UCRTRAC Accumulative Research Summary
Section A: Irrigation Water Use Efficiency Including Utilization of Effluent Water
Project 10

Title: Irrigation Water Banking on Tall Fescue Maintained in the Inland Climatic Conditions of Riverside.

Objective:

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

2. During key times of the study, determine the influence of irrigation treatments on visual turfgrass quality, color, and drought symptoms, clipping yield, clipping water content, relative leaf water content, leaf water content, and volumetric soil water content and soil water tension.

- This study was conducted concurrently with a second, "The Development of Irrigation and Nitrogen Fertilization Programs on Tall Fescue to Facilitate Irrigation-Water Savings and Fertilizer-Use Efficiency", Chapter One, Project VII. The latter study was conducted on 10.0- x 20.0-ft plots of Shortstop tall fescue in each 20.0- x 20.0-ft irrigation cell.

- Irrigation treatments were applied from April 1998 to December 2002 in 20.0- x 20.0-ft irrigation cells. Each cell contained of 10.0- x 20.0-ft plot Jaguar III tall fescue, established from seed in January 1994.

- 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 ET_o 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, 4, and 8). 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 (Table 3, 4, and 8).

- Annual summary of ET_o, historical ET_o, rainfall, and applied irrigation is presented in Tables 5 to 7.

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- Rainfall was not subtracted from either the 3-month (treatments A, B, C) or weekly (treatment D) allotment, but may have resulted in cancellation of an irrigation event if rainfall > 0.5 inches (Tables 5 to 7, line 12). This occurred in 1998, but not in 1999 and 2000.

- More information about methods and measurements of this study are listed in Table 8.

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

Duration: 3 years.

Funding Source: Metropolitan Water District of Southern California.

Findings:

80% historical ET_o or 80% ET_o (real time) is not sufficient irrigation to maintain generally acceptable tall fescue in Riverside (Table 1). It should be noted that 1) average irrigation cell distribution uniformity was 86%, which is higher than typical landscapes and that 2) rainfall was relatively low during 1999 and 2000 (Tables 6 and 7).

Irrigation water banking treatments (treatment B and C) improved turfgrass performance during the critical July to September period (Table 2). Specifically, the number of rating dates on which visual turfgrass quality was $\geq$ 5.5.

Status: A 3-year study was completed and a Final Report was prepared. We plan to prepare a technical article for a scientific journal.

Table 1. The effect of four irrigation treatments regimes on annual overall visual turfgrass quality (scale: 1 – 9, 9 = best, 5 = minimally acceptable) of Jaguar III tall fescue during April 1998 to December 2000.

Irrigation treatment	1998	1999	2000
80, 80, 80, 80% historical ET_o	5.8	5.1	5.5
40, 92, 91, 70% historical ET_o	6.2	5.2	5.6
40, 85, 97, 70% historical ET_o	6.0	5.0	5.5
80, 80, 80, 80% ET_o (real time)	6.2	5.1	5.4
LSD[Z]	*NS*	*NS*	*0.2*

[Z] Mean separation within columns by Fisher's protected LSD test, $P = 0.05$.

Table 2. The effect of four irrigation treatment regimes and 3-month periods on the number of rating dates that tall fescue visual quality and color was ≥ 5.5, from April 1998 to December 2000.

3-month period Number rating dates	Irrigation treatment			
	80, 80, 80, 80% historical ET_o Treatment A	40, 92, 91, 70% historical ET_o Treatment B	40, 85, 97, 70% historical ET_o Treatment C	80, 80, 80, 80% real-time ET_o Treatment D
January to March				
No. of rating dates	13	13	13	13
No. dates:				
Quality ≥5.5	4	3	3	5
Color ≥5.5	5	3	3	5
April to June				
No. of rating dates	19	19	19	19
No. dates:				
Quality ≥5.5	17	17	14	12
Color ≥5.5	18	17	15	16
July to September				
No. of rating dates	19	19	19	19
No. dates:				
Quality ≥5.5	3	11	11	6
Color ≥5.5	7	13	12	7
October to December				
No. of rating dates	16	16	16	16
No. dates:				
Quality ≥ 5.5	7	9	6	7
Color ≥ 5.5	10	10	7	12
3-yr totals: *January to December*				
No. of rating dates	67	67	67	67
No. dates:				
Quality ≥ 5.5	31	40	34	30
Color ≥ 5.5	40	43	37	30

Table 3. Protocol for 1998 for three irrigation treatments based on a percentage of historical reference ET_o for four quarterly (3-month) periods and one irrigation treatment based on real-time ET_o for 12 months.

