THIRD YEAR PROGRESS REPORT

for

I. Influence of Soil Moisture Level on Turfgrass Water Use and Growth

II. Cultivation Methods on Turfgrass Water Relationships and Growth Under Soil Compaction

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I. INTRODUCTION

The projects reported on were initiated on February 1, 1986 and this report covers the period from November 1, 1987 to November 1, 1988. The first year was for implementation and included site preparation, establishment, equipment acquisition, and hiring of personnel. In the current year (third), we concentrated on acclimating the grasses to irrigation or cultivation treatments and intensive measurement periods. The projects end December 31, 1988 and a detailed final report will be submitted in January 1989. The present report will summarize the most significant results to the present date; however, the final report will contain a full discussion of the results and implications. Also, included in this report is information on budget and publicity concerning this research.

II. STATUS OF THIRD YEAR ANNUAL PLAN OF WORK

PROJECT: INFLUENCE OF SOIL MOISTURE LEVEL ON TURFGRASS WATER USE AND GROWTH

1. To determine the annual and seasonal water requirements of major turfgrass species in the Southeast under non-limiting to moderate moisture stress conditions.

2. To evaluate turfgrass performance -- quality, shoot responses, root alterations -- under non-limiting to moisture stress conditions.

Three warm-season grasses (Tifway bermudagrass, Meyer zoysiagrass, common centipedegrass) were each irrigated at three irrigation regimes based on soil water content readings at 15 cm depth. Irrigation regimes were (a) 18.7% H_2O_{vol} = -0.1 MPa = 33% soil water depletion (SWD), (b) 14.3% H_2O_{vol} = -0.4 MPa = 56% SWD, and (c) 10.0% H_2O_{vol} = -0.7 MPa = 76% SWD. These will be referred to as well irrigated (WI), moderate stress (MS), and severe stress (SS), respectively.

Well-irrigated turf would be typical of highly maintained fairways and tees, while the moderate stress would be a common irrigation regime for many fairway situations. Except for golf course roughs or turf subjected to water restrictions, most turf would not be under the severe stress irrigation program.

The most informative data came from two prolonged dry down periods where intensive water use, water extraction, rooting profiles, and shoot growth parameters were measured. These data are in the following Tables:

Table 1.	Water use and extraction by depth 10-26 Aug. 1987.
Table 3.	Root length density and weight by depth for 10-26 Aug. 1987.
Table 4.	Total root length and root water extraction efficiency for 10-26 Aug. 1987.
Table 7.	Visual quality for 10-26 Aug. 1987.
Table 8.	Wilt, verdure, leaf extension rate, leaf angle for 10-26 Aug. 1987.
Table 9.	Color and leaf firing for 10-26 Aug. 1987.

Table 2. Water use and extraction by depth 11 May-8 July 1988.
Table 5. Root growth by depth for 26 June 1988
Table 6. Total root length and root water extraction efficiency 26 June 1988
Table 10. Visual quality wilt, and verdure for 11 May-8 July 1988.
Table 11. Color and turf coverage for 11 May-8 July 1988.

The rooting data (root length density, root weight, total root length, root water extraction efficiency) for 11 May-8 July 1988 are under sample preparation and analysis. This information will be in the final report.

Important results are

A. WATER USE (EVAPOTRANSPIRATION):

1. Comparison of species (Tables 1,2).

a). Under the WI regime, Tifway bermudagrass used 25 and 24% less water than Meyer zoysiagrass and common centipedegrass, respectively, in late summer. In late spring to mid-summer, bermudagrass used 19% less water than zoysiagrass and the same ET as centipedegrass.

b). With the MS irrigation regime, bermudagrass used 69 and 15% less water than zoysiagrass and centipedegrass, respectively, in the late summer period. Late spring to mid-summer ET rates were 24 and 30% less for bermudagrass than zoysiagrass and centipedegrass, respectively.

c). Comparisons of ET at the SS irrigation program revealed that bermudagrass used 15% more water than zoysiagrass in late summer, but 20% less than centipedegrass. A review of the shoot growth during this time period showed that zoysiagrass had a low average ET under the SS program because it went into a dormant state and lost considerable color (leaf senescence), quality, and density. Evapotranspiration rates in late spring to mid-summer illustrated that bermudagrass used 18% more water than zoysiagrass (again the zoysia became dormant) and 20% less than centipedegrass.

2. Irrigation program effects on ET (Tables 1,2).

a). When bermudagrass was subjected to increasing drought stress (WI → MS → SS), ET decreased by 13 to 15% from WI to MS irrigation programs; however, when going from MS to SS conditions, no further water use savings were noted. In fact, in Aug. 1987, an increase (9%) in ET occurred. This response appeared to be due to the ability of bermudagrass to maintain (and even increase) a viable root system under the SS conditions. Thus, the new roots could continue to extract moisture, particularly deeper in the soil profile.

b). As zoysiagrass went from WI to MS conditions, ET increased 11% in Aug. 1987 but decreased 9% in late spring to mid-summer 1988. The increase in 1987 was from better soil water extraction from the 11-60 cm zone under MS irrigation. As drought stress increased from MS to SS irrigation, water use declined by 33 to 45%. The change from MS to SS reduced water use but rooting decreased and turfgrass quality declined.

Table 1 Water extraction by soil depth and total water use (0-60 cm) from 10 to 26 August 1987 for three grasses at three irrigation regimes.

