DEVELOPMENT OF CULTIVATION PROGRAMS ON TURFGRASS TO REDUCE WATER USE AND IMPROVE TURF QUALITY

UNIVERSITY OF GEORGIA
Griffin, Georgia

Dr. Robert N. Carrow
Principal Investigator

1992 Research Grant: $18,000
(final year of support)

Adverse soil physical conditions interfere with turfgrass management and efficient water use by limiting water movement, reducing plant water uptake, reducing soil aeration, and decreasing root/shoot growth. Cultivation is a primary means of alleviating these problems; however, comparative research studies to evaluate different techniques have not been conducted. The objectives of this project were (a) to evaluate different cultivation techniques for their relative effectiveness in alleviating soil compaction, improving water use efficiency, and improving shoot/root growth, and (b) to develop "cultivation" programs for fairway/tee conditions based on using two or more different cultivation techniques. Objective (b) is the focus of this report.

Phase 1 (1989-1990) of this project focused on objective (a) and was summarized in the 1990 annual report; but new cultivation techniques were still evaluated over the last two years (1991-1992). The primary focus in 1991 through 1992, however, was to evaluate cultivation programs (i.e., objective b).

Seven cultivation treatments plus two control treatments were under irrigation in the 1991-1992 study (Table 1). From the previous study in Phase I, the most effective cultivation technique for deeper in the soil profile was the Verti-Drain, while hollow tine coring improved soil surface conditions. Thus, intensity of Verti-Drain treatment (i.e. 1X, 2X times over the plot area), as well as Verti-Drain plus hollow-tine coring combinations were explored. The Yeager-Twose Turf Conditioner (a subaerification unit) has not been evaluated in research studies for comparative effectiveness as a turfgrass cultivation unit. The vibrating shank goes to a depth of 7 inches and with proper attachments can inject granular components to this depth. Since high aluminum (Al) saturation of the cation exchange complex of Piedmont soils is a major cause of limited rooting, injection of gypsum or lime should be of benefit. Gypsum was included since it has higher solubility than lime. Also, these soils have a high bulk density (i.e., soil strength), especially in the B horizon. The Turf Conditioner thus has the potential for both physical and chemical modification of the soil.

All plots except the noncompacted control were compacted with a smooth power roller at near soil saturation. The soil is a Cecil sandy clay loam with 55.1% sand, 17.6% silt, 27.3% clay and 2.14% organic matter content. A common bermudagrass (Cynodon dactylon) mowed at 0.75 to 1.0 inch was used. Fertilization in both 1991 and 1992 were at 1.0 lb N/1000 ft^2 in mid-April (10-10-10), mid-June (33-0-0) and early August (33-0-0).

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Adverse soil physical conditions interfere with turfgrass management and efficient water use by limiting water movement, reducing plant water uptake, reducing soil aeration, and decreasing root/shoot growth. Compaction of the soil surface amd excessively fine-textured (i.e., high in clay and silt content) soil profiles are two of the most common adverse soil physical properties. Cultivation is a primary means of alleviating these problems; however, comparative research studies to evaluate different techniques have not been conducted.

The objectives of this project were (a) to evaluate different cultivation techniques for their relative effectiveness in alleviating soil compaction, improving water use efficiency, and improving shoot/root growth, and (b) to develop "cultivation" programs for fairway/tee conditions based on using two or more different cultivation techniques. Objective (b) is the focus of this report.

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Seven cultivation treatments plus two control treatments were under irrigation in the 1991-1992 study (Table 1). From the previous study in Phase I, the most effective cultivation technique for deeper in the soil profile was the Verti-Drain, while hollow tine coring improved soil surface conditions. Thus, intensity of Verti-Drain treatment (i.e. 1X, 2X times over the plot area), as well as Verti-Drain plus hollow-tine coring combinations were explored.

The Yeager-Twose Turf Conditioner (a subaerification unit) has not been evaluated in research studies for comparative effectiveness as a turfgrass cultivation unit. The vibrating shank goes to a depth of 7 inches and with proper attachments can inject granular components to this depth. Since high aluminum (Al) saturation of the cation exchange complex of Piedmont soils is a major cause of limited rooting, injection of gypsum or lime should be of benefit. Gypsum was included since it has higher solubility than lime. Also, these soils have a high bulk density (i.e., soil strength), especially in the B horizon. The Turf Conditioner thus has the potential for both physical and chemical modification of the soil.

All plots except the noncompacted control were compacted with a smooth power roller at near soil saturation on 4 April (30X = 30 times per plot area), 23 April (4X), 27 May (3X) 1991; and 8 April (8X), 21 April (3X) and 23 July (4X) 1992. The soil is a Cecil sandy clay loam with 55.1% sand, 17.6% silt, 27.3% clay and 2.14% organic matter content. A common bermudagrass (Cynodon dactylon) mowed at 0.75 to 1.0 inch was used. Fertilization in both 1991 and 1992 were at 1.0 lb N/1000 ft^2 in mid-April (10-10-10), mid-June (33-0-0) and early August (33-0-0).

