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

1998 Research Grant: $20,000
(Third 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 (OM) in the surface 0 to 2 inch zone of a USGA green from an initial level of 1.0 to 4.0% (by weight) at establishment to 8 to 12% or more after 2 years. Organic matter accumulation occurs even under excellent management and regardless of specification (i.e., it is not dependent on specifications) due to the abundance of roots produced by bentgrass within this surface zone along with any thatch/mat accumulation. A considerable portion of the OM in the surface zone is as root tissue that can contribute to soil macropore plugging or sealing. The two proposed problems arising from surface OM occur at different times of the year and are the basis of two projects:

I. **Summer Bentgrass Decline in Response to Root Deterioration and Plugging of the Macropores that are Essential for Soil O_2 Exchange and Maintenance of Water Infiltration.** A project was initiated in late spring 1996 to investigate the influence of treatments (summer cultivation, sand topdressing, sand substitutes, wetting agents) on maintaining infiltration, soil O_2 status, and roots. This field study continued until fall 1998. It is proposed that high temperatures, especially in conjunction with high humidity, causes an increase in the rate of summer death (dieback) of roots. Since many roots reside in the surface 0 to 2 inches, death of a substantial percentage of these roots in a narrow time frame can alter the form of organic matter from live roots (with a "structure") to gel-like fresh, dead organic matter that rapidly plugs surface macropores. Any water applied at this point causes a saturated zone due to a low infiltration rate, thereby inducing low soil O_2 levels as gas exchange declines. Turfgrass and soil microorganism O_2 demands are very high under hot, moist weather and severe O_2 stress (similar to wet wilt without necessarily having standing water but with a saturated surface zone) occurs. This triggers very rapid enhancement of summer bentgrass decline and further root dieback. The initial field study on this problem will continue until fall 1998. Observations to date are:

a. Percent OM by weight was 9.8% at 30 months after initiation of treatments for the untreated Control in the surface 0 to 3.0 cm (0 to 1.2 inch) zone. The **Control** received light, frequent sand topdressing at 0.5 to 1.0 ft^3 per 1000 ft^2 every 3 weeks as did all treatments but not core aeration. **Core aeration (CA)** with a heavy topdressing (6.2 ft^3 per 1000 ft^2) in March was the only treatment to reduce percent OM (i.e., by 25% to 7.8% OM) while all other treatments ranged from 8.9 to 10.3% OM. Such high OM contents in this surface zone indicates that OM controls soil physical properties more than the sand matrix. Thus, soil physical properties within this zone were substantially different from the specification ranges of a USGA root zone mix:

Parameter	Surface 0-3 cm Range for Study Treatments[a]	USGA Specification Range
Bulk density (g cm^{-3})	.61 to .76	1.20 to 1.60
Total Porosity (%)	66.9 to 73.2	35.0 to 55.0
Aeration Porosity (%) (-0.004 M Pa)	17.4 to 24.3	15.0 to 30.0
Moisture Retention (%) (-0.004 M Pa)	42.5 to 54.7	15.0 to 25.0

[a] At 30 months after study initiation.

Since OM content is the primary factor affecting these soil physical properties of the surface 0 to 3 cm zone, OM would be expected to influence soil O_2 status and water infiltration.

b. Measurement of soil oxygen diffusion rate (ODR) was made in three treatments (**CA**, core aeration in Mar; **HJR**, Toro Hydro-Ject† raised to create a 0.25 inch dia. hole to a depth of 4 to 8 inches every 3 weeks June through September; **HJR + WA**, same as HJR but with wetting agent applied every 3 weeks from mid-May through September. ODR was ≤ 0.20 μg O_2 cm^{-2} min^{-1} (the ODR rate at which soil O_2 becomes limiting for roots) 38, 43, and 24% of readings at 2.5 cm (1.0 inch) for CA, HJR, and HJR + WA, respectively over 3 summers. At 10 cm (4 inch) ODR readings were equal or below the limiting value on 0, 14, and 14% of readings, respectively, over 2 summers. Thus, even with these cultivation treatments, limiting ODR values were observed at 3 to 26 hours after irrigation within the surface zone.

c. Treatments that enhanced average water infiltration (as saturated hydraulic conductivity, SHC) at 17 to 26 days after cultivation greater than the **Control** (128 mm hr^{-1}) were: **HJR + Sand** (451 mm hr^{-1}) (HJR + additional topdressing at 0.75 ft^3 per 1000 ft^2 every 3 weeks); **HJR + WA** (406); **HJR** (400); **HJR + B** (395) (HJR + Biostimulant, cytokinin); **HJR + Sand + WA** (371); **HJR + Sand + WA + B** (361); **HJL** (331) (Hydro-Ject lowered position for 0.125 inch dia. hole); and **HJR + Greenschoice** (269 mm hr^{-1}) (HJR + Greenschoice topdressing at 0.75 ft^3 per 1000 ft^2). The normal desirable SHC for a high rainfall region is at least 120 mm hr^{-1} with the **Control** and **CA** treatments below this value 50 and 43% of readings. High SHC in the summer is essential: to allow rapid water movement across the 0 to 3 cm zone that controls field SHC; to prevent standing water and excessively long periods of saturation; and to enhance O_2 movement into the soil.

† Use of trade names is for explanation only and does not imply an endorsement.

d. Percent of shoot density ratings significantly greater than the **Control** was highest for **HJL** (38% of readings), **HJR + WA** (29), **HJR** (24), and **HJR + Sand + WA** (24), while treatments exhibiting lower shoot density than control were **LP + G** (LandPride cultivation with vertical injection of Greenschoice into holes) (33%) and **CA** (29%). Root data are still in progress.

II. **Stimulation of Root Development (in Spring/Fall) from the Zone of High Organic Matter Content**. The hypothesis in this project was that high OM content in the surface zone in cool weather was due in major part to shallow roots. As roots developed in mid-fall to late spring, they may result in sufficient plugging of surface macropores in the surface zone to cause periods of suboptimal soil O_2 and low water infiltration. While adverse shoot responses to low soil O_2 may not be apparent in cool periods (as they are in summer where summer bentgrass decline can occur very rapidly), deep root development from late fall through late spring could be reduced, thereby limiting deep rooting going into the summer. A second project was initiated in winter 1996 to investigate the influence of selected cultivation procedures, that are non-disruptive to turfgrass shoots, on root development. Wetting agent and sand substitute treatments were also included. The objectives were to enhance SHC, soil ODR, and root development. Observations to date are:

a. Percent OM by weight in the surface 0 to 3 cm zone for the **Control** (received light, frequent sand topdressing at 0.75 ft^3 per 1000 ft^2 every 3 weeks as did all treatments but no core aeration) at 30 months after study initiation was 16.1%. Core aeration (**CA**) treatment in March and September with 6.2 ft^3 per 1000 ft^2 had OM of 9.3% while other treatments ranged from 9.8 to 16.8%. As in Study 1, OM in the surface dominated the physical properties of the root zone.

b. For the three treatments where soil ODR was determined, ODR at 3.5 cm (1.0 inch) was ≤ 0.20 μg O_2 cm^{-2} min^{-1} (the limiting value) 59 to 62% of readings in October to June and 25 to 38% at 10 cm (4.0 inch). The three treatments were **CA, HJR + WA** (Hydro-Ject Raised for 0.25 in dia. hole plus wetting agent, both at 3 week intervals); **HJR + G + WA** where G = Greenschoice topdressing at 70% sand plus 30% G every 3 weeks at 0.75 ft^3 per 1000 ft^2 above the base sand topdressing of all treatments. Lowest ODR and SHC values occurred in December/January and May periods and values were lower than summer ODR and SHC values of an adjacent study (i.e., Study 1).

c. Maintaining high SHC across the 0 to 3 cm zone should increase soil O_2 and minimize periods of standing water or surface saturation that may inhibit rooting. Treatments that increased average SHC compared to the **Control** (71 mm hr^{-1}) at 24 to 41 days after cultivation were: **HJR + WA** (221 mm hr^{-1}); **HJR** (214); **HJR + G + WA** (183); **HJR + G** (152) and **AW** (Aerway Slicer, 100 tines, 4 inch penetration) (145 mm hr^{-1}). Lowest average SHC at 24 to 41 DAC were exhibited by **QT + G** (Solid quad tine of 0.25 inch dia. with Greenschoice) (53) and **AW + G** (63); where both of these treatments were not significantly different than the Control.

d. Treatments with 0 to 6% of shoot density rating less than the Control and 0 to 22% ratings greater than the control were **AW + G, HJR**, and **HJR + G + WA**. Treatments with highest percent of readings less than the Control were **QT** (28%), **LP + GI** (LandPride cultivation with Greenschoice vertical injection) (19), and **QT + G** (17). Root data are in progress.

Results from these two projects will be used in Phase II to formulate potential annual management programs (cultivation, topdressing, wetting agents, etc.) that a) would allow maximum root growth development in spring/fall without the decrease in rooting depth now observed on high sand golf greens a couple years after grass establishment, and b) would maintain root viability in the summertime and minimize summer bentgrass decline caused by low soil O_2 exchange.

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PROJECT 1:

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

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 "summer bentgrass decline" was reported to be due to root Phythium species. However, the sequence of injuries I believe is causing this problem is:

Summer Bentgrass Decline

Indirect High Temperature Stress.
* **Depletion of carbohydrates by an imbalance of PS and Res adversely affects root maintenance.**

↓

Root Growth and Viability Declines.
* **Moderate to massive root death may occur during summer months.**

↓

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 may form and enhance the rate of root dieback and soon cause shoot injury. This is most likely in very hot, humid periods.**
4. **Water and Nutrient Uptake Declines.**
5. **Shoot Tissue Succulent and Less Wear Tolerant.**
6. **Disease Organisms May Increase With Slow Plant Growth, Abundant O.M., and Moisture Surface Conditions.**
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, especially under hot, humid weather patterns. 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 is an example of surface organic matter dynamics where the nature of the O.M. is altered and:

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

Objectives

To determine the effectiveness of summer cultivation practices and amendments to create macropore channels and/or enhance macroporosity on:

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

Procedures

See Table 1.1 for list of treatements.

The dates of treatment application in 1996, 1997, and 1998 were:

Treatment	1996
CA	29 Mar; 1 Oct
HJL, HJR, LP + GI	6, 24 Jun; 16 Jul; 8 Aug; 5 Sep
Sand Top., Greenschoice Top.	15 May; 11 Jun; 8, 30 Jul
Wetting Agent	16 May; 11 Jun; 9, 29 Jul; 12 Aug
Biostimulant	11 Jun; 9 Jul; 9 Aug; 13 Sep

Treatment	1997
CA	15 Mar
HJL, HJR, LP + GI	3, 25 Jun; 15 Jul; 11 Aug; 4 Sep
Sand Top., Greenschoice Top.	15 May; 10 Jun; 10 Jul; 6, 28 Aug
Wetting Agent	15 May; 11 Jun; 10 Jul; 7, 28 Aug
Biostimulant	11 Jun; 11 Jul; 7, 28 Aug

Treatment	1998
CA	23 Mar
HJL, HJR, LP + GI	3, 25Jun; 20 Jul; 10 Aug
Sand Top., Greenschoice Top.	11 May; 9 Jun; 8, 10 Jul; 4 Aug
Wetting Agent	12 May; 9 Jun; 10 Jul; 4 Aug
Biostimulant	9 Jun; 10 Jul; 4 Aug

In addition to the above treatments, all plots received light, frequent topdressing throughout the year at 0.50 (summer) to 1.00 (rest of year) ft^3 per 1000 ft^2 on a 3-week schedule. Thus, these sand topdressing treatments are in addition to any treatment topdressing applications.

Table 1-1. Treatments for study T-109.

Treat No.	Description	Target Dates
1.	No cultivation	None
2.[a]	Core Aerate, H.T., 5/8 dia. Apply 14,000 ml sand per plot after cultivation = 6.2 ft^3 per 1000 ft^2	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
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[e] 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. Watered lightly to remove from leaves.

[d] Biostimulant is CytoGro (.005% active ingredient of kinetin) applied at 1 fl. oz per 1000 ft^2. Not irrigated to wash off leaves.

[e] LandPride + Greenschoice Injection = In 1996 and 1997, Greenschoice was injected into vertical holes created by the LandPride. In 1998, these plots received HJR + Topdressing with 70% sand + 30% Greenschoice at 0.75 ft^3 per 1000 ft^2.

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

Results

All data has been obtained relative to treatment effects on a) soil physical conditions (Tables 1-2 to 1-9), and b) shoot responses (Tables 1-10 to 1-28). Rooting data are available for 1996 (Table 1-29) and root data for 1997 and 1998 will be added when available. At that time, a complete discussion of results will be made.

Summary tables are:

- Table 1-5. Saturated hydraulic conductivity.
- Table 1-9. Soil ODR.
- Table 1-28. Shoot responses.

Table 1-2. Bulk density, organic matter content, and mineral matter content in the surface 0 to 3 cm zone in June and August 1997 (T-109).