Species / Irrigation	Water extraction by depth 0-10 cm	11-20 cm	21-60 cm	0-60 cm
	cm day^{-1}			
Bermuda (1)				
-0.10 mPa (1)	0.124 (33%)†	0.103 (28%)	0.147 (39%)	0.374
-0.40 mPa (2)	0.097 (32%)	0.072 (24%)	0.136 (45%)	0.305
-0.70 mPa (3)	0.108 (32%)	0.084 (25%)	0.142 (43%)	0.334
Zoysia (2)				
-0.10 mPa	0.222 (48%)	0.113 (24%)	0.131 (28%)	0.466
-0.40 mPa	0.178 (35%)	0.146 (28%)	0.191 (37%)	0.515
-0.70 mPa	0.098 (35%)	0.082 (29%)	0.104 (37%)	0.284
Centipede (3)				
-0.10 mPa	0.187 (40%)	0.097 (21%)	0.178 (38%)	0.463
-0.40 mPa	0.120 (34%)	0.083 (24%)	0.141 (40%)	0.351
-0.70 mPa	0.087 (20%)	0.089 (21%)	0.253 (59%)	0.428
CV (%)	18	17	35	21
ANOVA				
G (grass)	**	**	NS‡	*
I (irr.)	**	*	NS	NS‡
GxI	**	**	NS‡	*
Contrasts				
G1 vs G2 at I1	**	NS	NS	*
G1 vs G3 at I1	**	NS	NS	*
G1 vs G2 at I2	**	**	*	**
G1 vs G3 at I2	NS	NS	NS	NS
G2 vs G3 at I2	**	**	NS	**
G1 vs G2 at I3	NS	NS	NS	NS
G1 vs G3 at I3	NS	NS	**	*
G2 vs G3 at I3	NS	NS	**	**

*,**Significant at the 0.05 and 0.01 levels, respectively.

† Value in ( ) is percent of the water extracted from that depth.

‡ Significant at the 0.10 level.

Table 2 Water extraction by soil depth and total water use (0-60 cm) from 11 May to 8 July 1988 for three grasses at three irrigation regimes.

Species Irrigation	Water extraction by depth 0-10 cm	 11-20 cm	 21-60 cm	 0-60 cm
	----------cm day^{-1}----------			
Bermuda (1)				
-0.10 mPa (1)	0.130 (45%)†	0.076 (26%)	0.084 (29%)	0.290
-0.40 mPa (2)	0.104 (41%)	0.052 (21%)	0.095 (38%)	0.251
-0.70 mPa (3)	0.105 (41%)	0.057 (22%)	0.094 (37%)	0.256
			0.091	
Zoysia (2)				
-0.10 mPa	0.172 (50%)	0.089 (26%)	0.083 (24%)	0.344
-0.40 mPa	0.145 (46%)	0.086 (28%)	0.081 (26%)	0.312
-0.70 mPa	0.106 (51%)	0.050 (24%)	0.053 (25%)	0.209
			0.072	
Centipede (3)				
-0.10 mPa	0.134 (47%)	0.062 (22%)	0.090 (31%)	0.286
-0.40 mPa	0.158 (48%)	0.075 (23%)	0.083 (28%)	0.326
-0.70 mPa	0.141 (46%)	0.078 (25%)	0.087 (28%)	0.306
			0.090	
CV (%)	10	20	15	9
ANOVA				
G (grass)	**	**	* (.01%)‡	**
I (irr.)	**	**	NS	**
GxI	**	**	NS	**
Contrasts				
G1 vs G2 at I1	**	*	-	**
G1 vs G3 at I1	NS	*	-	NS
G1 vs G2 at I2	**	**	-	**
G1 vs G3 at I2	**	*	-	**
G2 vs G3 at I2	*	*	-	NS
G1 vs G2 at I3	NS	NS	-	**
G1 vs G3 at I3	**	**	-	**
G2 vs G3 at I3	**	**	-	**

*,**Significant at the 0.05 and 0.01 levels, respectively.

†Value in ( ) is percent of the water extracted from that depth.

‡Value in ( ) is the LSD (.05) for main effect comparisons.

c.) Reducing irrigation from WI to MS on centipedegrass decreased water use by 24% in Aug. 1987 but in late spring to mid-summer 1988 ET increased 14%. Aug. 1987 rooting data reveal reduced root length density (RLD) and root weights at MS versus WI irrigation. Rooting data for 1988 may help explain the increase in ET in 1988. When centipedegrass was subjected to SS, ET increased in Aug. 1987 by 22% compared to MS, while in 1988 water use decreased by 9% for the same comparison. Increased root development in the 0-10 and 11-20 cm zones in 1987, while maintaining similar rooting at 21-60 cm would explain the ability of the SS plant to extract more water from the soil than the MS plant. Also, in the 21-60 cm zone, the SS roots exhibited considerably better root water extraction efficiency (i.e. higher water uptake per unit length of root).

3. Seasonal ET changes (Tables 1,2).
Averaging across all irrigation regimes, late summer ET rates were 27, 48, and 35% higher for bermudagrass, zoysiagrass, and centipedegrass, respectively, than late spring to mid-summer.

