UCRTRAC Accumulative Research Summary
Section E: Production of Quality Putting Greens
Project 4

Title: Management of Annual Bluegrass Putting Greens in California.

Objective:

1. To determine the influence of the annual nitrogen and potassium fertility programs and foliar iron applications on plant performance [visual estimates of turfgrass quality and color, plant stress (e.g. mottling/patchiness and leaf wilting and rolling), disease activity, scalping and seedhead coverage; root mass density, crown mass, and shoot density counts from cores; clipping yield; and concentrations of key nutrients in clipping tissue and soil]. Plant performance during the warm season is of special interest.

2. To determine the influence of water injection cultivation (WIC) treatments during the warm season on plant performance (see objective No. 1, except for clipping yield and concentrations of key nutrients in clipping tissue and soil).

3. To determine the influence of the fertility and WIC treatments on important plant characteristics (visual estimates of turfgrass quality, color, seedhead coverage, and disease activity; clipping yield; and concentrations of key nutrients in clipping tissue) during the cool season.

4. To determine fertility treatment effects on key nutrients in clipping tissue once every 6 weeks, utilizing both standard laboratory and near infrared reflectance spectroscopy (NIRS) methodologies. It should be noted that target ranges for elements in clipping tissue of annual bluegrass have been previously lacking.

- Treatments included: high and low nitrogen treatments (10.0 and 5.0 lb/1000 ft^2 per year, respectively); high and low potassium treatments (12.0 and 4.0 lb K_2O/1000 ft^2 per year, respectively); iron applications not made or made (2.0 oz $FeSO_4$ applied foliarly every 3 weeks); and WIC applications not made or made (once every 3 to 4 weeks from April to October).

- More information about treatments can be found in Executive Summary and Methods for Treatments.

- Measurements included visual ratings of turfgrass quality and color, percent coverage of mottling/patchiness, leaf wilting and rolling, disease activity, seedheads, and scalping; elemental analysis of clipping tissue; soil sampling for various fertility, salinity, and physio-chemical characteristics; analysis of shoot density, crown mass, and root mass density from cores; and other measurements.

Continued…

- More information about measurements can be found in Executive Summary and Methods for Treatments.

- The practice green was maintained in the same way as the other greens on the golf course. Form more information, see Methods for Plot Maintenance.

Location: Industry Hills Golf Courses, City of Industry, Calif., on an annual bluegrass practice putting green constructed to USGA specifications in 1978. The putting green was approximately 80% annual bluegrass and 20% creeping bentgrass. More information about the location can be found in Executive Summary and Location of Project.

Duration: 3 years

Funding Source: California GCSA
GCSAA
(Note: Considerable assistance from Bert Spivey and Kent Davidson and their staff and from The Toro Company).

Findings:

- During a 12-month period, effluent irrigation supplied 0.96 lb N/1000 ft^2 (≈ 1.0 lb N). Thus, high and low nitrogen treatments will be considered 11.0 and 6.0 lb/1000 ft^2 per year, respectively.

- 6.0 lb N/1000 ft^2 per year is probably close to optimal in terms of plant performance and total N content in clipping tissue. See Executive Summary for more information.

- Foliar $FeSO_4$ applications increased color and had no effect on root mass density.

- The approximate ratio of 3 N:2 to 3 K_2O for an annual fertilizer amount is probably best for annual bluegrass greens maintained on sand rootzones. This information is based on plant performance and total K content in clipping tissue.

- WIC treatments during the summer reduced leaf wilting and rolling on two of four rating dates and neither harmed nor enhanced root mass density. The latter is notable because in a previous study on the same green, WIC treatments during the summer significantly increased field infiltration rates and lowered soil EC_e compared to check plots; also, root mass density was neither harmed nor enhanced by WIC treatments.

Status: A 3-year study was completed and Progress, Annual, and Final Reports were prepared. Information associated with this study was presented in a poster at an annual GCSAA Conference and in oral presentations at monthly meetings to four GCSAA chapters (GCSA Southern California, GCSA Northern California, San Diego GCSA, and Central California GCSA). Information associated with this study was published in *California Fairways* and *Better Turf Thru Agronomics*. We plan to prepare a technical article for a scientific journal.

Executive Summary

Most golf course superintendents in California are managing annual bluegrass as their putting green turfgrass. The major reason for this norm is the relatively mild climate of the region which usually results in newly established creeping bentgrass putting greens converting to annual bluegrass putting greens in 5 to 7 years. An exception to this rule is the more inland, hotter locations, such as Palm Springs, where bermudagrass and, less frequently, creeping bentgrass putting greens are maintained.

