UNIVERSITY OF GEORGIA

ORGANIC MATTER DYNAMICS IN THE SURFACE ZONE OF A USGA GREEN: PRACTICES TO ALLEVIATE PROBLEMS

1996 Research Grant: $20,000
(First Year of Support)

Dr. Robert N. Carrow
Principal Investigator

It is the hypothesis of the author that two turfgrass grower problems arise by accumulation of organic matter in the surface 0 to 2 inch zone of a USGA green from 1.5 to 2.0% (by weight) at establishment to 8 to 12% after 2 years. Organic matter accumulation occurs even under excellent management and regardless of specification (i.e., it is not dependent on specifications). The two problems are:

I. Summer Bentgrass Decline in Response to Root Deterioration and Plugging of the Macropores that are Important for Soil O_2 and Infiltration of Water. A project was initiated in late spring to investigate the influence of treatments (summer cultivation, sand topdressing, sand substitutes, wetting agents) on maintaining infiltration, soil O_2 status, and root viability. Observations to date are:

   a) O_2 levels in the surface 1 inch can be below the acceptable minimum for 9 to 26 hours after irrigation. This indicates that O_2 stress may be a common occurrence as bentgrass roots deteriorate and the organic matter changes from live roots to dead material in the summer months.

   b) Cultivating with the Hydro-Ject in a raised position (nozzles 4 inches off the surface) created approximately 0.25 inch dia. holes that maintained acceptable infiltration rates for about 3 weeks. Wetting agent further enhanced infiltration.

II. Inhibition of Root Development (in Spring/Fall) from the Zone of High Organic Matter Content: A second project was initiated in winter 1996 to investigate the influence of selected cultivation procedures, that are non-disruptive, on root development. Wetting agent and sand substitute treatments were also included. The goal is to determine whether better root growth/depth can be achieved by increasing macropores in the surface 0 to 2 inch zone without conducting the traditional spring/fall core aeration operation. Rooting data are unavailable at this time but improvements in O_2 status and water infiltration have been noted from selected treatments.

Personnel devoted to and funded by this project include a full-time, soft-funded technician (50%) and part-time assistant (50%). Expenditures to date or set aside for the year are: salary and benefits ($16,000), operating ($1,041), travel ($200), and indirect costs ($2,759).

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It is the hypothesis of the author that two turfgrass grower problems arise from accumulation of organic matter in the surface 0 to 2 inch zone of a USGA green. Organic matter accumulation occurs even under excellent maintenance. The two problems are:

Problem 1. Within the southern zones of creeping bentgrass use, prolonged high temperature stress arises from the long, hot summers and high humidity of the Southeast. Previously "bentgrass summer decline" was reported to be due to root Phythium species. However, the sequence of injuries I believe is causing this problem is:

Bentgrass Summer Decline

Indirect High Temperature Stress
* **depletion of carbohydrates by an imbalance of PS and Res.**

↓

Root Growth and Viability Declines
* **massive root death may occur**

↓

1. **Death of Root Cells Result in Abundant Fresh Organic Matter**
2. **Thatch - Soil Interface Seals (low infiltration)**
3. **Zone of Low Soil O_2 forms and enhances the rate of root dieback and soon causes shoot injury.**
4. **Water and Nutrient Uptake Declines**
5. **Shoot Tissue Succulent and Less Wear Tolerant**
6. **Disease Organisms May Increase With Slow Plant Growth and Abundant O.M.**
7. **Soluble Salts May Increase in Surface**

Carbohydrates are produced in the photosynthesis (PS) process while respiration (Res.) is a major process that uses (depletes) carbohydrates. Essentially, carbohydrate depletion occurs under high temperatures where photosynthesis increases but at a slower rate than does respiration. When carbohydrates become limited the shoot tissues have priority over root cells; thereby, roots start to decline in health and dieback. Once root death starts, these roots lose their "structure", lyse, and become more gel-like; thereby, reducing infiltration and enhancing the potential for O_2 stress (especially under the high O_2 demand of summer). Unless infiltration is improved, soil O_2 stress rapidly causes further root decline. This example of surface organic matter dynamics;

* is primarily an issue of maintaining root viability in the summer months via maintenance of surface infiltration/soil O_2 status.

* occurs primarily in the southern region of bentgrass use, and especially where humidity is high; but may occur with unusually humid/hot weather patterns of northern locations (such as in 1995) and/or humid, low-air drainage greens.

* and, research has focused mainly on secondary aspects (i.e., root Pythiums) and not summer cultivation or topdressing as means of maintaining root viability.

Problem 2. Creeping bentgrass produces a very high root mass within the surface 2 or 3 inches that can fill much of the pore space (i.e., organic matter content within the 0 to 2-inch zone can be 10% on a weight basis compared to about 2% by weight for the initial rootzone mix). Thus, USGA golf green rootzone components are selected to have very high infiltration rates in the lab: once in the field and turf has formed a) infiltration rates decline to 25-40% of initial laboratory rates due to plugging of the surface pores by living (i.e., roots) and dead organic matter, and b) rooting depth invariability declines to less than observed with the first 1 or 2 years. This example of organic matter dynamics;

* is a problem primarily of how to enhance root development during the months when roots are developing (i.e. spring, fall).

* occurs across all regions where USGA greens are constructed

* this problem occurs every year

* and, research pertaining to enhancing root development has focused mainly on hollow-tine core aeration in early spring and early fall. The role of less injurious cultivation methods (Hydro-Ject, Quad-tine, etc.) have not been evaluated specific to this problem.

I. Problem 1 Project

CULTIVATION AND AMENDMENTS ON SUMMER BENTGRASS DECLINE AND ROOTING ON A USGA GREEN (T-109)

Objectives

To determine the effectiveness of summer cultivation practices and amendments on:

- rooting maintenance and viability in the summer
- shoot performance
- soil O_2 status
- water infiltration

The emphasis is on treatments to create macropore channels and/or enhance macroporosity.

Procedures

Table 1. Treatments.

Treat No.	Description	Dates
1.	No cultivation	None
2.[a]	Core Aerate, H.T., 5/8 dia. Apply 14,000 ml sand per plot after cultivation.	Mar 15 Oct 2
3.[b]	Hydro-Ject, Lowered = HJL	June 1 + every 3 weeks
4.[b]	Hydro-Ject, Raised = HJR	June 1 + every 3 weeks
5.	HJR + sand = HJR+S Sand topdressing at 1700 ml per 80 ft^2 plot. This is a 0.75 ft^3 per 1000 ft^2 rate.	Cultivation - see #3 Topdressing - May 15, Jun 10, Jul 10, Aug 10
6.	HJR + Greenschoice = HJR+G Greenschoice applied as topdressing at 1700 ml per 80 ft^2.	Cultivation - see #3 Topdressing - see #5
7.[c]	HJR + Wetting Agent = HJR+WA Wetting Agent is Naiad.	Cultivation - see #3 WA - May 15, Jun 10, Jul 1 & 22, Aug 15

Table 1. Cont'd

Treat No.	Description	Dates
8.[d]	HJR + Biostimulant = HJR+B Biostimulant is CytoGro.	Cultivation - see #3 B - Jun 10, Jul 5, Aug 5, Sep 5
9.	HJR + Sand + WA = HJR + S + WA	Cultivation - see #3 Sand - see #5 WA - see #7
10.	HJR + Sand + WA + B = HJR + S + WA + B	Cultivation - see #3 Sand - see #5 WA - see #7 B - see #8
11.	LandPride+Greenschoice Injection = LP+GI	Cultivation - see #3

[a] Core aerate at 2 x 2" spacing. Topdressing rate is about 6 ft^3 per 1000 ft^2.

[b] HJR = #2 setting, 3½ inch spacing, ¼" dia. hole.
HJL = #2 setting, 3 inch spacing, ⅛" dia. hole.