Month	Monthly historical ET_o (inch)[z]	Quarter	Quarterly historical ET_o (inch)[z]	Irrigation treatment[y] A	B	C	D	Fertilization: Date of application	Source of N	Rate (lb N/1000 ft^2)
Jan.	2.07	1								
Feb.	2.87	1	8.97	80% ET_o (7.18 inch)	58% ET_o (5.20 inch)	58% ET_o (5.20 inch)	80% ET_o (real-time)	1 Mar.	$CaNO_3$	1.125
Mar.	4.03	1								
Apr.	4.13	2								
May	6.10	2	17.32	80% ET_o (13.86 inch)	90% ET_o (15.59 inch)	96% ET_o (16.63 inch)	80% ET_o (real-time)	15 May	NH_4NO_3	1.125
June	7.09	2								
July	7.93	3								
Aug.	7.57	3	21.64	80% ET_o (17.31 inch)	90% ET_o (19.48 inch)	85% ET_o (18.39 inch)	80% ET_o (real-time)	15 Aug.	NH_4NO_3	1.125
Sep.	6.14	3								
Oct.	4.15	4								
Nov.	2.60	4	8.70	80% ET_o (6.96 inch)	58% ET_o (5.05 inch)	58% ET_o (5.05 inch)	80% ET_o (real-time)	15 Oct.	$CaNO_3$	1.125
Dec.	1.95	4								
Total	56.63		56.63	45.31 inch	45.32 inch	45.27 inch	TBD[x]			4.5

[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]The MWD portion of this study was a randomized complete block design, with irrigation treatments assigned to 20.0 x 20.0 ft irrigation cells that were arranged in three randomized complete blocks. All plant and soil measurements for the MWD project were collected from the Jaguar III plots. Treatment A reflects an annual average cool-season turfgrass crop coefficient of 0.8, while treatments B and C reflect adjustments to this annual average. These treatments were based on the 3-month allotment and scheduled utilizing the application rates of each main plot and the total number of irrigation events per quarter (irrigation run times were set the first day of each three-month period). Treatment D was based on the previous 7-d cumulative ET_o (from an on-site CIMIS station 169 ft from the research plot) and was scheduled utilizing the application rates of each main plot and the two irrigation events per week (irrigation run times were set weekly on Tuesdays). All treatments were applied in two irrigation events per week–Saturday and Wednesday morning before sunrise. Irrigation events for all treatments were cycled to prevent runoff. Rain was not subtracted from either the three-month or weekly allotment but may have resulted in cancellation of an irrigation event.

[x]TBD = to be determined.

Table 4. Protocol for 1999 and 2000 for three irrigation treatments based on a percentage of historical reference ET_o for four, quarterly (3-month) periods and one irrigation treatment based on real-time ET_o for 12 months.

