CC 9609-096

Executive Summary

UNIVERSITY OF GEORGIA **November 2000**

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

2000 Research Grant: $10,000 USGA; $10,000 GCSAA
(Fifth 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 (O.M.) In the surface 0 to 1.25 inch zone of a USGA green from an initial level of 1.0 to 3.0% (by weight) at establishment to 5 to 12% or more after 2 years. Organic matter accumulation often 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 O.M. in the surface zone is as root tissue that can contribute to soil macropore plugging or sealing, under the conditions of : (a) O.M. content accumulates within this zone to an excessive level, or (b) the nature or characteristics of the O.M. is dramatically altered by rapid death of roots during summer months in this zone (i.e., causing a gel-like condition that greatly limits soil O_2 diffusion). The two proposed problems arising from surface O.M. occur at different times of the year and are the basis of two projects in Phase 1 (1996 to 1998).

Results from the two projects of Phase I were used in Phase II (1999 to 2000)to formulate potential annual management programs (cultivation, topdressing) 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. Also, the availability of a new type of verticutter (Graden) that can remove considerable O.M. without severe surface injury is being incorporated into the second phase. Some golf course superintendents have used this device on bentgrass greens in place of spring core aeration because healing seems to occur more rapidly and this may allow earlier treatment and/or multiple spring treatment. Phase II study has been initiated in Spring 1999 and the treatments will allow for evaluation of whether the Graden can be used to replace all or part of core aeration operations.

Results To Date

All data have been obtained but root samples and core (0 to 3 cm; 3 to 6 cm) samples for soil physical parameter analysis are currently being processed.

The "control" plots which did not receive any cultivation operations and received approximately 50% of the total annual topdressing exhibited the highest frequency (91%) in the top statistical category for shoot performance. Core Aeration (2x per year) plots also ranked at 91% in the top grouping. Plots receiving more intensive cultivation operations demonstrated

somewhat lower turf quality but the magnitude was not great. However, the highest SHC (saturated hydraulic conductivity) and soil O_2 content values were observed under the more intensive cultivation treatments. Treatment differences were greater in 1999 (hot, humid) versus 2000 (hot, drier) where hot, humid conditions favor summer bentgrass decline.

Cultivation programs involving less intrusive cultivation practices (QT= solid, quad-tines, 1/4" dia.; HJR= Hydro Ject in raised position, 1/4" dia. holes) averaged: a) soil O_2 contents of 16.3% (1999) and 14.5% (2000), versus 12.0% (1999) and 14.1% (2000) for treatments not containing there operations, and b) SHC of 223 mm hr^{-1} (1999) and 174 (2000), versus 163 mm hr^{-1} (1999) and 157 (2000) for cultivation programs without there operations.

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Phase I (1996-1998)

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.

II. Inhibition of Root Development, Soil O_2 Diffusion, and Infiltration (in SPRING/FALL) from the Zone of High Organic Matter Content.

The results for Phase I studies were summarized in the 1998 report.

Phase II (1999-2000)

Results from the two projects of Phase I were used in Phase II to formulate potential annual management programs (cultivation, topdressing) 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.

Also, the availability of a new type of verticutter (Graden) that can remove considerable O.M. without severe surface injury is being incorporated into the second phase. Some golf course superintendents have used this device on bentgrass greens in place of spring core aeration because healing seems to occur more rapidly and this may allow earlier treatment and/or multiple spring

treatment. Phase II study has been initiated in Spring 1999 and the treatments will allow for evaluation of whether the Graden can be used to replace all or part of core aeration operations.

The description of the Phase II study is noted below:

USGA Bent Study Phase II
T-123

Objective: To determine the influence of various cultivation methods (core aeration, Garden verticutter, Solid Quad-tine, Hydroject) and programs on Penncross creeping bentgrass on:

- Soil O_2 status.
- Soil saturated hydraulic conductivity (SHC).
- Bentgrass shoot/ root performance.
- Soil surface (0-3 cm) physical properties.
- Soil subsurface (3-6 cm) physical properties.