[c] Wetting Agent. Use Naiad at 3 oz per 1000 ft^2 with 2-wheel cart sprayer, 2 nozzles, 40" patterns, twice (2X) over plot area. Mix 108 ml Naiad plus 4350 ml water. Water in briefly to get off leaves.

[d] Biostimulant is CytoGro (.005% active ingredient of kinetin) applied at 1 fl. oz per 1000 ft^2. Use 2-wheel cart sprayer, 2 nozzles, 40" pattern, 2X over plot area. Mix 24 ml of CytoGro in 3000 ml water. Do not wash off leaves.

Treatments are applied to 8 x 10 ft plots in a randomized complete block with 4 blocks (reps).

Results.

Data obtained to date during the first year are:

a. Saturated hydraulic conductivity obtained in the field to determine water permeability through the surface zone. Desirable ranges in our climate are 150 to 300 mm hr^{-1}. See Table 2.

b. Oxygen diffusion and moisture content of the surface 0 to 3 cm zone at various times after irrigation. ODR values <0.20 $\mu gO_2 \cdot cm^{-2}\ min^{-1}$ are considered limiting. Table 3.

c. Visual quality (Table 6), shoot density (Table 7), and color (Table 8).

d. Canopy reflectance and associated data. (Tables 9-16). Reflectance in the 507 to 706 nm range is considered the photosynthetically active range (PAR) and the ideal is low reflectance (i.e., this equals high absorption). Physiological stress, disease, reduced photosynthetic pigments, or reduced leaf area index (LAI) increase 507 to 706 nm reflectance and tend to decrease 750 to 1100 nm (near infrared region) reflectance. Stress information often improves by looking at combinations of spectral ranges, such as:

- ND. Defined in tables.
- IR/R. Defined in tables.
- Others that will be calculated and evaluated for potential use such as the "red edge" and physiological reflectance index (PR).

Other data (root samples in June and August; surface organic matter content) have been taken but are not processed. From this initial year, some adjustments will be made in research protocol.

- ODR measurements: More probes per plot will be used to reduce the data variability; the time sequence will increase to cover a 30 to 40 hour period. Data variation precluded identifying treatment differences, the ODR values of <20 μg O_2 cm^{-2} min^{-1} indicated that O_2 is often limiting for a number of hours after irrigation or rainfall; a second set of probes at 10 cm will monitor ODR below the 0 to 3 cm zone; a rapid system for determining air permeability across the 0 to 3 cm zone will be explored; and, additional treatment(s) may be added for ODR evaluation.
- Canopy reflectance data and indices will be evaluated against shoot and root growth parameters to assess usefulness of each data set.

II. Problem 2 Project

CULTIVATION AND AMENDMENTS ON ROOT DEVELOPMENT OF BENTGRASS ON A USGA GREEN (T-108)

Objectives

To determine the effectiveness of selected fall/spring applied cultivation practices and amendments on enhancement of:

- bentgrass root development
- water infiltration (late spring, late fall)
- soil O_2 status (late spring, late fall)

Procedure

Treatments were selected to create macropore channels (cultivation) or to potentially increase macroporosity by amending the surface organic zone (0 to 50 mm).

Table 17. Treatments.

Treat No.	Description	Dates
1.	No cultivation	None
2.[a]	Core Aeration H.T., 5/8" diameter = CA (sand topdress at 14,000 ml per plot)	Mar 15 Sep 20
3.[b]	Hydro-Ject Raised = HJR	Mar 1 Sep 10-15 Apr 1 Oct 1 May 15 Nov 1 Dec 1
4.	Quad-Tine. Solid, ¼" dia. = QD	Cultivation dates - see #3
5.	Solid Tine. solid, ½" dia. = ST	Cultivation dates - see #3
6.	HJR plus Greenschoice = HJR+G Topdress (Greenschoice) rate is 1700 ml per plot or 0.75 ft^3 per 1000 ft^2.	Cultivation dates - see #3 Top dressing on: Feb 15 Sep 20 Mar 15 Oct 15 Apr 15 Nov 15
7.	QD plus Greenschoice = QD+G	Cultivation dates - see #3 Topdressing same as #6
8.	ST plus Greenschoice = ST+G	Cultivation dates - see #3 Topdressing same as #6
9.[b]	HJR plus wetting agent = HJR+WA (WA foliar applied)	Cultivation dates - see #3 WA same as topdressing on #6
10.[c]	HJR plus Greenschoice plus WA = HJR+G+WA	Cultivation dates - see #3 Topdressing same as #6 WA same as #6
11.	LandPride plus Greenschoice Injection = LP+GI LP at 1.5" spacing, large nozzle	Cultivation dates - see #3

[a] Core aeration at 2 x 2" spacing followed by topdressing with sand.

[b] HJR = #2 setting, 3½ " spacing, raised for ¼" hole (dia.)

[c] Wetting Agent. Use Naiad as a spray application at 3 ounces Naiad per 1000 ft^2. Use cart

sprayer, 2 nozzles at 40" coverage. For treatments 9 and 10, use 72 ml Naiad in 3000 ml water and go over each plot twice (2X). Water in briefly to get off of leaves.

Treatments are applied to 8 x 10 ft. plots in a randomized complete block with 4 blocks (reps).

Results.

Data obtained to date in this initial year are:

a. Saturated hydraulic conductivity. Table 17.

b. Visual quality (Table 18), shoot density (Table 19), and color (Table 20).

c. Canopy reflectance and associated data (Tables 21-27).

See the Results section of Study I for a general discussion of these aspects.

Additional data that have been taken but not processed are root samples and surface organic matter content.

Table 2. Saturated hydraulic conductivity at selected days after the previous cultivation operation (DAC) in summer 1996.

Treatment and Contrast ‡	Saturated Hydraulic Conductivity (SHC)					
	19 Jul 3 DAC	6 Aug 21 DAC	15 Aug 7 DAC	3 Sep 26 DAC	9 Sep 4 DAC	23 Sep 18 DAC
	mm hr^{-1}					
Control vs.	199	219	67	137	223	53
CA (29 Mar, 1 Oct)	299	93	116	116	223	64
HJL	190	222	192	764*	538	390*
HJR	448	190	470	775*	652*	457*
HJR + Sand§	838**	217	830**	1136**	622†	599**
HJR + Greenschoice§	488	160	776*	545†	883**	307†
HJR + WA§	791**	145	1024**	505	961**	737**
HJR + B§	636*	100	861**	413	868**	379*
HJR + Sand + WA§	658*	123	830**	821**	705*	385*
HJR + Sand + WA + B§	930**	108	343	446	608†	500**
LP + Greenschoice§	176	80	233	100	323	234
LSD (.05) =	322	197	579	506	427	256
F-test	**	.78	**	**	**	**
CV (%)	43	91	77	67	49	49

‡ Contrast versus Control based on LSD.

**, *, † Significant difference at P≤.01, .05, and .10.

§ Sand topdressing and Greenschoice applied 8 and 30 July. Wetting agent applied 9 and 29 July. Biostimulant applied 9 July and 9 August. Cultivation treatments were on 16 July and 8 August, except for CA on 29 March and 9 October.

Table 3. Oxygen diffusion (ODR), moisture content, and change (Δ) of these parameters over time in the surface 0 to 3 cm zone. Readings initiated 2 August 1996, 0830 hr.

Treatment	ODR 2.5 hrs	ODR 8 hrs	ΔODR
	$\mu g\ O_2\ cm^{-2}\ min^{-1}$		
Control	.14	.26	+ .12
CA (29 March)	.09	.19	+ .10
HJR	.10	.24	+ .14
HJR + WA	.13	.25	+ .12
LSD (.05)	.13	.18	.19
F-test	.79	.79	.97
CV (%)	69	50	100
	Moisture Content		Δ MC
	% (Vol.)		
Control	47.9	49.3	+ 1.4
CA (29 March)	52.1	50.1	- 2.0
HJR	50.3	49.8	- 0.5
HJR + WA	50.7	46.7	- 4.0†
LSD (.05)	5.1	6.9	4.5
F-test	.38	.67	†
CV (%)	6.4	8.8	20

**, *, † Significant difference at P≤.01, .05, and .10.

Table 4. Oxygen diffusion (ODR), moisture retention, and change (Δ) of these parameters over time in the surface 0 to 3 cm zone. Readings initiated 13 August 1996, 0830 hr.