Treatment and Contrast‡	Bulk Density 1997 6 Jul	Bulk Density 1997 18 Aug	Bulk Density 1998 24 Aug	Percent Organic Matter 1997 6 Jun	Percent Organic Matter 1997 18 Aug	Percent Organic Matter 1998 24 Aug	Organic Matter Content§ 1997 6 Jun	Organic Matter Content§ 1997 18 Aug	Organic Matter Content§ 1998 24 Aug	Mineral Matter Content§ 1997 6 Jun	Mineral Matter Content§ 1997 18 Aug	Mineral Matter Content§ 1998 24 Aug
	g cm^{-3}			% (wt.)			g			g		
Control vs.	.51	.62	.67	10.2	10.1	9.8	7.5	9.3	10.1	67.5	84.4	92.9
CA (Mar)	.70**	.69	.76	4.1**	7.7*	7.3*	4.4*	8.8	8.3*	99.1**	105.7*	108.2†
HJL	.54	.58	.63	9.7	10.2	9.9	7.7	9.1	9.6	69.8	81.7	87.4
HJR	.48	.60	.69	11.5	11.7	9.1	8.3	10.0	9.8	62.6	75.7	99.6
HJR + Sand	.57	.63	.66	9.4	10.6	9.3	7.7	9.7	9.4	74.9	82.4	91.8
HJR + Greenschoice	.56	.54†	.66	7.4	10.2	9.3	5.8	9.0	9.4	73.5	79.2	91.7
HJR + WA	.59	.58	.73	9.1	10.0	8.9	7.6	9.3	9.7	80.2	85.5	102.4
HJR + B	.52	.59	.62	8.4	10.1	10.3	6.2	9.7	9.4	70.2	88.2	85.5
HJR + Sand + WA	.51	.59	.61	10.1	11.1	10.0	7.7	9.3	9.0*	68.4	75.7	81.6
HJR + Sand + WA + B	.52	.60	.68	8.5	11.4	9.1	6.4	10.2	9.5	69.4	79.2	94.9
LP + Greenschoice I	.52	.54†	.71	10.0	11.1	9.0	6.9	9.4	9.7	68.8	76.1	99.2
LSD (.05) =	.12	.10	.12	4.3	2.2	2.2	3.0	1.3	1.0	18.9	16.8	18.0
F-test	†	.20	.30	†	†	.38	.39	.56	.16	*	*	.16
CV (%)	15	11	12	33	14	16	31	10	8	18	14	13
Desired Range		1.20 to 1.60			2.0 to 4.5			—			—	

‡ Contrast versus Control based on LSD.
**, *, † Significant difference at P ≤.01, .05, and .10.
§ Weight is grams per 50 cm^2 surface area X 3.0 cm deep.

Table 1-3. Total Porosity, aeration porosity (macroporosity) and moisture retention in the surface 0 to 3 cm zone in 1997 and 1998 (T-109).

Treatment and Contrast‡	Total Porosity			Aeration Porosity (-0.004 MPa)			Moisture Retention (-0.004 MPa)		
	1997		1998	1997		1998	1997		1998
	6 Jun	18 Aug	24 Aug	6 Jun	18 Aug	24 Aug	6 Jun	18 Aug	24 Aug
	% (Vol.)								
Control vs.	74.2	76.7	72.1	17.3	22.5	17.4	56.9	54.1	54.7
CA (Mar)	68.8†	71.4†	66.9*	21.9	21.9	24.3*	46.8*	49.4	42.5*
HJL	75.0	76.7	72.6	21.1	27.1	20.0	53.9	49.7	52.6
HJR	75.7	72.6	73.2	17.2	19.9	20.4	58.5	52.7	52.8
HJR + Sand	73.1	74.3	70.6	21.1	22.2	22.3	52.0	52.0	48.3
HJR + Greenschoice	75.3	77.1	73.1	21.2	21.4	20.6	54.1	55.7	52.5
HJR + WA	73.2	74.1	71.6	19.3	21.9	21.5	53.9	52.2	50.2
HJR + B	76.2	76.6	72.5	22.1	22.3	21.7	54.1	54.3	50.8
HJR + Sand + WA	76.6	78.7	70.4	20.9	27.5	22.0	55.6	51.2	48.4
HJR + Sand + WA + B	73.5	75.6	69.4	22.6†	21.8	18.0	50.9	53.8	51.4
LP + Greenschoice I	75.5	76.6	72.9	18.2	23.1	20.0	57.3	53.5	52.9
LSD (.05) =	5.6	5.6	4.5	6.1	8.5	5.9	8.0	9.7	9.0
F-test	.29	.30	.17	.59	.78	.53	.23	.96	.36
CV (%)	5	5	4	21	26	20	10	13	12
Desired Range	35.0 to 55.0			15.0 to 30.0			15.0 to 25.0		

‡ Contrast versus Control based on LSD.

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

Table 1-4. Saturated hydraulic conductivity at selected days after the previous HJR cultivation operation (DAC) in summer 1996, 1997, and 1998. (T-109)

Treatment and Contrast ‡§	Saturated Hydraulic Conductivity (SHC)													
	1996						1997				1998			
	19 Jul	6 Aug	15 Aug	3 Sep	9 Sep	23 Sep	16 Jul	4 Aug	12 Aug	28 Aug	21 Jul	6 Aug	10 Aug	1 Sep
	3 DAC	21 DAC	7 DAC	26 DAC	4 DAC	18 DAC	1 DAC	20 DAC	1 DAC	17 DAC	1 DAC	17 DAC	1 DAC	21 DAC
	mm hr^{-1}													
Control vs.	199	219	67	137	223	53	101	190	304	96	55	183	82	20
CA (Mar)	299	93	116	116	223	64	277	364	230	148	346*	156	117	78
HJL	190	222	192	764*	538	390*	500	255	674	477	98	101	65	110
HJR	448	190	470	775*	652*	457*	827**	254	1062†	322	253†	394†	397**	408**
HJR + Sand	838**	217	830**	1136**	622†	599**	503	342	751	447	245	55	413**	288**
HJR + Greenschoice	488	160	776*	545†	883**	307†	454	290	506	223	244	189	186	167†
HJR + WA	791**	145	1024**	505	961**	737**	719*	298	578	749*	186	181	227†	230*
HJR + B	636*	100	861**	413	868**	379*	548†	595†	685	855**	270†	237	158	184†
HJR + Sand + WA	658*	123	830**	821**	705*	385*	488	474	508	210	169	384†	184	205*
HJR + Sand + WA + B	930**	108	343	446	608†	500**	496	385	737	484	407**	236	238†	371**
LP + Greenschoice I	176	80	233	100	323	234	233	134	151	103	119	160	142	220*
LSD (.05) =	322	197	579	506	427	256	557	439	772	575	242	220	166	165
F-test	**	.78	**	**	**	**	.36	.69	.48	†	.15	†	**	**
CV (%)	43	91	77	67	49	49	83	93	95	106	77	73	57	55

‡ Contrast versus Control based on LSD.

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

§ Treatment Dates:

	1996	1997	1998
CA	29 Mar; 1 Oct	15 Mar	23 Mar
HJL, HJR, LP + GI	6, 24 Jun; 16 Jul; 8 Aug; 5 Sep	3, 25 Jun; 15 Jul; 11 Aug; 4 Sep	3, 25 Jun, 20 Jul, 10 Aug
Sand Top., Greenschoice Top.	15 May; 11 Jun; 8, 30 Jul	15 May; 10 Jun; 10 Jul; 6, 28 Aug	11 May, 9 Jun, 10 Jul, 4 Aug
Wetting Agent	16 May; 11 Jun; 9, 29 Jul; 12 Aug	15 May; 11 Jun; 10 Jul;,7, 28 Aug	12 May, 9 Jun, 10 Jul, 4 Aug
Biostimulant	11 Jun; 9 Jul; 9 Aug; 13 Sep	11 Jun; 11 Jul; 7, 28 Aug	9 Jun, 10 Jul, 4 Aug

Table 1-5. Summary of saturated hydraulic conductivity (SHC) data for 1996 to 1998 (T-109).

Treatment and Contrast‡	Average SHC (1996 to 1998) Minimum			Percent of Readings Greater Than Control¶			Percent of Reading Less Than 120 mm hr^{-1}		
	1-7 DAC	17-26 DAC	SHC	1-7 DAC	17-26 DAC	Total	1-7 DAC	17-26 DAC	Total
	mm hr^{-1}			%			%		
Control vs.	147	128	20	–	–	–	57	43	50
CA (Mar)	233	146	64	14	0	7	29	57	43
HJL	322	331*	65	0	29	15	29	29	29
HJR	587**	400**	190	71	57	64	0	0	0
HJR + Sand	600**	451**	156	57	43	50	0	14	7
HJR + Greenschoice	505**	269†	160	29	43	36	0	0	0
HJR + WA	641**	406**	145	71	43	57	0	0	0
HJR + B	575**	395*	100	71	57	64	0	0	0
HJR + Sand + WA	506**	371*	123	43	57	50	0	0	0
HJR + Sand + WA + B	537**	361*	108	57	29	43	0	14	7
LP + Greenschoice I	197	147	80	0	14	7	14	43	29
LSD (.05) =	243	172	–	–	–	–	–	–	–
F-test	**	**	–	–	–	–	–	–	–
CV (%)	38	39	–	–	–	–	–	–	–

‡ Contrast versus Control based on LSD.

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

§ Minimum SHC for "accelerated range" is 300 to 600 mm hr^{-1} (lab) or assuming a 60% reduction in the field under normal conditions this would be 120 to 240 mm hr^{-1} (4.7 to 9.4 inches hr^{-1}).

¶ Based on statistical significant difference from control (P ≤ .10).

Table 1-6. Oxygen diffusion rate (ODR) at 3 cm and moisture content at 0 to 6 cm in the surface zone in 1996 at different times after irrigation (T-109). DAC = days after cultivation for HJR.

	2 Aug (17 DAC)		13 Aug (5 DAC)			4 Sep (27 DAC)	
Treatment	2.5 hrs	8 hrs	2.5 hrs	8.5 hrs	26 hrs	2.5 hrs	9 hrs
ODR (μg O_2 cm^{-2} min^{-1})							
CA (Mar) vs.	.09	.19	.09	.14	.19	.12	.15
HJR	.10	.24	.10	.11	.15	.18	.19
HJR + WA	.13	.25	.18	.18	.25	.12	.16
LSD (.05)	.13	.18	.16	.16	.16	.15	.14
F-test	.79	.79	.37	.67	.59	.67	.90
CV (%)	69	50	89	75	53	60	51
Moisture Content (% Vol.) (0 to 6.0 cm)							
CA (Mar) vs.	52.1	50.1	50.6	47.8	47.4	52.3	51.0
HJR	50.3	49.8	49.7	46.5	48.5	51.9	50.1
HJR + WA	50.7	46.7	49.3	46.6	47.4	52.3	49.3
LSD (.05)	5.1	6.9	7.3	7.2	7.2	4.6	5.7
F-test	.38	.67	.94	.95	.96	.72	.88
CV (%)	6	9	9	9	9	6	7

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

Table 1-7. Oxygen diffusion rate (ODR) at 3 and 10 cm depths and moisture retention at 0 to 6 cm depth in 1997 at different times after irrigation (T-109). DAC = days after the last HJR cultivation.

	28 Jul (13 DAC)				13 Aug (2 DAC)				5 Sep (1 DAC)			
	3 cm		10 cm		3 cm		10 cm		3 cm		10 cm	
Treatment	26 hrs	50 hrs	26 hrs	50 hrs	2.5 hrs	26 hrs	2.5 hrs	26 hrs	2.5 hrs	26 hrs	2.5 hrs	26 hrs
ODR (μg O_2 cm^{-2} min^{-1})												
CA (Mar) vs.	.31	.22	.28	.23	.30	.28	.28	.32	.38	.29	.35	.35
HJR	.26	.20	.18	.14†	.27	.25	.26	.36	.48†	.26	.37	.32
HJR + WA	.34	.31	.18	.16	.34	.29	.22	.24	.54*	.26	.32	.35
LSD (.05)	.29	.16	.15	.11	.13	.10	.14	.17	.11	.07	.19	.10
F-test	.85	.22	.48	.35	.68	.72	.50	.26	*	.32	.80	.76
CV (%)	57	38	48	41	26	34	24	38	14	15	31	19
Moisture Content (% Vol.) (0 to 6 cm)												
CA (Mar) vs.	37.0	30.9	—	—	—	—	—	—	44.7	41.0	—	
HJR	41.2	37.0	—	—	—	—	—	—	47.1	42.3	—	
HJR + WA	36.1	29.4	—	—	—	—	—	—	44.6	38.1	—	
LSD (.05)	10.7	18.6	—	—	—	—	—	—	9.0	18.5	—	
F-test	.45	.80	—	—	—	—	—	—	.85	.75	—	
CV (%)	17	37	—	—	—	—	—	—	26	11	—	

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

Table 1-8. Oxygen diffusion rate (ODR) at 3 and 10 cm depths and moisture retention at 0 to 6 cm depth in 1998 at different times after irrigation (T-109). DAC = days after the last HJR cultivation.

	29 Jul (9 DAC)				5 Aug (16 DAC)				13 Aug (3 DAC)				1 Sep (22 DAC)			
	3 cm		10 cm		3 cm		10 cm		3 cm		10 cm		3 cm		10 cm	
Treatment	2.5 hrs	26 hrs	2.5 hrs	26 hrs	2.5 hrs	26 hrs	2.5 hrs	26 hrs	2.5 hrs	26 hrs	2.5 hrs	26 hrs	2.5 hrs	26 hrs	2.5 hrs	26 hrs
ODR (μg O_2 cm^{-2} min^{-1})																
CA (Mar) vs.	.23	.29	.29	.28	.23	.32	.39	.32	.22	.28	.40	.32	.19	.29	.36	.21
HJR	.12	.32	.34	.32	.13	.33	.37	.34	.24	.24	.33	.30	.30	.30	.37	.25
HJR + WA	.27	.35	.41	.35	.28	.32	.40	.29	.25	.31	.34	.29	.44	.26	.37	.21
LSD (.05)	.16	.38	.23	.18	.17	.13	.17	.09	.17	.18	.15	.14	.38	.23	.20	.15
F-test	†	.76	.68	.75	.15	.96	.89	.43	.39	.85	.33	.64	.34	.90	.99	.73
CV (%)	54	33	42	36	47	24	25	16	51	42	27	29	70	47	33	38
Moisture Content (% Vol.) (0 to 6.0 cm)																
CA (Mar) vs.	50.4	48.3	—	—	49.3	46.3	—	—	50.1	48.7	—	—	48.2	46.3	—	—
HJR	53.9*	49.1	—	—	53.2	48.6	—	—	51.9	50.1	—	—	50.4	50.5	—	—
HJR + WA	51.2	47.9	—	—	51.3	47.3	—	—	50.6	48.9	—	—	48.2	49.1	—	—
LSD (.05)	3.5	5.3	—	—	5.4	4.9	—	—	4.2	5.5	—	—	9.1	8.3	—	—
F-Test	†	.29	—	—	.29	.55	—	—	.43	.75	—	—	.79	.50	—	—
CV (%)	4	7	—	—	6	6	—	—	5	7	—	—	11	10	—	—

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

Table 1-9. Summary of oxygen diffusion rate (ODR) and surface moisture retention (0 to 6 cm) data for 1996 to 1998 (T-109).