Treatments/ Procedures: The six treatments were laid out on 15 April 1999 in a completely randomized block design with 4 blocks (reps) of 14 x 14 ft. The study will run until October 2000. Treatments are:

Treat. No.	Treatments	
1.	**Control**	No cultivation
2.	**Core Aerate (2)**	
	C.A. (5/8") (2)	Topdressing
	April 15	9.1 $ft.^3/M^2$=9.1 $ft.^3$/1000 $ft.^2$
	October 10	9.1 $ft.^3/M^2$
3.	**Graden Verticut (2)**	
	GRA (deep set) (2)	Topdressing
	April 15 (d)+ top	7.7 $ft.^3/M^2$
	Oct. 10 (d)+ top	7.7 $ft.^3/M^2$

4. **Graden (2) + QT/ HJR (11)**

GRA (d) (2)	QT/ HJR (11)	
April 15 (d)+ top	February 15 (QT)	July 18 (HJR)
Oct. 10 (d)+ top	March 15 (QT)	August 6 (HJR)
	May 15 (QT)	August 26 (HJR)
	June 6 (QT)	September 16 (HJR)
d = deep = 1 3/4"	June 26 (QT)	November 15 (QT)
Topdressing - see 3. above		December 5 (QT)

5. **Graden (5) + QT/ HJR (7)**

GRA (5)	QT/ HJR (7)	
March 15 (L)+ top	February 15 (QT)	August 6 (HJR)
April 15 (d)+ top	June 6 (QT)	August 26 (HJR)
May 15 (d)+ top	June 26 (QT)	September 16 (HJR)
Oct. 10 (d)+ top	July 28 (HJR)	
Dec. 1 (L)+ top		

d = deep = 1 3/4", L = 3/4"

Topdress for Light Graden = 3.5 $ft.^3/M^2$

6. **Core Aerate (2) & Graden (3) + QT/ HJR (7)**

CA (5/8") (2)	GRA (3)	QT/ HJR (7)
April 15 + top	March 15 (L) + top	Feb 15 (QT) Aug 6 (HJR)
Oct 10 + top	May 15 (L) + top	June 6 (QT) Aug 26 (HJR)
	Dec 1 (L) + top	June 26 (QT) Sep 16 (HJR)
		July 18 (HJR)

L = 3/4"

Note: (a) all plots receive topdressing every 3-4 weeks at 0.75 to 1.50 $ft.^3$ per 1,000 $ft.^2$. (b) Study initiated with 4-12-99 treatments. (c) All deep Graden and Core aeration cultivations receive the heavy topdressings noted in treatment 2 and 3. When the light Graden operation is

used, the topdressing is at 3.5 ft.^{3}/ 1000 ft.^{2}. (d) Replication. 4 reps in 14 x 14 ft. plots. (e) **QT** = Solid (1/4" dia.) quad-tine at 2 x 2 spacing, 3" depth. (f) **HJR** = Hydro-Ject raised for 1/4" hole on 2 ½" x 2 ½" spacing.

Treatment Summary:

Treatment Description

	Annual Cultivations				Top
Cultivation	CA	GV	QT	HJR	Applied‡
Control	-	-	-	-	12
Core Aeration (CA) (2)	2	-	-	-	38
Graden Verticut (GV) (2)	-	2	-	-	34
GV (2) + QT/ HJR (11)	-	2	7	4	34
GV (5) + QT/ HJR (7)	-	5	3	4	49
CA (2) + GV (3) + QT/ HJR (7)	2	3	3	4	48

‡ Approximate topdressing on annual basis in cubic feet (ft.^{3}) per 1,000 ft.^{2}.

Data: 1. TQ, TD, TC. Monthly.
2. Crop Scan. June, July, August, September, October.
3. Roots at 1-4" and 4-8" by root.
4. Soil physical conditions at 0-3 cm. and 3-6 cm. June 1-15, September 1-15.
5. Soil O_2 and SHC.
   After May 15 GRA and HJR treatments for DAT 1-7, 20-25.
   After August 26 HJR treatments for DAT 1-7, 20-25.
   Before February 15 QT and the 2-3 days after.
   After March 15 GRA and HJR treatments for DAT 1-7, 20-25.