	ODR			Δ ODR	
Treatment	2.5 hrs	8.5 hrs	26 hrs	Δ 8.5 hrs-2.5 hrs	Δ 26 hrs-2.5 hrs
	$\mu g\ O_2\ cm^{-2}\ min^{-1}$				
Control	.06	.11	.18	+ .05	+ .07
CA (29 March)	.09	.14	.19	+ .05	+ .05
HJR	.10	.11	.15	+ .01	+ .04
HJR + WA	.18	.18	.25	0	+ .07
LSD (.05)	.16	.16	.16	.13	.13
F-test	.37	.67	.59	.77	.69
CV (%)	89	75	53	347	101

	Moisture Content			Δ Moisture Control	
	% (Vol.)				
Control	51.0	47.8	48.4	- 3.2	- 2.6
CA (29 March)	50.6	47.8	47.4	- 2.8	- 3.2
HJR	49.7	46.5	48.5	- 3.2	- 1.2
HJR + WA	49.3	46.6	47.4	- 2.7	- 1.9
LSD (.05)	7.3	7.2	7.2	3.7	4.2
F-test	.94	.95	.96	.98	.73
CV (%)	9.1	9.4	9.3	78	118

**, *, † Significant difference at P≤.01, .05, and .10.

Table 5. Oxygen diffusion (ODR), moisture content, and change (Δ) of these parameters over time in the surface 0 to 3 cm zone. Readings initiated 4 September 1996, 0830 hr.

Treatment	ODR 2.5 hrs	ODR 9 hrs	ΔODR
	$\mu g\ O_2\ cm^{-2}\ min^{-1}$		
Control	.18	.19	+ .01
CA (29 March)	.12	.15	+ .03
HJR	.18	.19	+ .01
HJR + WA	.12	.16	+ .04
LSD (.05)	.15	.14	.07
F-test	.67	.90	.65
CV (%)	60	51	233

	Moisture Content		Δ MC
	% (Vol.)		
Control	50.3	51.0	+ 0.7
CA (29 March)	52.3	51.0	- 1.3
HJR	51.9	50.1	- 1.8
HJR + WA	52.3	49.3	- 3.0
LSD (.05)	4.6	5.7	4.7
F-test	.72	.88	.31
CV (%)	5.5	7.1	203

**, *, † Significant difference at $P \leq .01$, .05, and .10.

Table 6. Visual quality in 1996.

Treatment and Contrast ‡	Visual Quality							
	12 Jun	27 Jun	9 Jul	23 Jul	16 Aug	30 Aug	10 Sep	15 Oct
	—— 9.0 = ideal density, color, uniformity; 1.0 = no live turf ——							
Control vs.	7.7	8.0	7.5	7.4	7.2	7.3	7.4	7.4
CA	7.8	8.0	7.6	7.5	7.3	7.3	7.2	6.0**
HJL	7.9	8.0	7.7	7.5	7.3	7.5	7.5	7.6
HJR	7.8	7.9	7.7	7.6	7.6†	7.6	7.5	7.6
HJR + Sand	7.7	7.9	7.4	7.5	7.2	7.5	7.4	7.6
HJR + Greenschoice	7.7	7.9	7.6	7.5	7.3	7.5	7.5	7.2†
HJR + WA	7.8	7.8	7.5	7.6	7.2	7.5	7.5	7.5
HJR + B	7.7	7.9	7.8	7.6	7.4	7.5	7.5	7.4
HJR + Sand + WA	7.7	7.9	7.4	7.5	7.3	7.6	7.5	7.5
HJR + Sand + WA + B	7.8	8.0	7.6	7.4	7.3	7.5	7.5	7.4
LP + Greenschoice	7.6	7.6	7.1*	7.2	6.6*	6.7**	6.6**	6.9*
LSD (.05) =	.31	.29	.40	.26	.47	.40	.40	.33
F-test	.60	.34	†	.20	*	**	**	**
CV (%)	3	3	4	2	4	4	4	3

‡ Contrast versus Control based on LSD.

**, *, † Significant difference at P≤.01, .05, and .10.

Table 7. Shoot density in 1996.

Treatment and Contrast ‡	Shoot Density 12 Jun	27 Jun	9 Jul	23 Jul	16 Aug	30 Aug	10 Sep	15 Oct
	9.0 = ideal shoot density; 1.0 = no live turf							
Control vs.	7.7	8.1	7.5	7.5	7.5	7.4	7.4	7.5
CA	7.8	8.1	7.7	7.5	7.4	7.4	7.3	7.2*
HJL	8.0	8.1	7.9*	7.6	7.4	7.6	7.6†	7.7†
HJR	7.8	8.0	7.7	7.7	7.7	7.6	7.6†	7.7†
HJR + Sand	7.7	7.9	7.5	7.5	7.5	7.5	7.5	7.6
HJR + Greenschoice	7.7	7.9	7.7	7.6	7.5	7.6	7.6†	7.4
HJR + WA	7.8	7.9	7.7	7.6	7.5	7.6	7.6†	7.6
HJR + B	7.8	8.0	8.0*	7.6	7.6	7.6	7.5	7.6
HJR + Sand + WA	7.7	8.0	7.6	7.6	7.6	7.6	7.6†	7.6
HJR + Sand + WA + B	7.8	8.1	7.7	7.5	7.6	7.6	7.5	7.5
LP + Greenschoice	7.6	7.8	7.4	7.4	7.1*	7.0*	7.1*	7.4
LSD (.05) =	.29	.31	.35	.21	.33	.31	.28	.22
F-test	.54	.73	*	.54	*	**	**	**
CV (%)	3	3	3	2	3	3	3	2

‡ Contrast versus Control based on LSD.

**, *, † Significant difference at P≤.01, .05, and .10.

Table 8. Turfgrass color in 1996.

Treatment and Contrast ‡	Color							
	12 Jun	27 Jun	9 Jul	23 Jul	16 Aug	30 Aug	10 Sep	15 Oct
	9.0 = dark green; 1.0 = no green, all brown							
Control vs.	7.8	8.0	7.6	7.5	7.5	7.3	7.4	7.4
CA	7.8	8.1	7.9*	7.5	7.5	7.3	7.3	7.7
HJL	7.9	8.0	7.8†	7.5	7.4	7.6†	7.6	7.6
HJR	7.8	8.0	7.8†	7.6	7.7	7.6†	7.6	7.6
HJR + Sand	7.8	7.9	7.8†	7.6	7.4	7.5	7.6	7.6
HJR + Greenschoice	7.8	7.9	7.7	7.5	7.4	7.6†	7.6	7.5
HJR + WA	7.9	7.9	7.7	7.5	7.3	7.5	7.5	7.5
HJR + B	7.8	8.0	7.9*	7.6	7.5	7.6†	7.5	7.5
HJR + Sand + WA	7.7	7.9	7.7	7.6	7.4	7.6†	7.6	7.5
HJR + Sand + WA + B	7.9	8.1	7.8†	7.5	7.6	7.5	7.6	7.5
LP + Greenschoice	7.8	7.9	7.5	7.5	7.0	6.9*	7.1†	7.3
LSD (.05) =	.19	.22	.26	.19	.37	.37	.34	.29
F-test	.62	.43	†	.53	.20	*	†	.20
CV (%)	2	2	2	2	4	3	3	3

‡ Contrast versus Control based on LSD.

**, *, † Significant difference at P≤.01, .05, and .10.

Table 9. Canopy reflectance at 7 wave lengths, normalized vegetation index (ND), and IR/R ratio on 13 June 1996 (sun angle 11°; irradiance 850 Wm^{-2}).