Month	Monthly historical ET_o (inch)[z]	Monthly historical rainfall (inch)[y]	Quarter	Quarterly historical ET_o (inch)[z]	Irrigation treatment[x]				Fertilization		
					A	B	C	D	Date of application	Source of N $N\text{-}P_2O_5\text{-}K_2O$	Rate (lb N/1000 ft^2)
Jan.	2.07	1.85	1								
Feb.	2.87	2.05	1	8.97	80% ET_o (7.18 inch)	40% ET_o (3.59 inch)	40% ET_o (3.59 inch)	80% ET_o (real-time)	1 Mar.	Polyon 43-0-0	1.5
March	4.03	1.65	1								
April	4.13	1.02	2								
May	6.10	0.28	2	17.32	80% ET_o (13.86 inch)	92% ET_o (15.93 inch)	85% ET_o (14.72 inch)	80% ET_o (real-time)	15 May	Polyon 42-0-0	1.5
June	7.09	0.04	2								
July	7.93	0.00	3								
Aug.	7.57	0.12	3	21.64	80% ET_o (17.31 inch)	91% ET_o (19.69 inch)	97% ET_o (20.99 inch)	80% ET_o (real-time)	15 Aug.	Polyon 42-0-0	1.5
Sep.	6.14	0.20	3								
Oct.	4.15	0.39	4								
Nov.	2.60	1.02	4	8.70	80% ET_o (6.96 inch)	70% ET_o (6.09 inch)	70% ET_o (6.09 inch)	80% ET_o (real-time)	15 Oct.	Polyon 43-0-0	1.5
Dec.	1.95	1.81	4								
Total	56.63	10.43		56.63	45.31 inch	45.30 inch	45.39 inch	TBD[w]			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 MWD portion of this study was a randomized complete block design, with irrigation treatments assigned to 20.0 x 20.0 ft irrigation cells that were arranged in three randomized complete blocks. All plant and soil measurements for the MWD project were collected from the Jaguar III plots. Treatment A reflects an annual average cool-season turfgrass crop coefficient of 0.8, while treatments B and C reflect adjustments to this annual average. These treatments were based on the 3-month allotment and scheduled utilizing the application rates of each main plot and the total number of irrigation events per quarter (irrigation run times were set the first day of each 3-month period). Treatment D was based on the previous 7-d cumulative ET_o (from an on-site CIMIS station 169 ft from the research plot) and was scheduled utilizing the application rates of each main plot and the two irrigation events per week (irrigation run times were set weekly on Tuesdays). All treatments were applied in two irrigation events per week–Saturday and Wednesday morning before sunrise. Irrigation events for all treatments were cycled to prevent runoff. Rain was not subtracted from either the 3-month or weekly allotment but may have resulted in cancellation of an irrigation event.

[w]TBD = to be determined.

Table 5. 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]
1) 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
2) Historical ET_o (mm)	228	228	228	228	440	440	440	440	550	550	550	550	221	221	221	221	1439	1439	1439	1439
3) ET_{crop} ($ET_o \times K_c$ month) (mm)	134	134	134	134	399	399	399	399	441	441	441	441	169	169	169	169	1143	1143	1143	1143
4) Rainfall (mm)	366	366	366	366	43	43	43	43	14	14	14	14	24	24	24	24	447	447	447	447
5) Historical rainfall (mm)[x]	141	141	141	141	34	34	34	34	8	8	8	8	82	82	82	82	265	265	265	265
6) Applied water (mm)[w]	53	60	60	66	296	336	358	219	444	497	466	433	178	128	131	201	971	1021	1015	919
7) 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
8) (Applied water/ET_{crop}) ×100	40	45	45	49	74	84	90	55	101	113	106	98	105	76	78	119	85	89	89	80
9) (Applied water/real-time ET_o) × 100	27	31	31	34	71	80	86	52	87	97	91	84	73	52	53	82	71	74	74	67
10) (Applied water/historical ET_o) × 100	23	26	26	29	67	76	81	50	81	90	85	79	81	58	59	91	67	71	71	64
11) No. irrigation events	10	10	10	10	22	22	22	19	27	27	27	27	26	26	26	26	85	85	85	82
12) 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 California, 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 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 was calculated as (actual water time per day / system precipitation rate) x no. irrigation events. Numbers for each irrigation treatment were 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 6. Summary of ET_o and historical ET_o, rainfall, and applied irrigation water in 1999.

	Variable	1999 Quarter																1999 Annual			
		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]
1)	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
2)	Historical ET_o (mm)	228	228	228	228	440	440	440	440	550	550	550	550	221	221	221	221	1439	1439	1439	1439
3)	ET_{crop} ($ET_o \times K_c$ month) (mm)	166	166	166	166	389	389	389	389	436	436	436	436	201	201	201	201	1192	1192	1192	1192
4)	Rainfall (mm)	48	48	48	48	58	58	58	58	3	3	3	3	38	38	38	38	147	147	147	147
5)	Historical rainfall (mm)[x]	141	141	141	141	34	34	34	34	8	8	8	8	82	82	82	82	265	265	265	265
6)	Applied water (mm)[w]	184	90	94	202	357	423	367	319	438	498	525	418	173	154	162	232	1152	1165	1148	1171
7)	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
8)	(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
9)	(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
10)	(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
11)	No. irrigation events	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	104	104	104	104
12)	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 California, 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 approximately 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 was calculated as (actual water time per day / system precipitation rate) x no. irrigation events. Numbers for each irrigation treatment were 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 7. Summary of ET_o and historical ET_o, rainfall, and applied irrigation water in 2000.