4. Ranking of species by ET (i.e. water use) Tables 1,2).
According to Dr. J. B. Beard (Turfgrass Water Conservation, Univ. of Calif. Pub 21405, Chapter 5, 1985), water use rankings for Tifway bermudagrass, Meyer zoysiagrass, and common centipedegrass were 4.7-6.8 (low to med.), 5.8-7.2 (med-low to med-high), and 5.5-8.5 mm day^{-1} (med low to high), respectively. Based on our data, the grass ranking would be 2.5-3.7 (very low), 3.1-5.5 (very low to med low) and 2.9-4.6 mm day^{-1} (very low to low), respectively. The ranking in 1985 was for all data available on turfgrass water use but all warm-season grass data came from arid or semi-arid climates. Our data suggests that under humid climates, the ET decreases 54 to 66% and a separate ranking scale or revised scale may be needed to reflect actual ET in humid areas. It is interesting to note that our data was taken in hot and drier periods than normal and these ET values may actually be somewhat high for the region.

B. ROOT GROWTH AND DYNAMICS:

1. Comparison of species (Tables 3,4)

a). Under WI conditions, root length density (RLD) rankings for species comparison changed with soil depth. In the 0-10 and 11-20 cm zones, centipedegrass exhibited highest RLD and zoysiagrass lowest. However, at the 21-60 cm depth, bermudagrass had the highest RLD and zoysiagrass least.

b). At MS irrigation, bermudagrass and centipedegrass RLD values were similar at all depths, while zoysiagrass RLD's were consistently lower.

c). When subjected to SS irrigation, surface (0-10 cm) and (11-20 cm) RLD values were on the order of centipedegrass (highest), bermudagrass, and zoysiagrass (least). At 21-60 cm, bermudagrass had highest RLD, followed by centipedegrass and zoysia. Comparisons of RLD at 21-60 cm between bermudagrass and centipedegrass were not significant but root weights were.

Table 3. Root growth data on 28 Aug. 1987 for three grasses under three irrigation regimes.

Species / Irrigation	Root Length Density 0-10 cm	Root Length Density 11-20 cm	Root Length Density 21-60 cm	Total Root Length 0-60 cm	Root Weight Density 0-10 cm	Root Weight Density 11-20 cm	Root Weight Density 21-60 cm	Root Weight 0-60 cm
	cm cm-3			cm cm-2	mg cm-3			mg/100 cm^2
Bermuda (1)								
-0.10 mPa (1)	4.37	1.60	1.39	115	0.96	0.34	0.16	1940
-0.40 mPa (2)	4.92	2.12	0.96	109	0.42	0.15	0.15	2124
-0.70 mPa (3)	5.90	1.95	1.22	127	0.39	0.19	0.19	2330
		1.89	1.19		1.07	0.38	0.17	2131
Zoysia (2)								
-0.10 mPa	3.54	0.97	0.24	55	0.84	0.16	0.04	1165
-0.40 mPa	2.56	0.56	0.17	38	0.13	0.03	0.03	852
-0.70 mPa	1.59	0.55	0.37	36	0.12	0.05	0.05	646
		0.69	0.26		0.59	0.14	0.04	888
Centipede (3)								
-0.10 mPa	13.78	3.39	1.04	213	1.79	0.56	0.12	2845
-0.40 mPa	5.71	2.59	0.90	119	0.92	0.36	0.10	1675
-0.70 mPa	6.95	3.46	0.88	139	1.15	0.57	0.09	2085
		3.15	0.94		1.29	0.50	0.10	2202
CV (%)	35	45	44		39	46	56	50
ANOVA								
G (grass)	**	**(.86)	**(.36)	**	**(.41)	**(.16)	**(.06)	*(645)
I (irr.)	**	NS	NS	NS	NS	NS	NS	NS
GxI	**	NS	NS	**	NS	NS	**	NS
Contrasts								
G1 vs G2 at I1	NS	-	-	**	-	-	-	-
G1 vs G3 at I1	*	-	-	**	-	-	-	-
G1 vs G2 at I2	**	-	-	**	-	-	-	-
G1 vs G3 at I2	NS	-	-	NS	-	-	-	-
G2 vs G3 at I2	**	-	-	**	-	-	-	-
G1 vs G2 at I3	*	-	-	**	-	-	-	-
G1 vs G3 at I3	NS	-	-	NS	-	-	-	-
G2 vs G3 at I3	*	-	-	**	-	-	-	-

*,**Significant at the 0.05 and 0.01 levels, respectively.
Where no main effect interaction occurred, the value in ( ) is LSD (.05) for the main effect comparison.

Table 4. Total root length and root water extraction efficiency on 28 Aug. 1987 for three grasses under three irrigation regimes.

Species Irrigation	Total root length 0-60 cm	Root water extraction efficiency†		
		0-10 cm	11-21 cm	21-60 cm
	$cm\ cm^{-2}$			
Bermuda				
-0.10 MPa	115	0.88	1.99	0.82
-0.40 MPa	109	0.70	1.21	1.26
-0.70 MPa	127	0.70	1.64	1.11
Zoysia				
-0.10 MPa	55	0.74	1.37	1.60
-0.40 MPa	38	0.51	1.92	2.07
-0.70 MPa	36	0.79	1.90	0.90
Centipede				
-0.10 MPa	213	0.63	1.32	1.97
-0.40 MPa	119	0.71	1.08	1.33
-0.70 MPa	139	0.41	0.84	2.34

$$\dagger\text{RWEE} = \frac{\dfrac{\text{water extracted in the layer}}{\text{total water extracted from all layers}}}{\dfrac{\text{root length in the layer}}{\text{total root length of all layers}}}$$

Range of RWEE: 0.01 (low) 6.0 (very high)

Table 5. Root growth data on 26 June 1988 for three grasses under three irrigation regimes.