Treatment and Contrast ‡	Reflectance 13 June 1996								
	507 nm	559 nm	661 nm	706 nm	760 nm	813 nm	935 nm	ND§	IR¶ R
	%							1 = best	
Control vs.	4.9	8.8	4.4	16.6	75.3	58.7	61.1	.87	13.9
CA	5.0	9.2†	4.3	17.2*	75.3	59.0	61.8	.87	14.4
HJL	4.8	8.9	4.0	16.8	75.6	59.4	61.5	.88	15.4†
HJR	5.0	9.1	4.3	17.0†	73.1	58.6	60.3	.87	14.0
HJR + Sand	4.8	8.6	4.1	16.1*	68.3*	53.9**	55.8**	.86	13.6
HJR + Greenschoice	4.7	8.4†	4.3	15.6*	64.1**	49.5**	50.4**	.84*	11.7*
HJR + WA	4.9	8.8	4.2	16.9	75.9	59.6	62.4	.87	14.9
HJR + B	4.8	8.8	4.2	16.7	75.4	58.9	60.8	.87	14.5
HJR + Sand + WA	4.8	8.9	4.1	16.5	69.1*	54.2*	55.1**	.86	13.4
HJR + Sand + WA + B	4.5*	8.4†	3.9	15.9*	68.8*	53.0**	54.9**	.87	14.1
LP + Greenschoice	5.0	9.0	4.3	16.7	72.0	57.0	58.1*	.86	13.5
LSD (.05) =	.28	.45	.36	.44	4.2	2.3	3.0	.02	1.6
F-test	*	*	.21	**	**	**	**	**	**
CV (%)	4	3	6	2	4	3	4	1	8

‡ Contrast versus Control based on LSD.

**, *, † Significant difference at P≤.01, .05, and .10.

§ ND = $R_{935} - R_{661} / R_{935} + R_{661}$, where R_{935} = reflectance at 935 nm (790 to 1080 nm) and R_{661} = reflectance at 661nn (648 to 674 nm). Often correlated with green biomass.

¶ IR/R = R_{935} / R_{661}. Often correlated with leaf area index (LAI).

Table 10. Canopy reflectance at 7 wave lengths, normalized vegetation index (ND), and IR/R ratio on 25 June 1996 (sun angle 50°; irradiance 570 Wm^{-2}).

Treatment and Contrast ‡	Reflectance 25 June 1996								
	507 nm	559 nm	661 nm	706 nm	760 nm	813 nm	935 nm	ND§	IR¶ R
	%							1 = best	
Control vs.	6.0	10.3	5.1	17.4	58.1	59.6	62.4	.85	12.2
CA	6.1	10.6	4.9	17.4	58.3	59.4	61.8	.85	12.6
HJL	6.6*	11.4*	5.4	18.4*	60.8	62.2†	64.5	.85	11.9
HJR	6.1	10.4	5.3	17.5	57.2	58.7	61.8	.84*	11.7
HJR + Sand	6.0	10.5	4.9	17.3	61.0	60.3	62.6	.85	12.8
HJR + Greenschoice	6.0	10.3	4.8	17.0	59.2	58.6	60.8	.85	12.7
HJR + WA	6.3	10.7	5.2	17.7	61.5†	60.9	63.3	.85	12.2
HJR + B	6.5*	11.0†	5.4	18.0	61.2†	60.8	63.5	.84*	11.8
HJR + Sand + WA	6.0	10.3	4.9	17.1	59.3	58.6	60.9	.85	12.4
HJR + Sand + WA + B	6.4†	10.9	5.2	17.7	60.8	60.1	62.5	.85	12.0
LP + Greenschoice	6.0	10.3	4.9	17.0	56.2	57.1†	59.5*	.85	12.1
LSD (.05) =	.46	.73	.52	.90	3.9	2.7	2.6	.01	1.3
F-test	†	†	.20	†	†	*	*	.70	.68
CV (%)	5	5	7	4	5	3	3	1	7

‡ Contrast versus Control based on LSD.

**, *, † Significant difference at P≤.01, .05, and .10.

§ $ND = R_{935} - R_{661} / R_{935} + R_{661}$, where R_{935} = reflectance at 935 nm (790 to 1080 nm) and R_{661} = reflectance at 661nn (648 to 674 nm). Often correlated with green biomass.

¶ $IR/R = R_{935} / R_{661}$. Often correlated with leaf area index (LAI).

Table 11. Canopy reflectance at 7 wave lengths, normalized vegetation index (ND), and IR/R ratio on 12 July 1996 (sun angle 39°; irradiance 770 Wm^{-2}).

Treatment and Contrast ‡	Reflectance 12 July 1996								
	507 nm	559 nm	661 nm	706 nm	760 nm	813 nm	935 nm	ND§	IR¶ R
	%							1 = best	
Control vs.	4.8	8.3	4.1	15.2	77.6	61.0	65.1	.88	15.9
CA	4.9	8.6	4.1	15.6	81.5	63.4*	67.3*	.89†	16.4
HJL	4.9	8.6	4.1	15.6	83.5	62.3	66.7†	.88	16.3
HJR	4.9	8.5	4.2	15.5	84.1	61.6	65.6	.88	15.6
HJR + Sand	4.8	8.4	4.2	15.2	78.8	57.1*	61.0**	.87†	14.5†
HJR + Greenschoice	4.9	8.4	4.1	14.9	74.0	54.5**	57.0**	.87†	13.9*
HJR + WA	4.9	8.5	4.2	15.5	82.2	62.2	66.6	.88	15.9
HJR + B	4.8	8.3	4.2	15.2	81.4	60.6	65.1	.88	15.5
HJR + Sand + WA	4.8	8.4	4.2	15.3	79.6	57.5*	60.9*	.87†	14.5†
HJR + Sand + WA + B	4.8	8.2	4.2	15.0	79.9	56.3*	60.1**	.87†	14.3*
LP + Greenschoice	4.9	8.4	4.3	15.4	80.4	60.3	64.3	.87†	15.0
LSD (.05) =	.30	.52	.45	.70	7.1	2.2	2.0	.01	1.6
F-test	.98	.89	.99	.45	.25	**	**	†	*
CV (%)	4	4	7	3	6	3	2	1	7

‡ Contrast versus Control based on LSD.

**, *, † Significant difference at P≤.01, .05, and .10.

§ ND = $R_{935} - R_{661} / R_{935} + R_{661}$, where R_{935} = reflectance at 935 nm (790 to 1080 nm) and R_{661} = reflectance at 661nn (648 to 674 nm). Often correlated with green biomass.

¶ IR/R = R_{935} / R_{661}. Often correlated with leaf area index (LAI).

Table 12. Canopy reflectance at 7 wave lengths, normalized vegetation index (ND), and IR/R ratio on 7 August 1996 (sun angle 20°; irradiance 1000 Wm^{-2}).

Treatment and Contrast ‡	Reflectance 7 August 1996								
	507 nm	559 nm	661 nm	706 nm	760 nm	813 nm	935 nm	ND§	IR¶ R
	%							1 = ideal	
Control vs.	6.4	11.1	5.7	18.9	82.1	54.0	55.1	.81	9.7
CA	6.3	11.2	5.5	18.9	70.1	55.8	56.6	.82	10.3
HJL	6.3	11.1	5.5	18.7	73.3	55.1	55.9	.82	10.2
HJR	6.1	10.8	5.3	18.3†	72.2	55.4	56.3	.83	10.6
HJR + Sand	6.2	10.8	5.3	18.2*	71.5	52.9	53.4	.82	10.1
HJR + Greenschoice	6.1	10.9	5.1	18.0*	71.2	53.7	53.2	.83	10.4
HJR + WA	6.1	10.9	5.2	18.5	73.4	56.5	57.0	.83	11.0
HJR + B	6.0	10.6	5.2	18.1*	71.4	54.5	55.1	.83	10.6
HJR + Sand + WA	6.1	10.9	5.3	18.3†	74.0	54.0	54.0	.82	10.2
HJR + Sand + WA + B	6.0	10.8	5.2	18.1*	73.3	53.7	53.9	.82	10.4
LP + Greenschoice	6.1	10.8	5.5	18.4	69.9	52.7	53.8	.81	9.8
LSD (.05) =	.30	.54	.48	.69	8.7	3.4	2.9	.02	1.3
F-test	.25	.55	.39	†	.35	.46	†	.80	.80
CV (%)	3	3	6	3	8	4	4	2	9

‡ Contrast versus Control based on LSD.