Treatments	Percent Reading ≤0.20 μg O_2 cm^{-2} min^{-1} †								Moisture Content at 0 to 6 cm			
	3 cm				10 cm							
	1996	1997	1998	AVE	1996	1997	1998	AVE	1996	1997	1998	AVE
									% (Vol)			
CA (Mar)	100	0	13	38	—	0	0	0	50.2	38.4	48.5	49.3
HJR	86	16	25	43	—	33	0	14	49.5	41.9	51.0	48.5
HJR + WA	71	0	0	24	—	33	0	14	48.9	37.1	49.3	46.5
									49.5	39.1	49.6	

	Average ODR (μg O_2 cm^{-2} min^{-1})							
	3 cm				10 cm			
	1996	1997	1998	AVE	1996	1997	1998	AVE
CA	.14	.30	.26	.23	—	.30	.32	.31
HJR	.15	.29	.25	.23	—	.27	.33	.30
HJR + WA	.18	.35	.28	.27	—	.25	.33	.30
	.16	.31	.26			.27	.33	

† An ODR rate of ≤0.20 μg O_2 cm^{-2} min^{-1} is considered as limiting for maximum root function.

Table 1-10. Visual quality in 1996. (T-109)[§]

Treatment and Contrast [‡]	Visual Quality 12 Jun	27 Jun	9 Jul	23 Jul	16 Aug	30 Aug	10 Sep	15 Oct	25 Nov
	--------- 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	7.5
CA (Mar)	7.8	8.0	7.6	7.5	7.3	7.3	7.2	6.0**	7.1*
HJL	7.9	8.0	7.7	7.5	7.3	7.5	7.5	7.6	7.5
HJR	7.8	7.9	7.7	7.6	7.6†	7.6	7.5	7.6	7.7†
HJR + Sand	7.7	7.9	7.4	7.5	7.2	7.5	7.4	7.6	7.6
HJR + Greenschoice	7.7	7.9	7.6	7.5	7.3	7.5	7.5	7.2†	7.5
HJR + WA	7.8	7.8	7.5	7.6	7.2	7.5	7.5	7.5	7.5
HJR + B 7.7	7.9	7.8	7.6	7.4	7.5	7.5	7.4	7.5	
HJR + Sand + WA	7.7	7.9	7.4	7.5	7.3	7.6	7.5	7.5	7.6
HJR + Sand + WA + B	7.8	8.0	7.6	7.4	7.3	7.5	7.5	7.4	7.4
LP + Greenschoice I	7.6	7.6	7.1*	7.2	6.6*	6.7**	6.6**	6.9*	7.5
LSD (.05) =	.31	.29	.40	.26	.47	.40	.40	.33	.21
F-test	.60	.34	†	.20	*	**	**	**	**
CV (%)	3	3	4	2	4	4	4	3	2

[‡] Contrast versus Control based on LSD.

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

[§] Treatment Dates:

CA	29 Mar; 1 Oct
HJL, HJR, LP + GI	6, 24 Jun; 16 Jul; 8 Aug; 5 Sep
Sand Top., Greenschoice Top.	15 May; 11 Jun; 8, 30 Jul
Wetting Agent	16 May; 11 Jun; 9, 29 Jul; 12 Aug
Biostimulant	11 Jun; 9 Jul; 9 Aug; 13 Sep

Table 1-11. Visual quality in 1997. (T-109)[§]

Treatment and Contrast [‡]	Visual Quality 8 Apr	16 May	12 Jun	15 Jul	7 Aug	22 Aug	15 Oct
	--------- 9.0 = ideal density, color, uniformity; 1.0 = no live turf ----------						
Control vs.	7.6	7.5	7.7	7.5	7.4	7.5	7.3
CA (Mar)	6.7**	7.4	7.7	7.7	7.4	7.3	7.2
HJL	7.6	7.5	7.8	7.5	7.7*	8.0**	7.6*
HJR	7.5	7.7	7.7	7.6	7.6	7.7	7.3
HJR + Sand	7.5	7.5	7.8	7.6	7.6	7.6	7.3
HJR + Greenschoice	7.5	7.6	7.7	7.6	7.5	7.6	7.3
HJR + WA	7.6	7.6	7.7	7.5	7.6	7.8[†]	7.5
HJR + B	7.6	7.4	7.7	7.5	7.5	7.4	7.6*
HJR + Sand + WA	7.4[†]	7.5	7.7	7.5	7.4	7.7	7.3
HJR + Sand + WA + B	7.5	7.6	7.8	7.6	7.5	7.6	7.4
LP + Greenschoice I	7.5	7.5	7.4*	7.5	7.1*	6.8**	7.1
LSD (.05) =	.25	.28	.30	.23	.26	.33	.30
F-test	**	.30	.27	.88	**	**	*
CV (%)	2	3	3	2	2	3	3

[‡] Contrast versus Control based on LSD.

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

[§] Treatment Dates:

CA	15 Mar
HJL, HJR, LP + GI	3, 25 Jun; 15 Jul; 11 Aug; 4 Sep
Sand Top., Greenschoice Top.	15 May; 10 Jun; 10 Jul; 6, 28 Aug
Wetting Agent	15 May; 11 Jun; 10 Jul; 7, 28 Aug
Biostimulant	11 Jun; 11 Jul; 7, 28 Aug

Table 1-12. Visual quality in 1998 (T-109).[§]

Treatment and Contrast[‡]	Visual Quality 1 May	8 Jun	17 Jul	21 Aug	17 Sep
	9.0 = ideal density, color, uniformity; 1.0 = no live turf				
Control vs.	7.2	7.6	7.3	7.3	7.2
CA (Mar)	6.6**	7.0**	6.9*	7.2	7.3
HJL	7.5*	7.5	7.4	7.5	7.4
HJR	7.4	7.4	7.5	7.6†	7.4
HJR + Sand	7.3	7.4	7.5	7.4	7.4
HJR + Greenschoice	7.4	7.3*	7.4	7.5	7.4
HJR + WA	7.6*	7.7	7.4	7.4	7.6*
HJR + B	7.5*	7.5	7.5	7.5	7.5†
HJR + Sand + WA	7.5*	7.6	7.6†	7.7*	7.6*
HJR + Sand + WA + B	7.3	7.5	7.3	7.5	7.4
LP + Greenschoice I	7.3	7.2*	7.2	7.0†	7.4
LSD (.05) =	.27	.28	.34	.31	.34
F-test	**	**	*	**	.39
CV (%)	3	3	3	3	3

‡ Contrast versus Control based on LSD.

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

§ Treatment Dates:

CA	23 Mar
HJL, HJR, LP + GI	3, 25 Jun; 20 Jul; 10 Aug
Sand Top., Greenschoice Top.	11 May; 9 Jun; 10 Jul; 4 Aug
Wetting Agent	12 May; 9 Jun; 10 Jul; 4 Aug
Biostimulant	9 Jun; 10 Jul; 4 Aug

Table 1-13. Shoot density in 1996. (T-109)[§]

Treatment and Contrast [‡]	Shoot Density 12 Jun	27 Jun	9 Jul	23 Jul	16 Aug	30 Aug	10 Sep	15 Oct	25 Nov
	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	7.5
CA	7.8	8.1	7.7	7.5	7.4	7.4	7.3	7.2*	7.3*
HJL	8.0	8.1	7.9*	7.6	7.4	7.6	7.6†	7.7†	7.6
HJR	7.8	8.0	7.7	7.7	7.7	7.6	7.6†	7.7†	7.8
HJR + Sand	7.7	7.9	7.5	7.5	7.5	7.5	7.5	7.6	7.6
HJR + Greenschoice	7.7	7.9	7.7	7.6	7.5	7.6	7.6†	7.4	7.6
HJR + WA	7.8	7.9	7.7	7.6	7.5	7.6	7.6†	7.6	7.5
HJR + B 7.8	8.0	8.0*	7.6	7.6	7.6	7.5	7.6	7.6	
HJR + Sand + WA	7.7	8.0	7.6	7.6	7.6	7.6	7.6†	7.6	7.7*
HJR + Sand + WA + B	7.8	8.1	7.7	7.5	7.6	7.6	7.5	7.5	7.5
LP + Greenschoice I	7.6	7.8	7.4	7.4	7.1*	7.0*	7.1*	7.4	7.5
LSD (.05) =	.29	.31	.35	.21	.33	.31	.28	.22	.19
F-test	.54	.73	*	.54	*	**	**	**	**
CV (%)	3	3	3	2	3	3	3	2	2

‡ Contrast versus Control based on LSD.

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

§ Treatment Dates:

CA	29 Mar; 1 Oct
HJL, HJR, LP + GI	6, 24 Jun; 16 Jul; 8 Aug; 5 Sep
Sand Top., Greenschoice Top.	15 May; 11 Jun; 8 Jul; 30 Jul
Wetting Agent	16 May; 11 Jun; 9, 29 Jul; 12 Aug
Biostimulant	11 Jun; 9 Jul; 9, 13 Sep

Table 1-14. Shoot density in 1997. (T-109)[§]

Treatment and Contrast [‡]	Shoot Density 8 Apr	16 May	13 Jun	15 Jul	7 Aug	22 Aug	15 Oct
	9.0 = ideal shoot density; 1.0 = no live turf						
Control vs.	7.6	7.5	7.7	7.6	7.5	7.5	7.5
CA (Mar)	7.1**	7.5	7.7	7.7	7.4	7.4	7.3
HJL	7.7	7.5	7.8	7.7	7.7†	8.0**	7.7*
HJR	7.5	7.7†	7.7	7.7	7.6	7.7	7.4
HJR + Sand	7.6	7.6	7.8	7.7	7.6	7.6	7.4
HJR + Greenschoice	7.6	7.6	7.7	7.7	7.6	7.6	7.4
HJR + WA	7.6	7.7†	7.7	7.7	7.7†	7.8†	7.5
HJR + B	7.6	7.4	7.7	7.7	7.6	7.5	7.7*
HJR + Sand + WA	7.5	7.5	7.7	7.6	7.5	7.7	7.4
HJR + Sand + WA + B	7.5	7.6	7.9	7.7	7.5	7.6	7.6†
LP + Greenschoice I	7.5	7.5	7.5	7.6	7.3†	7.1*	7.2
LSD (.05) =	.26	.21	.26	.20	.22	.32	.31
F-test	**	.19	.44	.99	*	**	*
CV (%)	2	2	2	2	2	3	3

‡ Contrast versus Control based on LSD.

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

§ Treatment Dates:

CA	15 Mar
HJL, HJR, LP + GI	3, 25 Jun; 15 Jul; 11 Aug; 4 Sep
Sand Top., Greenschoice Top.	15 May; 10 Jun; 10 Jul; 6, 28 Aug
Wetting Agent	15 May; 11 Jun; 10 Jul; 7, 28 Aug
Biostimulant	11 Jun; 11 Jul; 7, 28 Aug

Table 1-15. Shoot density in 1998 (T-109).[§]

Treatment and Contrast[‡]	Shoot Density 1 May	8 Jun	17 Jul	21 Aug	17 Sep
	9.0 = ideal density, color, uniformity; 1.0 = no live turf				
Control vs.	7.3	7.6	7.3	7.4	7.2
CA (Mar)	6.7**	7.3*	7.2	7.2†	7.3
HJL	7.5	7.5	7.5	7.6†	7.5†
HJR	7.4	7.4	7.5	7.6†	7.5†
HJR + Sand	7.3	7.4	7.5	7.4	7.4
HJR + Greenschoice	7.4	7.4	7.4	7.5	7.5†
HJR + WA	7.6*	7.6	7.4	7.5	7.6*
HJR + B	7.5	7.5	7.5	7.5	7.5†
HJR + Sand + WA	7.5	7.6	7.6†	7.7*	7.6*
HJR + Sand + WA + B	7.3	7.5	7.4	7.5	7.5†
LP + Greenschoice I	7.3	7.2*	7.2	7.2†	7.4
LSD (.05) =	.28	.26	.33	.25	.33
F-test	**	*	.41	*	.46
CV (%)	3	2	3	2	3

‡ Contrast versus Control based on LSD.

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

§ Treatment Dates:

CA	23 Mar
HJL, HJR, LP + GI	3, 25 Jun; 20 Jul; 10 Aug
Sand Top., Greenschoice Top.	11 May; 9 Jun; 10 Jul; 4 Aug
Wetting Agent	12 May; 9 Jun; 10 Jul; 4 Aug
Biostimulant	9 Jun; 10 Jul; 4 Aug

Table 1-16. Turfgrass color in 1996. (T-109)[§]

Treatment and Contrast [‡]	Color								
	12 Jun	27 Jun	9 Jul	23 Jul	16 Aug	30 Aug	10 Sep	15 Oct	25 Nov
	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	7.5
CA	7.8	8.1	7.9*	7.5	7.5	7.3	7.3	7.7	7.3
HJL	7.9	8.0	7.8†	7.5	7.4	7.6†	7.6	7.6	7.6
HJR	7.8	8.0	7.8†	7.6	7.7	7.6†	7.6	7.6	7.6
HJR + Sand	7.8	7.9	7.8†	7.6	7.4	7.5	7.6	7.6	7.5
HJR + Greenschoice	7.8	7.9	7.7	7.5	7.4	7.6†	7.6	7.5	7.6
HJR + WA	7.9	7.9	7.7	7.5	7.3	7.5	7.5	7.5	7.5
HJR + B 7.8	8.0	7.9*	7.6	7.5	7.6†	7.5	7.5	7.6	
HJR + Sand + WA	7.7	7.9	7.7	7.6	7.4	7.6†	7.6	7.5	7.6
HJR + Sand + WA + B	7.9	8.1	7.8†	7.5	7.6	7.5	7.6	7.5	7.5
LP + Greenschoice I	7.8	7.9	7.5	7.5	7.0	6.9*	7.1†	7.3	7.6
LSD (.05) =	.19	.22	.26	.19	.37	.37	.34	.29	.27
F-test	.62	.43	†	.53	.20	*	†	.20	.70
CV (%)	2	2	2	2	4	3	3	3	2

‡ Contrast versus Control based on LSD.