Species / Irrigation	Root Length Density 0-10 cm	Root Length Density 11-20 cm	Root Length Density 21-60 cm	Total Root Length 0-60 cm	Root Weight Density 0-10 cm	Root Weight Density 11-20 cm	Root Weight Density 21-60 cm	Root Weight 0-60 cm
	-----------cm cm^{-3}	--------		--cm cm^{-2}--	----------mg cm^{-3}	----------		mg/100 cm^2
Bermuda (1)								
-0.10 MPa (1)	7.80	2.26	0.89	136	2.06	0.73	0.24	3770
-0.40 MPa (2)	4.50	2.04	0.70	94	1.89	0.77	0.19	3430
-0.70 MPa (3)	6.51	2.77	0.76	123	1.90	0.79	0.23	3610
		2.36			1.95	0.76	0.22	3603
Zoysia (2)								
-0.10 MPa	2.22	0.48	0.13	32	0.68	0.13	0.03	910
-0.40 MPa	1.53	0.80	0.38	38	0.54	0.19	0.05	950
-0.70 MPa	2.31	0.72	0.15	37	0.74	0.13	0.04	1020
		0.67			0.65	0.15	0.04	960
Centipede (3)								
-0.10 MPa	3.34	1.30	0.27	57	1.10	0.35	0.05	1650
-0.40 MPa	5.23	1.63	0.67	96	1.59	0.30	0.14	2450
-0.70 MPa	5.62	1.41	0.28	82	1.74	0.34	0.08	2380
		1.45			1.48	0.33	0.09	2160
CV (%)	32	51	37	23	20	32	37	38
ANOVA								
G (grass)	**	**(.75)	**	**	**(.27)	**(.13)	**(.17)	*(825)
I (irr.)	NS	NS	*	NS	NS	NS	NS	NS
GxI	*	NS	*	*	NS	NS	NS	NS
Contrasts								
G1 vs G2 at I1	**	-	**	**	-	-	-	-
G1 vs G3 at I1	**	-	**	**	-	-	-	-
G1 vs G2 at I2	*	-	*	**	-	-	-	-
G1 vs G3 at I2	NS	-	NS	NS	-	-	-	-
G2 vs G3 at I2	**	-	*	**	-	-	-	-
G1 vs G2 at I3	**	-	**	**	-	-	-	-
G1 vs G3 at I3	NS	-	**	**	-	-	-	-
G2 vs G3 at I3	**	-	NS	**	-	-	-	-

Table 6. Total root length and root water extraction efficiency on 26 June 1988 for three grasses under three irrigation regimes.

Species / Irrigation	Total root length 0-60 cm	Root water extaction efficiency† 0-10 cm	11-20 cm	21-60 cm
	$cm\ cm^{-2}$			
Bermuda				
-0.10 MPa	136	0.78	1.58	1.11
-0.40 MPa	94	0.86	0.95	1.27
-0.70 MPa	123	0.78	0.99	1.49
	118			
Zoysia				
-0.10 MPa	32	0.72	1.73	1.48
-0.40 MPa	38	1.15	1.31	0.65
-0.70 MPa	37	0.81	1.23	1.57
	36			
Centipede				
-0.10 MPa	57	0.80	0.95	1.67
-0.40 MPa	96	0.89	1.35	0.91
-0.70 MPa	82	0.67	1.48	2.07
	78			

$$^{\dagger}\text{RWEE} = \frac{\dfrac{\text{water extracted in the layer}}{\text{total water extracted from all layers}}}{\dfrac{\text{root length in the layer}}{\text{total root length of all layers}}}$$

Range of RWEE: 0.01 (low) 6.0 (very high) d). The RLD values for bermudagrass and centipedegrass compare favorably for those reported on agronomic crops: winter wheat (0.10-6.2), spring wheat (0.10-6.6), oats (0-10-3.9), soybean (0.02-8.9 cm cm^{-3}).

2. Irrigation program effects on root growth (Tables 3,4).

a). Bermudagrass. RLD root weights were very stable over all irrigation regimes. There was a tendency for root growth to increase as drought stress increased as shown by the total root length and total root weight data.

b). Zoysiagrass rooting (RLD, weights) declined in the 0-10 and 11-20 cm depths as moisture stress increased. Slight improvement (not significant) seemed to occur in the 21-60 cm zone. Total root length and total root weights reveal a consistent decrease in rooting in response to drought stress. Additionally, those roots in the 21-60 cm zone had lower RWEE at SS than MS irrigations, while bermudagrass and centipedegrass showed equivalent or better RWEE between these irrigation programs.

These responses by zoysiagrass indicate that it does not enhance drought avoidance by improved root growth. Our soil conditions (Cecil sandy loam) include the surface 30 cm at pH 5.6 and bulk density of 1.50 g cm^{-3}, while the 30-60 cm horizon has a pH of 5.6 and bulk density of 1.61 g cm^{-3}.