**, *, † Significant difference at P≤.01, .05, and .10.

§ ND = $R_{935} - R_{661} / R_{935} + R_{661}$, where R_{935} = reflectance at 935 nm (790 to 1080 nm) and R_{661} = reflectance at 661nn (648 to 674 nm). Often correlated with green biomass.

¶ IR/R = R_{935} / R_{661}. Often correlated with leaf area index (LAI).

Table 13. Canopy reflectance at 7 wave lengths, normalized vegetation index (ND), and IR/R ratio on 30 August 1996 (sun angle 32°; irradiance 495 Wm^{-2}).

Treatment and Contrast ‡	Reflectance 30 August 1996								
	507 nm	559 nm	661 nm	706 nm	760 nm	813 nm	935 nm	ND§	IR¶ R
	%							1 = ideal	
Control vs.	5.9	9.6	5.2	17.5	27.4	51.1	56.7	.83	10.9
CA	6.0	9.8	5.1	17.8	28.7	52.9	58.3	.84	11.4
HJL	5.8	9.6	4.9	17.3	28.8	53.5	59.0	.85	12.0
HJR	5.6	9.4	5.0	17.1	27.8	51.7	57.3	.84	11.5
HJR + Sand	5.9	9.5	5.1	17.3	28.4	52.0	57.8	.84	11.3
HJR + Greenschoice	5.5	9.2	4.7	16.8	28.6	53.0	58.5	.85	12.4
HJR + WA	5.9	9.6	5.1	17.4	29.7	53.2	58.6	.84	11.5
HJR + B	5.7	9.3	4.9	17.1	30.8	53.2	58.7	.85	12.0
HJR + Sand + WA	5.8	9.5	5.0	17.3	30.0	52.7	58.4	.84	11.7
HJR + Sand + WA + B	5.8	9.3	4.8	17.0	30.1	53.3	58.6	.85	12.2
LP + Greenschoice	6.0	9.7	5.3	17.7	27.9	52.0	57.6	.83	10.9
LSD (.05) =	.35	.53	.46	.68	2.6	2.3	2.0	.02	1.3
F-test	.19	.30	.36	.21	.16	.55	.44	.44	.38
CV (%)	4	4	6	3	6	3	2	2	8

‡ Contrast versus Control based on LSD.

**, *, † Significant difference at P≤.01, .05, and .10.

§ ND = $R_{935} - R_{661} / R_{935} + R_{661}$, where R_{935} = reflectance at 935 nm (790 to 1080 nm) and R_{661} = reflectance at 661nn (648 to 674 nm). Often correlated with green biomass.

¶ IR/R = R_{935} / R_{661}. Often correlated with leaf area index (LAI).

Table 14. Canopy reflectance at 7 wave lengths, normalized vegetation index (ND), and IR/R ratio on 11 September 1996 (sun angle 29°; irradiance 570 Wm^{-2}).

Treatment and Contrast ‡	Reflectance 11 September 1996								
	507 nm	559 nm	661 nm	706 nm	760 nm	813 nm	935 nm	ND§	IR¶ R
	%							1 = ideal	
Control vs.	8.1	14.3	7.1	24.1	59.5	72.1	76.8	.83	10.8
CA	8.3	14.8	7.2	25.0	60.9	74.0	79.1	.83	11.0
HJL	8.0	14.3	6.7†	24.3	63.1**	77.5**	82.5**	.85**	12.3*
HJR	8.1	14.3	7.1	24.4	61.1	73.1	78.0	.83	11.0
HJR + Sand	7.9	14.0	6.9	23.9	60.4	74.1	79.3	.84*	11.5
HJR + Greenschoice	7.9	14.1	6.7†	24.0	62.3*	76.1*	81.4*	.85**	12.1*
HJR + WA	8.2	14.4	6.9	24.5	61.6*	75.6*	80.9*	.84*	11.7†
HJR + B	7.7	13.7	6.6*	23.7	61.0	74.9†	80.3*	.85**	12.2*
HJR + Sand + WA	8.1	14.3	7.0	24.5	62.2*	74.4	79.6†	.84*	11.4
HJR + Sand + WA + B	7.8	14.0	6.7†	24.1	62.7*	76.5*	81.2*	.85*	12.1*
LP + Greenschoice	8.3	14.5	7.6	24.4	56.6*	67.6*	71.8**	.81**	9.4*
LSD (.05) =	.45	.72	.45	.94	2.1	3.2	3.4	.01	1.1
F-test	.14	.23	**	.38	**	**	**	**	**
CV (%)	4	3	4	3	2	3	3	1	6

‡ Contrast versus Control based on LSD.

**, *, † Significant difference at P≤.01, .05, and .10.

§ ND = $R_{935} - R_{661} / R_{935} + R_{661}$, where R_{935} = reflectance at 935 nm (790 to 1080 nm) and R_{661} = reflectance at 661nn (648 to 674 nm). Often correlated with green biomass.

¶ IR/R = R_{935} / R_{661}. Often correlated with leaf area index (LAI).

Table 15. Canopy reflectance at 7 wave lengths, normalized vegetation index (ND), and IR/R ratio on 18 September 1996 (sun angle 47°; irradiance 670 Wm^{-2}).

Treatment and Contrast ‡	Reflectance 18 September 1996								
	507 nm	559 nm	661 nm	706 nm	760 nm	813 nm	935 nm	ND§	IR¶ R
	%							1 = best	> = best
Control vs.	7.2	13.2	6.5	23.5	60.6	70.8	72.7	.84	11.3
CA	7.6	14.0	6.6	24.3	62.0	72.2	73.7	.84	11.2
HJL	7.4	13.6	6.2	23.7	64.5**	74.9**	76.4**	.85	12.3
HJR	7.1	13.0	6.2	23.1	62.1	72.4	73.7	.85	12.1
HJR + Sand	7.4	13.5	6.6	23.8	62.3†	72.7†	74.6†	.84	11.4
HJR + Greenschoice	7.3	13.3	6.3	23.4	63.3*	73.8*	75.3*	.85	12.0
HJR + WA	7.2	13.4	6.3	23.7	62.8*	73.2*	74.5†	.84	11.8
HJR + B	7.3	13.5	6.4	23.7	63.4*	73.8*	75.3*	.84	11.7
HJR + Sand + WA	7.2	13.4	6.3	23.5	62.5†	72.7†	74.1	.84	11.7
HJR + Sand + WA + B	7.2	13.4	6.3	23.6	63.2*	73.5*	75.2*	.84	11.9
LP + Greenschoice	7.1	13.0	6.4	23.0	59.7	69.5	71.1	.84	11.3
LSD (.05) =	.55	.96	.64	1.1	2.0	2.4	2.2	.02	1.4
F-test	.86	.72	.95	.67	**	**	**	.77	.74
CV (%)	5	5	7	3	2	2	2	1	8

‡ Contrast versus Control based on LSD.

**, *, † Significant difference at P≤.01, .05, and .10.

§ ND = $R_{935} - R_{661} / R_{935} + R_{661}$, where R_{935} = reflectance at 935 nm (790 to 1080 nm) and R_{661} = reflectance at 661nn (648 to 674 nm). Often correlated with green biomass.

