we identified appropriate venues in which to present oral presentations. We had two articles published and presented eight talks at six venues over the course of the research project.

In order to both obtain audience feedback regarding the oral presentation, and also in order to assess what the audience considered to be generally accepted BMPs for turfgrass management, we submitted a survey and evaluation form immediately following the presentations in 1998 and 1999. The respondents included our primary target audience of decision-makers, with the vast majority (88%) indicating they were always or usually responsible for making turfgrass management decisions or recommendations at their sites. The survey results showed that turfgrass managers (as opposed to advisors), in particular sports turfgrass managers, were the most committed to implementing the BMPs listed in the survey. Overall, the respondents considered BMPs to be both important and not highly difficult to implement. The limitations to the adoption of BMPs were indicated to be a lack of financial backing, employee training, and necessary time – all of which could be remedied with a sufficient commitment of resources by the turfgrass industry.

Table 1. The effect of four irrigation-level and three N-fertility rate treatments on annual overall visual turfgrass quality (scale: 1-9, 9=best, 5=minimally acceptable) of Shortstop tall fescue during April 1998 to December 2000.

Treatments	Year		
	1998	1999	2000
Irrigation-level treatments			
80%, 80%, 80%, 80% hist. ET_o	5.5	5.1	5.2
58%, 90%, 90%, 58% hist. ET_o (1998) 40%, 92%, 91%, 70% hist. ET_o (1999-2000)	5.6	5.1	5.4
58%, 96%, 85%, 58% hist. ET_o (1998) 40%, 85%, 97%, 70% hist. ET_o (1999-2000)	5.5	5.0	5.3
80%, 80%, 80%, 80% ET_o	5.8	5.0	5.2
LSD[z]	NS	NS	NS
N-fertility rate treatments			
3.0 lb N/1000 ft^2/year (1998) 4.0 lb N/1000 ft^2/year (1999-2000)	5.4	4.8	5.1
4.5 lb N/1000 ft^2/year (1998) 6.0 lb N/1000 ft^2/year (1999-2000)	5.6	5.0	5.2
6.0 lb N/1000 ft^2/year (1998) 7.7 lb N/1000 ft^2/year (1999-2000)	5.8	5.3	5.5
LSD[z]	0.1	0.2	0.2

[z]Mean separation within columns and treatment factors by Fisher's protected LSD test, P=0.05.

Table 2. The effect of irrigation-level treatment and N-fertility rate treatment on the percent of rating dates that tall fescue visual turfgrass quality was ≥5.0, ≥5.5, and ≥6.0 for four, 3-month quarters over 3 years and the 3-year total for 1998, 1999, and 2000.

	1998-2000 quarter												1998-2000		
	January to March[z]			April to June			July to September			October to December			January to December		
	Visual quality rating			Visual quality rating			Visual quality rating			Visual quality rating			Visual quality rating		
Treatments	≥5.0	≥5.5	≥6.0	≥5.0	≥5.5	≥6.0	≥5.0	≥5.5	≥6.0	≥5.0	≥5.5	≥6.0	≥5.0	≥5.5	≥6.0
	--- % of 13 rating dates ---			*---- % of 19 rating dates ----*			*----- % of 18 rating dates ----*			*---- % of 16 rating dates ----*			*------ % of 66 rating dates ----*		
Irrigation-level treatments															
80%, 80%, 80%, 80% hist. ET_o[y]	62	31	8	95	68	16	50	11	0	63	31	0	68	36	6
58%, 90%, 90%, 58% hist. ET_o (1998) 40%, 92%, 91%, 70% hist. ET_o (1999-2000)	54	23	0	95	84	16	89	33	0	69	44	0	79	48	5
58%, 96%, 85%, 58% hist. ET_o (1998) 40%, 85%, 97%, 70% hist. ET_o (1999-2000)	31	15	0	100	63	16	100	28	0	56	19	0	76	33	5
80%, 80%, 80%, 80% ET_o[x]	62	23	8	100	58	21	56	28	0	81	19	6	76	33	9
N-fertility rate treatments[w]															
3.0 lb N/1000 ft^2/year (1998) 4.0 lb N/1000 ft^2/year (1999-2000)	23	8	0	95	42	11	61	11	0	50	13	0	61	20	3
4.5 lb N/1000 ft^2/year (1998) 6.0 lb N/1000 ft^2/year (1999-2000)	46	23	0	100	63	16	78	11	0	63	19	0	74	30	5
6.0 lb N/1000 ft^2/year (1998) 7.7 lb N/1000 ft^2/year (1999-2000)	85	38	23	100	89	42	89	33	6	88	63	13	91	58	21