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

§ Treatment Dates:

CA	29 Mar; 1 Oct
HJL, HJR, LP + GI	6, 24 Jun; 16 Jul; 8 Aug; 5 Sep
Sand Top., Greenschoice Top.	15 May; 11 Jun; 8, 30 Jul
Wetting Agent	16 May; 11 Jun; 9, 29 Jul; 12 Aug
Biostimulant	11 Jun; 9 Jul; 9 Aug; 13 Sep

Table 1-17. Turfgrass color in 1997. (T-109)[§]

Treatment and Contrast [‡]	Turf Color 8 Apr	16 May	12 Jun	15 Jul	7 Aug	22 Aug	15 Oct
	9.0 = dark green; 1.0 = no green, all brown						
Control vs.	7.7	7.6	7.8	7.5	7.4	7.6	7.5
CA (Mar)	7.2**	7.5	7.8	7.5	7.6	7.6	7.5
HJL	7.7	7.5	7.8	7.5	7.7*	8.0*	7.7
HJR	7.6	7.7	7.7	7.6	7.5	7.7	7.6
HJR + Sand	7.6	7.7	7.9	7.6	7.6	7.7	7.6
HJR + Greenschoice	7.6	7.6	7.7	7.6	7.6	7.7	7.6
HJR + WA	7.7	7.7	7.8	7.5	7.7*	7.8	7.7
HJR + B	7.6	7.4	7.7	7.5	7.6	7.5	7.7
HJR + Sand + WA	7.5	7.5	7.7	7.6	7.5	7.7	7.6
HJR + Sand + WA + B	7.6	7.7	7.9	7.6	7.6	7.7	7.7
LP + Greenschoice I	7.5	7.7	7.6*	7.5	7.3	7.3[†]	7.6
LSD (.05) =	.26	.30	.18	.22	.25	.30	.24
F-test	*	.52	.16	.93	[†]	**	.39
CV (%)	2	3	2	2	2	3	2

[‡] Contrast versus Control based on LSD.

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

[§] Treatment Dates:

CA	15 Mar
HJL, HJR, LP + GI	3, 25 Jun; 15 Jul; 11 Aug; 4 Sep
Sand Top., Greenschoice Top.	15 May; 10 Jun; 10 Jul; 6, 28 Aug
Wetting Agent	15 May; 11 Jun; 10 Jul; 7, 28 Aug
Biostimulant	11 Jun; 11 Jul; 7, 28 Aug

Table 1-18. Turfgrass color in 1998 (T-109).[§]

Treatment and Contrast[‡]	Color 1 May	8 Jun	17 Jul	21 Aug	17 Sep
	9.0 = ideal density, color, uniformity; 1.0 = no live turf				
Control vs.	7.4	7.5	7.3	7.4	7.4
CA (Mar)	7.1*	7.4	7.3	7.3	7.4
HJL	7.5	7.5	7.5	7.5	7.5
HJR	7.4	7.5	7.5	7.5	7.5
HJR + Sand	7.5	7.6	7.5	7.4	7.5
HJR + Greenschoice	7.4	7.5	7.5	7.5	7.4
HJR + WA	7.6†	7.6	7.5	7.4	7.6
HJR + B	7.6†	7.4†	7.6†	7.5	7.7†
HJR + Sand + WA	7.5	7.7†	7.5	7.6	7.7†
HJR + Sand + WA + B	7.5	7.6	7.4	7.5	7.5
LP + Greenschoice I	7.5	7.4	7.3	7.0*	7.6
LSD (.05) =	.23	.23	.36	.30	.32
F-test	*	.14	.82	*	.54
CV (%)	2	2	3	3	3

‡ Contrast versus Control based on LSD.

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

§ Treatment Dates:

CA	23 Mar
HJL, HJR, LP + GI	3, 25 Jun; 20 Jul; 10 Aug
Sand Top., Greenschoice Top.	11 May; 9 Jun; 10 Jul; 4 Aug
Wetting Agent	12 May; 9 Jun; 10 Jul; 4 Aug
Biostimulant	9 Jun; 10 Jul; 4 Aug

Table 1-19. Canopy reflectance data presented as the IR/R index in 1996. IR/R = R_{935} / R_{661}; it is often correlated with LAI. (T-109)[§]

Treatment and Contrast [‡]	IR/R							
	13 Jun	25 Jun	12 Jul	7 Aug	30 Aug	11 Sep	18 Sep	8 Oct
	Higher Value = Best							
Control vs.	13.9	12.2	15.9	9.7	10.9	10.8	11.3	12.8
CA	14.4	12.6	16.4	10.3	11.4	11.0	11.2	4.4**
HJL	15.4[†]	11.9	16.3	10.2	12.0[†]	12.3*	12.3	13.9
HJR	14.0	11.7	15.6	10.6	11.5	11.0	12.1	12.7
HJR + Sand	13.6	12.8	14.5[†]	10.1	11.3	11.5	11.4	13.2
HJR + Greenschoice	11.7*	12.7	13.9*	10.4	12.4*	12.1*	12.0	13.2
HJR + WA	14.9	12.2	15.9	11.0[†]	11.5	11.7[†]	11.8	12.2
HJR + B 14.5	11.8	15.5	10.6	12.0[†]	12.2*	11.7	13.9	
HJR + Sand + WA	13.4	12.4	14.5[†]	10.2	11.7	11.4	11.7	13.2
HJR + Sand + WA + B	14.1	12.0	14.3[†]	10.4	12.2[†]	12.1*	11.9	12.9
LP + Greenschoice I	13.5	12.1	15.0	9.8	10.9	9.4*	11.3	12.8
LSD (.05) =	1.6	1.3	1.6	1.3	1.3	1.1	1.4	1.9
F-test	**	.68	*	.80	.38	**	.74	**
CV (%)	8	7	7	9	8	6	8	11

[‡] Contrast versus Control based on LSD.

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

[§] Treatment Dates:

CA	29 Mar; 1 Oct
HJL, HJR, LP + GI	6, 24 Jun; 16 Jul; 8 Aug; 5 Sep
Sand Top., Greenschoice Top.	15 May; 11 Jun; 8, 30 Jul
Wetting Agent	16 May; 11 Jun; 9, 29 Jul; 12 Aug
Biostimulant	11 Jun; 9 Jul; 9 Aug; 13 Sep

Table 1-20. Canopy reflectance data presented as the IR/R index in 1997. IR/R = R_{935} / R_{661}; it is often correlated with LAI. (T-109)[§]

Treatment and Contrast [‡]	IR/R						
	30 Apr	23 May	20 Jun	25 Jul	19 Aug	30 Sep	5 Nov
	---------- Higher Value = Best ----------						
Control vs.	10.1	16.5	12.5	11.8	16.7	15.8	13.1
CA	8.7*	15.7	12.8	12.4	16.1	16.3	12.3
HJL	9.8	15.8	12.4	12.2	16.1	18.1*	14.0
HJR	9.8	16.2	11.9	12.1	16.2	15.8	13.4
HJR + Sand	10.5	16.1	13.2	11.7	15.3†	16.3	13.1
HJR + Greenschoice	10.0	16.3	13.4†	12.4	16.6	16.0	12.4
HJR + WA	10.2	16.6	13.1	12.1	16.2	16.4	13.2
HJR + B	9.8	15.3	12.3	10.9	15.4	17.2	13.9
HJR + Sand + WA	9.7	15.5	12.4	12.4	15.8	15.7	12.8
HJR + Sand + WA + B	9.8	15.9	12.6	12.1	15.6	17.7†	13.9
LP + Greenschoice I	9.6	15.0	11.9	11.3	15.3†	15.5	12.5
LSD (.05) =	.89	1.98	1.16	1.52	1.65	2.17	1.26
F-test	†	.89	.19	.61	.73	.29	†
CV (%)	6	9	6	9	7	9	7

‡ Contrast versus Control based on LSD.

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

§ Treatment Dates:

CA	15 Mar
HJL, HJR, LP + GI	3, 25 Jun; 15 Jul; 11 Aug; 4 Sep
Sand Top., Greenschoice Top.	15 May; 10 Jun; 10 Jul; 6, 28 Aug
Wetting Agent	15 May; 11 Jun; 10 Jul; 7, 28 Aug
Biostimulant	11 Jun; 11 Jul; 7, 28 Aug

Table 1-21. Canopy reflectance data presented as the IR/R index in 1998. IR/R = R_{935} / R_{661}; it is often correlated with LAI. (T-109)[§]

Treatment and Contrast[‡]	IR/R 13 May	18 Jun	31 Jul	21 Aug	10 Sep
	Higher Value = Best				
Control vs.	11.9	11.5	18.8	13.4	16.1
CA (Mar)	11.0	12.3	20.0	13.6	16.0
HJL	11.2	11.3	19.4	13.7	14.9
HJR	12.0	11.5	19.3	13.6	16.5
HJR + Sand	11.4	11.2	19.7	13.6	16.3
HJR + Greenschoice	9.8**	10.8	19.6	13.8	15.9
HJR + WA	11.8	11.4	19.9	14.1	16.7
HJR + B	11.6	11.0	20.0	14.0	15.2
HJR + Sand + WA	10.5*	11.1	18.7	13.8	16.0
HJR + Sand + WA + B	10.6*	10.6	18.8	13.8	14.4
LP + Greenschoice I	12.1	11.4	19.4	13.2	16.9
LSD (.05) =	1.12	1.50	2.5	1.4	3.1
F-test	**	.68	.97	.97	.87
CV (%)	7	9	9	7	13

[‡] Contrast versus Control based on LSD.

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

[§] Treatment Dates:

CA	23 Mar
HJL, HJR, LP + GI	3, 25 Jun; 20 Jul; 10 Aug
Sand Top., Greenschoice Top.	11 May; 9 Jun; 10 Jul; 4 Aug
Wetting Agent	12 May; 9 Jun; 10 Jul; 4 Aug
Biostimulant	9 Jun; 10 Jul; 4 Aug

Table 1-22. Canopy reflectance presented as normalized difference vegetation index (NDVI) in 1996. NDVI = $R_{935} - R_{661} / R_{935} + R_{661}$, where R_{935} = reflectance at 790 - 1080 nm and R_{661} = reflectance at 648 to 674 nm. NDVI is often correlated to green biomass, PAR absorption, and LAI. (T-109)[§]

	NDVI							
Treatment and Contrast [‡]	13 Jun	25 Jun	12 Jul	7 Aug	30 Aug	11 Sep	18 Sep	8 Oct
	1.00 = ideal; 0 = no PAR absorption							
Control vs.	.87	.85	.88	.81	.83	.83	.84	.85
CA	.87	.85	.89[†]	.82	.84	.83	.84	.63**
HJL	.88	.85	.88	.82	.85	.85*	.85	.86
HJR	.87	.84[†]	.88	.83	.84	.83	.85	.85
HJR + Sand	.86	.85	.87	.82	.84	.84[†]	.84	.86
HJR + Greenschoice	.84*	.85	.87	.83	.85	.85*	.85	.86
HJR + WA	.87	.85	.88	.83	.84	.84[†]	.84	.84
HJR + B .87	.84[†]	.88	.83	.85	.85*	.84	.86	
HJR + Sand + WA	.86	.85	.87[†]	.82	.84	.84[†]	.84	.86
HJR + Sand + WA + B	.87	.85	.87[†]	.82	.85	.85*	.84	.85
LP + Greenschoice I	.86	.85	.87[†]	.81	.83	.81*	.84	.85
LSD (.05) =	.02	.01	.01	.02	.02	.01	.02	.03
F-test	**	.70	*	.80	.44	**	.77	**
CV (%)	1	1	7	2	2	1	1	2

[‡] Contrast versus Control based on LSD.

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

[§] Treatment Dates:

CA	29 Mar; 1 Oct
HJL, HJR, LP + GI	6, 24 Jun; 16 Jul; 8 Aug; 5 Sep
Sand Top., Greenschoice Top.	15 May; 11 Jun; 8, 30 Jul
Wetting Agent	16 May; 11 Jun; 9, 29 Jul; 12 Aug
Biostimulant	11 Jun; 9 Jul; 9 Aug; 13 Sep

Table 1-23. Canopy reflectance presented as normalized difference vegetation index (NDVI) in 1997. NDVI = $R_{935} - R_{661} / R_{935} + R_{661}$, where R_{935} = reflectance at 790 - 1080 nm and R_{661} = reflectance at 648 to 674 nm. NDVI is often correlated to green biomass, PAR absorption, and LAI. (T-109)[§]

Treatment and Contrast [‡]	NDVI						
	30 Apr	23 May	20 Jun	25 Jul	19 Aug	30 Sep	5 Nov
	1.00 = ideal; 0 = no PAR absorption						
Control vs.	.82	.88	.85	.84	.89	.88	.86
CA	.79*	.88	.85	.85	.88	.88	.85
HJL	.82	.88	.85	.85	.88	.90	.87
HJR	.81	.88	.84	.85	.88	.88	.86
HJR + Sand	.83	.88	.86	.83	.88	.88	.86
HJR + Greenschoice	.82	.88	.86	.85	.88	.88	.85
HJR + WA	.82	.89	.86	.85	.88	.88	.86
HJR + B	.81	.88	.85	.83	.88	.89	.87
HJR + Sand + WA	.81	.88	.85	.85	.88	.88	.85
HJR + Sand + WA + B	.82	.88	.85	.85	.88	.89	.86
LP + Greenschoice I	.81	.87	.84	.83	.88	.88	.85
LSD (.05) =	.016	.014	.013	.024	.011	.015	.013
F-test	†	.90	.20	.71	.80	.40	†
CV (%)	1	1	1	2	1	1	1

‡ Contrast versus Control based on LSD.