The major problems of managing annual bluegrass putting greens include: summer decline, which includes several issues, such as high temperature stress, disease activity, and salinity stress; seedhead production, especially in the spring; and puffiness during the growing season (October to December and February to June). We investigated fertility and water injection cultivation (WIC) treatments to improve plant performance and soil conditions during the warm season. However, it is possible that these treatments also may influence important plant characteristics during the cool season.

The objectives of this study were: 1) to determine the influence of the annual nitrogen and potassium fertility programs and foliar iron applications on plant performance [visual estimates of turfgrass quality and color, plant stress (e.g. mottling/patchiness and leaf wilting and rolling), disease activity, scalping, and seedhead coverage; root mass density, crown mass, and shoot density counts from plant cores; clipping yield; and concentrations of key nutrients in clipping tissue and soil]; 2) to determine the influence of WIC treatments during the warm season on plant performance; 3) to determine the influence of the fertility and WIC treatments on plant performance during the cool season; and 4) to determine fertility treatment effects on key nutrients in clipping tissue once every 6 weeks, utilizing both standard laboratory and near infrared reflectance spectroscopy (NIRS) methodologies. It should be noted that target ranges for elements in the clipping tissue of annual bluegrass basically have not been reported.

The location of this study was at Industry Hills Golf Courses, City of Industry, California, on an annual bluegrass practice putting green constructed to USGA specifications in 1978. The climate of this location, like much of southern California, is Mediterranean. Visual estimates indicated that the putting green was approximately 80% annual bluegrass and 20% creeping bentgrass. Results from a soil test taken on 3 June 1998, prior to the application of fertility treatments, showed: pH=6.7; EC_e=1.07 $dS{\cdot}m^{-1}$ (685 ppm total dissolved salts); SAR=2; ESP=2%; Fe=78.9 ppm; CEC=12.0 meq/100 g; OM=3.21%; Olsen-P=45.5 ppm; exchangeable K, Ca, Mg, Na=39, 1443, 170 and 115 ppm, respectively; and 88%, 10%, and 2% sand, silt, clay, respectively. The putting green was irrigated with effluent water with 1999 to 2000 average values as follows: pH=7.2; EC=1.01 $dS{\cdot}m^{-1}$ (646 ppm total dissolved salts); and SAR=3.2. The effluent irrigation annually supplied N at the approximate rate of 1.0 lb/1000 ft^2.

Eight liquid-applied fertility treatments and two summer-applied WIC treatments were arranged in a strip-plot design with four blocks (replications). Two nitrogen, two potassium, and two iron levels were factorially arranged into eight fertility treatments and were randomly assigned to 5.5- x 12.0-ft main plots that were within each 44.0- x 12.0-ft block. The fertility treatments are shown in a table below. The two WIC treatments were: a Toro HydroJect operated in the raised position once every 3 to 4 weeks from April through October and no WIC treatment. There were a total of 64, 5.5- x 6.0-ft subplots in this study.

Eight liquid-applied fertility treatments were tested in the annual bluegrass putting green management study. Fertility treatments were applied once every 3 weeks.

Treatment designation			lb/1000 ft^2 per year		
N	K_2O	Fe[z]	N	P_2O_5	K_2O
High	High	+	10.0	3.0	12.0
High	High	–	10.0	3.0	12.0
High	Low	+	10.0	3.0	4.0
High	Low	–	10.0	3.0	4.0
Low	High	+	5.0	3.0	12.0
Low	High	–	5.0	3.0	12.0
Low	Low	+	5.0	3.0	4.0
Low	Low	–	5.0	3.0	4.0

[z] Fe only applied to treatments indicated with "+" at 2.0 oz/1000 ft^2 $FeSO_4$ applied foliarly every 3 weeks.

Measurements that were collected during the study included: visual turfgrass quality and color ratings; Minolta spectrophotometer readings; elemental analyses of clippings; clipping yield; irrigation water analyses; soil elemental analyses; shoot density, crown mass, and root mass density from plant cores; and on-site air and soil temperatures. Visual estimates of turfgrass plant stress (e.g. coverage of mottling/patchiness and leaf wilting and rolling), disease activity coverage, seedhead coverage, and scalping coverage were taken on an as-needed basis. The purpose of these measurements was to help adequately describe plant and soil status and plant and soil responses to treatments and other effects, such as temperatures and turfgrass management practices. The practice putting green was managed in a similar manner as the greens on the golf course.