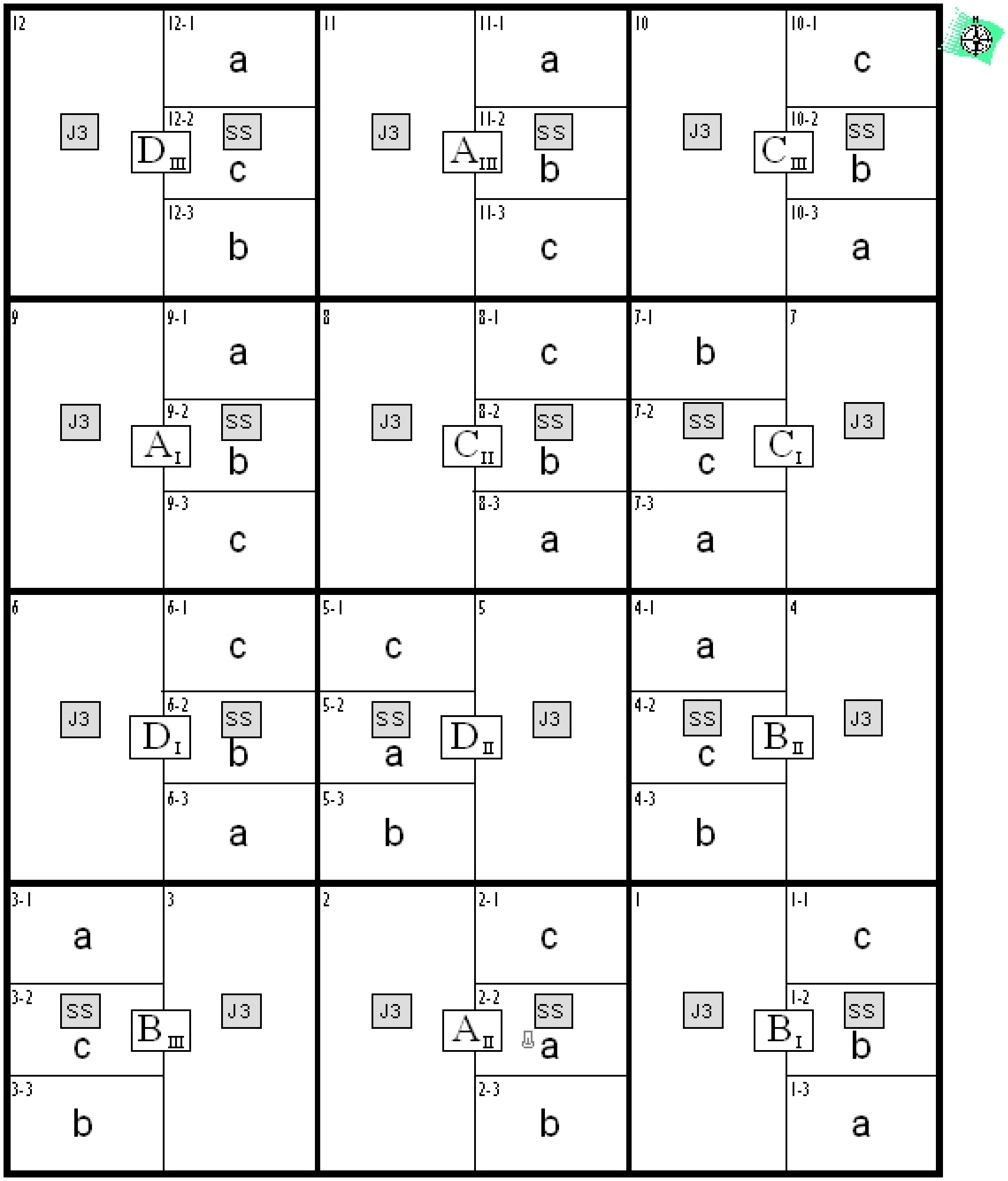
[z]Percentages include data for 1999 and 2000 only; there are no rating dates for this quarter in 1998.

[y]Historical ET_o. Goldhamer, D. A. and R. L. Snyder. 1989. Irrigation scheduling: A guide for efficient on-farm water management. Univ. of Calif., Division of Agricultural and Natural Resources. Publ. 21454 (see p.62).

[x]Real-time ET_o based on 7 d cumulative ET_o from an on-site CIMIS station 51 m (169 ft) from the center of the research plot.

[w]Applied 10 Mar., 18 May, 14 Aug., and 16-17 Oct 1998; 5 Mar., 14 May, 13 Aug., and 15 Oct. 1999; 3 Mar., 12 May, 11 Aug., and 13 Oct. 2000.