Variable	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)			
	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]
1) 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
2) Historical ET_o (mm)	228	228	228	228	440	440	440	440	550	550	550	550	221	221	221	221	1439	1439	1439	1439
3) 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
4) Rainfall (mm)	96	96	96	96	16	16	16	16	4	4	4	4	14	14	14	14	130	130	130	130
5) Historical rainfall (mm)[x]	141	141	141	141	34	34	34	34	8	8	8	8	82	82	82	82	265	265	265	265
6) Applied water (mm)[w]	191	92	99	160	358	413	367	381	447	503	544	447	177	154	162	159	1173	1162	1172	1147
7) 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
8) (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
9) (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
10) (Applied water/historical ET_o) x 100	84	40	44	70	81	94	83	87	81	91	99	81	80	70	73	72	82	81	81	80
11) No. irrigation events	26	26	26	26	26	26	26	26	27	27	27	27	26	26	26	26	105	105	105	105
12) 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 California, 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 approximately 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 was calculated as (actual water time per day / system precipitation rate) x no. irrigation events. Numbers for each irrigation treatment were 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 8. Materials and methods outline for the 1998 to 2000 irrigation water banking of tall fescue maintained in the inland climatic conditions of Riverside study.

Objectives:	1. Test irrigating tall fescue at a defined annual amount (80% historical ET_o) 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 addition of warm-season irrigation. These treatments were compared to irrigating tall fescue at a constant rate of 1) 80% historical ET_o and 2) 80% ET_o (real-time). 2. During key times of the study, determine the influence of irrigation treatments on visual turfgrass quality and color, drought symptoms, RLWC, leaf water content, clipping yield, clipping water content, and volumetric soil water content and soil water tension. These measurements were collected on the Jaguar III plot within each irrigation cell. 3. In conjunction with irrigation treatments, test the influence of the annual N-fertility rate on the performance of tall fescue. It should be noted that this objective was part of a project funded by the CDFA-FREP. It was conducted on the Shortstop tall fescue plot within each irrigation cell.
Species:	Jaguar III turf-type tall fescue (*Festuca arundinacea* Schreb.)
Location and root zone:	Block 12 E, plot number 2, UCR Turfgrass Field Research Facility. Root zone is a well-drained native alluvial soil (Hanford fine sandy loam: coarse-loamy, mixed, Thermic Haplic Durixeralf).
Experimental design:	Randomized complete block design with 3 replications for each of four irrigation treatments. Irrigation cells were 20.0 × 20.0 ft and were blocked according to irrigation system DU. MWD data were collected from each 10.0- × 20.0-ft Jaguar III plot within each irrigation cell.
Fertilization:	*1998*: Nitrogen was applied quarterly at a rate of 1.125 lb N/1000 ft^2 using a calibrated 30-inch Gandy drop spreader. Nitrogen source was $CaNO_3$ in March and October, and NH_4NO_3 in May and August. *1999-2000*: Nitrogen was applied quarterly at a rate of 1.5 lb N/1000 ft^2 using a calibrated 30-inch Gandy drop spreader. Nitrogen source was Polyon® polymer-coated urea (43-0-0) for March and October applications and Polyon® polymer-coated urea (42-0-0) in May and August. P_2O_5 was applied as needed, according to an annual soil test in December. K_2O was 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). Dec. 97 soil test: 1.42% OM, 11% clay, 47% sand, and 42 % silt; pH=7.2; P-Olsen=44.4 ppm; exchangeable K, Ca, Mg, and Na=0.276, 8.6, 1.7, 0.3 meq/100g, respectively. CEC=12.5 meq/100 g; SAR=1; ESP (%)<1; soluble Ca, Na, Mg=8.0, 3.0, 2.2 meq/L, respectively. DTPA extractable Fe=23 ppm.
Mowing:	Each Friday, using a walk-behind, rotary mower set at a 1.5-inch mowing height. Clippings were collected. Blade sharpness was checked every 2 weeks and sharpened as needed.