Initial cultivation treatments (Verti-Drain, Turf Conditioner) were made on 26-30 April and repeated on 29 July 1991. Core aeration applications were on 11 June and 14 August 1991. Gypsum and lime injection was achieved at 72 lb and 90 lbs per 1000 ft^2, respectively, at the April treatment. This was an adequate rate so lime and gypsum were not injected again when cultivation was applied in 1991 or 1992. In 1992, Verti-Drain and Turf Conditioner cultivation were applied 6 May and again in the 30 July-10 August period. Core aeration treatments were on 2 June and 18 August.

Descriptions of the cultivation methods are: (a) Verti-Drain. Solid tines of 12 in length, 0.50 in dia., spaced at 6 x 3 inch grid. (b) Core aeration. Hollow tines of 3 in. length, 0.63 inch dia., 2x2 inch grid. Cores returned after breaking up with a verticutter, and (c) Turf Conditioner. Vibrating blades 7 inch keep on 10-inch centers. Appreciation is expressed to Russ Baker of Turf Care Concepts, Conyers, Georgia for Verti-Drain application and Russ Hill of Hendrix and Dail, Inc., Tifton, Georgia for Turf Conditioner treatment.

A summary of results to date is:

Shoot Responses. The most reasonable treatment comparison is for a cultivation treatment to be compared to the compacted control. Using this approach, Turf Conditioner + Gypsum resulted in significantly improved visual quality in the 17 June to 19 July 1991 period, while Verti-Drain (2X) + Core Aeration plots exhibited higher quality in late August (Table 1). Several cultivation treatments caused a temporary decline in quality following treatment application; for example, Verti-Drain (1X) on 24 May, Verti-Drain (1X, 2X) + Core Aeration on 17 June, Turf Conditioner alone, 24 May and 8 August, and Turf Conditioner + Lime on 8 August.

In 1992, the only treatment that exhibited higher visual quality than the compacted control was the Verti-Drain (2X) on 25 May (Table 2). Cultivation treatments with lower quality ratings than the compacted control were: Turf Conditioner + Lime (23 June and 24 August); and on 24 August Turf Conditioner and Verti-Drain (1X, 2X) + Core Aeration. For the Verti-Drain (1X, 2X) + Core Aeration on 24 August, injury was from the core aeration application 6 days prior to rating. In both years, decreased visual quality after a cultivation operation was temporary (i.e., 1-2 weeks duration). Fewer adverse effects of cultivation in 1992 may be due to higher rainfall in 1992 (Table 30).

The number of dates that a treatment resulted in the highest and lowest visual quality ratings is one way to compare the effects of treatments. Based on this criteria, the most effective cultivation treatments in terms of improving visual quality were: Turf Conditioner + Gypsum (8, 0), Verti-Drain (1X) (6, 1), and Verti-Drain (2X) (6, 1); where the first number in parentheses is the number of high ratings and the second the number of low ratings out of 13 total. Least effective were Turf Conditioner (3, 4) and Turf Conditioner + Lime (3, 2).

Turf Conditioner + Gypsum improved shoot density relative to the compacted control on 3 out of 6 rating dates in 1991 (Table 3). Also, the Verti-Drain (1X, 2X) treatment plots exhibited higher shoot density in late August. A reduction in shoot density was observed for Turf Conditioner (24 May, 8 August), Turf Conditioner + Lime (8 August), and Verti-Drain (2X) + Core Aeration (16 June).

Improvements in shoot density by cultivation operations over the compacted control did not occur in 1992 (Table 4). Only on 24 August were any adverse effects on shoot density note; namely, for Turf Conditioner + Gypsum, Turf Conditioner + Lime, and Verti-Drain (1X, 2X) + Core Aeration. As with visual quality, shoot density treatment differences may have been fewer in 1992 due to higher rainfall.

Shoot growth as measured by <u>clipping yield</u> revealed only two instances of clipping yields greater than the compacted control (Table 5). These occurred in late August of 1991 for Turf Conditioner + Gypsum and Verti-Drain (1X) operations. Verti-Drain (1X) + Core Aeration resulted in the lowest clipping yields on 4 out of 7 sample dates.

Compared to the compacted control, <u>turf color</u> was significantly better for the Turf Conditioner + Gypsum on 5 out of 11 dates (Tables 6, 7) with most differences occurring in 1991. Verti-Drain (2X) + Core Aeration plots revealed higher color ratings on 4 out of 11 dates. The few instances of reduced color occurred immediately after a cultivation operation and was transitory in nature.

Significant shoot responses, especially in 1991, of the Turf Conditioner + Gypsum versus Turf Conditioner plots indicate chemical modification was sufficient to influence shoot growth. Soil samples were taken on 30 October 1991 (Table 28) and 25 September 1992 (Table 29). Within the first year of the study, lime had the greatest effect on soil chemical properties. Within the surface 0 to 10 cm zone, base saturation increased, while H level decreased. In the 15 to 25 cm zone where most of the lime and gypsum were deposited, lime tended to increase Ca and Mg levels and pH, while H level decreased. Gypsum also tended to increase Ca levels in the lower zone but differences were not significant. Results from the 1992 sampling are not available at this time.