Results:

Results of turfgrass shoot performance under the various cultivation programs are presented in Tables 1 and 2 (quality); Tables 3 and 4 (color); and Tables 3 and 5 (shoot density).

Soil oxygen (O_2) content measurements were obtained periodically at a depth of 3.5 inches and data are summarized in Table 6 over 1999 and 2000, while Table 9 and 10 contain the complete data for 1999 and 2000, respectively.

Saturated hydraulic conductivity (SHC) data are summarized in Table 6. Tables 7 (1999) and 8 (2000) contain the annual data.

Root samples (1 to 10 cm; 10 to 20 cm) and surface soil samples (0 to 3 cm; 3 to 6 cm) were taken periodically. Samples are under preparation and/ or data are under analysis. The

project terminated October 24, 2000.

Activities Related To This Project

Carrow, R.N., P. O'Brien, C. Hartwiger, and R.R. Duncan. 2001. Why Do Golf Greens Sometimes Fail? USGA Green Section Record. Special Supplement Issue. March/ April. (accepted, in revision). NOTE: *This extensive article will be a complete issue of the USGA Green Section Record published as a supplement (i.e., 2nd issue along with the normal issue). This is only the second time in 37 years the USGA has allowed this approach. We detail 12 reasons for failure of golf course greens, regions in the world where the particular problem may occur and very specific management approaches. Our approach is to address these problems in a in-depth manner, integrating the research of others, and providing specific management information/ options to positively impact golf green management around the globe. Research results from this project will be incorporated into appropriate sections of the bulletin. This publication goes world-wide to golf courses as one of the two most used trade publications for golf course superintendents.*

Table 1. Turfgrass quality ratings in 1999 (Phase II).

Treatment										
	Cultivations									
	14 April to 31 December 1999				Topdress. Applied in ft.[3]	Turf Quality				
Cultivation	CA	GV	QT	HJR	per 1000 ft.[2]	13 May	30 June	6 August	16 September	30 October
						9 = ideal				
Control	-	-	-	-	12	7.5a	7.7a	7.0a	6.8	7.5a
Core Aeration (CA)	2	-	-	-	30	7.1a	7.7a	7.3a	6.9a	7.2a
Graden Verticut (GV)	-	2	-	-	27	6.5	7.5a	7.1a	6.8	6.3
GV + QT + HJR	-	2	5	4	27	6.7	7.5a	7.2a	7.1a	6.7
GV + QT/ HJR	-	4	2	4	39	7.1a	7.4	7.2a	6.8	6.8
CA + GV + QT + HJR	2	3	2	4	37	7.1a	7.5a	7.4a	7.1a	7.1a
LSD (.05) =						.59	.21	.64	.25	.42
F-test =						*	*	.85	*	**
CV (%) =						6	2	6	6	4

**, *, † Significant difference at 0.01, 0.05, and 0.10 probability, respectively.
‡ The "a" denotes the values in the top (best) statistical category.
§ Treatment Dates in 1999.
CA- 14 April; 12 October.
GV- 14 April; 18 May; 12 October; 29 November.
QT- 18 May; 3, 26 June; 22 November; 15 December.
HJR- 15 July; 16 August; 3 September; 1 October.

Table 2. Turfgrass visual quality ratings in 2000 and a summary for 1999 through 2000 (Phase II).