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

§ Treatment Dates:

CA	15 Mar
HJL, HJR, LP + GI	3, 25 Jun; 15 Jul; 11 Aug; 4 Sep
Sand Top., Greenschoice Top.	15 May; 10 Jun; 10 Jul; 6, 28 Aug
Wetting Agent	15 May; 11 Jun; 10 Jul; 7, 28 Aug
Biostimulant	11 Jun; 11 Jul; 7, 28 Aug

Table 1-24. Canopy reflectance presented as normalized difference vegetation index (NDVI) in 1998. NDVI = $R_{935} - R_{661} / R_{935} + R_{661}$, where R_{935} = reflectance at 790 to 1080 nm and R_{661} = reflectance at 648 to 674 nm. NDVI is often correlated to green biomass, PAR absorption, and LAI (T-109).[§]

Treatment and Contrast[‡]	NDVI				
	13 May	18 Jun	31 Jul	21 Aug	10 Sep
	1.00 = ideal; 0 = no PAR absorption				
Control vs.	.84	.84	.90	.86	.88
CA (Mar)	.83	.85	.90	.86	.88
HJL	.84	.84	.90	.86	.87
HJR	.84	.84	.90	.86	.88
HJR + Sand	.84	.84	.90	.86	.88
HJR + Greenschoice	.81*	.83	.90	.86	.88
HJR + WA	.84	.84	.90	.87†	.89
HJR + B	.84	.83	.90	.87†	.87
HJR + Sand + WA	.82*	.83	.90	.86	.88
HJR + Sand + WA + B	.83	.83	.90	.86	.87
LP + Greenschoice I	.85	.84	.90	.86	.88
LSD (.05) =	.02	.02	.01	.01	.02
F-test	**	.70	.94	.93	.94
CV (%)	1	1	1	1	2

‡ Contrast versus Control based on LSD.

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

§ Treatment Dates:

CA	23 Mar
HJL, HJR, LP + GI	3, 25 Jun; 20 Jul; 10 Aug
Sand Top., Greenschoice Top.	11 May; 9 Jun; 10 Jul; 4 Aug
Wetting Agent	12 May; 9 Jun; 10 Jul; 4 Aug
Biostimulant	9 Jun; 10 Jul; 4 Aug

Table 1-25. Canopy reflectance at 661 nm in 1996 (T-109). Range 648-674 nm (Red, PAR). Low percent reflectance = higher PAR absorption.[§]

Treatment and Contrast [‡]	Reflectance (661 nm) 13 Jun	25 Jun	12 Jul	7 Aug	30 Aug	11 Sep	18 Sep	8 Oct
	%							
Control vs.	4.4	5.1	4.1	5.7	5.2	7.1	6.5	5.5
CA	4.3	4.9	4.1	5.5	5.1	7.2	6.6	7.9**
HJL	4.0*	5.4	4.1	5.5	4.9	6.7†	6.2	5.4
HJR	4.3	5.3	4.2	5.3†	5.0	7.1	6.2	5.8
HJR + Sand	4.1†	4.9	4.2	5.3†	5.1	6.9	6.6	5.3
HJR + Greenschoice	4.3	4.8	4.1	5.1*	4.7	6.7†	6.3	5.5
HJR + WA	4.2	5.2	4.2	5.2*	5.1	6.9	6.3	5.8
HJR + B 4.2	5.4	4.2	5.2*	4.9	6.6*	6.4	5.3	
HJR + Sand + WA	4.1†	4.9	4.2	5.3†	5.0	7.0	6.3	5.5
HJR + Sand + WA + B	3.9*	5.2	4.2	5.2*	4.8	6.7†	6.3	5.7
LP + Greenschoice I	4.3	4.9	4.3	5.5	5.3	7.6*	6.4	5.6
LSD (.05) =	.36	.52	.45	.48	.46	.45	.64	.67
F-test	.21	.20	.99	.39	.36	**	.95	**
CV (%)	6	7	7	6	6	4	7	8

‡ Contrast versus Control based on LSD.

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

§ Treatment Dates:

CA	29 Mar; 1 Oct
HJL, HJR, LP + GI	6, 24 Jun; 16 Jul; 8 Aug; 5 Sep
Sand Top., Greenschoice Top.	15 May; 11 Jun; 8, 30 Jul
Wetting Agent	16 May; 11 Jun; 9, 29 Jul; 12 Aug
Biostimulant	11 Jun; 9 Jul; 9 Aug; 13 Sep

Table 1-26. Canopy reflectance at 661 nm in 1997 (T-109). Range 648-674 nm (Red, PAR). Low percent reflectance = higher PAR absorption.[§]

Treatment and Contrast[‡]	Reflectance (661 nm) 30 Apr	23 May	20 Jun	25 Jul	19 Aug	30 Sep	5 Nov
	%						
Control vs.	4.8	3.8	4.8	5.0	4.0	4.1	4.7
CA	5.3*	4.0	4.7	5.0	4.2	4.1	5.1†
HJL	4.9	4.0	4.8	5.1	4.2	3.7*	4.6
HJR	5.0	3.8	4.9	5.0	4.1	4.1	4.7
HJR + Sand	4.7	3.9	4.6	5.4	4.3	4.0	4.8
HJR + Greenschoice	4.8	3.8	4.5†	5.0	4.0	4.1	5.1†
HJR + WA	4.9	3.8	4.6	5.1	4.2	4.0	4.8
HJR + B	4.9	4.1	4.8	5.6†	4.3	3.8†	4.5
HJR + Sand + WA	4.9	3.9	4.7	4.9	4.2	4.1	4.8
HJR + Sand + WA + B	4.8	3.9	4.8	5.1	4.3	3.7*	4.6
LP + Greenschoice I	5.0	4.1	4.9	5.2	4.2	4.2	4.9
LSD (.05) =	.37	.39	.30	.72	.38	.39	.42
F-test	.16	.84	†	.80	.79	.18	.17
CV (%)	5	7	4	10	6	7	6

‡ Contrast versus Control based on LSD.

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

§ Treatment Dates:

CA	15 Mar
HJL, HJR, LP + GI	3, 25 Jun; 15 Jul; 11 Aug; 4 Sep
Sand Top., Greenschoice Top.	15 May; 10 Jun; 10 Jul; 6, 28 Aug
Wetting Agent	15 May; 11 Jun; 10 Jul; 7, 28 Aug
Biostimulant	11 Jun; 11 Jul; 7, 28 Aug

Table 1-27. Canopy reflectance at 661 nm in 1998 (T-109). Range 648 - 674 nm (Red, PAR). Low percentage = higher PAR absorption.[§]

Treatment and Contrast[‡]	Reflectance (661 nm) 13 May	18 Jun	31 Jul	21 Aug	10 Sep
	%				
Control vs.	4.7	5.2	3.3	4.4	4.1
CA (Mar)	5.0	4.9	3.2	4.4	4.1
HJL	5.2*	5.4	3.3	4.3	4.4
HJR	4.7	5.3	3.2	4.3	4.1
HJR + Sand	4.8	5.2	3.2	4.2	4.1
HJR + Greenschoice	5.1[†]	5.2	3.2	4.1	4.2
HJR + WA	4.9	5.3	3.2	4.1[†]	3.9
HJR + B	5.0	5.6	3.2	4.1[†]	4.3
HJR + Sand + WA	5.0	5.4	3.3	4.2	4.2
HJR + Sand + WA + B	5.1[†]	5.6	3.3	4.2	4.5
LP + Greenschoice I	4.7	5.0	3.2	4.4	3.9
LSD (.05) =	.49	.66	.29	.35	.69
F-test	.27	.52	.98	.73	.84
CV (%)	7	9	6	6	11

‡ Contrast versus Control based on LSD.

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

§ Treatment Dates:

CA	23 Mar
HJL, HJR, LP + GI	3, 25 Jun; 20 Jul; 10 Aug
Sand Top., Greenschoice Top.	11 May; 9 Jun; 10 Jul; 4 Aug
Wetting Agent	12 May; 9 Jun; 10 Jul; 4 Aug
Biostimulant	9 Jun; 10 Jul; 4 Aug

Table 1-28. Summary of bentgrass shoot growth responses (visual quality, shoot density, color) and shoot physiological health responses (IR/R, NDVI, Ref. 661 nm) relative to the Control for 1996 to 1998 (T-109).

Treatment and Contrast‡	Visual‡ Quality		Shoot‡ Density		Turf‡ Color		IR/R¶		NDVI¶		Reflect¶ 661 nm		All Indexes	
	<	>	<	>	<	>	<	>	<	>	<	>	<	>
	%													
Control vs.	—	—	—	—	—	—	—	—	—	—	—	—	—	—
CA (Mar)	29	0	29	0	10	5	10	0	10	5	15	0	17	2
HJL	0	19	0	38	0	19	0	20	0	5	5	15	1	19
HJR	0	14	0	24	0	10	0	0	5	0	0	5	1	9
HJR + Sand	0	0	0	0	0	5	10	0	0	5	0	10	2	3
HJR + Greenschoice	10	0	0	10	0	5	15	15	10	5	10	15	8	8
HJR + WA	0	14	0	29	0	10	0	10	0	10	0	10	0	14
HJR + B	0	14	0	14	0	29	0	10	5	10	5	20	2	16
HJR + Sand + WA	5	19	0	24	0	14	10	0	10	5	0	10	4	12
HJR + Sand + WA + B	0	0	0	10	0	5	10	15	5	5	5	20	3	9
LP + Greenschoice I	48	0	33	0	24	0	10	0	10	0	5	0	22	0

‡ Based on percent of ratings in 1996 (9), 1997 (7), and 1998 (5) when the treatment was less than (<) or greater than (>) the Control.
¶ IR/R = R_{935} / R_{661}; NDVI = $R_{935} - R_{661} / R_{935} + R_{661}$; Reflectance 661 nm where less reflectance is best.

Table 1-29. Root length density (RLD) by depth, change in RLD by depth, total root length (TRL), and change in TRL in 1996. Sample dates were 25 June and 11 September 1996 (T-109).

Treatment and Contrast[§]	Root Length Density (RLD) 25 Jun 96 3 to 10 cm	25 Jun 96 10 to 20 cm	11 Sep 96 3 to 10 cm	11 Sep 96 10 to 20 cm	Percent Roots (RLD) Retained Jun to Sep 3 to 10 cm	Percent Roots (RLD) Retained Jun to Sep 10 to 20 cm	Total Root Length (TRL) 25 Jun	Total Root Length (TRL) 11 Sep	Percent Roots (TRL) Retained Jun to Sep
	cm cm^{-3}				%		cm cm^{-2}		%
Control vs.	19.66	2.13	4.85	0.96	25	45	169	47	27
CA	15.99	2.56	5.14	0.47*	32	18	145	43	30
HJL	18.08	1.77	5.12	0.49*	28	28	153	43	28
HJR	14.70	1.46	6.87	0.61†	47	42	125	58	46
HJR + Sand	17.39	2.22	6.06	0.79	35	36	153	53	35
HJR + Greenschoice	23.12	1.69	9.66†	0.52*	42	31	190	78†	41
HJR + WA	14.91	2.52	4.67	0.63†	31	25	137	41	30
HJR + B	22.01	3.10	4.88	0.88	22	28	196	45	23
HJR + Sand + WA	21.53	2.28	6.60	0.80	31	35	184	58	32
HJR + Sand + WA + B	19.68	2.01	6.16	0.53*	31	26	168	52	31
LP + Greenschoice I	17.56	3.37	7.18	0.73	41	22	165	61	37
LSD (.05) =	9.60	1.87	4.90	0.38	31	61	80	37	26
F-test	.69	.62	.67	.15	.92	.34	.76	.93	.84
CV (%)	36	56	56	39	60	101	34	47	53

‡ Contrast versus Control based on LSD.
**, *, † Significant difference at P≤.01, .05, and .10.

PROJECT 2:

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

R. N. Carrow

Proposed Problem. Creeping bentgrass produces a very high root mass within the surface 1 or 2 inches that can fill much of the pore space (i.e., organic matter content within the 0 to 2-inch zone can be 8 to12% or more on a weight basis compared to about 1% to 4% 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, infiltration rates decline to 25-40% of initial laboratory rates. It is the hypothesis of the author that the degree of pore plugging/sealing in the fall to spring period by primarily live root tissue is sufficient to a) cause low soil O_2 and infiltration rates during this root development period, and b) cause reduced root growth. This is proposed as the reason for the observation that rooting depth invariability declines to less than observed within the first 1 or 2 years of a new USGA green. This example of organic matter dynamics:

* is a problem primarily of how to enhance root development during the cool 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.

Objectives

To determine the effectiveness of selected fall/spring applied cultivation practices and amendments that may enhance macroporosity for improvement of:

- shoot performance
- bentgrass root development
- water infiltration (early fall to late spring)
- soil O_2 status (early fall to late spring)

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 2-1 contains the list of treatments. The dates of treatment application in 1996 to 1998 were:

Treatment†	1996	
CA	22 Mar	19 Sep
HJR, Quad, ST	28 Mar, 18 Apr, 13 May	19 Sep, 8 Oct, 3 Dec
Greenschoice Top.	29 Mar, 22 Apr	19 Sep, 9 Oct, 3 Dec (¼ X)
Wetting Agent	2 Apr, 23 Apr	19 Sep, 10 Oct, 3 Dec
LP + GI	11 Jun	19 Sep, 8 Oct, 3 Dec

Treatment†	1997	
CA	6 Mar	15 Oct
HJR, Quad, AW	6 Mar, 3 Apr, 15 May	23 Sep, 14 Oct, 11 Nov
Greenschoice Top.	28 Mar, 17 Apr, 7 May	3 Oct, 27 Oct, 30 Nov
Wetting Agent	11 Mar, 17 Apr, 8 May	1 Oct, 27 Oct, 30 Nov
LP + GI	7 Mar, 3 Apr, 15 May	24 Sep, 27 Oct

Treatment†	1998
CA	4 Mar
HJR, Quad, AW	5 Feb, 3 Mar, 1 Apr, 12 May
Greenschoice Top.	11 Mar, 23 Mar, 13 Apr
Wetting Agent	4 Mar, 24 Mar, 13 Apr
LP + GI	Received HJR application same as HJR treatment in 1998

† In 1996 a solid tine (ST) of ½ inch diameter was used but changed to an Aerway (AW) Slicer in 1997 and 1998.

In addition to the above treatment applications, all plots received light, frequent topdressing through the year at 0.50 (summer) to 1.00 (rest of year) ft^3 per 1000 ft^2 on a 3-week schedule. Thus, Greenschoice topdressing treatment is in addition to these applications.