<u>Root Growth and Water Extraction</u>. In June 1991, the Verti-drain (1X) + Core Aeration treatment improved surface (3 to 10 cm) root length density (RLD) and total root length (Table 8). However, the Verti-Drain (2X) + Core Aeration plots exhibited much lower RLD in the 3 to 10 cm zone and total root lengths. The Turf Conditioner + Gypsum plots also had low surface zone RLD values and total root length. However, this same treatment demonstrated high root water extraction from the 0 to 20 cm zone during the June dry-down period (Table 12).

By mid-September 1991, highest RLD in the surface 3 to 10 cm zone occurred for Turf Conditioner + Lime and least for Verti-Drain (2X) + Core Aeration (Table 9). Within the 20 to 60 cm zone, highest RLD values were apparent for Turf Conditioner and lowest for Verti-Drain (2X) + Core Aeration. Water extraction data during the August dry-down revealed that the greatest water extraction from the 20 to 6-cm zone occurred for the Verti-Drain (2X) + Core Aeration treatment (Table 14). Thus, high RLD values do not necessarily reflect the ability of the roots to extract water. The severe treatment of the Verti-Drain (2X) + Core Aeration may injure some existing roots (thereby the lower RLD values), but this treatment also was most effective in reducing penetration resistance (Tables 19-25) deeper in the soil profile. The roots that are present may be more viable (due to better soil physical conditions) or may reflect recently produced roots after cultivation.

Root data for 1992 are not analyzed at this date but root water extraction data are presented in Table 15 and 16. As in 1991, Verti-Drain (2X) + Core Aeration plots exhibited the highest deep water extraction over the June (Table 15) and late August (Table 16) dry-downs. Verti-Drain (2X) plots also had high water extraction from the 20 to 60 cm zone in late August (Table 16).

Comparison of the three Turf Conditioner treatments reveals no difference in rooting in 1992 (Tables 8, 9). Water extraction from the surface 10 cm zone was higher in June 1991 for Turf Conditioner + Gypsum compared to Turf Conditioner alone or Turf Conditioner + Lime (Table 12). However, by late August 1991, best water extraction in the 0 to 10 cm zone was observed for Turf Conditioner + Lime (Table 14). In 1992, Turf Conditioner alone exhibited the best root water extraction (0 to 10 cm on 15 to 19 June; 10 to 20 cm on 22 to 26 June; 20 to 60 cm on 28 August to 1 September) relative to Turf Conditioner + Gypsum (Tables 15, 16), while Turf Conditioner + Lime was intermediate. Over the whole duration of the two dry-down periods, no significant differences in Turf Conditioner treatments were noted.

Cultivation influenced evapotranspiration (ET) in both years (Tables 17, 18). Compared to the compacted control, ET rates were higher on 5 and 4 dates out of 13 for Verti-Drain (2X) + Core Aeration and Turf Conditioner + Lime, respectively. Higher ET would be considered as favorable since soil compaction reduces efficient water use. For the Verti-Drain (2X) + Core Aeration plots, ET was enhanced by 28 to 96% and by 17 to 69% for the Turf Conditioner + Lime.

Penetration Resistance. Tables 19 to 25 contain penetration resistance data over the period of the study with lower values being beneficial. Primary observations are:

a). Not until after the second set of cultivation treatments did improvements in penetration resistance appear (Tables 19, 20, 21). Verti-Drain (2X) + Core Aeration was most effective by the end of the first summer but all Verti-Drain operations improved penetration resistance by this time.

b). In March 1992, only the Verti-Drain (2X) + Core Aeration plots still exhibited significantly lower penetration resistance (5 to 15 cm zone) (Table 22).

c). Differences between Verti-Drain (1X) versus Verti-Drain (2X) treatments were still apparent in 1992 but less in magnitude than in 1991. Thus, Verti-Drain (1X) with or without Core Aeration was almost as effective as Verti-Drain (2X) with or without Core Aeration (Tables 23 to 25).

d). The coring operation timed to be between Verti-Drain applications improved the effectiveness of Verti-Drain treatment in 1991; thereafter, no further benefit was noted. During the first year, core aeration may have loosened the soil surface to allow better penetration and effectiveness of the Verti-Drain. But, after two Verti-Drain applications (i.e., April and July), the soil was sufficiently loosened to allow good penetration without core aeration.

e). By early July 1992, all Turf Conditioner procedures resulted in lower penetration resistance in the 15 to 25 cm soil zone (Table 23); however, by late July only Turf Conditioner + Lime plots continued to have lower values than the compacted control (Table 24).

f). At the 18 July 1991 penetration resistance readings, some evidence for a compacted pan layer at 20 to 25 cm appeared for Turf Conditioner + Gypsum and Verti-Drain (2X) + Core Aeration methods (Table 20). This proved to be transient in nature and was not noted again for the Verti-Drain (2X) + Core Aeration treatment. Again, in late September 1992, a slight increase in penetration resistance at 20 to 25 cm for Turf Conditioner + Gypsum was noted (Table 25).

Soil Properties at the Soil Surface. In early and late 1992, soil physical properties of the surface 0 to 3 cm were determined (Table 26). In March, Verti-Drain (1X) plots exhibited higher total porosity and aeration porosity than the compacted control. On this date, all cultivation treatments except Turf Conditioner alone had higher total porosity. By mid-October, the only difference in soil surface physical conditions was for a lower bulk density for the Verti-Drain (1X) treatment.