Treatment						Visual Quality						
	Cultivations											
	1 March to 12 September 2000				Topdress. Applied in ft.^{3} per 1000 ft.^{2}							Times in The Top Statistical Group in 1999 and 2000
Cultivation	CA	GV	QT	HJR		7 May	23 June	10 July	28 July	12 Sept	24 Oct	
						----------9 = ideal----------						11 = Best
Control	-	-	-	-	18	7.8a	7.4a	7.5a	7.4a	7.3a	7.4a	10
Core Aeration (CA)	1	-	-	-	27	7.4	7.7a	7.5a	7.6a	7.2a	7.1a	10
Graden Verticut (GV)	-	1	-	-	25	7.1	7.3a	7.4a	7.1	7.2a	7.1a	6
GV + QT + HJR	-	1	5	3	25	7.2	7.7a	7.5a	7.2	7.4a	7.2a	7
GV + QT/ HJR	-	2	3	3	29	7.2	7.0	7.3a	7.0	7.3a	7.2a	5
CA + GV + QT + HJR	1	2	3	3	38	6.8	7.1	7.0	7.0	7.5a	7.3a	7
LSD (.05) =						.33	.53	.36	.39	.31	.46	-
F-test =						**	†	†	*	.33	.60	-
CV (%) =						3	5	3	4	3	4	-

**, *, † Significant difference at 0.01, 0.05, and 0.10 probability, respectively.
‡ The "a" denotes the values in the top (best) statistical category.
§ Treatment Dates in 2000.
CA- 11 April. QT- 1, 31 March; 16 May; 6 June; 11 July. GV- 3, 12 April; 16 May. HJR- 28 July; 21 August; 12 Sept.

Table 3. Turfgrass color and shoot density ratings in 1999 (Phase II).

Treatment															
	Cultivations 1 March to 12 Sept 2000				Topdress. Applied in ft.^{3} per 1000 ft.^{2}	Turf Color					Turf Shoot Density				
Cultivation	CA	GV	QT	HJR		13 May	30 June	6 Aug	16 Sept	30 Oct	13 May	30 June	6 Aug	16 Sept	30 Oct
						----------9 = ideal----------					----------9 = ideal----------				
Control	-	-	-	-	18	7.4a	7.7a	7.3a	7.1a	7.5a	7.6a	7.6a	7.1a	6.8a	7.5a
Core Aeration (CA)	1	-	-	-	27	7.4a	7.7a	7.4a	7.2a	7.5a	7.3a	7.7a	7.4a	6.9a	7.4a
Graden Verticut (GV)	-	1	-	-	25	7.2a	7.5a	7.5a	7.1a	7.3a	6.9	7.5a	7.1a	6.9a	6.6
GV+QT+HJR	-	1	5	3	25	7.2a	7.6a	7.4a	7.2a	7.4a	6.8	7.6a	7.3a	7.1a	6.9
GV+QT/HJR	-	2	3	3	29	7.4a	7.6a	7.4a	7.1a	7.3a	7.3a	7.4	7.2a	6.9a	6.9
CA+GV+QT+HJR	1	2	3	3	38	7.3a	7.6a	7.6a	7.3a	7.4a	7.2a	7.5	7.5a	7.2a	7.2a
LSD (.05) =						.37	.12	.38	.33	.26	.41	.21	.55	.48	.34
F-test =						.62	.26	.60	.66	.51	**	†	.59	.45	**
CV (%)						3	1	3	3	2	4	2	5	5	3

**, *, † Significant difference at 0.01, 0.05, and 0.10 probability, respectively.
‡ The "a" denotes the values in the top (best) statistical category.
§ Treatment Dates in 1999.
CA- 14 April; 12 October
GV- 14 April; 18 May; 12 October; 29 November
QT-18 May; 3, 26 June; 22 November; 15 December
HJR- 15 July; 16 August; 3 September; 1 October

Table 4. Turfgrass color ratings in 2000 and a summary for 1999 through 2000 (Phase II).

Treatment												
	Cultivations											
	1 March to 12 Sept 2000				Topdress. Applied in ft.^{3} per 1000 ft.^{2}	Turf Color						Times in The Top Statistical Group in 1999 and 2000
Cultivation	CA	GV	QT	HJR		7 May	23 June	10 July	28 July	12 Sept	24 Oct	
						----------9 = ideal----------						11 = Best
Control	-	-	-	-	18	7.8a	7.4a	7.4a	7.5a	7.4a	7.4a	11
Core Aeration (CA)	1	-	-	-	27	7.6a	7.6a	7.5a	7.6a	7.3a	7.2a	11
Graden Verticut (GV)	-	1	-	-	25	7.4	7.6a	7.4a	7.4a	7.4a	7.0a	10
GV+QT+HJR	-	1	5	3	25	7.5	7.7a	7.5a	7.4a	7.4a	7.2a	10
GV+QT/HJR	-	2	3	3	29	7.4	7.2	7.4a	7.3a	7.4a	7.2a	9
CA+GV+QT+HJR	1	2	3	3	38	7.5	7.3	7.4a	7.3a	7.5a	7.3a	9
LSD (.05) =						.24	.35	.19	.33	.27	.49	-
F-test =						*	†	.55	.32	.59	.61	-
CV (%) =						2	3	2	3	2	4	-