Table 2-1. Treatments for study T-108.

Treat No.	Description	Target 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 (Aerway 100 Fine Tines, 97 = AW)	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 (Aerway 97 = AW+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 at about 6.2 ft^3 per 1000 ft^2.

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

[c] Wetting Agent. Used Naiad as a spray application at 3 ounces Naiad per 1000 ft^2. Water in briefly to get off of leaves.

[d] LandPride plug Greenschoice Injection = injection of Greenschoice into vertical holes created byf the LandPride. After 1997 these plots did not receive this treatment but it was altered to HJR + 70% sand, 30% Greenschoice as a topdressing.

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

All plots received light, frequent topdressing at 0.50 (summer) and 1.00 (rest of year) ft^3 per 1000 ft^2 on a 3-week schedule. Thus, topdressing treatments were in addition to this routine topdressing.

Results

All data has been obtained relative to treatment effects on a) soil physical conditions (Table 2-2 to 2-9), and b) shoot responses (Tables 2-10 to 2-22). Rooting data are presented in Tables 2-23 (1996) and 2-24 (1997). Root data for 1998 are in progress.

Summary tables are:

- Table 2-5. Saturated hydraulic conductivity.
- Table 2-9. Soil ODR.
- Table 2-22. Shoot responses.

Table 2-2. Total aeration and capillary (moisture retention) porosity of the surface 0 to 3.0 cm zone in June 1997 and 1998 (T-108).

Treatment and Contrast‡	Total Porosity		Aeration Porosity (-0.004 MPa)		Moisture Retention (-0.004 MPa)	
	2 Jun 97	2 Jun 98	2 Jun 97	2 Jun 98	2 Jun 97	2 Jun 98
	% (Vol.)					
Control vs.	82	74	9.5	19.4	72.0	54.8
CA (Mar, Sep)	79	70†	10.5	16.3	68.8	54.0
HJR	80	72	9.0	17.9	70.7	54.4
QT	79	72	8.7	16.6	70.5	55.7
AW	80	73	9.7	15.3	70.1	57.8
HJR + Greenschoice (G)	82	73	8.2	19.8	74.1	53.7
QT + Greenschoice	77†	71	7.9	16.1	69.2	54.8
AW + Greenschoice	80	71	8.6	20.2	71.5	51.0
HJR + Wet Agent (WA)	81	74	9.1	15.4	71.6	58.7
HJR + G + WA	80	70†	9.0	16.3	71.2	53.8
LP + GI	79	74	10.0	20.0	69.0	54.5
LSD (.05) =	5.0	4.6	2.1	5.7	4.1	5.4
F-test =	.79	.47	.33	.51	.33	.33
CV (%)	4	4	16	23	4	7
Desired Range	35-50		15-25		12-18	

**, *, † Significant difference at P ≤.01, .05, and .10.
‡ Contrast is versus Control by LSD.
§ Weight is grams per 50 cm^2 x 3.0 cm deep sample.

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Table 2-3. Soil physical properties of the surface 0 to 3.0 cm zone in June 1997 and 1998 (T-108).

Treatment and Contrast	Bulk Density		Percent Organic Matter		Organic Matter Content‡		Mineral Matter Content‡	
	2 Jun 97	2 Jun 98	2 Jun 97	2 Jun 98	2 Jun 97	2 Jun 98	2 Jun 97	2 Jun 98
	—— gcm^{-3} ——		—— % (Wt.) ——		—— g ——			
Control vs.	.38	.51	18.4	16.1	10.8	13.0	47.9	67.5
CA (Mar, Sep)	.50†	.69*	14.3†	9.3**	10.8	9.8**	64.7†	95.3*
HJR	.39	.52	18.5	16.5	11.1	13.6	48.8	68.7
QT	.49†	.56	15.0	13.8	11.2	13.2	63.0†	76.0
AW	.43	.60	17.2	13.1†	11.3	12.2	54.4	81.2
HJR + Greenschoice (G)	.40	.53	17.7	14.2	10.9	11.8*	50.7	71.4
QT + Greenschoice	.48†	.66*	15.0	9.8**	10.9	10.0**	61.9	92.0*
AW + Greenschoice	.46	.58	15.2	12.3*	10.8	11.0*	60.1	78.6
HJR + Wet Agent (WA)	.41	.50	17.9	16.8	11.2	13.5	51.4	66.9
HJR + G + WA	.47	.61	15.0	11.2*	10.8	10.6**	61.3	83.9
LP + GI	.41	.66*	16.3	9.8**	10.3	10.0**	52.7	91.7*
LSD (.05) =	.12	.14	4.5	3.1	.7	1.1	17.8	21.9
F-test =	.44	†	.61	.12	.23	.13	.45	†
CV (%) =	18	17	19	18	4	7	22	19
Desired Range	1.2 to 1.6		2.0 to 4.0		–		–	

**, *, † Significant difference at P ≤.01, .05, and .10. Contrast is versus Control by LSD.
‡ Weight is grams per 50 cm^2 x 3.0 cm deep sample.

Table 2-4. Saturated hydraulic conductivity (SHC) in 1996 to 1998. DAC = days after last HJR cultivation. (T-108)

Treatment and Contrast	1996 16 May (3 DAC)	6 Jun (24 DAC)	21 Oct (13 DAC)	5 Nov (28 DAC)	9 Dec (6 DAC)	1997 13 Jan (41 DAC)	21 May (6 DAC)	9 Jun (24 DAC)	21 Oct (7 DAC)	7 Nov (24 DAC)	1998 20 May (8 DAC)	12 Jun (31 DAC)
	mm hr^{-1}											
Control vs.	120	125	83	137	14	9	22	17	86	24	31	14
CA (Mar, Sep)	102	223	87	82	50	54	317**	100	636*	165**	117	58
HJR	684**	588**	444**	137	190**	109*	114	186*	256	28	262*	236**
QT	186	94	202	108	85	87†	152	28	195	43	42	35
AW§	392	432†	56	74	47	94†	194	139†	280	98	39	31
HJR + Greenschoice (G)	423†	333	207	170	142*	85†	206	43	146	59	502**	224**
QT + Greenschoice	83	90	138	39*	166**	23	72	52	175	54	37	56
AW + Greenschoice‡	503*	106	255*	95	60	25	41	54	228	51	28	50
HJR + Wet Agent (WA)	561*	528*	198	156	250**	193**	116	166	186	150**	397**	129*
HJR + G + WA	680**	437†	221†	115	125*	106*	286†	136†	390†	87	88	85
LP + GI	–	–	82	41*	38	135**	76	154†	80	49	212†	32
LSD (.05) =	380	340	160	95	102	89	266	138	330	102	206	111
F-test =	**	*	**	†	**	**	.39	†	†	†	**	**
CV (%) =	70	79	62	63	67	74	126	97	94	96	90	89

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

‡ In 1996 a solid tine (ST) of ½ inch diameter was used but changed to an Aerway (AW) Slicer in 1997 and 1998.

Table 2-5. Summary of saturated hydraulic conductivity (SHC) data at selected days after HJR cultivation operation (DAC) in 1996 to 1998 (T-108).

Treatment and Contrast‡	Average SHC		Percent of Readings Greater than Control‡		Percent of Readings ≥120 mm hr^{-1}	
	1-13 DAC	24-41 DAC	1-13 DAC	24-41 DAC	1-13 DAC	24-41 DAC
	mm hr^{-1}		%		%	
Control vs.	57	71	—	—	17	33
CA (Mar, Sep)	221*	114	33	17	33	33
HJR	339**	214**	67	50	83	67
QT	152	73	0	17	67	0
AW§	168	145†	0	50	50	33
HJR + Greenschoice (G)	256*	152*	50	17	100	50
QT + Greenschoice	105	53	17	0	50	0
AW + Greenschoice§	186†	63	33	0	50	0
HJR + Wet Agent (WA)	307**	221**	50	50	83	100
HJR + G + WA	283**	183*	83	50	83	50
LP + GI	86	83	0	33	20	40
LSD (.05) =	145	80	—	—	—	—
F-test =	**	**	—	—	—	—
CV (%) =	49	43	—	—	—	—

**, *, † Significant difference at P ≤.01, .05, and .10. Contrast is versus the Control by LSD.

§ In 1996 a solid tine (ST) of ½ inch diameter was used but in 1997 the Aerway (AW) Slicer was used.

‡ Percent of readings statistically greater than Control.

Table 2-6. Oxygen diffusion rate (ODR) and moisture retention data in the surface 3 cm zone in 1996 at different times after irrigation (T-108). DAC = days after HJR cultivation.

Treatment	29 Oct (21 DAC)			4 Dec (1 DAC)	
	2.5 hrs	8 hrs	31 hrs	3.0 hrs	26 hrs
ODR (μgO_2 cm^{-2} min^{-1})					
CA (Mar, Sep) vs.	.15	.14	.19	.10	.09
HJR + WA	.18	.15	.15	.08	.08
HJR + G + WA	.12	.15	.12	.06	.06
LSD (.05)	.12	.09	.10	.05	.04
F-test	.49	.89	.28	.16	.19
CV (%)	53	40	48	39	29
Moisture Retention (% Vol)					
CA (Mar, Sep) vs.	54.3	49.9	46.0	47.7	46.7
HJR + WA	54.2	50.0	46.5	48.0	47.3
HJR + G + WA	54.5	48.4	46.5	47.9	47.3
LSD (.05)	2.3	4.4	2.2	1.8	2.0
F-test	.81	.65	.90	.94	.54
CV (%)	3	6	3	2	3

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

Table 2-7. Oxygen diffusion rate (ODR) at 3 and 10 cm depths and moisture retention at 0 to 6 cm in 1997 at different times after irrigation (T-108). DAC = days after last HJR cultivation.

	21 May (8 DAC)				22 Oct (8 DAC)				4 Nov (20 DAC)				2 Dec (21 DAC)			
	3 cm		10 cm		3 cm		10 cm		3 cm		10 cm		3 cm		10 cm	
Treatment	3.0 hrs	26 hrs	3.0 hrs	26 hrs	3.0 hrs	26 hrs	3.0 hrs	26 hrs	3.0 hrs	26 hrs	3.0 hrs	26 hrs	3.0 hrs	26 hrs	3.0 hrs	26 hrs
ODR (μgO_2 cm^{-2} min^{-1})																
CA (Mar, Sep) vs.	.21	.29	.18	.19	.10	.21	.25	.27	.18	.28	.20	.18	.24	.20	.21	.18
HJR + WA	.15	.26	.20	.15	.20	.23	.21	.27	.19	.28	.14	.16	.25	.21	.26	.21
HJR + G + WA	.23	.26	.18	.16	.14	.22	.31	.25	.18	.26	.17	.18	.18	.23	.19	.19
LSD (.05)	.11	.07	.06	.05	.13	.12	.12	.13	.10	.13	.08	.06	.19	.13	.08	.07
F-test	.49	.25	.52	.48	.25	.91	.20	.93	.98	.80	.61	.51	.62	.50	.71	.65
CV (%)	38	16	23	20	49	31	27	29	33	17	45	19	49	35	21	21
Moisture Retention (% Vol)																
CA (Mar, Sep) vs.	45.8	45.4	—	—	52.0	51.7	—	—	50.6	49.6	—	—	52.0	49.7	—	—
HJR + WA	47.1	47.2	—	—	51.5	50.0	—	—	52.9	51.6	—	—	54.0	52.5	—	—
HJR + G + WA	46.8	46.7	—	—	51.5	51.4	—	—	52.4	51.7	—	—	53.0	51.9	—	—
LSD (.05)	1.7	2.4	—	—	3.3	5.7	—	—	4.2	4.2	—	—	3.2	3.7	—	—
F-test	.26	.30	—	—	.89	.75	—	—	.44	.43	—	—	.37	.22	—	—
CV (%)	2	3	—	—	4	6	—	—	5	5	—	—	4	4	—	—

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

Table 2-8. Oxygen diffusion rate (ODR) at 3 and 10 cm depths and moisture retention at 0 to 6 cm data in 1998 at different times after irrigation (T-108). DAC = days after last HJR cultivation.

	19 May (7 DAC)		25 May (13 DAC)				(10 Jun (29 DAC)			
	3 cm	10 cm	3 cm		10 cm		3 cm		10 cm	
Treatment	3.0 hrs	3.0 hrs	3.0 hrs	26 hrs	3.0 hrs	26 hrs	3.0 hrs	26 hrs	3.0 hrs	26 hrs
ODR (μgO_2 cm^{-2} min^{-1})										
CA (Mar, Sep) vs.	.14	.42	.17	.32	.37	.32	.13	.35	.29	.36
HJR + WA	.17	.34	.21	.44	.32	.42	.14	.41†	.36	.34
HJR + G + WA	.18	.45	.22	.45	.46	.45	.11	.44*	.38	.42
LSD	.06	.13	.11	.17	.19	.18	.08	.07	.20	.08
F-test	.29	.19	.46	.20	.24	.23	.69	*	.62	†
CV (%)	22	18	31	25	27	26	36	11	29	12
Moisture Retention (% Vol.)										
CA (Mar, Sep) vs.	52.6	—	49.8	48.0	—	—	53.6	52.9	—	—
HJR + WA	51.2	—	52.2	51.5	—	—	54.9	54.7	—	—
HJR + G + WA	54.8	—	52.1	50.8	—	—	54.9	53.6	—	—
LSD (.05)	11.6	—	4.1	5.3	—	—	2.4	2.8	—	—
F-test	.77	—	.32	.30	—	—	.37	.32	—	—
CV (%)	13	—	5	6	—	—	3	3	—	—

Table 2-9. Summary of oxygen diffusion rate (ODR) and surface moisture (0 to 6 cm) data for 1996 to 1998 (T-108).