Saturated Hydraulic Conductivity (SHC). SHC differences among treatments occurred on all three measurement dates (Table 27). Relative to the compacted control, Verti-Drain (2X) and Verti-Drain (1X) + Core Aeration treatments improved SHC on 2 out of 3 dates, while Verti-Drain (1X) enhanced SHC on 1 out of 3 dates. No cultivation treatment caused lower SHC than the compacted control.

Summary

Verti-Drain

Verti-Drain (2X) + Core Aeration combination:

a). Caused the most rapid reduction in penetration resistance with reductions from 43 to 45% throughout the surface 0 to 20 cm zone, compared to the compacted control after two repetitions of the above treatment sequence.

b). After the first year, the core aeration could be omitted and Verti-Drain (2X) alone produced similar results on penetration resistance (and deep water extraction by August 1992).

c). Verti-Drain (2X) + Core Aeration treatment resulted in the best root water extraction from deep (20 to 60 cm) in the soil zone in summer. Extraction in the 20 to 60 cm zone was 33 to 71% greater than the compacted control.

d). The Verti-Drain (2X) + Core Aeration treatment resulted in a reduction of total root length (June, September 1991) and deep rooting (September 1991); however, the roots were more efficient and able to extract more water than roots in the compacted control. Thus, root data may not always correlate to water uptake in cultivation studies. Also, this suggests that timing of Verti-Drain + Core Aeration on a cool-season turfgrass in late spring could markedly injure the root system. With a cool-season grass, summer regrowth of roots and maintenance of root viability would be much less likely than for the bermudagrass used in our study.

e). Verti-Drain (2X) + Core Aeration enhanced overall water uptake as demonstrated by ET rates often 28 to 96% higher than the compacted control.

f). Water infiltration and percolation, as measured by saturated hydraulic conductivity, was improved by Verti-Drain (2X) and Verti-Drain (1X) + Core Aeration treatments.

g). Overall, this research indicates that where a site has a fine-textured soil profile in conjunction with surface compaction, a vigorous cultivation program (Verti-Drain plus core aeration) can greatly improve turfgrass water use efficiency by enhancing water uptake from deeper soil zones.

Turf Conditioner

a). Turf Conditioner + Lime was the most beneficial of the three Turf Conditioner treatments for reducing penetration resistance. Improvement did not occur until after three treatments (i.e., second year) when penetration resistance was reduced by 16 to 28%, especially in the 15 to 25 cm zone.

b). Turf Conditioner + Lime plots exhibited better root water extraction in several instances but not always from the same soil zone. However, overall water uptake (ET) was greater by 13 to 32% than the compacted control on several measurement periods.

c). Turf Conditioner + Gypsum often improves root growth aspects without obvious changes in soil physical properties.

d). Based on the previous three observations, the Turf Conditioner cultivation procedure appears to be best used in conjunction with chemical modification (with lime, especially) for soils similar to that used in this project.

Further conclusions may be made after the 1992 rooting data are available.

Table 1. Visual quality as influenced by cultivation treatment in 1991.

Treatment Description				Visual Quality						Leaf Firing
Device	Application[†]		Compaction	24 May	17 Jun	19 Jul	8 Aug	29 Aug	12 Sep	12 Sep
				9=ideal density,color,uniformity;1=no live turf						— % —
Control	-	-	No	7.1abc	6.6cd	7.2c	7.1a	7.6c	7.3c	9.3ab
Control	-	-	Yes	7.4ab	7.0bc	7.5cb	7.3a	7.7bc	7.5abc	12.0ab
Turf Cond.	Apr. 1X	Jul 1X	Yes	6.9c	6.8c	7.4cb	6.1c	7.6c	7.5abc	10.8ab
Turf Cond. + Gypsum	Apr. 1X	Jul 1X	Yes	7.5a	7.8a	8.0a	7.2a	8.0ab	7.6abc	11.3ab
Turf Cond. + Lime	Apr. 1X	Jul 1X	Yes	7.3abc	6.9bc	7.6b	6.5bc	7.6c	7.4bc	12.8a
Verti-Drain	Apr. 1X	Jul 1X	Yes	6.9c	6.6cd	7.6b	7.5a	8.0ab	7.7a	8.0ab
Verti-Drain	Apr. 2X	Jul 2X	Yes	7.2abc	7.3b	7.7ab	7.1ab	8.1ab	7.6ab	5.5b
Verti-Drain + Core Aeration	Apr. 1X + Jun 1X	Jul 1X + Aug 1X	Yes	7.1abc	6.3d	7.6b	7.5a	8.0ab	7.6ab	7.8ab
Verti-Drain + Core Aertaion	Apr. 2X + Jun 1X	Jul 2X + Aug 1X	Yes	7.1abc	6.3d	7.6b	7.4a	8.2a	7.6ab	5.5b
LSD (.05) =				.52	.43	.32	.62	.40	.30	7.2
Sign. F-test =				.27	.001	.007	.001	.009	.20	.34
CV (%) =				5.0	4.3	2.9	6.0	6.0	2.7	5.3

[†]1X = one pass over the plot; 2X = two passes over the plot area.