**, *, † Significant difference at 0.01, 0.05 and 0.10 probability, respectively.
‡ The "a" denotes the values in the top (best) statistical category.
§ Treatment Dates in 2000.
CA- 11 April. QT- 1, 31 March; 16 May; 6 June; 11 July. GV- 3, 12 April; 16 May. HJR- 28 July; 21 August; 12 Sept.

Table 5. Turfgrass shoot density ratings in 2000 and a summary for 1999 through 2000 (Phase II).

Treatment												
	Cultivations											
	1 March to 12 Sept 2000				Topdress. Applied in $ft.^3$ per 1000 $ft.^2$	Turf Density						Times in The Top Statistical Group in 1999 and 2000
Cultivation	CA	GV	QT	HJR		7 May	23 June	10 July	28 July	12 Sept	24 Oct	
						----------9 = ideal----------						11 = Best
Control	-	-	-	-	18	7.9a	7.5a	7.5a	7.4a	7.4a	7.5a	11
Core Aeration (CA)	1	-	-	-	27	7.5	7.8a	7.6a	7.6a	7.2a	7.2a	10
Graden Verticut (GV)	-	1	-	-	25	7.2	7.5a	7.4a	7.2a	7.3a	7.1a	8
GV+QT+HJR	-	1	5	3	25	7.3	7.8a	7.5a	7.3a	7.4a	7.3a	8
GV+QT/ HJR	-	2	3	3	29	7.2	7.0	7.4a	7.1	7.3a	7.3a	6
CA+GV+QT+HJR	1	2	3	3	38	7.0	7.2	7.3a	7.1	7.5a	7.3a	7
LSD (.05) =						.24	.44	.24	.41	.28	.42	
F-test =						**	*	.14	†	.28	.54	
CV (%) =						2	4	2	4	2	4	

**, *, † Significant difference at 0.01, 0.05, and 0.10 probability, respectively.
‡ The "a" denotes the values in the top (best) statistical category.
§ Treatment Dates in 2000.
CA- 11 April. QT- 1, 31 March; 16 May; 6 June; 11 July. GV- 3, 12 April; 16 May. HJR- 28 July; 21 August; 12 Sept.

Table 6. Summary of soil oxygen content data and saturated hydraulic conductivity (SHC) data over 1999 and 2000 (Phase II).

Cultivation	Number of Cultivation Operations				Topdress. Applied in ft.^{3} per 1000 ft.^{2}	Average Soil O_2 Content		Average SHC Per Year		Percent SHC Measurements >120 mm hr.$^{-1}$
	CA	GV	QT	HJR		1999	2000	1999	2000	Baseline
						-----% O_2-----		—mm hr^{-1}----		----------%----------
Control VERSUS	-	-	-	-	12-18	11.9	13.6	139	168	42
Core Aeration (CA)	1-2	-	-	-	27-30	12.1	14.3	179	141	42
Graden Verticut (GV)	-	1-2	-	-	25-27	12.1	14.5	171	162	42
GV+QT+HJR	-	1-2	5	3-4	25-27	16.5a	14.9	196	175	47
GV+QT/ HJR	-	2-4	2-3	3-4	29-39	15.6	13.9	248a	180	63
CA+GV+QT+HJR	1-2	2	2-3	3-4	37-38	16.8a	14.8	224a	168	74
LSD (.05) =						3.9	1.6	84	67	-
F-test =						*	.35	**	.76	-
CV (%)						19	7	27	27	-

**, *, † Significant difference at 0.01, 0.05, and 0.10 probability, respectively.
‡ The "a" denotes the values that are statistically different from the "control" in paired comparisons.