Unless other zoysiagrasses exhibit substantial improvement in water use (at all irrigation regimes) and much better rooting when subjected to drought stress, this species may not prove to be one exhibiting low ET (water use) or good drought tolerance or good drought avoidance. Experimentals should be evaluated in several soil conditions (pH and bulk densities) to see if the above results are true for zoysia in all situations or just conditions similar to Piedmont soils.

c). From WI to MS, centipedegrss RLD, root weights, total root length, and total root weight values declined. However, as stress continued (MS to SS), these parameters increased. Apparently, centipedegrass expends considerable photosynthate for root development during well-irrigated times that it does not appear to need (as revealed by shoot growth when going from WI to MS). When subjected to a severe stress, root growth continues and even increases, similar to bermudagrass.

d). Combining the water use data with rooting information, illustrates that ET depends on root dynamics. The WI situation should result in ET rates similar to those reported for non-limiting moisture situations. Under this regime, the primary factors influencing ET are: climatic conditions, canopy resistance (a function of leaf extension rate and erectness of leaves). In contrast, under the MS situation, primary controlling factors for ET are: climatic conditions, root dynamics, soil water potential and to a lesser degree canopy resistance. At SS conditions, controlling factors are: climatic conditions, root dynamics, stomatal closure/openness, dormancy state (leaf firing). If grasses are to be developed to process low ET and good drought resistance (tolerance and/or avoidance), they must be evaluated in situations where these conditions of stress occur <u>and</u> ET and drought resistance be measured under these conditions. Data on ET under well-irrigated situations do not represent plant response under stress conditions. If these steps are not included in the turf evaluation process, a grass may be released with higher water use requirements than current cultivars. Also, grasses with deep rooting patterns under ideal soil situations must be proved to retain these patterns under the most common root limiting soil properties (low pH in the surface or subsoil, high bulk densities naturally or from compaction).

Another factor to consider in interpreting deep root growth verus soil water extraction from deeper soil zones is the long-term effect of water extraction. In a severe drought stress of 2-4 weeks, the increased rooting of bermudagrass and centipedegrass would provide a means of delaying or reducing stress. However, once this moisture is depleted, this mechanism of drought avoidance is no longer active. Common sense would seem to indicate that such 2-4 week benefits would be especially important during relatively short-term drought periods in the Southeast. In semi-arid or arid conditions, this would also be beneficial but once exhausted, the soil moisture may remain depleted for long periods unless recharged by irrigation.

C. <u>SHOOT GROWTH</u>.
(Tables 5, 6, 7, 8, 9)

a). All three grasses exhibited good visual quality under the WI and MS irrigations. There were several situations where somewhat better quality occurred at MS rather than for WI conditions. This is probably a result of somewhat slower growth under MS and better N relations over time. Comparison under these two irrigation levels reveals no differences in color or verdure. Some differences were noted for wilt with zoysia (24 June 1988) after a prolonged drought period and for turf cover of centipedegrass (6 May 1988) which may be a reflection of slow growth during spring greenup.

b). Under the SS irrigation, bermudgrass exhibited only a slight decline in visual quality compared to the WI and MS plots. Zoysiagrass showed a substantial reduction in quality at the SS regime, while centipedegrass was intermediate in response.

The decline in visual quality of zoysiagrass under drought stress could be attributed to the occurrence of severe wilt. Once soil moisture reached about -0.50 MPa (-5 bars) soil water potential at 15 cm depth, zoysiagrass exhibited rapid wilting which was followed within 1-3 days with significant leaf firing and color loss. The long-term effects of these responses were a reduction in verdure and turf cover.

Centipedegrass response to the SS regime included wilting but it did not occur as rapidly or to the extent of zoysiagrass. Leaf firing was not observed but an overall reduction in the degree of green was noted. Exposure to drought stress did reduce verdure and turf coverage.

D. IRRIGATION SCHEDULING INFORMATION.

1. Recommended irrigation regimes.

Water conservation can be achieved by reducing the frequency of irrigation but the adverse effects on shoot quality and growth must be considered. Based on water use savings and maintenance of adequate shoot quality/growth, the following irrigation regimes are suggested for growers using soil moisture sensors:

*Bermudagrass. Irrigation from -0.40 MPa to -0.70 MPa at 15 cm depth with high use turf receiving the more frequent irrigation program to allow for recovery from wear. Another way of representing these programs would be 56 to 76% soil water depletion (SWD) (of available soil moisture within the total rootzone).

*Zoysiagrass should be irrigated at -0.30 MPa to -0.40 MPa since at just below -0.40 MPa (at 15 cm depth), leaf firing and severe wilt occurs, as well as further deterioration of the root system. Heavily trafficked zoysiagrass should be irrigated at -0.30 MPa. In terms of available soil water depletion within the whole profile, this would represent 42 to 56% SWD.

*Centipedegrass irrigation would be best at between -0.50 to -0.60 MPa at 15 cm depth or 58 to 65% SWD over the whole profile. When using these suggested irrigation programs, the grower should irrigate in a manner that recharges the whole root profile (in this case 60 cm deep). Approximate water use rates (ET) for these turfgrasses for our conditions in the suggested irrigation programs would be;

*Bermudagrass	0.250-0.330 cm day^{-1}
*Zoysiagrass	0.320-0.500 cm day^{-1}
*Centipedegrass	0.315-0.360 cm day^{-1}

2. Irrigation scheduling techniques

The above reported information relates to the specific objectives of this project. However, due to the nature of the data collected to achieve these objectives, important additional information can be obtained from this project that may help reduce turfgrass water use (this was pointed out in the original project). The additional information concerns comparing different irrigation scheduling methods - i.e. procedures that aid a grower in when to irrigate.