¶ IR/R = R_{935} / R_{661}. Often correlated with leaf area index (LAI).

Table 16. Canopy reflectance at 7 wave lengths, normalized vegetation index (ND), and IR/R ratio on 8 October 1996 (sun angle 45°; irradiance 630 Wm^{-2}).

Treatment and Contrast ‡	Reflectance 8 October 1996								
	507 nm	559 nm	661 nm	706 nm	760 nm	813 nm	935 nm	ND§	IR¶ R
	%							1 = best	> = best
Control vs.	6.2	11.3	5.5	20.5	53.6	72.1	70.4	.85	12.8
CA	6.5	9.6**	7.9**	15.3**	26.1**	74.0	35.0**	.63**	4.4**
HJL	6.2	11.4	5.4	20.7	56.2	77.5*	73.3	.86	13.9
HJR	6.6	11.8†	5.8	21.3†	55.5	73.1	72.6	.85	12.7
HJR + Sand	6.1	10.9	5.3	20.0	53.1	74.1	69.7	.86	13.2
HJR + Greenschoice	6.2	11.4	5.5	20.6	54.9	76.1†	72.8	.86	13.2
HJR + WA	6.3	11.4	5.8	20.5	52.3	75.6	69.1	.84	12.2
HJR + B	5.9	11.1	5.3	20.4	55.5	75.0	72.8	.86	13.9
HJR + Sand + WA	6.2	11.2	5.5	20.5	54.9	74.4	72.4	.86	13.2
HJR + Sand + WA + B	6.4	11.3	5.7	20.8	54.7	76.5†	72.4	.85	12.9
LP + Greenschoice	6.2	11.4	5.6	20.7	54.7	67.6*	71.1	.85	12.8
LSD (.05) =	.54	.62	.67	.87	3.9	4.5	4.1	.03	1.9
F-test	.43	**	**	**	**	**	**	**	**
CV (%)	6	4	8	3	5	5	4	2	11

‡ Contrast versus Control based on LSD.

**, *, † Significant difference at P≤.01, .05, and .10.

§ $ND = R_{935} - R_{661} / R_{935} + R_{661}$, where R_{935} = reflectance at 935 nm (790 to 1080 nm) and R_{661} = reflectance at 661nn (648 to 674 nm). Often correlated with green biomass.

¶ $IR/R = R_{935} / R_{661}$. Often correlated with leaf area index (LAI).

Table 17. Saturated hydraulic conductivity (SHC) in 1996.

Treatment and Contrast	SHC 16 May (3 DAC)	SHC 6 Jun (24 DAC)	SHC 21 Oct (13 DAC)
	mm hr^{-1}		
Control vs.	120	125	83
CA (22 Mar, 19 Sep)	102	223	87
HJR	684**	588**	444**
QT	186	94	202
ST	392	432†	56
HJR + Greenschoice (G)	423†	333	207
QT + Greenschoice	83	90	138
ST + Greenschoice	503*	106	255*
HJR + Wet Agent (WA)	561*	528*	198
HJR + G + WA	680**	437†	221†
LP + G	–	–	82
LSD (.05) =	380	340	160
F-test =	**	*	**
CV (%) =	70	79	62

**, *, † Significant difference at P ≤.01, .05, and .10. Contrast is versus Control (no cultivation) by LSD.

Table 18. Bentgrass visual quality in 1996.

Treatment and Contrast	Visual Quality 9 May	30 May	12 Jun	26 Jun	23 Jul	30 Aug	3 Oct
	9 = ideal density, color, uniformity; 1 = no live turf						
Control vs.	7.7	7.9	7.7	7.8	7.5	7.4	7.5
CA (22 Mar, 19 Sep)	7.8	7.8	7.6	7.6	7.6	7.5	7.3
HJR	7.8	7.8	7.9	7.5†	7.7†	7.5	7.4
QT	7.8	7.9	7.8	7.6	7.8	7.6	7.5
ST	7.3*	7.3**	7.2*	6.8**	7.6	7.3	6.5**
HJR + Greenschoice (G)	7.5	7.7	7.8	7.8	7.5	7.6	7.5
QT + Greenschoice	7.7	7.9	7.8	7.6	7.7†	7.6	7.4
ST + Greenschoice	7.3*	7.4**	7.6	7.3*	7.6	7.4	6.6**
HJR + Wet Agent (WA)	7.6	8.0	7.7	7.7	7.6	7.6	7.4
HJR + G + WA	7.8	8.0	7.7	7.5†	7.8*	7.6	7.5
LP + G	–	–	7.7	7.7	7.6	7.5	7.2†
LSD (.05) =	.29	.28	.38	.31	.29	.21	.38
F-test =	**	**	*	**	.52	.17	**
CV (%) =	3	2	3	3	3	2	4

**, *, † Significant difference at P ≤.01, .05, and .10. Contrast is versus Control (no cultivation) by LSD.

Table 19. Bentgrass shoot density in 1996.

Treatment and Contrast	Shoot Density						
	9 May	30 May	12 Jun	26 Jun	23 Jul	30 Aug	3 Oct
	9 = ideal density; 1 = no live turf						
Control vs.	7.9	8.1	7.8	7.9	7.6	7.4	7.5
CA (22 Mar, 19 Sep)	7.9	7.9	7.7	7.7	7.6	7.5	7.6
HJR	7.9	8.0	8.0	7.6†	7.8	7.6	7.4
QT	7.9	8.0	7.9	7.6†	7.8	7.6	7.5
ST	7.4*	7.5**	7.3*	7.1**	7.6	7.5	7.3
HJR + Greenschoice (G)	7.6†	7.8†	7.8	7.8	7.5	7.6	7.5
QT + Greenschoice	7.8	8.0	7.8	7.7	7.7	7.7†	7.5
ST + Greenschoice	7.5*	7.7*	7.6	7.4*	7.7	7.5	7.3
HJR + Wet Agent (WA)	7.8	8.1	7.8	7.9	7.6	7.6	7.4
HJR + G + WA	7.9	8.1	7.7	7.7	7.8	7.7*	7.5
LP + G	–	–	7.7	7.9	7.6	7.6	7.3
LSD (.05) =	.35	.32	.40	.35	.31	.19	.26
F-test =	*	**	.14	**	.50	.18	.21
CV (%) =	3	3	4	3	3	2	2

**, *, † Significant difference at P ≤.01, .05, and .10. Contrast is versus Control (no cultivation) by LSD.

Table 20. Bentgrass color in 1996.

Treatment and Contrast	Color						
	9 May	30 May	12 Jun	26 Jun	23 Jul	30 Aug	3 Oct
	9 = dark green; 1 = no green, all brown						
Control vs.	7.8	7.9	7.8	7.8	7.6	7.4	7.6
CA (22 Mar, 19 Sep)	7.9	7.9	7.7	7.6†	7.7	7.5	7.6
HJR	7.8	7.9	7.9	7.6†	7.7	7.6	7.5
QT	7.9	7.9	7.8	7.6†	7.8	7.6	7.5
ST	7.4**	7.5*	7.5*	7.3**	7.6	7.5	7.2*
HJR + Greenschoice (G)	7.7	7.8	7.8	7.7	7.6	7.6	7.5
QT + Greenschoice	7.8	7.9	7.8	7.7	7.6	7.5	7.5
ST + Greenschoice	7.5*	7.7†	7.8	7.5*	7.7	7.5	7.3†
HJR + Wet Agent (WA)	7.7	8.0	7.8	7.7	7.7	7.6	7.5
HJR + G + WA	7.8	8.0	7.7	7.6†	7.8	7.6	7.5
LP + G	–	–	7.7	7.7	7.5	7.6	7.3†
LSD (.05) =	.21	.21	.25	.21	.25	.24	.30
F-test =	**	**	†	**	.52	.69	†
CV (%) =	2	2	2	2	2	2	3

**, *, † Significant difference at P ≤.01, .05, and .10. Contrast is versus Control (no cultivation) by LSD.

Table 21. Canopy reflectance, normalized vegetative index (ND), and IR/R ratio on 31 May 1996 (sun angle 28°; irradiance 945 Wm^{-2}).