In terms of the results of this study, it should be noted that the Mediterranean climate of this region is very conducive to the growth of annual bluegrass, resulting in it being more competitive than creeping bentgrass on putting greens. A second point that should be made is that the practice putting green was irrigated with effluent. This resulted in the constant spoon-feeding of numerous plant nutrients, including N, P, K, Ca, Mg, and others. The approximate annual 889 mm (35 inches) of irrigation supplied N at the annual rate of 1.0 lb/1000 ft^2. Thus, the high and low N treatment rates were actually 11.0 and 6.0 lb/1000 ft^2 per year, respectively.

Nitrogen

The high N treatment rate was excessive, resulting in plant stress compared to the low N treatment rate. The high N treatment rate had: a similar overall average visual turfgrass quality rating (6.1 on a 1 to 9 scale) with lower ratings during late spring and summer; a higher overall average visual turfgrass color rating (6.8 on a 1 to 9 scale); an overall average of 106% more seedhead coverage; an overall average of 313% more mottling/patchiness coverage (an indicator of plant stress, characterized by areas of turfgrass with a lighter green visual leaf color, lower visual shoot density, and greater vertical leaf extension rate); an overall average of 273% more leaf wilting and rolling coverage; an overall average of 55% more clipping yield; an overall average of 37% less root mass density of the 0.5- to 3.5-inch root zone; and an overall average of 17% less crown and plant mass.

The low N treatment rate may be close to the optimal N fertilizer rate for annual bluegrass. This is based on visual turfgrass quality (an overall average rating of 6.2) and color (an overall average rating of 6.3) and total N content of clippings. Both N treatments were basically within or higher than the target range of 4.5% to 6.0% total N in clippings of creeping bentgrass. The N rate of 6.0 lb/1000 ft^2 per year may need to be adjusted for other golf courses, depending on numerous conditions, such as: soil type, quality of irrigation water, infiltration rates, salinity and leaching requirements, climate, amount of rainfall, rounds of golf, N application schedule and N source, and Fe applications. Lastly, there is a need to define the minimal annual N fertilizer rate for annual bluegrass.

Iron

The foliar application of Fe as $FeSO_4$ at the rate of 2.0 oz/1000 ft^2 per 3 weeks increased visual turfgrass color ratings (plots treated with Fe had an overall average visual turfgrass color rating of 6.7 while plots not treated had a rating of 6.4) and total Fe content of clippings (however, both Fe treatments were basically within the target range of 100 to 300 ppm total Fe in clippings of creeping bentgrass). An Fe application once every 2 weeks would provide additional color improvement because our observations indicated that the turfgrass color response to $FeSO_4$ lasts for about 2 weeks. It is not unreasonable to believe that, in terms of visual turfgrass color, the amount of N fertilization may be reduced when a successful Fe fertilization program is used. This assumes that necessary growth is maintained.

Potassium

Other than total K content in clippings, we observed no difference between the high and low K treatments for all plant measurements. The high K_2O rate was 12.0 lb/1000 ft^2 per year while the low K_2O rate was 4.0 lb/1000 ft^2 per year. Our plant data were in spite of the fact that the low K treatment resulted in relatively low exchangeable K levels in the soil (overall average exchangeable K levels in the soil during 1999 and 2000 were 106.4 and 66.2 ppm for high and low K treatments, respectively). It should be noted that the effluent irrigation annually applied K at the approximate rate of 2.8 lb/1000 ft^2. Both K treatments were basically within or higher than the target range of 2.2% to 2.6% total K in clippings of creeping bentgrass. These data most likely support the approximate ratio of 3N:2 to 3 K_2O for a fertilizer schedule of a sand-based annual bluegrass putting green. Additional amounts of K above this ratio probably do not enhance the stress resistance of annual bluegrass.

Water injection cultivation during the summer

The summer WIC treatment significantly reduced leaf wilting and rolling during two of four rating dates. However, WIC treatments basically did not affect root mass density. Stated in the positive, WIC summer treatments neither harmed nor enhanced root mass density. This is notable because in a previous study on the same practice putting green, WIC treatments during the summer significantly increased field infiltration rates and lowered soil EC_e compared to check plots; also, root mass density was neither harmed nor enhanced by WIC treatments.

Introduction

Most golf course superintendents in California are managing annual bluegrass as their putting green turfgrass. The major reason for this norm is the relatively mild climate of the region which usually results in newly established creeping bentgrass putting greens converting to annual bluegrass putting greens in 5 to 7 years. An exception to this rule is the more inland, hotter locations, such as Palm Springs, where bermudagrass and, less frequently, creeping bentgrass putting greens are maintained.