	Percent Readings ≤0.20 μg O_2 cm^{-2} min^{-1} †								Moisture Content at 0 to 6 cm			
	3 cm				10 cm							
	1996	1997	1998	AVE	1996	1997	1998	AVE	1996	1997	1998	AVE
									% (Vol)			
CA (Mar, Sep)	100	25	60	62	–	63	0	32	48.9	49.6	51.4	50.0
HJR + WA	100	38	40	59	–	59	9	25	49.2	50.9	52.9	51.0
HJR + G + WA	100	38	40	59	–	75	0	38	48.9	50.7	53.3	51.0
									49.0	50.4	52.5	

	Average ODR (μg O_2 cm^{-2} min^{-1})							
	3 cm				10 cm			
	1996	1997	1998	AVE	1996	1997	1998	AVE
CA (Mar, Sep)	.13	.21	.22		–	.21	.35	
HJR + WA	.13	.22	.27		–	.20	.36	
HJR + G + WA	.10	.21	.28		–	.20	.43	
	.12	.21	.26			.20	.38	

† An ODR rate of ≤0.20 μg O_2 cm^{-2} min^{-1} is considered as limiting for maximum root function.

Table 2-10. Bentgrass visual quality in 1996. (T-108)

Treatment and Contrast	Visual Quality 9 May	30 May	12 Jun	26 Jun	23 Jul	30 Aug	3 Oct	30 Oct	25 Nov
	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	7.4	7.5
CA (Mar, Sep)	7.8	7.8	7.6	7.6	7.6	7.5	7.3	7.4	7.3
HJR	7.8	7.8	7.9	7.5†	7.7†	7.5	7.4	7.4	7.6
QT	7.8	7.9	7.8	7.6	7.8	7.6	7.5	6.6**	7.1*
ST	7.3*	7.3**	7.2*	6.8**	7.6	7.3	6.5**	6.9*	7.1*
HJR + Greenschoice (G)	7.5	7.7	7.8	7.8	7.5	7.6	7.5	7.6	7.6
QT + Greenschoice	7.7	7.9	7.8	7.6	7.7†	7.6	7.4	6.7*	7.0*
ST + Greenschoice	7.3*	7.4**	7.6	7.3*	7.6	7.4	6.6**	7.3	7.2†
HJR + Wet Agent (WA)	7.6	8.0	7.7	7.7	7.6	7.6	7.4	7.4	7.5
HJR + G + WA	7.8	8.0	7.7	7.5†	7.8*	7.6	7.5	7.5	7.5
LP + GI	–	–	7.7	7.7	7.6	7.5	7.2†	7.4	7.4
LSD (.05) =	.29	.28	.38	.31	.29	.21	.38	.49	.38
F-test =	**	**	*	**	.52	.17	**	**	**
CV (%) =	3	2	3	3	3	2	4	5	4

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

Table 2-11. Bentgrass visual quality in 1997 and 1998. (T-108)

Treatment and Contrast	1997						1998		
	8 Apr	16 May	12 Jun	15 Jul	7 Aug	15 Oct	29 Jan	1 May	8 Jun
	9 = ideal density, color, uniformity; 1 = no live turf								
Control vs.	7.5	7.5	7.6	7.2	7.2	7.4	7.3	7.4	7.4
CA (Mar, Sep)	7.0**	7.6	7.2†	7.2	7.0	6.9**	6.5**	7.0*	7.5
HJR	7.6	7.5	7.6	7.4	7.1	7.3	7.3	7.3	7.4
QT	6.5**	6.6**	6.8**	7.3	6.9*	7.0*	6.9†	7.3	7.6
AW	7.5	7.3	7.5	7.5*	7.3	7.1*	7.1	7.1*	7.5
HJR + Greenschoice (G)	7.6	7.6	7.6	7.4	7.4	7.5	7.5	7.1*	7.4
QT + Greenschoice	6.3**	6.8*	6.8**	7.1	7.0	7.0*	7.0	7.4	7.4
AW + Greenschoice	7.6	7.4	7.6	7.6*	7.3	7.1*	7.0	7.3	7.5
HJR + Wet Agent (WA)	7.5	7.6	7.8	7.5*	7.3	7.1*	7.5	7.4	7.6
HJR + G + WA	7.3	7.6	7.5	7.4†	7.2	7.3	7.4	7.3	7.4
LP + GI	7.4	7.4	7.5	7.5*	7.4	7.5	7.2	7.4	7.4
LSD (.05) =	.30	.60	.48	.27	.27	.29	.43	.27	.21
F-test =	**	**	**	**	**	**	**	†	.35
CV (%) =	3	6	5	3	3	3	4	3	2

**, *, † Significant difference at P ≤.01, .05, and .10. Contrast is versus Control by LSD.

Table 2-12. Bentgrass shoot density in 1996. (T-108)

Treatment and Contrast	Shoot Density								
	9 May	30 May	12 Jun	26 Jun	23 Jul	30 Aug	3 Oct	30 Oct	25 Nov
	9 = ideal density; 1 = no live turf								
Control vs.	7.9	8.1	7.8	7.9	7.6	7.4	7.5	7.5	7.6
CA (Mar, Sep)	7.9	7.9	7.7	7.7	7.6	7.5	7.6	7.6	7.4†
HJR	7.9	8.0	8.0	7.6†	7.8	7.6	7.4	7.5	7.7
QT	7.9	8.0	7.9	7.6†	7.8	7.6	7.5	7.4	7.4†
ST	7.4*	7.5**	7.3*	7.1**	7.6	7.5	7.3	7.4	7.4†
HJR + Greenschoice (G)	7.6†	7.8†	7.8	7.8	7.5	7.6	7.5	7.6	7.7
QT + Greenschoice	7.8	8.0	7.8	7.7	7.7	7.7†	7.5	7.3	7.2*
ST + Greenschoice	7.5*	7.7*	7.6	7.4*	7.7	7.5	7.3	7.5	7.4†
HJR + Wet Agent (WA)	7.8	8.1	7.8	7.9	7.6	7.6	7.4	7.5	7.6
HJR + G + WA	7.9	8.1	7.7	7.7	7.8	7.7*	7.5	7.6	7.6
LP + GI	–	–	7.7	7.9	7.6	7.6	7.3	7.5	7.5
LSD (.05) =	.35	.32	.40	.35	.31	.19	.26	.28	.25
F-test =	*	**	.14	**	.50	.18	.21	.46	**
CV (%) =	3	3	4	3	3	2	2	3	2

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

Table 2-13. Bentgrass shoot density in 1997 and 1998. (T-108)

Treatment and Contrast	1997 8 Apr	16 May	12 Jun	15 Jul	7 Aug	15 Oct	1998 29 Jan	1 May	8 Jun
	9 = ideal shoot density; 1 = no live turf								
Control vs.	7.7	7.7	7.6	7.3	7.3	7.5	7.5	7.4	7.4
CA (Mar, Sep)	7.4*	7.6	7.5	7.4	7.2	7.5	7.1**	7.0*	7.5
HJR	7.7	7.6	7.7	7.5	7.3	7.4	7.5	7.4	7.5
QT	7.3*	7.4*	7.2	7.4	7.1	7.6	7.3*	7.3	7.6†
AW	7.6	7.5†	7.6	7.7*	7.4	7.6	7.5	7.3	7.5
HJR + Greenschoice (G)	7.7	7.7	7.6	7.5	7.5	7.5	7.6	7.2	7.4
QT + Greenschoice	7.1**	7.5†	7.3	7.3	7.2	7.5	7.4	7.4	7.4
AW + Greenschoice	7.8	7.7	7.7	7.6†	7.4	7.5	7.5	7.3	7.6†
HJR + Wet Agent (WA)	7.5†	7.6	7.9	7.5	7.4	7.2*	7.5	7.4	7.6†
HJR + G + WA	7.5†	7.6	7.6	7.4	7.3	7.4	7.4	7.3	7.4
LP + GI	7.5†	7.5†	7.6	7.6†	7.5	7.5	7.3*	7.4	7.4
LSD (.05) =	.21	.24	.41	.35	.32	.29	.19	.26	.23
F-test =	**	.21	†	†	.38	.15	**	†	.38
CV (%) =	2	2	4	4	3	2	2	3	2

**, *, † Significant difference at P ≤.01, .05, and .10. Contrast is versus Control by LSD.

Table 2-14. Bentgrass color in 1996. (T-108)

Treatment and Contrast	Turf Color								
	9 May	30 May	12 Jun	26 Jun	23 Jul	30 Aug	3 Oct	30 Oct	25 Nov
	9 = dark green; 1 = no green, all brown								
Control vs.	7.8	7.9	7.8	7.8	7.6	7.4	7.6	7.4	7.5
CA (Mar, Sep)	7.9	7.9	7.7	7.6†	7.7	7.5	7.6	7.4	7.4
HJR	7.8	7.9	7.9	7.6†	7.7	7.6	7.5	7.4	7.6
QT	7.9	7.9	7.8	7.6†	7.8	7.6	7.5	7.2	7.4
ST	7.4**	7.5*	7.5*	7.3**	7.6	7.5	7.2*	7.4	7.5
HJR + Greenschoice (G)	7.7	7.8	7.8	7.7	7.6	7.6	7.5	7.5	7.6
QT + Greenschoice	7.8	7.9	7.8	7.7	7.6	7.5	7.5	7.2	7.2*
ST + Greenschoice	7.5*	7.7†	7.8	7.5*	7.7	7.5	7.3†	7.3	7.4
HJR + Wet Agent (WA)	7.7	8.0	7.8	7.7	7.7	7.6	7.5	7.4	7.6
HJR + G + WA	7.8	8.0	7.7	7.6†	7.8	7.6	7.5	7.4	7.5
LP + GI	–	–	7.7	7.7	7.5	7.6	7.3†	7.4	7.4
LSD (.05) =	.21	.21	.25	.21	.25	.24	.30	.33	.28
F-test =	**	**	†	**	.52	.69	†	.83	.22
CV (%) =	2	2	2	2	2	2	3	3	3

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

Table 2-15. Bentgrass color in 1997 and 1998 (T-108).

Treatment and Contrast	1997 8 Apr	16 May	12 Jun	15 Jul	7 Aug	15 Oct	1998 29 Jan	1 May	8 Jun
	9 = dark green; 1 = no green, all brown								
Control vs.	7.5	7.7	7.6	7.2	7.2	7.6	7.2	7.5	7.5
CA (Mar, Sep)	7.5	7.7	7.5	7.3	7.2	7.6	6.9	7.2†	7.6
HJR	7.7	7.6	7.6	7.4	7.2	7.3	7.4	7.5	7.5
QT	7.1*	7.5	7.4	7.5*	7.1	7.6	7.2	7.4	7.6
AW	7.5	7.5	7.6	7.5*	7.3	7.6	7.2	7.3	7.6
HJR + Greenschoice (G)	7.7	7.7	7.6	7.5*	7.4	7.5	7.5	7.4	7.4
QT + Greenschoice	7.2†	7.8	7.1*	7.4	7.2	7.5	7.3	7.4	7.5
AW + Greenschoice	7.7	7.8	7.8	7.5*	7.3	7.6	7.3	7.4	7.6
HJR + Wet Agent (WA)	7.6	7.7	7.8	7.5*	7.3	7.3*	7.4	7.4	7.6
HJR + G + WA	7.4	7.6	7.5	7.4	7.2	7.5	7.4	7.3	7.5
LP + GI	7.7	7.6	7.5	7.5*	7.5†	7.6	7.0	7.5	7.4
LSD (.05) =	.38	.25	.39	.26	.32	.33	.42	.30	.18
F-test =	*	.26	*	.31	.45	.47	.20	.57	.22
CV (%) =	4	2	4	2	3	3	4	3	2

**, *, † Significant difference at P ≤.01, .05, and .10. Contrast is versus Control by LSD.

Table 2-16. Canopy reflectance data presented as the IR/R index in 1996. IR/R = R_{935} / R_{661}; often correlated with LAI. (T-108)

Treatment and Contrast‡	IR/R (1996) 31 May	14 Jun	24 Jun	14 Jul	12 Aug	13 Sep	14 Oct	14 Nov
	Higher Value = Best							
Control vs.	16.1	15.8	15.2	16.4	12.2	11.0	12.7	15.6
CA	16.1	15.4	14.8	16.0	11.6	10.8	10.8*	16.2
HJR	15.9	15.6	15.3	13.7	12.2	12.2	12.1	16.0
QT	15.8	15.5	14.5	14.2	11.8	11.3	10.6*	13.1
ST	14.4	15.4	14.5	17.3	11.7	11.6	11.4	14.8
HJR + Greenschoice (G)	15.5	15.3	15.1	16.5	12.0	11.5	10.5*	17.4
QT + Greenschoice	15.9	15.8	15.1	17.3	11.7	11.4	9.9*	15.4
ST + Greenschoice	14.3†	15.4	15.2	17.1	11.8	11.1	9.6*	14.6
HJR + Wet Agent (WA)	16.7	16.6*	15.2	14.5	12.0	11.9	12.0	16.3
HJR + G + WA	16.1	15.8	14.6	18.3	12.4	11.1	9.3**	14.9
LP + GI	6.4**	15.6	15.4	17.2	12.1	11.7	11.7	16.9
LSD (.05) =	2.3	.78	1.93	5.5	1.31	1.49	1.83	3.66
F-test	**	†	.98	.81	.97	.76	**	.55
CV (%)	11	3	9	24	8	9	12	16

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

Table 2-17. Canopy reflectance data presented as the IR/R index in 1997 and 1998. IR/R = R_{935} / R_{661}; often correlated with LAI. (T-108)