Figure 1. Plot plan for the tall fescue irrigation and N-fertility study.



Key:
Genotype: SS = Shortstop tall fescue, J3 = Jaguar III tall fescue

Irrigation treatments [6.10 x 6.10 m (20.00 x 20.00 ft)]:
A = 80%, 80%, 80%, 80% hist. ET_o
B = 58%, 90%, 90%, 58% hist. ET_o (1998) or 40%, 92%, 91%, 70% hist. ET_o (1999 and 2000)
C = 58%, 96%, 85%, 58% hist. ET_o (1998) or 40%, 85%, 97%, 70% hist. ET_o (1999 and 2000)
D = 80%, 80%, 80%, 80% ET_o
I, II, III = replications (blocked according to irrigation distribution uniformity of each plot)

Fertility treatments – subplots [2.03 x 3.05 m (6.67 x 10.00 ft)]:
a = 3.0 lb N/1000 ft^2 per year (1998) or 4.0 lb N/1000 ft^2 per year (1999 and 2000)
b = 4.5 lb N/1000 ft^2 per year (1998) or 6.0 lb N/1000 ft^2 per year (1999 and 2000)
c = 6.0 lb N/1000 ft^2 per year (1998) or 7.7 lb N/1000 ft^2 per year (1999 and 2000)

Table 3. Protocol for irrigation treatments based on a percentage of historical (hist.) ET_o (three treatments) and for ET_o (one treatment) for four, 3-month quarters and three N-fertility treatments based on the annual N-fertility rate for 1998.

Month (Quarter)	Monthly historical ET_o (inch)[z]	Monthly historical rainfall (inch)[y]	Quarterly historical ET_o (inch)[z]	Irrigation treatment[x] A	B	C	D	N-fertility treatment[w] Date of application	Source of N	Rate (lb N/1000 ft^2) a	b	c
Jan. (1)	2.07	1.85										
Feb. (1)	2.87	2.05	8.97	80% hist. ET_o (7.18 inch)	58% hist. ET_o (5.20 inch)	58% hist. ET_o (5.20 inch)	80% ET_o	1 Mar.	$CaNO_3$	0.75	1.125	1.5
Mar. (1)	4.03	1.65										
Apr. (2)	4.13	1.02										
May (2)	6.10	0.28	17.32	80% hist. ET_o (13.86 inch)	90% hist. ET_o (15.59 inch)	96% hist. ET_o (16.63 inch)	80% ET_o	15 May	NH_4NO_3	0.75	1.125	1.5
June (2)	7.09	0.04										
July (3)	7.93	0.00										
Aug. (3)	7.57	0.12	21.64	80% hist. ET_o (17.31 inch)	90% hist. ET_o (19.48 inch)	85% hist. ET_o (18.39 inch)	80% ET_o	15 Aug.	NH_4NO_3	0.75	1.125	1.5
Sept. (3)	6.14	0.20										
Oct. (4)	4.15	0.39										
Nov. (4)	2.60	1.02	8.70	80% hist. ET_o (6.96 inch)	58% hist. ET_o (5.05 inch)	58% hist. ET_o (5.05 inch)	80% ET_o	15 Oct.	$CaNO_3$	0.75	1.125	1.5
Dec. (4)	1.95	1.81										
Total	56.63	10.43	56.63	45.31 inch	45.32 inch	45.27 inch	TBD[v]			3.0	4.5	6.0

[z] Goldhamer, D. A. and R. L. Snyder. 1989. Irrigation scheduling: A guide for efficient on-farm water management. Univ. of California, Division of Agricultural and Natural Resources. Publ. 21454 (see page 62).

[y] Anonymous. 1981. California rainfall summary, monthly total precipitation, 1949-1980. SDWR. 54 pp. plus microfiche.

[x] The CDFA study is a split-plot design, with irrigation treatments assigned to 20.0 x 20.0-ft irrigation cells that are arranged in three randomized complete blocks. Treatments A, B, and C reflect reported monthly turfgrass crop coefficients (Table 5) and are applied in two irrigation events per week–Saturday and Wednesday morning before sunrise. These treatments are based on the 3-month irrigation treatment quantity and scheduled utilizing the application rates of each irrigation cell and the total number of irrigation events per quarter (irrigation run times are set the first day of each 3-month quarter). Treatment D is based on the previous 7 d accumulative ET_o [from an on-site CIMIS station 51 m (169 ft) from the center of the research plot] and are applied in two irrigation events per week–Saturday and Wednesday morning before sunrise. This treatment is scheduled utilizing the application rates of each irrigation cell and the two irrigation events per week (irrigation run times are set on Tuesdays). Irrigation events for all treatments are cycled to prevent runoff. Rain is not subtracted from either the 3-month or weekly irrigation treatment quantity but may result in cancellation of an irrigation event.