The major problems of managing annual bluegrass putting greens include: summer decline, which includes several issues, such as high temperature stress, disease activity, and salinity stress; seedhead production, especially in the spring; and puffiness during the growing season (October to December and February to June). We investigated fertility and water injection cultivation (WIC) treatments to improve plant performance and soil conditions during the warm season. However, it is possible that these treatments also may influence important plant characteristics during the cool season.

Objectives

1. To determine the influence of the annual nitrogen and potassium fertility programs and foliar iron applications on plant performance [visual estimates of turfgrass quality and color, plant stress (e.g. mottling/patchiness and leaf wilting and rolling), disease activity, scalping, and seedhead coverage; root mass density, crown mass, and shoot density counts from plant cores; clipping yield; and concentrations of key nutrients in clipping tissue and soil]. Plant performance during the warm season was of special interest.

2. To determine the influence of WIC treatments during the warm season on plant performance (visual estimates of turfgrass quality and color, plant stress, disease activity, scalping, and seedhead coverage; root mass density, crown mass, and shoot density counts from plant cores).

3. To determine the influence of the fertility and WIC treatments on important plant characteristics (visual estimates of turfgrass quality, color, seedhead coverage, and disease activity; clipping yield; and concentrations of key nutrients in clipping tissue) during the cool season.

4. To determine fertility treatment effects on key nutrients in clipping tissue once every 6 weeks, utilizing both standard laboratory and near infrared reflectance spectroscopy (NIRS) methodologies. It should be noted that target ranges for elements in the clipping tissue of annual bluegrass basically have not been reported.

Location of Project

The location of this study was at Industry Hills Golf Courses, City of Industry, California, on an annual bluegrass practice putting green constructed to USGA specifications in 1978. The climate of this location, like much of southern California, is Mediterranean. Visual estimates indicated that the putting green was approximately 80% annual bluegrass and 20% creeping bentgrass. Results from a soil test taken on 3 June 1998, prior to the application of fertility treatments, showed: pH=6.7; EC_e=1.07 dS·m^{-1} (685 ppm total dissolved salts); SAR=2; ESP=2%; Fe=78.9 ppm; CEC=12.0 meq/100 g; OM=3.21%; Olsen-P=45.5 ppm; exchangeable K, Ca, Mg, Na=39, 1443, 170 and 115 ppm, respectively; and 88%, 10%, and 2% sand, silt, clay, respectively. The putting green was irrigated with effluent water with 1999 to 2000 average values as follows: pH=7.2; EC=1.01 dS·m^{-1} (646 ppm total dissolved salts); and SAR=3.2. The effluent irrigation annually supplied N at the approximate rate of 48.8 kg·ha^{-1} (1.0 lb/1000 ft^2).

Methods for Treatments

Eight liquid-applied fertility treatments and two WIC treatments were arranged in a strip-plot design with four blocks (replications). Two nitrogen, two potassium, and two iron levels were factorially arranged into eight fertility treatments and were randomly assigned to 1.7- x 3.7-m (5.5- x 12.0-ft) main plots that were within each 13.4- x 3.7-m (44.0- x 12.0-ft) block. Two WIC treatments were stripped across the fertility main plots and formed subplots. There were a total of 64, 1.7- x 1.8-m (5.5- x 6.0-ft) subplots in this study. More details concerning these treatments can be seen in Tables 1 to 3 and Figure 1.

Table 1. Eight liquid-applied fertility treatments tested in the annual bluegrass putting green management study.

Treatment designation			kg·ha^{-1} per year (lb/1000 ft^2 per year)		
N	K_2O	Fe[z]	N	P_2O_5	K_2O
High	High	+	487.9 (10.0)	146.4 (3.0)	585.5 (12.0)
High	High	–	487.9 (10.0)	146.4 (3.0)	585.5 (12.0)
High	Low	+	487.9 (10.0)	146.4 (3.0)	195.2 (4.0)
High	Low	–	487.9 (10.0)	146.4 (3.0)	195.2 (4.0)
Low	High	+	244.0 (5.0)	146.4 (3.0)	585.5 (12.0)
Low	High	–	244.0 (5.0)	146.4 (3.0)	585.5 (12.0)
Low	Low	+	244.0 (5.0)	146.4 (3.0)	195.2 (4.0)
Low	Low	–	244.0 (5.0)	146.4 (3.0)	195.2 (4.0)

[z] Fe only applied to treatments indicated with "+" at 6.1 kg·ha^{-1} (2.0 oz/1000 ft^2) $FeSO_4$ applied foliarly every 3 weeks. Fe treatments were individually applied to each plot, utilizing a CO_2 sprayer mounted on a cart, and not watered in. Finish spray volume was 855.3 L·ha^{-1} (2.1 gal/1000 ft^2).