Treatment and Contrast ‡	Reflectance (31 May 1996) 507 nm	559 nm	661 nm	706 nm	760 nm	813 nm	935 nm	ND§	IR¶ R
	%							1 = best	> = best
Control vs.	4.8	8.4	4.1	16.0	51.4	60.8	65.9	.88	16.1
CA	4.8	8.4	4.1	16.1	60.3	61.7	66.6	.88	16.2
HJR	4.7	8.2	4.1	15.9	50.6	60.5	65.5	.88	16.0
QT	4.7	8.4	4.1	16.2	57.8	60.3	65.1	.88	15.9
ST	4.8	8.5	4.5	16.3	57.1	59.8	65.1	.87	14.5
HJR + Greenschoice (G)	4.8	8.4	4.2	16.0	49.2	60.5	65.5	.88	15.6
QT + Greenschoice	4.6	8.1	4.1	15.7	57.8	60.6	65.5	.88	16.0
ST + Greenschoice	4.9	8.6	4.5	16.3	56.2	58.9	64.1	.87	14.2†
HJR + Wet Agent (WA)	4.6	8.1	4.0	15.8	50.3	61.3	66.3	.89	16.6
HJR + G + WA	4.8	8.4	4.1	16.1	59.5	61.8	66.6	.88	16.2
LP + G	6.1**	9.1	10.1**	17.8	46.5	42.9**	48.8**	.66**	4.8**
LSD (.05) =	.63	.71	2.3	1.6	13.0	5.6	5.8	.093	2.3
F-test	**	.44	**	.42	.39	**	**	**	**
CV (%)	9	6	33	7	17	7	6	7	11

**, *, † Significant difference at P≤.01, .05, and .10. Contrast is versus Control (no cultivation) by LSD.

§ $ND = R_{935} - R_{661} / R_{935} + R_{661}$, where R_{935} = reflectance at 935 nm (790 to 1080 nm) and R_{661} = reflectance at 661nn (648 to 674 nm). Often correlated with green biomass.

¶ $IR/R = R_{935} / R_{661}$. Often correlated with leaf area index (LAI).

Table 22. Canopy reflectance, normalized vegetative index (ND), and IR/R ratio on 14 June 1996 (sun angle 31°; irradiance 480 Wm^{-2}).

Treatment and Contrast ‡	Reflectance (14 June 1996) 507 nm	559 nm	661 nm	706 nm	760 nm	813 nm	935 nm	ND§	IR¶ R
	%							1 = best	> = best
Control vs.	4.9	8.6	4.0	16.3	66.9	58.7	63.4	.88	15.9
CA	4.9	8.8	4.2*	16.5	67.2	59.3	64.4†	.88	15.3
HJR	4.9	8.7	4.2*	16.5	67.9†	59.9*	64.8*	.88	15.4
QT	4.8	8.6	4.1	16.3	66.1	58.1	62.9	.88	15.3
ST	4.8	8.5	4.1	16.1	65.8†	57.9	63.2	.88	15.4
HJR + Greenschoice (G)	4.9	8.5	4.1	16.2	67.0	58.8	63.6	.88	15.5
QT + Greenschoice	4.8	8.4	4.0	16.1	66.6	58.5	63.4	.88	15.9
ST + Greenschoice	4.8	8.6	4.1	16.3	66.2	58.2	63.3	.88	15.4
HJR + Wet Agent (WA)	4.7	8.3	3.9	16.0	68.3*	60.3*	64.9*	.89*	16.6†
HJR + G + WA	4.8	8.6	4.0	16.2	66.8	58.9	63.6	.88	15.9
LP + G	4.7	8.2	3.9	15.6*	64.7**	56.7**	61.3**	.88	15.7
LSD (.05) =	.17	.39	.19	.54	1.3	1.2	1.2	.006	.78
F-test	.18	.16	†	†	**	**	**	.13	†
CV (%)	2	3	3	2	1	1	1	1	3

**, *, † Significant difference at P≤.01, .05, and .10. Contrast is versus Control (no cultivation) by LSD.

§ $ND = R_{935} - R_{661} / R_{935} + R_{661}$, where R_{935} = reflectance at 935 nm (790 to 1080 nm) and R_{661} = reflectance at 661nn (648 to 674 nm). Often correlated with green biomass.

¶ $IR/R = R_{935} / R_{661}$. Often correlated with leaf area index (LAI).

Table 23. Canopy reflectance, normalized vegetative index (ND), and IR/R ratio on 25 June 1996 (sun angle 38°; irradiance 750 Wm^{-2}).

Treatment and Contrast ‡	Reflectance (24 June 1996) 507 nm	559 nm	661 nm	706 nm	760 nm	813 nm	935 nm	ND§	IR¶ R
	%							1 = best	>= best
Control vs.	5.1	9.0	4.0	15.6	59.2	58.1	60.3	.88	15.1
CA	5.1	9.1	4.1	15.8	58.8	57.4	60.9	.87	14.9
HJR	5.0	8.9	4.0	15.4	59.2	57.5	60.8	.88	15.2
QT	5.2	9.3	4.2	15.9	59.8	57.9	60.0	.87	14.3
ST	5.1	9.1	4.2	15.8	58.9	57.7	60.5	.87	14.4
HJR + Greenschoice (G)	5.1	9.1	4.2	16.1	61.7	60.3	62.9	.87	15.0
QT + Greenschoice	5.0	9.0	4.0	15.7	60.4	58.1	60.3	.88	15.1
ST + Greenschoice	5.1	9.1	4.0	15.7	60.7	59.3	61.5	.88	15.4
HJR + Wet Agent (WA)	5.0	8.9	4.1	15.6	60.7	58.5	61.4	.87	15.0
HJR + G + WA	5.2	9.1	4.2	15.8	60.7	58.5	61.2	.87	14.6
LP + G	4.6	8.4	3.8	15.0	59.2	56.8	59.0	.88	15.5
LSD (.05) =	.44	.68	.48	.93	3.8	3.1	3.3	.015	1.93
F-test	.36	.47	.88	.60	.86	.64	.65	.98	.98
CV (%)	6	5	8	4	4	4	4	1	9

**, *, † Significant difference at P≤.01, .05, and .10. Contrast is versus Control (no cultivation) by LSD.

§ ND = $R_{935} - R_{661} / R_{935} + R_{661}$, where R_{935} = reflectance at 935 nm (790 to 1080 nm) and R_{661} = reflectance at 661nn (648 to 674 nm). Often correlated with green biomass.

¶ IR/R = R_{935} / R_{661}. Often correlated with leaf area index (LAI).

Table 24. Canopy reflectance, normalized vegetative index (ND), and IR/R ratio on 14 July 1996 (sun angle 34°; irradiance 860 Wm^{-2}).