Table 7. Saturated hydraulic conductivity measurements in 1999 (Phase II).

Cultivation	Treatment: Cultivations 14 April to 31 Dec 1999 CA	GV	QT	HJR	Topdress. Applied in ft.^{3} per 1000 ft.^{2}	Sat. Hydraulic Conductivity ¶ 24 May	8 Jun	9 Aug	20 Aug	2 Sept	24 Sept	14 Nov	22 Nov	22 Dec
						mm hr^{-1}								
Control VERSUS	-	-	-	-	12	73	67	78	123	15	7	361	268	260
Core Aeration (CA)	2	-	-	-	30	72	63	54	101	47	71	609	183	407a
Graden Verticut (GV)	-	2	-	-	27	57	46	12	11	12	149a	238	379	257
GV+QT+HJR	-	2	5	4	27	27	60	35	183	71	131a	358	281	620a
GV+QT/ HJR	-	4	2	4	39	65	63	71	258	121a	171a	953a	210	317
CA+GV+QT+HJR	2	2	2	4	37	36	54	181a	339a	154a	192a	325	292	440a
LSD (.05) =						51	35	73	170	72	120	554	203	74
F-test =						.32	.56	***	***	***	**	†	.43	**
CV (%)						53	42	68	67	69	67	77	50	14

**, *, † Significant difference at 0.01, 0.05, and 0.10 probability, respectively.
‡ The "a" denotes the values that are statistically different from the "control" in paired comparisons.
§ Treatment Dates in 1999.
CA- 14 April; 12 Oct. QT- 18 May; 3, 26 June; 22 Nov; 15 Dec.
GV- 14 April; 18 May; 12 Oct; 29 Nov. HJR- 15 July; 16 Aug; 3 Sept; 1 Oct.
¶ Desired Sat. Hydraulic Conductivity is > 120 to 240 mm hr^{-1} (4.7 to 9.4 inches per hour). This assumes a laboratory SHC of 300 to 600 mm hr^{-1} and 60% reduction under field conditions.

Table 8. Saturated hydraulic conductivity measurements in 2000 (Phase II).

Treatment															
	Cultivations														
	1 March to 12 Sept 2000				Topdress . Applied in ft.^{3} per 1000 ft.^{2}	Sat. Hydraulic Conductivity ¶									
Cultivation	CA	GV	QT	HJR		20 Mar	5 Apr	27 Apr	9 May	6 Jun	30 Jun	1 Aug	18 Aug	11 Sep	13 Sep
						mm hr^{-1}									
Control VERSUS	-	-	-	-	18	32	134	90	528	119	41	82	177	45	426
Core Aeration (CA)	1	-	-	-	27	39	44	149	470	84	62	122	167	32	245
Graden Verticut (GV)	-	1	-	-	25	48	115	99	554	26	76	143	188	31	377
GV+QT+HJR	-	1	5	3	25	160a	107	96	540	73	50	197	176	42	364
GV+QT/HJR	-	2	3	3	29	48	131	85	730	136	70	114	137	149a	313
CA+GV+QT+HJR	1	2	3	3	38	83	160	206a	401	213	79	194	188	44	111a
LSD (.05) =						67	114	110	432	166	83	129	133	54	250
F-test =						.20	.45	.20	.70	.30	.90	.37	.96	**	.16
CV (%) =						76	66	61	53	102	88	60	51	63	54

**, *, † Significant difference at 0.01, 0.05, and 0.10 probability, respectively.
‡ The "a" denotes the values that are statistically different from the "control" in paired comparisons.
§ Treatment Dates in 2000.
CA-11 Apr QT-1, 31 Mar; 16 May; 6 June; 11 July GV-3, 12 Apr; 16 May HJR-28 July; 21 Aug; 12 Sept
¶ Desired SHC is > 120 to 240 mm hr^{-1} (4.7 to 9.4 inches per hour).