Methods for Treatments

Table 2. N, P_2O_5, and K_2O application schedule for the annual bluegrass putting green management study.

Fertilizer component	Application date: 6 Jan.	27 Jan.	17 Feb.	10 Mar.	31 Mar.	21 Apr.	12 May	2 June	23 June	14 July	4 Aug.	25 Aug.	15 Sept.	6 Oct.	27 Oct.	17 Nov.	8 Dec.	22 Dec.	Annual total
	$kg \cdot ha^{-1}$ ($lb/1000\ ft^2$)																		
N (high rate)	24.4 (.50)	29.3 (.60)	36.6 (.75)	36.6 (.75)	36.6 (.75)	36.6 (.75)	26.8 (.55)	19.5 (.40)	14.6 (.30)	14.6 (.30)	14.6 (.30)	14.6 (.30)	14.6 (.30)	41.5 (.85)	36.6 (.75)	36.6 (.75)	29.3 (.60)	24.4 (.50)	487.9 (10.0)
N (low rate)	6.1 (.125)	9.8 (.20)	9.8 (.20)	23.2 (.475)	14.6 (.30)	14.6 (.30)	14.6 (.30)	9.8 (.20)	9.8 (.20)	9.8 (.20)	9.8 (.20)	9.8 (.20)	9.8 (.20)	34.2 (.70)	19.5 (.40)	19.5 (.40)	19.5 (.40)	–	244.0 (5.0)
P_2O_5	–	–	–	24.4 (.50)	24.4 (.50)	24.4 (.50)	–	–	–	–	–	–	–	24.4 (.50)	24.4 (.50)	24.4 (.50)	–	–	146.4 (3.0)
K_2O (high rate)	48.8 (1.0)	48.8 (1.0)	48.8 (1.0)	48.8 (1.0)	48.8 (1.0)	48.8 (1.0)	48.8 (1.0)	36.6 (.75)	14.6 (.30)	14.6 (.30)	14.6 (.30)	14.6 (.30)	14.6 (.30)	39.0 (.80)	36.6 (.75)	34.2 (.70)	24.4 (.50)	–	585.5 (12.0)
K_2O (low rate)	–	–	–	–	36.6 (.75)	36.6 (.75)	36.6 (.75)	31.7 (.65)	14.6 (.30)	9.8 (.20)	9.8 (.20)	9.8 (.20)	9.8 (.20)	–	–	–	–	–	195.2 (4.0)