[w] N-fertility treatments applied uniformly to subplots by hand application. Note that N-fertility of the Jaguar III tall fescue (Fig. 1) follows the "b" N-fertility treatment and is applied using a calibrated drop spreader. P_2O_5 applied as needed, according to annual soil test in December. K_2O applied in April, May, June, November and December at the rate of 1.2 lb K_2O/1000 ft^2 per application (for a total of 6.0 lb K_2O applied during the year). Note: irrigation used to water in fertilizer is subtracted from irrigation treatments.

[v] TBD = to be determined.

Table 4. Protocol for irrigation treatments based on a percentage of historical (hist.) ET_o (three treatments) and for ET_o (one treatment) for four, 3-month quarters and three N-fertility treatments based on the annual N-fertility rate for 1999 to 2000.

Month (Quarter)	Monthly historical ET_o (inch)[z]	Monthly historical rainfall (inch)[y]	Quarterly historical ET_o (inch)[z]	Irrigation treatment[x] A	Irrigation treatment[x] B	Irrigation treatment[x] C	Irrigation treatment[x] D	N-fertility treatment[w] Date of application	N-fertility treatment[w] Source of N N-P_2O_5-K_2O	Rate (lb N/1000 ft^2) a	Rate (lb N/1000 ft^2) b	Rate (lb N/1000 ft^2) c
Jan. (1)	2.07	1.85										
Feb. (1)	2.87	2.05	8.97	80% hist. ET_o (7.18 inch)	40% hist. ET_o (3.59 inch)	40% hist. ET_o (3.59 inch)	80% ET_o	1 Mar.	Polyon 43-0-0	1.0	1.5	2.00
Mar. (1)	4.03	1.65										
Apr. (2)	4.13	1.02										
May (2)	6.10	0.28	17.32	80% hist. ET_o (13.86 inch)	92% hist. ET_o (15.93 inch)	85% hist. ET_o (14.72 inch)	80% ET_o	15 May	Polyon 42-0-0	1.0	1.5	1.85
June (2)	7.09	0.04										
July (3)	7.93	0.00										
Aug. (3)	7.57	0.12	21.64	80% hist. ET_o (17.31 inch)	91% hist. ET_o (19.69 inch)	97% hist. ET_o (20.99 inch)	80% ET_o	15 Aug.	Polyon 42-0-0	1.0	1.5	1.85
Sept. (3)	6.14	0.20										
Oct. (4)	4.15	0.39										
Nov. (4)	2.60	1.02	8.70	80% hist. ET_o (6.96 inch)	70% hist. ET_o (6.09 inch)	70% hist. ET_o (6.09 inch)	80% ET_o	15 Oct.	Polyon 43-0-0	1.0	1.5	2.00
Dec. (4)	1.95	1.81										
Total	56.63	10.43	56.63	45.31 inch	45.30 inch	45.39 inch	TBD[v]			4.0	6.0	7.7

[z] Goldhamer, D. A. and R. L. Snyder. 1989. Irrigation scheduling: A guide for efficient on-farm water management. Univ. of California, Division of Agricultural and Natural Resources. Publ. 21454 (see page 62).

[y] Anonymous. 1981. California rainfall summary, monthly total precipitation, 1949-1980. SDWR. 54 pp. plus microfiche.

[x] The CDFA study is a split-plot design, with irrigation treatments assigned to 20.0 x 20.0-ft irrigation cells that are arranged in three randomized complete blocks. Treatments A, B, and C reflect reported monthly turfgrass crop coefficients (Table 5) and are applied in two irrigation events per week–Saturday and Wednesday morning before sunrise. These treatments are based on the 3-month irrigation treatment quantity and scheduled utilizing the application rates of each irrigation cell and the total number of irrigation events per quarter (irrigation run times are set the first day of each 3-month quarter). Treatment D is based on the previous 7 d accumulative ET_o [from an on-site CIMIS station 51 m (169 ft) from the center of the research plot] and are applied in two irrigation events per week–Saturday and Wednesday morning before sunrise. This treatment is scheduled utilizing the application rates of each irrigation cell and the two irrigation events per week (irrigation run times are set on Tuesdays). Irrigation events for all treatments are cycled to prevent runoff. Rain is not subtracted from either the 3-month or weekly irrigation treatment quantity but may result in cancellation of an irrigation event.