Treatment and Contrast ‡	Reflectance (14 July 1996) 507 nm	559 nm	661 nm	706 nm	760 nm	813 nm	935 nm	ND§	IR¶ R
	%							1 = best	> = best
Control vs.	4.9	9.0	3.9	15.6	78.1	60.5	64.4	.89	16.5
CA	4.9	8.9	4.0	15.6	73.2	60.7	64.8	.88	16.2
HJR	5.3	9.1	7.0	17.3	64.8	57.3	62.9	.80	9.0
QT	5.2	9.1	5.3	16.6	75.5	58.4	63.2	.85	11.9
ST	4.6	8.5	3.7	15.0	74.0	60.6	64.6	.89	17.5
HJR + Greenschoice (G)	4.7	8.6	4.0	15.3	75.3	60.8	65.0	.88	16.3
QT + Greenschoice	4.7	8.7	3.8	15.3	79.8	61.3	64.9	.89	17.1
ST + Greenschoice	4.6	8.4	3.8	15.0	75.3	60.6	64.9	.89	17.1
HJR + Wet Agent (WA)	5.2	8.9	7.0	16.9	68.3	56.3	61.8	.80	8.8
HJR + G + WA	4.5	8.3	3.6	14.8	80.5	61.5	65.5	.90	18.2
LP + G	4.8	8.7	3.9	15.4	72.0	61.8	65.9	.89	16.9
LSD (.05) =	.82	.72	4.26	2.6	11.9	7.9	5.9	.13	5.5
F-test	.60	.31	.66	.53	.28	.91	.95	.68	.81
CV (%)	12	6	65	11	11	9	6	10	24

**, *, † Significant difference at P≤.01, .05, and .10. Contrast is versus Control (no cultivation) by LSD.

§ ND = $R_{935} - R_{661} / R_{935} + R_{661}$, where R_{935} = reflectance at 935 nm (790 to 1080 nm) and R_{661} = reflectance at 661nn (648 to 674 nm). Often correlated with green biomass.

¶ IR/R = R_{935} / R_{661}. Often correlated with leaf area index (LAI).

Table 25. Canopy reflectance, normalized vegetative index (ND), and IR/R ratio on 12 August 1996 (sun angle 18°; irradiance 640 Wm^{-2}).

Treatment and Contrast ‡	Reflectance (12 August 1996) 507 nm	559 nm	661 nm	706 nm	760 nm	813 nm	935 nm	ND§	IR¶ R
	%							1 = best	> = best
Control vs.	6.0	10.8	5.0	18.0	75.6	57.3	59.7	.85	12.2
CA	6.3	11.2	5.2	18.3	74.4	57.8	59.7	.84	11.6
HJR	6.0	10.8	5.0	18.0	77.5	58.8	60.0	.85	12.2
QT	6.2	11.1	5.2	18.4	75.4	58.1	60.3	.84	11.8
ST	6.2	10.9	5.1	18.0	74.8	58.0	59.4	.84	11.7
HJR + Greenschoice (G)	6.1	10.9	4.9	18.0	74.9	58.4	59.4	.85	12.0
QT + Greenschoice	6.3	11.2	5.2	18.5	76.5	58.4	60.1	.84	11.7
ST + Greenschoice	6.3	11.2	5.1	18.3	76.9	59.0	60.1	.84	11.8
HJR + Wet Agent (WA)	6.1	10.8	5.0	18.0	74.1	58.2	59.4	.85	12.0
HJR + G + WA	6.1	10.9	5.0	18.1	79.3	59.0	60.7	.85	12.4
LP + G	6.0	10.7	4.9	17.4	73.4	56.7	58.7	.85	12.1
LSD (.05) =	.48	.81	.49	.96	5.5	2.5	2.4	.016	1.31
F-test	.93	.93	.89	.71	.62	.76	.89	.97	.97
CV (%)	5	5	7	4	5	3	3	1	8

**, *, † Significant difference at P≤.01, .05, and .10. Contrast is versus Control (no cultivation) by LSD.

§ ND = $R_{935} - R_{661} / R_{935} + R_{661}$, where R_{935} = reflectance at 935 nm (790 to 1080 nm) and R_{661} = reflectance at 661nn (648 to 674 nm). Often correlated with green biomass.

¶ IR/R = R_{935} / R_{661}. Often correlated with leaf area index (LAI).

Table 26. Canopy reflectance, normalized vegetative index (ND), and IR/R ratio on 13 September 1996 (sun angle 38°; irradiance 680 Wm^{-2}).

Treatment and Contrast ‡	Reflectance (13 September 1996) 507 nm	559 nm	661 nm	706 nm	760 nm	813 nm	935 nm	ND§	IR¶ R
	%							1 = best	>= best
Control vs.	7.6	13.6	6.9	24.8	61.7	72.8	75.5	.83	11.0
CA	7.9	14.0	7.1	25.1	62.3	73.5	76.2	.83	10.8
HJR	7.2	12.9	6.4	23.9	63.5	74.5	77.3	.85	12.2
QT	7.6	13.7	6.9	24.7	63.0	74.2	76.7	.83	11.3
ST	7.4	13.4	6.7	24.2	63.0	74.4	76.9	.84	11.6
HJR + Greenschoice (G)	7.4	13.4	6.7	24.5	63.0	74.2	77.1	.84	11.5
QT + Greenschoice	7.7	13.8	6.9	25.0	63.9	75.0	77.4	.84	11.4
ST + Greenschoice	7.7	14.0	7.0	25.0	63.4	74.7	77.3	.83	11.1
HJR + Wet Agent (WA)	7.4	13.2	6.5	24.1	63.5	74.4	77.4	.84	11.9
HJR + G + WA	7.7	13.9	7.0	25.1	63.4	74.5	77.3	.83	11.1
LP + G	7.5	13.6	6.8	24.8	64.8	75.6	78.6	.84	11.7
LSD (.05) =	.57	.92	.69	1.3	3.2	3.3	2.9	.019	1.49
F-test	.46	.43	.66	.52	.86	.93	.77	.72	.76
CV (%)	5	5	7	4	4	3	3	2	9

**, *, † Significant difference at P≤.01, .05, and .10. Contrast is versus Control (no cultivation) by LSD.

§ ND = $R_{935} - R_{661} / R_{935} + R_{661}$, where R_{935} = reflectance at 935 nm (790 to 1080 nm) and R_{661} = reflectance at 661nn (648 to 674 nm). Often correlated with green biomass.

¶ IR/R = R_{935} / R_{661}. Often correlated with leaf area index (LAI).

Table 27. Canopy reflectance, normalized vegetative index (ND), and IR/R ratio on 14 October 1996 (sun angle 54°; irradiance 590 Wm^{-2}).

Treatment and Contrast ‡	Reflectance (14 October 1996) 507 nm	559 nm	661 nm	706 nm	760 nm	813 nm	935 nm	ND§	IR¶ R
	%							1 = best	> = best
Control vs.	6.7	12.3	6.1	23.1	59.6	71.4	76.4	.85	12.7
CA	7.1	13.0	6.7	23.6	56.1	66.7†	71.6†	.83	10.8*
HJR	7.0	12.7	6.5	23.6	59.7	71.7	77.0	.85	12.1
QT	7.9	14.1	7.4	25.6*	61.5	73.7	79.0	.83	10.6*
ST	7.3	13.3	6.9	24.5	59.8	72.0	77.8	.84	11.4
HJR + Greenschoice (G)	6.5	11.8	5.9	21.3†	50.6**	59.8**	61.9**	.82*	10.5*
QT + Greenschoice	7.1	12.8	6.7	22.9	52.6**	62.7*	65.9**	.81*	9.9**
ST + Greenschoice	7.3	13.1	6.9	23.2	53.1**	62.6*	65.4**	.81*	9.6**
HJR + Wet Agent (WA)	6.9	12.6	6.3	23.6	59.5	71.2	75.1	.85	12.0
HJR + G + WA	7.5	13.0	6.9	23.1	51.9**	60.8**	63.6**	.80**	9.3**
LP + G	6.2	11.5	5.7	21.3†	53.1**	63.1*	66.1**	.84	11.7
LSD (.05) =	1.08	1.69	1.20	2.4	4.6	5.6	6.0	.027	1.83
F-test	.20	.21	.19	*	**	**	**	**	**
CV (%)	10	9	13	7	6	6	6	2	12

**, *, † Significant difference at P≤.01, .05, and .10. Contrast is versus Control (no cultivation) by LSD.

§ ND = $R_{935} - R_{661} / R_{935} + R_{661}$, where R_{935} = reflectance at 935 nm (790 to 1080 nm) and R_{661} = reflectance at 661nn (648 to 674 nm). Often correlated with green biomass.

¶ IR/R = R_{935} / R_{661}. Often correlated with leaf area index (LAI).