Table 2. Visual quality as influenced by cultivation treatments in 1992.

Treatment Description				Visual Quality						
Device	Application†		Compaction	25 May	23 Jun	29 Jun	29 Jul	24 Aug	3 Sep	6 Oct
				— 9=ideal density,color,uniformity;1=no live turf —						
Control	-	-	No	6.0ab	7.2ab	7.3	7.4abc	7.4ab	7.6	7.4
Control	-	-	Yes	5.9b	7.2ab	7.3	7.4abc	7.6a	7.5	7.4
Turf Cond.	Apr. 1X	Jul 1X	Yes	6.1ab	7.1abc	7.5	7.2c	7.2b	7.6	7.8
Turf Cond. + Gypsum	Apr. 1X	Jul 1X	Yes	6.1ab	7.3a	7.4	7.5ab	7.3ab	7.6	7.5
Turf Cond. + Lime	Apr. 1X	Jul 1X	Yes	6.0ab	6.7c	7.3	7.3bc	7.2b	7.5	7.6
Verti-Drain	Apr. 1X	Jul 1X	Yes	6.3ab	7.0abc	7.4	7.4abc	7.6a	7.5	7.5
Verti-Drain	Apr. 2X	Jul 2X	Yes	6.4a	7.4a	7.4	7.4abc	7.5a	7.6	7.6
Verti-Drain + Core Aeration	Apr. 1X + Jun 1X	Jul 1X + Aug 1X	Yes	6.3ab	6.8bc	7.4	7.6a	6.5c	7.7	7.6
Verti-Drain + Core Aertaion	Apr. 2X + Jun 1X	Jul 2X + Aug 1X	Yes	6.3ab	6.9abc	7.4	7.5ab	6.3c	7.5	7.6
LSD (.05)	=			.49	.54	.23	.23	.32	.28	.37
Sign. F-test	=			.48	.14	.70	.13	.001	.71	.67
CV (%)	=			5	5	2	2	3	3	3

†1X = one pass over the plot; 2X = two passes over the plot area.

Table 3. Turfgrass shoot density as influenced by cultivation treatment in 1991.

Treatment Description				Shoot Density					
Device	Application†		Compaction	24 May	16 Jun	19 Jul	8 Aug	29 Aug	12 Sep
				9 = ideal shoot density; 1 = no live turf					
Control	-	-	No	8.2ab	7.5bcd	7.6c	7.6ab	7.8d	7.6c
Control	-	-	Yes	8.4a	7.7bc	7.7bc	7.6ab	8.0cd	7.7abc
Turf Cond.	Apr. 1X	Jul 1X	Yes	7.9b	7.5bcd	7.6c	7.3c	7.9cd	7.8abc
Turf Cond. + Gypsum	Apr. 1X	Jul 1X	Yes	8.4a	8.3a	8.3a	7.8a	8.4a	7.9ab
Turf Cond. + Lime	Apr. 1X	Jul 1X	Yes	8.1ab	7.7bc	7.9bc	7.3c	7.9cd	7.7abc
Verti-Drain	Apr. 1X	Jul 1X	Yes	8.1ab	7.6bc	7.8bc	7.8a	8.3ab	7.9ab
Verti-Drain	Apr. 2X	Jul 2X	Yes	8.5a	7.9b	7.9b	7.5bc	8.3ab	8.0a
Verti-Drain + Core Aeration	Apr. 1X + Jun 1X	Jul 1X + Aug 1X	Yes	8.3ab	7.3cd	7.8bc	7.8a	8.1bcd	7.8abc
Verti-Drain + Core Aeration	Apr. 2X + Jun 1X	Jul 2X + Aug 1X	Yes	8.2ab	7.2d	7.8bc	7.7a	8.2abc	7.7abc
LSD (.05) =				.47	.47	.29	.30	.33	.29
Sign. F-test =				.28	.002	.006	.007	.003	.19
CV (%) =				3.9	4.2	2.6	2.7	2.8	2.4

†1X = one pass over the plot; 2X = two passes over the plot area.

Table 4. Turfgrass shoot density as influenced by cultivation practices in 1992.

Treatment Description				Shoot Density						
Device	Application†		Compaction	25 May	23 Jun	29 Jun	29 Jul	24 Aug	3 Sep	6 Oct
				—— 9=ideal shoot density; 1=no live turf ——						
Control	-	-	No	7.2ab	7.5ab	7.4b	7.6ab	7.6ab	7.7	7.7c
Control	-	-	Yes	6.9ab	7.5ab	7.5ab	7.6ab	7.8a	7.7	7.8abc
Turf Cond.	Apr. 1X	Jul 1X	Yes	7.1ab	7.5ab	7.6a	7.5b	7.6ab	7.7	8.0a
Turf Cond. + Gypsum	Apr. 1X	Jul 1X	Yes	7.0ab	7.5ab	7.5ab	7.7ab	7.5bc	7.7	7.8abc
Turf Cond. + Lime	Apr. 1X	Jul 1X	Yes	6.8b	7.2b	7.4b	7.6ab	7.3c	7.8	8.0a
Verti-Drain	Apr. 1X	Jul 1X	Yes	7.3ab	7.5ab	7.6a	7.7ab	7.7ab	7.6	7.7c
Verti-Drain	Apr. 2X	Jul 2X	Yes	7.4a	7.6a	7.6a	7.6ab	7.7ab	7.8	7.9abc
Verti-Drain + Core Aeration	Apr. 1X + Jun 1X	Jul 1X + Aug 1X	Yes	7.4a	7.2b	7.5ab	7.8a	7.0d	7.8	7.9abc
Verti-Drain + Core Aertaion	Apr. 2X + Jun 1X	Jul 2X + Aug 1X	Yes	7.4a	7.2b	7.5ab	7.7ab	6.9d	7.7	7.8abc
LSD (.05)	=			.55	.35	.17	.23	.27	.24	.15
Sign. F-test	=			.33	.15	.52	.44	.001	.79	.30
CV (%)	=			5	3	2	2	2	2	2