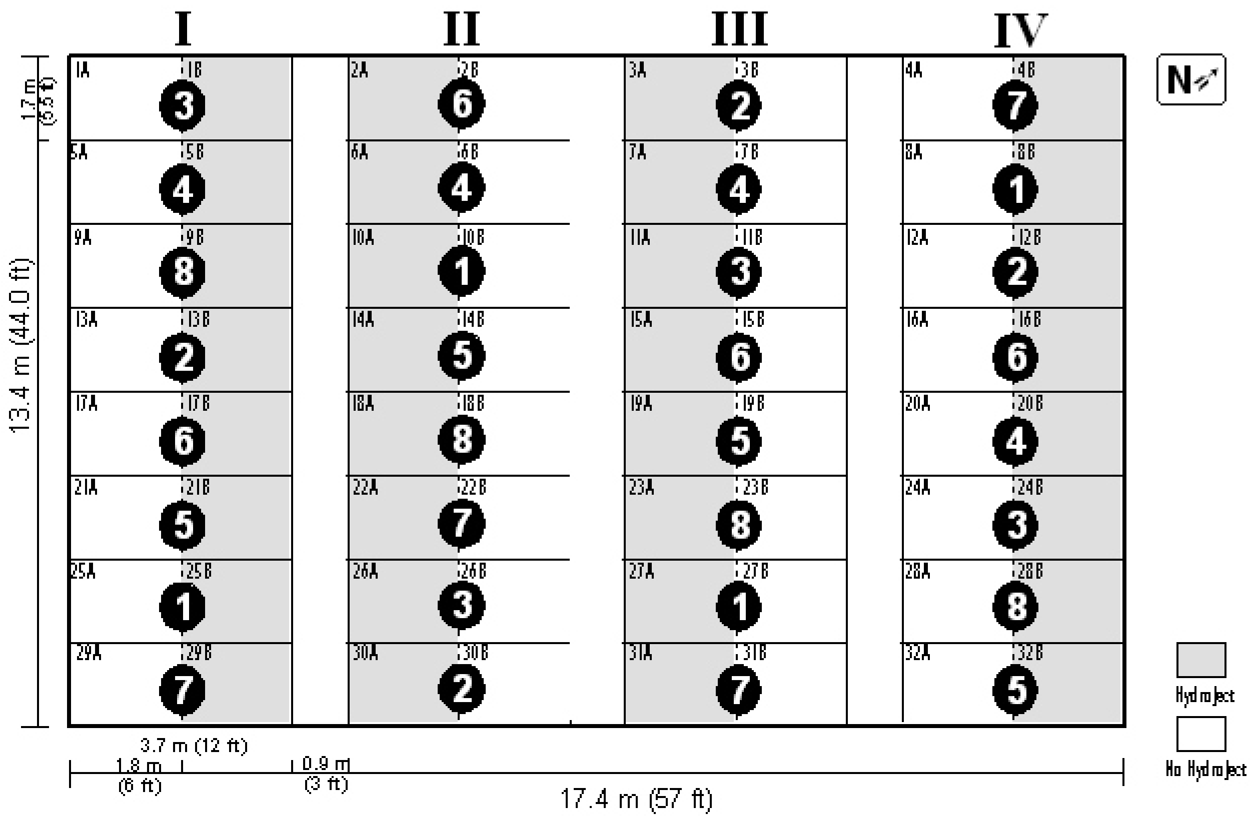
Note: N sources were ammonium nitrate [20-0-0; 1.27 $kg \cdot L^{-1}$ (10.55 lb/gal)] for December, January, and February; ammonium sulfate [8-0-0-9S; 1.23 $kg \cdot L^{-1}$ (10.22 lb/gal)] for March and April; and low biuret urea [20-0-0; 1.12 $kg \cdot L^{-1}$ (9.35 lb/gal)] from May through November. P source was ammonium polyphosphate [10-34-0; 1.38 $kg \cdot L^{-1}$ (11.5 lb/gal)]. K source was potassium sulfate ESP-K [1-0-8-2.5S; 1.17 $kg \cdot L^{-1}$ (9.7 lb/gal)]. Finish spray volume for each treatment application was 855.3 $L \cdot ha^{-1}$ (2.1 gal/1000 ft^2). All treatments were applied with a CO_2 sprayer mounted on a cart. N, P_2O_5, and K_2O treatments were watered in.

Table 3. Water injection cultivation treatments for the annual bluegrass putting green management study.

Treatment level	Treatment specifications	
Cultivation	*Equipment:*	Toro HydroJect 3000; #53 nozzles, 11 operating.
	Settings:	Run in the raised (transport) position; set to second greatest hole density.
	Result:	Hole spacing approximately 7.6 x 7.6 cm (3.0 x 3.0 inch). Holes created by the WIC treatment were 3 mm (0.1 inch) diameter x 108 mm (4.3 inches) deep. They also had a surface entry [9 mm (0.4 inch)] that was wider than the hole.
	Frequency:	Once every 3 to 4 weeks from April through October[z].
No cultivation	No WIC treatment.	

[z]Cultivation treatments applied as follows: in 1998, once every 4 weeks from June through October; in 1999, once every 3 weeks from May through October; and in 2000, once every 3 weeks from April through September.

Figure 1. Plot plan for the annual bluegrass management study.



Treatment designation	N	P_2O_5	K_2O	Treatment designation	N	P_2O_5	K_2O
	kg·ha^{-1} per year (lb/1000 ft^2 per year)				kg·ha^{-1} per year (lb/1000 ft^2 per year)		
1. High N/High K/+ Fe	487.9 (10.0)	146.4 (3.0)	585.5 (12.0)	5. Low N/High K/+ Fe	244.0 (5.0)	146.4 (3.0)	585.5 (12.0)
2. High N/High K/– Fe	487.9 (10.0)	146.4 (3.0)	585.5 (12.0)	6. Low N/High K/– Fe	244.0 (5.0)	146.4 (3.0)	585.5 (12.0)
3. High N/Low K/+ Fe	487.9 (10.0)	146.4 (3.0)	195.2 (4.0)	7. Low N/Low K/+ Fe	244.0 (5.0)	146.4 (3.0)	195.2 (4.0)
4. High N/Low K/– Fe	487.9 (10.0)	146.4 (3.0)	195.2 (4.0)	8. Low N/Low K/– Fe	244.0 (5.0)	146.4 (3.0)	195.2 (4.0)

+ Fe = 6.1 kg·ha^{-1} (2 oz/1000 ft^2) $FeSO_4$ applied foliarly every 3 weeks.