[w] N-fertility treatments applied uniformly to subplots by hand application. Note that N-fertility of the Jaguar III tall fescue (Fig. 1) follows the "b" N-fertility treatment and is applied using a calibrated drop spreader. P_2O_5 applied as needed, according to annual soil test in December. K_2O applied in April, May, June, November and December at the rate of 1.2 lb K_2O/1000 ft^2 per application (for a total of 6.0 lb K_2O applied during the year). Note: irrigation used to water in fertilizer is subtracted from irrigation treatments.

[v] TBD = to be determined.

Table 5. Cool- and warm-season turfgrass crop coefficients developed in Irvine, Calif. with monthly, quarterly, semi-annual, and annual irrigation programming.

	Cool-season crop coefficients[z]				Warm-season crop coefficients[z]			
Month	Monthly	Quarterly	Semi-annually	Annually	Monthly	Quarterly	Semi-annually	Annually
April	1.04				0.72			
May	0.95	0.96			0.79	0.73		
June	0.88		0.90		0.68			
July	0.94				0.71		0.71	
August	0.86	0.85			0.71	0.68		
September	0.74				0.62			
October	0.75			0.80	0.54			0.60
November	0.69	0.68			0.58	0.56		
December	0.6		0.67		0.55		0.59	
January	0.61				0.55			
February	0.64	0.67			0.54	0.62		
March	0.75				0.76			

[z]Meyer, J.L., V.A. Gibeault, and V.B. Youngner. 1985. Irrigation of turfgrass below replacement of evapotranspiration as a means of water conservation: determining crop coefficient of turfgrasses, p. 357-364. In: F. Lemaire (ed.). Proc. 5th Intl. Turfgrass Res. Conf., Avignon, France, July 1985. INRA Publications, Versailles, France.

Table 6. Protocol for measurements collected during the tall fescue irrigation and N-fertility study.

	Measurement	Frequency	Method and other comments
1.	Visual turfgrass quality	Once every 2 weeks on Friday, which is the day of mowing. Ratings follow mowing.	1 to 9 scale, with 1 = worst quality and 9 = best quality for tall fescue
2.	Visual turfgrass color	Same time as visual turfgrass quality	1 to 9 scale, with 1 = worst color (brown) and 9 = best color (dark green) for tall fescue
3.	Visual estimate of percent leaves that are wilted and rolled	As needed	1 to 100 percent of entire canopy of each subplot
4.	Visual estimate of percent leaves that are fired and yellow to brown	As needed	1 to 100 percent of entire canopy of each subplot
5.	Clipping yield, TKN, and N uptake	Four growth periods, with each period spanning four consecutive weekly clipping yields. All periods start 5 weeks following each of the four N-fertility treatment application dates (Tables 3 and 4). Generally, periods are from 1-30 Apr., 15 June-15 July, 15 Sept.- 15 Oct., and 15 Nov.-15 Dec.	Weekly clipping yield, representing growth of 7 d, collected with the same mower used for the routine, Friday mowing, except a specially constructed collection box is attached to the mower. A subsample, 2.7 m^2 (28.9 ft^2), was harvested from each subplot. Weekly clipping yields were dried and weighed via standard procedures. The four weekly yields within each growth period were pooled by the 36 subplots and prepared for TKN analysis via standard procedures. TKN analysis was conducted at the DANR laboratory located at UC Davis. With appropriate calculations, N uptake during four, 4-week growth periods was determined along with the statistical effect of N-fertility and irrigation treatments.
6.	Volumetric soil-water content; soil-water tension	Once every month (volumetric soil-water content) and once every week (soil-water tension) on Tuesdays. Note that soil-water measurements were collected from Jaguar III tall fescue (Fig. 1).	Volumetric soil-water content at 22.9-, 30.5-, 45.7-, 61.0-, 91.4-, and 121.9-cm (9-, 12-, 18-, 24-, 36-, and 48-inch) depths via the neutron-scattering method (Campbell Pacific Nuclear, Model 503 Hydroprobe). Two neutron probe access tubes per irrigation cell, at the same center locations of each Jaguar III plot (Fig. 1). Soil-water tension at the 15.2- and 22.9-cm (6- and 12-inch) depths using Watermark granular matrix sensors connected to a Watermark soil-moisture meter. Two locations per irrigation cell, at the same center locations of each Jaguar III plot (Fig. 1).
7.	Soil NO_3-N, NH_4-N and TKN	1 Oct.	Soil samples collected from each subplot and prepared according to standard procedures. Analyses conducted at the DANR laboratory, located at UC Davis.
8.	Weather data	Continuous	Data obtained from a CIMIS station located 51 m (169 ft) from the center of the research plot. Soil-temperature data logger installed on the research plot at a depth of 10.2 cm (4 inch).