Table 9. Percent soil oxygen (O_2) content at 3.5 inches in 1999 (Phase II).

Treatment						Percent Soil O_2 Content at 3.5 inches							
	Cultivations												
	14 April to 31 Dec 1999				Topdress. Applied in ft.^{3} per 1000 ft.^{2}								
Cultivation	CA	GV	QT	HJR		17 Aug	23 Aug	24 Aug	10 Sept	24 Sept	9 Nov	22 Nov	22 Dec
						----------% O_2----------							
Control VERSUS	-	-	-	-	12	11.0	10.0	10.3	10.8	10.5	11.5	20.0	11.0
Core Aeration (CA)	2	-	-	-	30	13.0	12.5	11.8	11.5	11.3	14.8	12.5a	9.0
Graden Verticut (GV)	-	2	-	-	27	11.0	8.8	10.5	9.5	10.0	13.5	18.8	14.3a
GV+QT+HJR	-	2	5	4	27	18.3a	18.5	19.0	16.5	16.5a	14.0	17.5	11.8
GV+QT/HJR	-	4	2	4	39	15.0	14.8	14.8	14.5	16.8a	13.5	20.0	15.5a
CA+GV+QT+HJR	2	2	2	4	37	17.3	18.0	20.0a	15.8	16.0a	14.8	19.3	13.5
LSD (.05) =						6.8	8.7	9.0	6.4	4.4	5.0	5.3	3.2
F-test =						.15	.14	.13	.17	**	.75	†	**
CV (%) =						32	42	42	33	22	24	19	17

**, *, † Significant difference at 0.01, 0.05, and 0.10 probability, respectively.
‡ The "a" denotes the values that are statistically different than the "control" by paired comparisons.
§ Treatment Dates in 1999.
CA- 14 April; 12 October
GV- 14 April; 18 May; 12 October; 29 November
QT- 18 May; 3, 26 June; 22 November; 15 December
HJR- 15 July; 16 August; 3 September; 1 October

Table 10. Percent soil oxygen (O_2) content at 3.5 inches in 2000 (Phase II).

Cultivation	Treatment: Cultivations 1 March to 12 Sept 2000 CA	GV	QT	HJR	Topdress. Applied in ft.^{3} per 1000 ft.^{2}	Percent Soil O_2 Content at 3.5 inches: 20 Mar	5 Apr	27 Apr	9 May	9 Jun	30 Jun	1 Aug	18 Aug	12 Sep	13 Sep
						----------% O_2----------									
Control VERSUS	-	-	-	-	18	10.0	13.8	13.8	16.8	12.0	17.3	13.8	14.5	10.3	13.3
Core Aeration (CA)	1	-	-	-	27	16.5a	13.5	16.3	16.5	12.3	15.8	14.5	15.0	9.0	13.3
Graden Verticut (GV)	-	1	-	-	25	12.0	14.0	16.8a	14.8	15.0a	15.0	12.5	16.8	11.0	17.0
GV+QT+HJR	-	1	5	3	25	18.5a	14.3	16.5	14.8	16.0a	15.0	16.3	15.5	11.3	11.0
GV+QT/HJR	-	2	3	3	29	12.5	12.8	14.5	17.0	13.0	14.5	13.0	15.0	12.0	14.8
CA+GV+QT+HJR	1	2	3	3	38	18.5a	14.5	18.5a	16.0	13.8	13.3	13.3	14.8	10.5	14.3
LSD (.05) =						5.5	5.4	3.0	4.3	2.6	5.2	4.3	3.8	3.7	4.3
F-test =						**	.98	†	.78	*	.70	.51	.89	.63	.14
CV (%) =						25	26	13	18	13	23	21	16	23	20

**, *, † Significant difference at 0.01, 0.05, and 0.10 probability, respectively.
‡ The "a" denotes the values statistically different from the "control" plots by paired comparison.
§ Treatment Dates in 2000.
CA-11 Apr QT-1, 31 Mar; 16 May; 6 Jun; 11 Jul
GV-3, 12 Apr; 16 May HJR-28 Jul; 21 Aug; 12 Sept