†1X = one pass over the plot; 2X = two passes over the plot area.

Table 5. Relative clipping yield as affected by cultivation treatment in 1991 and 1992.

Treatment Description				Relative Clipping Yield						
				1991				1992		
Device	Application†		Compaction	7 Jun	19 Jul	30 Aug	23 Sep	6 Jun	21 Jul	8 Sep
				%						
Control	-	-	No	138a	104	114bc	106abc	149a	132a	107
Control	-	-	Yes	100ab	100	100cd	100abc	100b	100abc	100
Turf Cond.	Apr. 1X	Jul 1X	Yes	80b	86	103cd	105abc	88b	92bc	134
Turf Cond. + Gypsum	Apr. 1X	Jul 1X	Yes	94ab	96	167a	110abc	113ab	129ab	111
Turf Cond. + Lime	Apr. 1X	Jul 1X	Yes	105ab	99	113c	105abc	92b	108abc	119
Verti-Drain	Apr. 1X	Jul 1X	Yes	72b	88	144ab	115ab	99b	99abc	129
Verti-Drain	Apr. 2X	Jul 2X	Yes	88b	95	117bc	132a	94b	100abc	121
Verti-Drain + Core Aeration	Apr. 1X + Jun 1X	Jul 1X + Aug 1X	Yes	104ab	86	78d	79c	81b	77c	111
Verti-Drain + Core Aertaion	Apr. 2X + Jun 1X	Jul 2X + Aug 1X	Yes	82b	84	104cd	94bc	93b	83c	112
LSD (.05)	=			46	24	32	33	41	37	42
Sign. F-test	=			.22	.64	.001	.19	.09	.07	.79
CV (%)	=			33	17	19	22	28	25	25

†1X = one pass over the plot; 2X = two passes over the plot area.

Table 6. Turf color as affected by cultivation treatment in 1991.

Treatment Description: Device	Application†		Compaction	Turf Color: 24 May	16 Jun	19 Jul	8 Aug	29 Aug	12 Sep
				9 = dark green; 1 = no green					
Control	-	-	No	7.4b	6.9de	7.5c	7.4b	8.1ab	7.5ab
Control	-	-	Yes	7.6b	7.4bcd	7.8bc	7.6b	7.9b	7.5ab
Turf Cond.	Apr. 1X	Jul 1X	Yes	7.5b	7.1bcde	7.6bc	7.6b	7.9ab	7.6ab
Turf Cond. + Gypsum	Apr. 1X	Jul 1X	Yes	7.9a	8.5a	8.2a	8.3a	8.0ab	7.5ab
Turf Cond. + Lime	Apr. 1X	Jul 1X	Yes	7.5b	7.3bcd	7.7bc	7.5b	7.8b	7.4b
Verti-Drain	Apr. 1X	Jul 1X	Yes	7.6b	7.4bc	7.9b	7.7b	8.1ab	7.6ab
Verti-Drain	Apr. 2X	Jul 2X	Yes	7.5b	7.5b	7.7bc	7.5b	8.2a	7.6ab
Verti-Drain + Core Aeration	Apr. 1X + Jun 1X	Jul 1X + Aug 1X	Yes	7.5b	6.8e	7.8bc	7.7b	8.1ab	7.6ab
Verti-Drain + Core Aeration	Apr. 2X + Jun 1X	Jul 2X + Aug 1X	Yes	7.6b	7.0cde	7.8bc	7.7b	8.2a	7.7a
LSD (.05) =				.22	.44	.29	.35	.28	.27
Sign. F-test =				.009	.001	.003	.001	.125	.51
CV (%) =				2.0	4.2	2.5	3.1	2.4	2.5

†1X = one pass over the plot; 2X = two passes over the plot area.

Table 7. Turf color as affected by cultivation treatment in 1992.