Note: All measured variables, except weather data and soil-water data, were statistically analyzed according to a split-plot design, with main-plots arranged in a RCB design. Soil-water data were analyzed for the irrigation treatments as a RCB design. A repeated-measures design was used within and between years when appropriate. Weather data were summarized by week.

Table 7. Protocol for research plot management and associated information for the tall fescue irrigation and N-fertility study.

Activity	Comment
1. Mowing	Each Friday, using a walk-behind, rotary mower set at a 3.8-cm (1.5-inch) mowing height. Clippings collected. Note that the Jaguar III tall fescue was mowed the same as the Shortstop tall fescue (Fig. 1).
2. Irrigation	Two irrigation events per week, according to irrigation treatment protocol (Tables 3 and 4). Irrigations events were on Wednesday and Saturday mornings, before sunrise. Irrigation water quality was excellent because it was from the potable water supply of Riverside, Calif.
3. Irrigation-system check	The vertical of all heads, checked with a level and adjusted once every 2 weeks. Clock operation, irrigation run times via hour meters hooked parallel with solenoid values, and pressure of the irrigation system routinely monitored to ensure accurate irrigation treatments. Catch-can tests conducted on each irrigation cell in January and June. Most recent application rates of each irrigation cell were then used in calculating irrigation run times.
4. Fertility	P_2O_5 and K_2O applied as needed based on annual soil tests. Native soil = Hanford fine sand loam. The following information is from a soil test[z] taken 18 Dec. 1998: pH = 7.0; EC_e = 2.37 mmhos/cm; soluble Ca, Mg, and Na = 357, 49, and 182 ppm, respectively; SAR = 2.39; ESP = 2.22%; HCO_3 = 1159 ppm; Fe = 40 ppm; CEC = 10.2 meq/100 g; OM = 1.21%; P-bicarbonate = 29.4 ppm; extractable K, Ca, Mg, and Na = 117, 1804, 195, and 138 ppm, respectively; 15 % clay; 51% sand; and 34% silt.
5. Pesticide application	Pesticides were applied as needed to ensure representative tall fescue.

[z] For information regarding analytical methodologies, see Table A-3.

Table 8. Summary of ET_o and historical ET_o, rainfall, and applied irrigation water in 1998.

	1998 quarter																1998			
	January to March				April to June				July to September				October to December				January to December			
	Irrigation treatment (% quarterly ET_o)				Irrigation treatment (% quarterly ET_o)				Irrigation treatment (% quarterly ET_o)				Irrigation treatment (% quarterly ET_o)				Irrigation treatment (% quarterly ET_o)			
Variable	A (80% hist. ET_o)[z]	B (58% hist. ET_o)	C (58% hist. ET_o)	D (80% ET_o)[y]	A (80% hist. ET_o)[z]	B (90% hist. ET_o)	C (96% hist. ET_o)	D (80% ET_o)[y]	A (80% hist. ET_o)[z]	B (90% hist. ET_o)	C (85% hist. ET_o)	D (80% ET_o)[y]	A (80% hist. ET_o)[z]	B (58% hist. ET_o)	C (58% hist. ET_o)	D (80% ET_o)[y]	A (80%,80%, 80%, 80% hist. ET_o)[z]	B (58%,90%, 90%,58% hist. ET_o)	C (58%,96%, 85%,58% hist. ET_o)	D (80%,80%, 80%, 80% ET_o)[y]
Real-time ET_o (mm)	195	195	195	195	418	418	418	418	513	513	513	513	245	245	245	245	1371	1371	1371	1371
Historical ET_o (mm)	228	228	228	228	440	440	440	440	550	550	550	550	221	221	221	221	1439	1439	1439	1439
ET_{crop} (ET_o x K_c month) (mm)	134	134	134	134	399	399	399	399	441	441	441	441	169	169	169	169	1143	1143	1143	1143
Rainfall (mm)	366	366	366	366	43	43	43	43	14	14	14	14	24	24	24	24	447	447	447	447
Historical rainfall (mm)[x]	141	141	141	141	34	34	34	34	8	8	8	8	82	82	82	82	265	265	265	265
Applied water (mm)[w]	53	60	60	66	296	336	358	219	444	497	466	433	178	128	131	201	971	1021	1015	919
Total water (rainfall plus applied) (mm)	419	426	426	432	339	379	401	262	458	511	480	447	202	152	155	225	1418	1468	1462	1366
(Applied water/ET_{crop}) x 100	40	45	45	49	74	84	90	55	101	113	106	98	105	76	78	119	85	89	89	80
(Total water/ET_{crop}) x 100	313	318	318	322	85	95	101	66	104	116	109	101	120	90	92	133	124	128	128	120
(Applied water/real-time ET_o) x 100	27	31	31	34	71	80	86	52	87	97	91	84	73	52	53	82	71	74	74	67
(Applied water/historical ET_o) x 100	23	26	26	29	67	76	81	50	81	90	85	79	81	58	59	91	67	71	71	64
No. irrigation events	10	10	10	10	22	22	22	19	27	27	27	27	26	26	26	26	85	85	85	82
No. irrigation events canceled	16	16	16	16	4	4	4	7	0	0	0	0	0	0	0	0	20	20	20	23