Methods for Measurements

Measurements that were collected during the annual bluegrass putting green management study included: visual ratings; Minolta spectrophotometer readings; elemental analyses of clippings; clipping yield; irrigation water analyses; soil elemental analyses; shoot density, crown mass, and root mass density from plant cores; and on-site air and soil temperatures. The purpose of these measurements was to help adequately describe plant and soil status and plant and soil responses to treatments and other effects, such as temperatures and turfgrass management practices. An approximate schedule for routine measurement collection during the study is show in Table 4 while a brief description of the methods for the measurements is shown in Table 5.

Table 4. Approximate schedule for routine measurement collection during the annual bluegrass management study.

Date	Visual estimates of turfgrass quality and color	Minolta spectro-photometer readings	Clipping elemental analyses	Clipping yield	Irrigation water analyses	Soil elemental analyses	Plant morph-ological analyses
19 Jan.	*	*	*				
2 Mar.	*	*	*				
23 Mar.				*	*		
13 Apr.	*	*	*				
7 May						*	*
25 May	*	*	*				
6 July	*	*	*				
28 July				*	*		
17 Aug.	*	*	*				
10 Sept.						*	*
28 Sept.	*	*	*				
9 Nov.	*	*	*				
21 Dec.				*	*		

Note: Visual estimates of turfgrass plant stress (e.g. coverage of mottling/patchiness and leaf wilting and rolling), disease activity coverage, seedhead coverage, and scalping coverage were taken on an as-needed basis.

Methods for Measurements

Table 5. Brief description of the methods for the measurements taken during the annual bluegrass putting green management study.

1. Visual estimates of turfgrass putting green quality and color were taken every 6 weeks from subplots. Ratings were taken on a 1 to 9 scale, with 9=best quality putting green or darkest green color, 5=minimally acceptable quality or color, and 1=worst quality putting green or brown color. Starting 9 Feb. 2000, color ratings were normally taken every 3 weeks. Measurements were normally taken 13 to 14 d after fertilizer treatment applications.

2. Spectrophotometer readings were taken with a Minolta CM-525i using L*a*b* color space. Measurements were taken once every 6 weeks from main plots, three subsamples per main plot (one from each of the subplots and one between the two subplots). Starting 9 Feb. 2000, spectrophotometer readings were normally taken every 3 weeks. Measurements were normally taken 13 to 14 d after fertilizer treatment application.

3. Visual estimates of percent coverage of mottling/patchiness, leaf wilting and rolling, disease activity, seedheads, and scalping were taken from subplots on an as-needed basis. Mottling/patchiness coverage was an indicator of plant stress and characterized by areas of turfgrass with a lighter green visual leaf color, lower visual shoot density, and greater vertical leaf extension rate (data not shown).

4. Elemental analyses of clippings were collected from main plots once every 6 weeks. Analyses were conducted by laboratory methodology: total N, C, and S using the combustion gas analyzer method; total P, K, Ca, Mg, Na, Fe, Zn, Mn, Cu, B, Mo, Al, and Ti using the dry ashing, leachate, and inductively coupled Ar plasma (ICAP) emission spectrometry method (Table A-8). Samples were normally collected 13 to 14 d after fertilizer treatment applications.

5. Clipping yield of 1 d growth was collected from each main plot on 21 Dec. 1998; 23 Mar., 30 July, and 21 Dec. 1999; and 22 Mar. and 26 July 2000. Samples represented 66% of the total surface area of the main plots and were reported as g dry clippings/2.0 m^2 (22 ft^2) per day. Samples were collected 13 to 16 d after fertilizer treatment application.

6. Irrigation water samples were collected on the same dates as clipping yield. Frozen samples were sent to Division of Agriculture and Natural Resources (DANR) Analytical Laboratory and analyzed for pH, EC, Ca, Mg, Na, SAR, ESP, Cl, B, HCO_3, CO_3, SO_4-S, NH_4-N, NO_3-N, P, K-soluble, Cu, Fe, Mn, Se, and Zn. Irrigation water samples also were collected from May 2000 to Aug. 2001 and analyzed for ammonia N, organic N, nitrate N, and nitrite N at the laboratory of the San Jose Creek Water Reclamation Plant, East.