Water use data in this project has been measured by daily monitoring of soil water content at three depths during periods when no leaching or runoff occurs. Time-domain reflectrometry (TDR) has been used to measure soil water content. We can then compare other methods to the TDR procedure. Currenty we are comparing:

Method	Basis for Scheduling Irrigation
TDR	Soil based to estimate ET
CWSI[1]	Plant based to estimate degree of drought stress
SDD[2]	Plant based to estimate degree of drought stress
Weather pan	Climate based to estimate ET
Penman equation	Climate based to estimate ET

[1]Crop water stress index

[2]Summation of stress degree days between irrigations

Results to date include these observations;

(a) The TDR procedure is very accurate for measuring soil water content, but it cannot be automated at this time.

(b) CWSI is based on determining canopy temperatures (T_c) minus air temperatures (T_a) on days when water is not limiting. This provides a lower baseline that is also influenced by humidity. From this, an upper baseline (T_c - T_a for non-transpiring conditions), can be calculated. For any particular day that we know the humidity at the time T_c and T_a are measured, the theoretical CWSI can range from 0 (on the lower baseline) to 1 (on the upper baseline). If a particular CWSI value could be consistently correlated to a known soil water content, then the CWSI would be useful for indicating to a grower when to irrigate. We determined baselines for each species and calculated CWSI values just prior to irrigation. These were very inconsistent for all three species in contrast to more consistent CWSI indices reported by Throssell and Carrow (1987, Agron. J. 27:126-131) for Kentucky bluegrass. One contributing factor was the scattering of data for the lower baseline which may be due to a humid climate versus semi-arid or arid conditions for most CWSI literature.

(c) The ΣSDD is based on summing $T_c - T_a$ values for each day after an irrigation until a critical value is reached that would suggest the need for irrigation. ΣSDD values were much more consistent than CWSI indices, except for zoysiagrass at -0.4 MPa irrigation regime. This may be due to the tendency of zoysiagrass to lose considerable water on the first day after irrigation, especially on days with low humidity. An upright leaf structure may contribute to this water loss.

(d) Crop coefficients were calculated for a U.S. Weather Bureau pan. These should be useful guidelines for any growers using weather pan evaporation to guide irrigation.

(e) Penman values have not been calculated as of this date. They will be compared to daily ET estimates by the weather pan and TDR procedures. These comparisons will be provided in the final report.

Table 7 Visual quality data in 1987 for three grasses under three irrigation regimes.

Species / Irrigation	6 July	21 July	18 Aug.	20 Aug.	22 Aug.	24 Aug.	26 Aug.	29 Aug.	18 Sept.
	Visual quality: 9 = ideal density, color, uniformity; 1 = no live turf								
Bermuda (1)									
-0.10 mPa (1)	7.2	7.8	7.9	7.7	7.9	7.6	7.8	7.9	7.7
-0.40 mPa (2)	6.3	7.6	8.0	7.9	8.1	8.0	7.9	8.0	8.1
-0.70 mPa (3)	6.7	7.6	7.8	7.8	7.6	7.4	7.4	7.4	7.6
		7.7	7.9						7.8
Zoysia (2)									
-0.10 mPa	8.1	7.7	7.6	7.7	7.2	8.0	8.0	8.2	8.1
-0.40 mPa	8.6	8.2	7.6	7.6	8.1	8.3	8.4	8.4	8.0
-0.70 mPa	8.0	7.7	7.3	5.2	4.5	3.8	5.4	6.6	7.1
		7.9	7.5						7.7
Centipede (3)									
-0.10 mPa	7.7	7.9	7.9	8.5	8.5	8.6	8.2	8.5	8.3
-0.40 mPa	8.1	7.7	7.9	7.7	8.2	8.2	7.8	8.2	8.0
-0.70 mPa	7.7	7.7	8.0	8.2	7.8	6.8	7.5	8.1	8.3
		7.8	7.9						8.2
CV (%)	6	3	3	10	8	6	8	6	6
ANOVA									
G (grass)	**	NS	*(.3)†	**	**	**	NS	*	NS
I (irr.)	NS	NS	NS	*	**	**	**	**	NS
GxI	*	NS	NS	*	**	**	**	*	NS
Contrasts									
G1 vs G2 at I1	NS	-	-	NS	NS	NS	NS	NS	-
G1 vs G3 at I1	NS	-	-	NS	NS	**	NS	*	-
G1 vs G2 at I2	**	-	-	NS	NS	NS	*	NS	-
G1 vs G3 at I2	**	-	-	NS	NS	NS	NS	NS	-
G2 vs G3 at I2	NS	-	-	NS	NS	NS	*	NS	-
G1 vs G2 at I3	*	-	-	*	**	**	*	NS	-
G1 vs G3 at I3	*	-	-	NS	NS	NS	NS	NS	-
G2 vs G3 at I3	NS	-	-	*	**	**	*	*	-

*,**Significant at the 0.05 and 0.01 levels, respectively.

†Where no main effect interaction is present, the value in ( ) is LSD (.05) for the main effect comparison.

Table 8 Wilt, verdure, leaf extension rate, and leaf angle data in 1987 for three grasses under three irrigation regimes.