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General maintenance:	1. Irrigation systems of each irrigation cell were checked every 2 weeks for proper operation. (see section below). 2. Weeds were controlled as needed with manual cultivation and herbicides. 3. Vegetative growth in proximity to neutron probe access tubes was trimmed as needed for easy access.
Irrigation:	Two irrigation events/week, according to irrigation treatment protocol. Irrigation events were on Wednesday and Saturday morning, before sunrise. Irrigation water was from the Riverside potable water supply and has an analysis as follows: pH=8.4, EC=0.60 mmhos/cm, Ca=3.9 meq/L, Mg=1.1 meq/L, Na=1.5 meq/L, SAR<1, Cl=8.6 meq/L, B=0.1 ppm, HCO_3=3.4 meq/L, CO_3 <0.1 meq/L, SO_4-S=24 ppm. Irrigation cells were irrigated by four Hunter PGM® rotors equipped with 1.0 gpm nozzles and located at the four corners of each plot.
Irrigation system checks:	Vertical of all heads was checked with a level and adjusted once every 2 weeks. Catch-can tests were performed in the spring to determine system precipitation rates and the DU of each irrigation cell. Maximum DUs were obtained by ensuring system operating pressures (measured at solenoid valve) were close to manufacturer's recommendation (40 psi), and by maintaining head alignment and arc adjustment. Most recent precipitation rates of each irrigation main plot were used in calculating irrigation run times. Proper clock (Rainbird ISC24+) operation was monitored by 24 VAC hour meters (IVO model B148) wired in parallel with solenoid valves.
Irrigation programming and rainfall:	Quarterly historical ET_o quantities were calculated from monthly historical ET_o tables. This quantity was multiplied by the irrigation treatment percentage for the quarter to yield irrigation treatment quantity. Irrigation treatment quantity was then divided equally among the number of Wednesday and Saturday irrigation events for the quarter and multiplied by respective main plot precipitation rate (min/mm) to yield individual irrigation event run times. These times were programmed into the Rainbird ISC controller, and divided into multiple cycles. Each cycle was less than 15 minutes for maximum infiltration: 1. Historical 3-month ET_o x quarterly % = *irrigation treatment quantity.* 2. Irrigation treatment quantity ÷ number of Wed., Sat. irrigation events = *Irrigation quantity per event.* 3. *Irrigation quantity per event* x plot precipitation rate (min/mm) = *Irrigation event run time (minutes).* 4. *Irrigation event run time* ÷ number of cycles = *Irrigation controller run time* Rainfall was not subtracted from the 3-month irrigation treatment quantity, but individual rainfall events totaling 0.5 inch or more resulted in cancellation of an irrigation event. Careful records of rainfall amounts and irrigation events were maintained.

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Irrigation treatment D [80% ET_o (real time)] was programmed into the controller every Tuesday based on the previous 7-d ET_o from a CIMIS station located 169 ft from the research plot. Accumulative 7-d ET_o was multiplied by 0.8, multiplied by plot precipitation rate (min/mm), then divided by two irrigation events per week to determine run time per day. Run time per day was divided by the number of irrigation cycles per day (four) to determine run time per cycle – the number programmed into the controller. Hour meter readings were recorded and compared with the previous weeks' readings to check for proper clock operation.

Measurements: **Turfgrass visual ratings**

Quality and color ratings

- Visual turfgrass quality measured on a 1 to 9 scale with 1= worst, 5=minimally acceptable, and 9=best tall fescue.
- Visual turfgrass color measured on a 1 to 9 scale with 1= brown, 5=minimally acceptable, and 9=best dark green tall fescue color.

Turfgrass visual color and quality ratings were taken every 2 weeks on Friday, after mowing.

Drought ratings

- Percent brown leaves. Scale was 1% to 100% of total plot surface area affected.
- Percent rolled and/or wilted leaves. Scale was 1% to 100% of total plot surface area affected.