Treatment Description				Turf Color				
Device	Application[†]		Compaction	25 May	23 Jun	29 Jun	29 Jul	24 Aug
				9 = dark green; 1 = no live turf				
Control	-	-	No	6.6c	7.4	7.5ab	7.5ab	7.4cd
Control	-	-	Yes	6.7c	7.5	7.4bc	7.4c	7.7a
Turf Cond.	Apr. 1X	Jul 1X	Yes	6.6c	7.4	7.5ab	7.5ab	7.7a
Turf Cond. + Gypsum	Apr. 1X	Jul 1X	Yes	6.7c	7.6	7.6a	7.4c	7.6ab
Turf Cond. + Lime	Apr. 1X	Jul 1X	Yes	6.7c	7.5	7.3c	7.5ab	7.5bcd
Verti-Drain	Apr. 1X	Jul 1X	Yes	6.8bc	7.4	7.5ab	7.6a	7.7a
Verti-Drain	Apr. 2X	Jul 2X	Yes	6.9ab	7.5	7.4bc	7.5ab	7.6ab
Verti-Drain + Core Aeration	Apr. 1X + Jun 1X	Jul 1X + Aug 1X	Yes	7.1a	7.5	7.5ab	7.5ab	7.4cd
Verti-Drain + Core Aeration	Apr. 2X + Jun 1X	Jul 2X + Aug 1X	Yes	7.0a	7.5	7.6a	7.6a	7.4cd
LSD (.05) =				.21	.20	.16	.15	.17
Sign. F-test =				.01	.83	.04	.19	.01
CV (%) =				2	2	2	1	2

[†]1X = one pass over the plot; 2X = two passes over the plot area.

Table 8. Root growth by soil depth on 26 June 1991.

Treatment Description				Root Length Density			Total Root Length
Device	Application†		Compaction	3 to 10 cm	10 to 20 cm	20 to 60 cm	3 to 60 cm
				cm•cm^{-3}			cm•cm^{-2}
Control	-	-	No	.70ab	.300	.077	3.67b
Control	-	-	Yes	1.14ab	.239	.089	4.64ab
Turf Cond.	Apr. 1X	Jul 1X	Yes	.74ab	.275	.113	4.14b
Turf Cond. + Gypsum	Apr. 1X	Jul 1X	Yes	.56b	.184	.092	3.14b
Turf Cond. + Lime	Apr. 1X	Jul 1X	Yes	.65ab	.220	.119	3.84b
Verti-Drain	Apr. 1X	Jul 1X	Yes	.99ab	.309	.090	4.53ab
Verti-Drain	Apr. 2X	Jul 2X	Yes	.94ab	.286	.088	4.31ab
Verti-Drain + Core Aeration	Apr. 1X + Jun 1X	Jul 1X + Aug 1X	Yes	1.34a	.431	.113	6.07a
Verti-Drain + Core Aeration	Apr. 2X + Jun 1X	Jul 2X + Aug 1X	Yes	.71ab	.316	.080	3.79b
LSD (.05) =				.74	.265	.054	1.90
Sign. F-test =				.44	.77	.71	.17
CV (%) =				58	64	39	55

†1X = one pass over the plot; 2X = two passes over the plot area.

Table 9. Root growth by soil depth on 19 September 1991.

Treatment Description				Root Length Density			Total Root Length
Device	Application[†]		Compaction	3 to 10 cm	10 to 20 cm	20 to 60 cm	3 to 60 cm
				cm•cm^{-3}			cm•cm^{-2}
Control	-	-	No	1.30ab	.382	.140abc	6.18ab
Control	-	-	Yes	1.05ab	.324	.150ab	5.53ab
Turf Cond.	Apr. 1X	Jul 1X	Yes	.97ab	.564	.179a	6.54ab
Turf Cond. + Gypsum	Apr. 1X	Jul 1X	Yes	1.51ab	.425	.135abc	6.73a
Turf Cond. + Lime	Apr. 1X	Jul 1X	Yes	1.76a	.417	.150ab	7.49a
Verti-Drain	Apr. 1X	Jul 1X	Yes	1.46ab	.370	.111bc	6.11ab
Verti-Drain	Apr. 2X	Jul 2X	Yes	1.04ab	.395	.135abc	5.55ab
Verti-Drain + Core Aeration	Apr. 1X + Jun 1X	Jul 1X + Aug 1X	Yes	1.30ab	.600	.103bc	6.41ab
Verti-Drain + Core Aeration	Apr. 2X + Jun 1X	Jul 2X + Aug 1X	Yes	.75b	.400	.098c	4.38b
LSD (.05) =				.80	.288	.051	2.23
Sign. F-test =				.29	.57	.064	.30
CV (%) =				47	46	26	45

[†]1X = one pass over the plot; 2X = two passes over the plot area.

Table 12. Root water extraction by soil depth during the 3 to 12 June 1991 soil dry-down period.