7. Analyses were made of the 1.3- to 8.9-cm (0.5- to 3.5-inch) root-zone soil for TKN; Olsen-P; exchangeable K; exchangeable Ca; exchangeable Mg; exchangeable Na; EC_e; SAR; and soluble Ca, Mg, and Na (pH and CEC were included in analyses for 2000). Samples included 14 to 20, 2-cm diameter cores taken with Oakfield tubes collected from each main plot over three of the four replications. A grid was used to ensure that no portion of the plot was sampled more than once for the duration of the study. Sample dates were 7 May and 10 Sept. 1999; and 5 May and 8 Sept. 2000 (16 d after fertilizer treatment applications). Samples were sent to the DANR Analytical Laboratory for analyses.

8. Analyses of shoot density, crown mass, and root mass density [1.3- to 8.9 cm (0.5- to 3.5-inch root zone)] were made from five 2-cm diameter cores taken with Oakfield tubes. Samples were collected from each subplot over three of the four replications. A grid was used to ensure that no portion of the subplot was sampled more than once for the duration of the study. Samples were collected on the same dates as soil analyses (16 d after fertilizer treatment applications). Samples analyzed at the UC Riverside Turfgrass Project laboratory facility.

9. On-site air and soil temperatures were taken hourly with Onset Stowaway XTI data microloggers and downloaded every 3 weeks. The air temperature sensor was located at a 1.83 m (6.0 ft) height within the canopy of a tree adjacent to the research plot, and was protected from the direct light of the sun with a lamp-shade-shaped metal shield. The soil temperature sensor was installed 5.1 cm (2.0 inches) below the soil surface of the research plot. These data were collected from 7 June 1998 to 23 Sept. 2000.

Methods for Plot Maintenance

The practice putting green was managed in a similar manner as the greens on the golf course. Table 6 shows the turf management practices.

Table 6. Plot maintenance protocol for the annual bluegrass management study from June 1998 to Sept. 2000.

1. Depending on the season of the year, mowed at a 3.30- to 4.75-mm (0.130- to 0.187-inch) height of cut, four or more times per week with a Jacobsen 56-cm (22-inch) walking greensmower or a Toro triplex mower (used on weekends, except prior to tournaments).
2. Cultivation in October with 1.59-cm (0.625-inch) hollow tines (cores removed) followed by topdressing with sand with a Turfco Metr-Matic at setting 4 (total sand applied = 1.25 hoppers of sand; total of 10 passes with topdresser). Plots also cultivated, according to protocol, with Toro HydroJect once every 4 weeks from June through Oct. 1998, once every 3 weeks from May through Oct. 1999, and once every 3 weeks from Apr. through Sept. 2000.
3. Verticut [1.59-mm (0.063-inch) bench setting] and topdressed June, July, September, November, December, February, March and April. In 1998, verticut on 16 June, 29 June, 27 July, 8 Sept., 19 Nov., and 11 Dec. (with groomers); in 1999 on 2 Feb., 2 Mar., 29 Mar., 9 Apr., 4 May, 10 May, 1 June, 22 June, and 31 Aug.; and in 2000 on 4 Jan., 3 Feb., 7 Mar., 10 Apr., 26 Apr., 8 May, 6 June, and 5 Sept.
4. Grooming as needed.
5. Light topdressing as needed. Applied Oct., Nov., Dec. 1998; Feb., Mar., May, July, Aug., Oct. 1999; and Jan., Feb., Mar., May, June, July, and Sept. 2000.
6. Insecticides and herbicides applied as needed (from June 1998 to Sept. 2000); fungicides applied to prevent moderate to severe disease activity. Applications were made to control cutworms (Dursban or Scimitar); to prevent anthracnose (Banner or a combination of Heritage and Daconil); to control cool-season brown patch (combination of Prostar and Banner); to prevent dollar spot (Heritage or Heritage in combination with Curalain or Fore); to control dollar spot (Chipco, Daconil, or Eagle); to control pink snow mold [Terraclor (PCNB)]; to prevent summer patch (Banner, Heritage, or Heritage in combination with Curalain, Daconil or Fore); and crabgrass preemergence (Betasan 4E).
7. Plots irrigated for optimum growth and playability.
8. Plots syringed and hand-watered to prevent drought symptoms, as needed.
9. Plots leached with 39 to 78 mm (1.5 to 3.0 inches) of water the last Sunday of each summer month, or as needed. Leaching occurred in June, July, Sept. 1998; Feb., June, July, Aug., Sept. 1999; and May 2000 (a natural leaching occurred in Apr. 2000 due to rainfall and leaching events scheduled for June and July 2000 were canceled due to high temperatures).