Drought ratings were always taken 2 weeks following fertilizer applications, and then monthly during each quarter. Drought ratings were taken on Fridays, prior to mowing.

Other plant measurements

- Clipping yield was measured during April, June, September, and November. Specific dates were as per calendar, but always followed fertilizer applications by 4 weeks. Clippings were collected from an area representing 17.5% of subplot surface area (two 10-ft × 21-inch passes) using a 21-inch Toro commercial rotary mower equipped with a yield box attachment. Clippings were dried at 140 °F for at least 48 h in a forced draft oven, weighed, and reported as g/35 ft^2 per 7 d.

- Clipping water content was measured concurrently with clipping yields [(fresh weight - dry weight)/dry weight)]. Clippings from yield box attachment were placed in a tared paper bag, then immediately weighed on a top-loading scale to the nearest 0.1 gram. Clippings were then dried as described above for dry weights.

- Relative leaf water content was measured periodically. Sampling was conducted between 10:30 am and 12:00 pm (after dew had evaporated). Eight to 10 fully expanded, nonsenescent, representative leaf blades were cut with scissors. Any frayed edges that resulted from mowing were cut off. Two subsamples were harvested from representative areas within each subplot. Data collected from the two subsamples were averaged together.

Leaves were immediately placed in small plastic petri dishes within a cooler, and subsequently weighed in the laboratory for fresh weight. Petri dishes were then

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filled with distilled water and placed in a refrigerator (39 °F) for 12 to 16 h. Water was then decanted and leaves blotted dry and weighed for rehydrated weight. Leaf tissue was then dried for 48 h at 140 °F and dry weights recorded.

RLWC was calculated as [(fresh weight - dry weight)/(rehydrated weight - dry weight)] × 100. Leaf water content was also calculated from these samples as (fresh weight-dry weight/dry weight).

Soil water tension and soil water content

- Soil water tension at 6- and 12-inch depths was measured using Watermark granular matrix sensors (Irrometer Co., Riverside, Calif.) connected to remote readers at the edge of the research plot. Sensors were located next to neutron probe access tubes in two locations within each Jaguar III subplot. Measurements from the two locations within each Jaguar III subplot were averaged. Sensors were read weekly with a Watermark Soil Moisture Meter on Tuesday and Wednesday (before and after irrigation).

- Volumetric soil water content was measured with neutron scattering (Boart Longyear CPN 503DR Hydroprobe) to a 4-ft depth (9, 12, 24, 36, 48 inches) in two locations within each Jaguar III subplot (24 locations). Measurements from the two locations within each Jaguar III subplot were averaged. Readings were taken from PVC access tubes monthly on Tuesdays. The calibration curve relating count ratio to volumetric soil water content was derived from 39 soil samples extracted from the research plot and two other plots. The equation is:
Volumetric soil water content = (36.379*count ratio) - 12.927 where R^2=0.9 and count ratio was the ratio of recorded neutron counts to a standard count measured periodically.

Climatic Information and Datalogger

- Meteorological data from a CIMIS weather station located 169 ft from the research plot included: ET_o; precipitation; solar radiation ($W \bullet m^{-2}$); minimum, maximum and average air temperature (°C); minimum, maximum, and average relative humidity (%); dew point (°C); average wind speed ($m \bullet s^{-1}$); wind run (km); and average soil temperature at a 6-inch depth.

- Rainfall was recorded from a tipping bucket rain gauge connected to the adjacent CIMIS station.

- Soil temperature was measured with a temperature probe at a 4-inch depth. Data was recorded with a StowAway XTI micrologger (Onset Computer Corporation, Pocasset, Mass.) and downloaded monthly.

Statistical analyses of measurements: All MWD data was subjected to a randomized complete block ANOVA according to the general linear models procedure of the Statistical Analysis System (SAS Institute Inc., Cary, N.C.). A repeated measures ANOVA also was performed for visual turfgrass quality and color, percent leaves rolled and/or wilted, percent brown leaves, clipping water content, RLWC, leaf water content, and soil water content and tension with date as the repeated measures factor. Means of irrigation treatments were compared by using a Fisher's Protected LSD test.