[z]Historical ET_o. Goldhamer, D. A. and R. L. Snyder. 1989. Irrigation scheduling: A guide for efficient on-farm water management. Univ. of Calif., Division of Agricultural and Natural Resources. Publ. 21454 (see p. 62).

[y]Real-time ET_o based on 7 d cumulative ET_o from an on-site CIMIS station 51 m (169 ft) from the center of the research plot.

[x]Anonymous. 1981. California summary, monthly total precipitation, 1949-1980. SDWR. 54 pp. plus microfiche.

[w]Applied water is calculated as (actual water time per day / system precipitation rate) x no. irrigation events. Numbers for each irrigation treatment are calculated as the average of three replicate plots.

Note: Within each column, underlined percentages can be compared to the percentages that are listed directly below the letters (A, B, C, D) that designate irrigation treatments.

Table 9. Summary of ET_o and historical ET_o, rainfall, and applied irrigation water in 1999.

Variable	1999 quarter																1999			
	January to March				April to June				July to September				October to December				January to December			
	Irrigation treatment (% quarterly ET_o)				Irrigation treatment (% quarterly ET_o)				Irrigation treatment (% quarterly ET_o)				Irrigation treatment (% quarterly ET_o)				Irrigation treatment (% quarterly ET_o)			
	A (80% hist. ET_o)[z]	B (40% hist. ET_o)	C (40% hist. ET_o)	D (80% ET_o)[y]	A (80% hist. ET_o)[z]	B (92% hist. ET_o)	C (85% hist. ET_o)	D (80% ET_o)[y]	A (80% hist. ET_o)[z]	B (91% hist. ET_o)	C (97% hist. ET_o)	D (80% ET_o)[y]	A (80% hist. ET_o)[z]	B (70% hist. ET_o)	C (70% hist. ET_o)	D (80% ET_o)[y]	A (80%,80%, 80%, 80% hist. ET_o)[z]	B (40%,92%, 91%,70% hist. ET_o)	C (40%,85%, 97%,70% hist. ET_o)	D (80%,80%, 80%, 80% ET_o)[y]
Real-time ET_o (mm)	245	245	245	245	411	411	411	411	518	518	518	518	291	291	291	291	1465	1465	1465	1465
Historical ET_o (mm)	228	228	228	228	440	440	440	440	550	550	550	550	221	221	221	221	1439	1439	1439	1439
ET_{crop} (ET_o x K_c month) (mm)	166	166	166	166	389	389	389	389	436	436	436	436	201	201	201	201	1192	1192	1192	1192
Rainfall (mm)	48	48	48	48	58	58	58	58	3	3	3	3	38	38	38	38	147	147	147	147
Historical rainfall (mm)[x]	141	141	141	141	34	34	34	34	8	8	8	8	82	82	82	82	265	265	265	265
Applied water (mm)[w]	184	90	94	202	357	423	367	319	438	498	525	418	173	154	162	232	1152	1165	1148	1171
Total water (rainfall plus applied) (mm)	232	138	142	250	415	481	425	377	441	501	528	421	211	192	200	270	1299	1312	1295	1318
(Applied water/ET_{crop}) x 100	111	54	57	122	92	109	94	82	100	114	120	96	86	77	81	115	97	98	96	98
(Total water/ET_{crop}) x 100	140	83	86	151	107	124	109	97	101	115	121	97	105	96	100	134	109	110	109	111
(Applied water/real-time ET_o) x 100	75	37	38	82	87	103	89	78	85	96	101	81	59	53	56	80	79	80	78	80
(Applied water/historical ET_o) x 100	81	39	41	89	81	96	83	73	80	91	95	76	78	70	73	105	80	81	80	81
No. irrigation events	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	104	104	104	104
No. irrigation events canceled	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[z] Historical ET_o. Goldhamer, D. A. and R. L. Snyder. 1989. Irrigation scheduling: A guide for efficient on-farm water management. Univ. of Calif., Division of Agricultural and Natural Resources. Publ. 21454 (see p. 62).