Treatment and Contrast‡	1997 12 Mar	30 Apr	28 May	20 Jun	19 Aug	30 Sep	5 Nov	1998 15 Mar	13 May	18 Jun
	Higher Value = Best									
Control vs.	11.0	11.9	16.3	15.6	15.1	13.9	13.3	8.4	12.6	11.9
CA (Mar, Sep)	10.3	11.9	15.5	15.4	15.6	14.2	11.9	7.9	11.0*	11.6
HJR	11.5	12.2	15.6	15.3	15.2	13.8	11.9	9.1	12.5	13.4*
QT	9.5	10.9	15.3	14.2	14.8	12.4	11.3†	8.7	12.0	12.5
AW	10.7	10.9	15.3	14.4	15.9	13.7	12.7	9.0	11.7	12.1
HJR + Greenschoice (G)	12.2	12.3	15.8	15.7	15.8	14.8	14.0	8.6	12.0	12.8
QT + Greenschoice	9.6	11.3	15.9	15.1	15.8	15.0	12.2	7.7	12.0	12.4
AW + Greenschoice	11.4	11.5	16.3	15.9	14.8	13.0	12.7	7.3	11.4†	11.4
HJR + Wet Agent (WA)	10.9	12.0	16.8	15.9	15.3	14.1	12.7	9.5	12.9	13.3†
HJR + G + WA	10.2	11.3	14.8	14.7	14.7	13.9	11.8	7.1†	12.2	12.8
LP + GI	12.5	12.4	15.6	16.5	16.3†	17.0*	14.5	7.8	12.6	11.9
LSD (.05) =	2.04	1.31	1.92	1.90	1.38	2.30	2.50	1.63	1.46	1.50
F-test =	†	.18	.71	.37	.33	*	.29	†	.30	.13
CV (%) =	13	8	8	9	6	11	14	14	8	8

**, *, † Significant difference at P ≤.01, .05, and .10.
‡ Contrast is versus Control by LSD.

Table 2-18. Canopy reflectance data presented as normalized difference vegetation index (NDVI) in 1996. NDVI = $R_{935} - R_{661} / R_{935} + R_{661}$, where R_{935} = reflectance 790 to 1080 nm and R_{661} = reflectance at 648 to 674 nm. NDVI is often correlated with green biomass, PAR absorption, and LAI. (T-108)

Treatment and Contrast‡	NDVI (1996)							
	31 May	14 Jun	24 Jun	14 Jul	12 Aug	13 Sep	14 Oct	14 Nov
	1.00 = ideal; 0 = no PAR absorption							
Control vs.	.88	.88	.88	.89	.85	.83	.85	.88
CA	.88	.88	.87	.88	.84	.83	.83	.88
HJR	.88	.88	.88	.80	.85	.85	.85	.88
QT	.88	.88	.87	.85	.84	.83	.83	.86†
ST	.87	.88	.87	.89	.84	.84	.84	.87
HJR + Greenschoice (G)	.88	.88	.87	.88	.85	.84	.82*	.89
QT + Greenschoice	.88	.88	.88	.89	.84	.84	.81*	.87
ST + Greenschoice	.87	.88	.88	.89	.84	.83	.81*	.87
HJR + Wet Agent (WA)	.89	.89*	.87	.80	.85	.84	.85	.88
HJR + G + WA	.88	.88	.87	.90	.85	.83	.80**	.87
LP + GI	.66**	.88	.88	.89	.85	.84	.84	.89
LSD (.05) =	.093	.006	.015	.13	.016	.019	.027	.025
F-test	**	.13	.98	.68	.97	.72	**	.44
CV (%)	7	1	1	10	1	2	2	2

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

Table 2-19. Canopy reflectance data presented as normalized difference vegetation index (NDVI) in 1997 and 1998. NDVI = $R_{935} - R_{661} / R_{935} + R_{661}$, where R_{935} = reflectance 790 to 1080 nm and R_{661} = reflectance at 648 to 674 nm. NDVI is often correlated with green biomass, PAR absorption, and LAI. (T-108)

Treatment and Contrast‡	1997							1998		
	12 Mar	30 Apr	28 May	20 Jun	19 Aug	30 Sep	5 Nov	15 Mar	13 May	18 Jun
	1.00 = ideal; 0 = no PAR absorption									
Control vs.	.83	.84	.88	.88	.88	.86	.86	.78	.85	.84
CA (Mar, Sep)	.82	.84	.88	.88	.88	.87	.84	.77	.83*	.84
HJR	.84	.85	.88	.88	.88	.86	.84	.80	.85	.86*
QT	.81	.83	.88	.87	.87	.85	.84	.79	.85	.85
AW	.83	.83	.88	.87	.88	.86	.85	.80	.84	.85
HJR + Greenschoice (G)	.85	.85	.88	.88	.88	.87	.87	.79	.85	.85
QT + Greenschoice	.81	.84	.88	.88	.88	.87	.85	.77	.85	.85
AW + Greenschoice	.85	.85	.88	.88	.87	.86	.86	.76	.84	.84
HJR + Wet Agent (WA)	.83	.85	.89	.88	.88	.87	.85	.81	.86	.86*
HJR + G + WA	.82	.84	.87	.87	.87	.86	.84	.74*	.85	.85
LP + GI	.85	.85	.88	.89	.88	.89*	.87	.77	.85	.84
LSD (.05) =	.030	.017	.014	.014	.010	.020	.028	.040	.017	.018
F-test =	†	.16	.76	.45	.35	†	.41	†	.27	.15
CV (%) =	3	1	1	1	1	2	2	4	1	1

**, *, † Significant difference at P ≤.01, .05, and .10.
‡ Contrast is versus Control by LSD.

Table 2-20. Canopy reflectance at 661 nm in 1996 (T-108). Lowest reflectance is best since it represents high PAR absorpance. Range 648-674 nm (Red, PAR).

Treatment and Contrast‡	Reflectance (661 nm)							
	31 May	14 Jun	24 Jun	14 Jul	12 Aug	13 Sep	14 Oct	14 Nov
	%							
Control vs.	4.1	4.0	4.0	3.9	5.0	6.9	6.1	5.3
CA	4.1	4.2*	4.1	4.0	5.2	7.1	6.7	5.2
HJR	4.1	4.2*	4.0	7.0	5.0	6.4	6.5	5.2
QT	4.1	4.1	4.2	5.3	5.2	6.9	7.4*	6.3†
ST	4.5	4.1	4.2	3.7	5.1	6.7	6.9	5.5
HJR + Greenschoice (G)	4.2	4.1	4.2	4.0	4.9	6.7	5.9	4.7
QT + Greenschoice	4.1	4.0	4.0	3.8	5.2	6.9	6.7	5.3
ST + Greenschoice	4.5	4.1	4.0	3.8	5.1	7.0	6.9	5.7
HJR + Wet Agent (WA)	4.0	3.9	4.1	7.0	5.0	6.5	6.3	5.0
HJR + G + WA	4.1	4.0	4.2	3.6	5.0	7.0	6.9	5.4
LP + GI	10.1**	3.9	3.8	3.9	4.9	6.8	5.7	4.7
LSD (.05) =	2.3	.19	.48	4.26	.49	.69	1.20	1.24
F-test	**	†	.88	.66	.89	.66	.19	.40
CV (%)	33	3	8	65	7	7	13	16

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

Table 2-21. Canopy reflectance at 661 nm in 1997 and 1998 (T-108). Lowest reflectance is best since it represents high PAR absorpance. Range 648-674 nm (Red, PAR).

Treatment and Contrast‡	1997							1998		
	12 Mar	30 Apr	28 May	20 Jun	19 Aug	30 Sep	5 Nov	15 Mar	13 May	18 Jun
	%									
Control vs.	6.3	4.4	3.6	4.0	4.3	5.1	4.7	6.0	4.4	5.1
CA (Mar, Sep)	6.5	4.5	3.9†	4.1	4.3	5.3	4.7	5.3	5.1*	5.3
HJR	6.0	4.5	3.8	4.2	4.4	5.3	5.1	5.5	4.5	4.6
QT	7.2	4.9*	3.8	4.3	4.4	5.8†	5.4	5.9	4.8	4.9
AW	6.5	4.7	3.8	4.3	4.2	5.4	5.0	5.7	4.8	5.1
HJR + Greenschoice (G)	5.6	4.3	3.7	4.0	4.2	5.0	4.2	5.1	4.6	4.8
QT + Greenschoice	7.1	4.6	3.7	4.1	4.2	4.9	4.6	5.8	4.5	4.9
AW + Greenschoice	6.2	4.6	3.6	4.0	4.5	5.6	4.7	5.9	4.8	5.3
HJR + Wet Agent (WA)	6.5	4.6	3.6	4.0	4.3	5.2	4.8	5.6	4.5	4.7
HJR + G + WA	6.8	4.7	3.9†	4.2	4.5	5.2	5.0	6.2	4.7	4.8
LP + GI	5.4	4.4	3.7	3.8	4.1	4.0*	4.2	5.6	4.2	5.0
LSD (.05) =	1.3	.48	.34	.49	.32	.85	1.09	1.07	.6	.61
F-test =	.21	.35	.50	.55	.30	*	.49	.57	.33	.31
CV (%) =	14	7	6	8	5	11	16	13.	9	8

**, *, † Significant difference at P ≤.01, .05, and .10.
‡ Contrast is versus Control by LSD.

Table 2-22. Summary of bentgrass shoot growth responses (visual quality, shoot density, color) and shoot physiological health responses (IR/R, NDVI, Ref. 661 nm) relative to the Control for 1996 to 1998 (T-108).

Treatment and Contrast	Visual‡ Quality		Shoot‡ Density		Turf‡ Color		IR/R¶		NDVI¶		Reflect¶ 661 nm		All Indexes	
	<	>	<	>	<	>	<	>	<	>	<	>	<	>
	%													
Control vs.	—	—	—	—	—	—	—	—	—	—	—	—	—	—
CA (Mar, Sep)	28	0	22	0	11	0	11	0	6	0	17	0	16	0
HJR	6	6	6	0	6	0	0	6	0	6	6	0	4	3
QT	44	0	28	6	11	6	11	0	6	0	22	0	20	2
AW§	22	11	11	11	0	11	0	0	0	0	0	0	6	6
HJR + Greenschoice (G)	6	0	11	0	0	6	6	0	6	0	0	0	5	1
QT + Greenschoice	33	6	17	6	11	0	6	0	6	0	0	0	12	2
AW + Greenschoice§	11	11	0	22	0	11	6	0	0	0	0	0	3	7
HJR + Wet Agent (WA)	6	6	11	6	6	6	0	11	0	11	0	0	4	7
HJR + G + WA	6	11	6	6	6	0	11	0	11	0	0	6	7	4
LP + GI	6	6	19	6	13	6	6	6	6	6	6	6	9	6

‡ Based on percent of ratings in 1996 (9), 1997 (6), and 1998 (3) when the treatment was significantly less than (<) or greater than (>) the Control.

§ In 1996 a ½ inch diameter solid tine (ST) was used which caused excessive injury. In 1997 and 1998, a greens type Aerway Slicer was used. Data reflects only Aerway (AW) effects.

¶ IR/R = R_{935}/R_{661}; NDVI = $R_{935} - R_{661}/R_{935} + R_{661}$; Reflectance 661 nm where less reflectance is best.

Table 2-23. Root length density (RLD) and total root length (TRL) for three root sampling dates from 19 June 1996 to 3 January 1997 (T-108).

Treatments and Contrasts‡	Root Length Density (RLD)						TRL (3-20 cm)		
	19 Jun 96		18 Sep 96		3 Jan 97				
	3-10 cm	10-20 cm	3-10 cm	10-20 cm	3-10 cm	10-20 cm	19 Jun 96	18 Sep 96	3 Jan 97
	cm cm $^{-3}$						cm cm $^{-2}$		
Control vs.	58.70	1.60	6.46	.37	36.18	2.67	456	52	298
CA (22 Mar, 19 Sep)	30.36**	1.53	7.88	.46	34.41	1.33*	243**	64	271
HJR	33.65**	1.42	14.65†	.39	54.20	.70**	267**	114	414
QT	33.33**	1.42	7.08	.24	44.58	1.07*	264**	56	345
AW	33.91**	1.87	16.18*	.24	30.06	.45**	273**	124†	230
HJR + Greenschoice (G)	26.72**	1.81	15.59*	.28	35.74	1.21†	219**	120†	280
QT + Greenschoice	31.35**	1.68	12.52	.15	36.36	1.11*	252**	95	284
AW + Greenschoice	32.95**	1.71	11.42	.19	29.79	1.13*	264**	88	235
HJR + Wet Agent (WA)	27.01**	2.87†	19.89**	.28	19.29	.94**	231**	152*	154
HJR + G + WA	41.12†	1.81	14.29†	.33	28.89	.46**	327†	110	221
LP + GI	45.40	1.46	13.82†	.27	42.83	.59**	355	106	327
LSD (.05) =	19.98	1.31	9.06	.37	24.71	1.52	150	82	184
F-test =	†	.63	.37	.87	.35	.23	†	.25	.34
CV (%) =	39	52	53	87	48	99	36	69	46

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

‡ Contrasts are versus Control using LSD.

Table 2-24. Root length density (RLD) and total root length (TRL) for three root sampling dates from 16 June to 10 December 1997 (T-108).

Treatments and Contrasts‡	Root Length Density (RLD)						TRL (3-20 cm)		
	16 Jun 97		18 Sep 97		10 Dec 97				
	3-10 cm	10-20 cm	3-10 cm	10-20 cm	3-10 cm	10-20 cm	16 Jun 97	18 Sep 97	10 Dec 97
	cm cm $^{-3}$						cm cm $^{-2}$		
Control vs.	26.88	4.35	22.15	.46	20.53	.28	242	170	157
CA (22 Mar, 19 Sep)	25.58	2.99*	18.82	.43	24.61	.32	219	145	188
HJR	29.62	2.49*	16.75	.53	38.66*	.94*	245	131	299*
QT	23.16	1.48**	15.33	.50	21.58	.47	187	120	167
AW	34.79	1.33**	18.51	.40	22.46	.38	273	142	172
HJR + Greenschoice (G)	28.35	2.00**	13.88	.76	24.50	.92*	231	111	193
QT + Greenschoice	25.84	1.71**	14.18	.78†	23.80	.42	209	114	183
AW + Greenschoice	20.88	0.73**	24.43	.31	20.11	.29	163†	186	154
HJR + Wet Agent (WA)	28.51	2.05**	27.88	.39	34.05†	.76†	233	212	273†
HJR + G + WA	33.77	2.63*	19.17	.64	30.69	.41	277	150	234
LP + GI	20.05	1.49**	14.78	.38	15.37	.30	164†	114	118
LSD (.05) =	12.74	1.33	15.71	.41	16.84	.50	95	118	127
F-test =	.37	**	.73	.32	.25	*	.24	.76	.21
CV (%) =	33	44	58	56	46	70	29	56	45

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

‡ Contrasts are versus Control using LSD.