Species Irrigation	Wilt 19 Aug.	Wilt 21 Aug.	Wilt 23 Aug.	Wilt 25 Aug.	Wilt 26 Aug.	Verdure 21 Sept.	Leaf Extension Rate 15-18 Sept.	Leaf Angle 18 Sept.
	----9 = no wilt; 1 = all turf wilted-----					mg cm^{-2}	mm d^{-1}	----0------
Bermuda (1)								
-0.10 mPa (1)	8.8	9.0	8.5	8.8	8.3	58.6	2.2	43
-0.40 mPa (2)	9.0	8.7	7.8	8.2	8.3	50.0	3.1	51
-0.70 mPa (3)	8.5	8.3	7.7	7.8	8.2	58.4	2.8	41
					8.3	55.7	2.7	45
Zoysia (2)								
-0.10 mPa	8.3	7.2	7.3	7.7	8.2	59.4	4.6	48
-0.40 mPa	7.8	7.2	8.2	8.2	8.5	51.6	5.3	43
-0.70 mPa	5.3	2.5	2.5	1.8	7.8	49.8	5.1	41
					8.2	53.6	5.0	44
Centipede (3)								
-0.10 mPa	8.8	9.0	8.7	8.7	8.5	52.0	6.1	29
-0.40 mPa	8.5	8.5	8.7	8.5	8.5	58.4	5.0	27
-0.70 mPa	8.5	8.5	7.5	5.7	8.2	41.4	5.4	28
					8.4	50.6	5.5	28
CV (%)	9	8	9	8	4	17	21	15
ANOVA								
G (grass)	**	**	**	**	NS	NS	**(2.1)†	**(11)
I (irr.)	**	**	**	**	NS	NS	NS	NS
GxI	*	**	**	**	NS	NS	NS	NS
Contrasts								
G1 vs G2 at I1	NS	**	*	NS	-	-	-	-
G1 vs G3 at I1	NS	NS	NS	NS	-	-	-	-
G1 vs G2 at I2	*	*	NS	NS	-	-	-	-
G1 vs G3 at I2	NS	NS	NS	NS	-	-	-	-
G2 vs G3 at I2	NS	*	NS	NS	-	-	-	-
G1 vs G2 at I3	*	**	**	**	-	-	-	-
G1 vs G3 at I3	NS	NS	NS	*	-	-	-	-
G2 vs G3 at I3	*	**	**	**	-	-	-	-

*,**Significant at the 0.05 and 0.01 levels, respectively.

†Where no main effect interaction occurred, the value in ( ) is LSD (.05) for the main effect comparison.

Table 9 Green color and leaf firing from desiccation of three grasses under three irrigation regimes in 1987.

Species / Irrigation	Color 21 Jul.	Color 18 Aug.	Color 18 Sept.	Leaf firing from desiccation‡ 19 Aug.	21 Aug.	23 Aug.	25 Aug.	29 Aug.
	--9=dark green; 1=no green--			---% leaves fired---				
Bermuda (1)								
-0.10 mPa (1)	8.2	8.5	8.0	0	0	2	0	0
-0.40 mPa (2)	8.2	8.4	8.3	0	1	2	2	0
-0.70 mPa (3)	8.0	8.7	7.8	0	0	2	5	1
	8.1	8.5	8.0					
Zoysia (2)								
-0.10 mPa	7.3	7.4	7.6	2	5	5	3	0
-0.40 mPa	8.0	7.3	7.6	4	5	4	4	2
-0.70 mPa	7.3	7.0	7.8	27	39	43	57	26
	7.5	7.2	7.7					
Centipede (3)								
-0.10 mPa	7.8	7.5	8.0	1	0	0	0	0
-0.40 mPa	7.7	7.7	8.0	0	0	0	0	0
-0.70 mPa	7.5	7.5	7.9	0	0	0	4	0
	7.7	7.6	8.0					
CV (%)	4	4	4	149	149	116	110	175
ANOVA								
G (grass)	**(.3)†	**(.3)	*(.3)	**	**	**	**	**
I (irr.)	NS	NS	NS	*	*	**	**	**
GxI	NS	NS	NS	*	**	**	**	**
Contrasts								
G1 vs G2 at I1	-	-	-	NS	*	*	**	NS
G1 vs G3 at I1	-	-	-	NS	NS	*	NS	NS
G1 vs G2 at I2	-	-	-	*	*	NS	NS	NS
G1 vs G3 at I2	-	-	-	NS	NS	NS	*	NS
G2 vs G3 at I2	-	-	-	*	*	*	**	NS
G1 vs G2 at I3	-	-	-	*	*	**	**	*
G1 vs G3 at I3	-	-	-	NS	NS	NS	NS	NS
G2 vs G3 at I3	-	-	-	*	*	**	**	*

*,**Significant at the 0.05 and 0.01 levels, respectively.

†Where no main effect interaction is present, the value in ( ) is LSD (.05) for the main effect comparison.

‡Leaf firing ratings were based on % of all leaves exhibiting severe firing which was complete browning (straw color) of the leaf.

Table 10 Visual quality, wilt, and verdure data in 1988 for three grasses under three irrigation regimes.