[y] Real-time ET_o based on 7 d cumulative ET_o from an on-site CIMIS station 51 m (169 ft) from the center of the research plot.

[x] Anonymous. 1981. California summary, monthly total precipitation, 1949-1980. SDWR. 54 pp. plus microfiche.

[w] Applied water is calculated as (actual water time per day / system precipitation rate) x no. irrigation events. Numbers for each irrigation treatment are calculated as the average of three replicate plots.

Note: Within each column, underlined percentages can be compared to the percentages that are listed directly below the letters (A, B, C, D) that designate irrigation treatments.

Table 10. Summary of ET_o and historical ET_o, rainfall, and applied irrigation water in 2000.

	2000 quarter																2000			
	January to March				April to June				July to September				October to December				January to December			
	Irrigation treatment (% quarterly ET_o)				Irrigation treatment (% quarterly ET_o)				Irrigation treatment (% quarterly ET_o)				Irrigation treatment (% quarterly ET_o)				Irrigation treatment (% quarterly ET_o)			
Variable	A (80% hist. ET_o)[z]	B (40% hist. ET_o)	C (40% hist. ET_o)	D (80% ET_o)[y]	A (80% hist. ET_o)[z]	B (92% hist. ET_o)	C (85% hist. ET_o)	D (80% ET_o)[y]	A (80% hist. ET_o)[z]	B (91% hist. ET_o)	C (97% hist. ET_o)	D (80% ET_o)[y]	A (80% hist. ET_o)[z]	B (70% hist. ET_o)	C (70% hist. ET_o)	D (80% ET_o)[y]	A (80%,80%, 80%, 80% hist. ET_o)[z]	B (40%,92%, 91%,70% hist. ET_o)	C (40%,85%, 97%,70% hist. ET_o)	D (80%,80%, 80%, 80% ET_o)[y]
Real-time ET_o (mm)	226	226	226	226	505	505	505	505	521	521	521	521	219	219	219	219	1471	1471	1471	1471
Historical ET_o (mm)	228	228	228	228	440	440	440	440	550	550	550	550	221	221	221	221	1439	1439	1439	1439
ET_{crop} (ET_o x K_c month) (mm)	155	155	155	155	480	480	480	480	448	448	448	448	150	150	150	150	1233	1233	1233	1233
Rainfall (mm)	96	96	96	96	16	16	16	16	4	4	4	4	14	14	14	14	130	130	130	130
Historical rainfall (mm)[x]	141	141	141	141	34	34	34	34	8	8	8	8	82	82	82	82	265	265	265	265
Applied water (mm)[w]	191	92	99	160	358	413	367	381	447	503	544	447	177	154	162	159	1173	1162	1172	1147
Total water (rainfall plus applied) (mm)	287	188	195	256	374	429	383	397	451	507	548	451	191	168	176	173	1303	1292	1302	1277
(Applied water/ET_{crop}) x 100	123	59	64	103	75	86	76	79	100	112	121	100	118	103	108	106	95	94	95	93
(Total water/ET_{crop}) x 100	185	121	126	165	78	89	80	83	101	113	122	101	127	112	117	115	106	105	106	104
(Applied water/real-time ET_o) x 100	85	41	44	71	71	82	73	75	86	97	104	86	81	70	74	73	80	79	80	78
(Applied water/historical ET_o) x 100	84	40	43	70	81	94	83	87	81	91	99	81	80	70	73	72	82	81	81	80
No. irrigation events	26	26	26	26	26	26	26	26	27	27	27	27	26	26	26	26	105	105	105	105
No. irrigation events canceled	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[z]Historical ET_o. Goldhamer, D. A. and R. L. Snyder. 1989. Irrigation scheduling: A guide for efficient on-farm water management. Univ. of Calif., Division of Agricultural and Natural Resources. Publ. 21454 (see p. 62).

[y]Real-time ET_o based on 7 d cumulative ET_o from an on-site CIMIS station 51 m (169 ft) from the center of the research plot.

[x]Anonymous. 1981. California summary, monthly total precipitation, 1949-1980. SDWR. 54 pp. plus microfiche.

[w]Applied water is calculated as (actual water time per day / system precipitation rate) x no. irrigation events. Numbers for each irrigation treatment are calculated as the average of three replicate plots.

Note: Within each column, underlined percentages can be compared to the percentages that are listed directly below the letters (A, B, C, D) that designate irrigation treatments.