Treatment Description				Root Water Extraction by Soil Depth								
				3 to 7 June			10 to 12 June			3 to 12 June		
Device	Application†		Compaction	0 to 10 cm	10 to 20 cm	20 to 60 cm	0 to 10 cm	10 to 20 cm	20 to 60 cm	0 to 10 cm	10 to 20 cm	20 to 60 cm
				cm								
Control	-	-	No	.31b	.32ab	.77ab	.55b	.58ab	1.45	.76b	.77	1.58
Control	-	-	Yes	.33b	.25b	.58ab	.56b	.54b	1.46	.74b	.62	1.15
Turf Cond.	Apr. 1X	Jul 1X	Yes	.35ab	.30ab	.52ab	.56b	.57ab	1.43	.77b	.74	1.24
Turf Cond. + Gypsum	Apr. 1X	Jul 1X	Yes	.50a	.45a	.50ab	.68a	.56ab	1.38	1.13a	.84	1.22
Turf Cond. + Lime	Apr. 1X	Jul 1X	Yes	.32b	.33ab	.86a	.58b	.59ab	1.54	.87b	.82	1.42
Verti-Drain	Apr. 1X	Jul 1X	Yes	.23b	.33ab	.50ab	.61ab	.59ab	1.60	.71b	.84	1.36
Verti-Drain	Apr. 2X	Jul 2X	Yes	.38b	.33b	.52ab	.29ab	.31abc	.46b	1.03c	1.02b	1.46c
Verti-Drain + Core Aeration	Apr. 1X Jun 1X	Jul 1X Aug 1X	Yes	.37ab	.33ab	.38b	.550b	.63a	1.47	.79b	.84	1.25
Verti-Drain + Core Aeration	Apr. 2X Jun 1X	Jul 2X Aug 1X	Yes	.30b	.24b	.53ab	.59ab	.58ab	1.48	.75b	.68	1.50
LSD (.05) =				.153	.147	.435	.09	.08	.39	.20	.23	.59
Sign. F-test =				. 10	. 34	. 48	.17	.58	.96	.01	.47	.80
CV (%) =				32	32	51	11	9	18	17	21	30

†1X = one pass over the plot; 2X = two passes over the plot area.

Table 13. Root water extraction by soil depth during the 6 to 9 August 1991 soil dry-down period.

Treatment Description				Root Water Extraction by Soil Depth 6 to 9 Aug		
Device	Application†		Compaction	0 to 10 cm	10 to 20 cm	20 to 60 cm
				cm		
Control	-	-	No	.19b	.24	.49
Control	-	-	Yes	.33a	.23	.46
Turf Cond.	Apr. 1X	Jul 1X	Yes	.29ab	.26	.52
Turf Cond. + Gypsum	Apr. 1X	Jul 1X	Yes	.28ab	.32	.49
Turf Cond. + Lime	Apr. 1X	Jul 1X	Yes	.31ab	.23	.24
Verti-Drain	Apr. 1X	Jul 1X	Yes	.25ab	.25	.41
Verti-Drain	Apr. 2X	Jul 2X	Yes	.21ab	.25	.43
Verti-Drain + Core Aeration	Apr. 1X Jun 1X	Jul 1X Aug 1X	Yes	.30ab	.26	.25
Verti-Drain + Core Aeration	Apr. 2X Jun 1X	Jul 2X Aug 1X	Yes	.23ab	.21	.43
LSD (.05) =				.132	.132	.299
Sign. F-test =				.38	.85	.47
CV (%) =				34	37	50

†1X = one pass over the plot; 2X = two passes over the plot area.

Table 14. Root water extraction by soil depth during the 28 August to 13 September 1991 soil dry-down period.

Treatment Description				Root Water Extraction by Soil Depth								
				28 Aug to 3 Sep			9 to 13 Sept			28 Aug to 13 Sep		
Device	Application†		Compaction	0 to 10 cm	10 to 20 cm	20 to 60 cm	0 to 10 cm	10 to 20 cm	20 to 60 cm	0 to 10 cm	10 to 20 cm	20 to 60 cm
				cm								
Control	-	-	No	.51ab	.33b	.52ab	.31ab	.31abc	.51ab	1.26abc	1.05ab	1.67abc
Control	-	-	Yes	.52ab	.47a	.47ab	.26b	.31abc	.45b	1.33ab	1.23ab	1.46c
Turf Cond.	Apr. 1X	Jul 1X	Yes	.48b	.54a	.49ab	.30ab	.25c	.55ab	1.25bc	1.33ab	1.61abc
Turf Cond. + Gypsum	Apr. 1X	Jul 1X	Yes	.50ab	.44ab	.47ab	.29ab	.28bc	.59ab	1.25bc	1.08ab	1.68abc
Turf Cond. + Lime	Apr. 1X	Jul 1X	Yes	.64a	.48a	.48ab	.30ab	.38a	.67a	1.50a	1.37a	1.84ab
Verti-Drain	Apr. 1X	Jul 1X	Yes	.43b	.42ab	.38b	.27b	.26c	.55ab	1.10bc	1.10ab	1.67abc
Verti-Drain	Apr. 2X	Jul 2X	Yes	.38b	.33b	.52ab	.29ab	.31abc	.46b	1.03c	1.02b	1.46c
Verti-Drain + Core Aeration	Apr. 1X Jun 1X	Jul 1X Aug 1X	Yes	.49b	.44ab	.53ab	.25b	.32abc	.53ab	1.27abc	1.30ab	1.56bc
Verti-Drain + Core Aeration	Apr. 2X Jun 1X	Jul 2X Aug 1X	Yes	.45b	.47a	.66a	.35a	.32ab	.60ab	1.24bc	1.35ab	1.94a
LSD (.05) =				.154	.142	.235	.076	.088	.198	.242	.333	.356
Sign. F-test =				. 10	. 08	. 57	. 28	. 13	. 43	. 04	. 21	. 15
CV (%) =				22	22	32	18	20	25	13	19	15

†1X = one pass over the plot; 2X = two passes over the plot area.