Species / Irrigation	Visual quality 6 May	25 May	7 June	24 June	28 June	19 July	Wilt† 24 June	Verdure 22 June
	9 = ideal density, color, uniformity; 1 = no live turf							mg cm^{-2}
Bermuda (1)								
-0.10 mPa (1)	7.1	7.7	8.2	8.5	8.7	8.4	9.0	25.2
-0.40 mPa (2)	7.3	7.8	8.4	8.6	8.7	8.6	8.9	28.0
-0.70 mPa (3)	7.0	7.7	8.1	7.9	8.1	8.6	7.8	25.8
	7.1	7.7						
Zoysia (2)								
-0.10 mPa	6.1	6.3	6.8	7.7	7.6	8.4	8.4	26.0
-0.40 mPa	6.0	5.7	5.8	6.6	7.1	7.7	5.5	20.4
-0.70 mPa	5.8	5.6	4.0	3.8	5.1	5.8	2.0	13.6
	6.0	5.9						
Centipede (3)								
-0.10 mPa	6.4	7.1	7.5	7.6	7.8	8.4	8.4	17.8
-0.40 mPa	6.8	7.0	6.9	7.2	8.0	8.1	6.7	20.6
-0.70 mPa	6.1	6.5	5.3	5.3	7.3	8.3	2.8	9.4
	6.4	6.9						
CV (%)	9	8	9	10	7	7	17	18
ANOVA								
G (grass)	**(.5)‡	**(.4)	**	**	**	**	**	**
I (irr.)	NS	NS	**	**	**	**	**	**
GxI	NS	NS	*	*	*	*	**	*
Contrasts								
G1 vs G2 at I1	-	-	*	NS	**	NS	NS	NS
G1 vs G3 at I1	-	-	NS	NS	*	NS	NS	*
G1 vs G2 at I2	-	-	**	*	**	NS	*	NS
G1 vs G3 at I2	-	-	*	NS	*	NS	NS	NS
G2 vs G3 at I2	-	-	NS	NS	*	NS	NS	NS
G1 vs G2 at I3	-	-	**	**	**	**	**	**
G1 vs G3 at I3	-	-	**	**	NS	NS	**	**
G2 vs G3 at I3	-	-	*	*	*	**	NS	NS

*,**Significant at the 0.05 and 0.01 levels, respectively.
†Wilt rating scale: 9 = no wilt; 1 = all turf wilted.
‡Where no main effect interaction is present, the value in ( ) is LSD (.05) for the main effect comparison.

Table 11 Color and percent turf cover data in 1988 for three grasses under three irrigation regimes.

Species / Irrigation	Color				Total cover		
	25 May	7 June	24 June	28 June	6 May	28 June	19 July
	-----9 = dark green; 1 = no green-----				--------------%--------------		
Bermuda (1)							
-0.10 mPa (1)	8.0	8.7	8.1	7.9	98	100	97
-0.40 mPa (2)	8.2	8.3	8.2	8.2	100	100	98
-0.70 mPa (3)	8.2	7.7	7.1	8.0	100	100	99
	8.1		7.8	8.0			98
Zoysia (2)							
-0.10 mPa	6.8	7.3	7.9	8.0	96	96	98
-0.40 mPa	6.5	7.0	7.6	7.8	94	94	94
-0.70 mPa	6.5	3.8	4.7	6.4	80	73	86
	6.6		6.7	7.4			93
Centipede (3)							
-0.10 mPa	7.5	7.5	7.4	7.8	100	97	98
-0.40 mPa	7.8	7.7	7.0	7.8	93	98	100
-0.70 mPa	7.7	5.5	5.0	7.7	90	94	99
	7.7		6.5	7.8			98
CV (%)	4	9	12	7	8	6	3
ANOVA							
G (grass)	**(.3)†	**	*(.9)	*(.5)	**	**	*(4)
I (irr.)	NS	**	**(.9)	*(.5)	*	*	NS
GxI	NS	*	NS	NS	*	*	NS
Contrasts							
G1 vs G2 at I1	-	*	-	-	NS	NS	-
G1 vs G3 at I1	-	*	-	-	NS	NS	-
G1 vs G2 at I2	-	*	-	-	*	NS	-
G1 vs G3 at I2	-	NS	-	-	*	NS	-
G2 vs G3 at I2	-	NS	-	-	NS	NS	-
G1 vs G2 at I3	-	**	-	-	**	**	-
G1 vs G3 at I3	-	*	-	-	*	NS	-
G2 vs G3 at I3	-	*	-	-	*	**	-

*,**Significant at the 0.05 and 0.01 levels, respectively.

†Where no main effect interaction is present, the value in ( ) is LSD (.05) for the main effect comparison.

PROJECT: CULTIVATION METHODS ON TURFGRASS WATER RELATIONSHIPS AND GROWTH UNDER SOIL COMPACTION

1. To determine on a compacted soil the effects of different cultivation methods on turfgrass - soil - water relationships, particularly water use.

2. To identify any important acclimation responses of the turf to compaction and how cultivation may alter such responses.

Tifway bermudagrass was used in this study to investigate the influence of different cultivation procedures to alleviate soil compaction. Treatments are listed in Table 12. Important results are:

A. SOIL PHYSICAL PROPERTIES

1. Oxygen diffusion (Figures 1-4)

Soil compaction can inhibit root growth and cause root dieback if oxygen becomes limiting. If a cultivation method increased the oxygen supply (as shown by higher ODR rates), then it should be beneficial for rooting and water uptake. Plots were saturated and ODR measurements made over the following 50 hours in June and Aug. 1987 and July 1988. Only the Aug. 87 data are included in this report in Tables 12-15. No significant treatment trends were noted. Average hours to achieve an ODR of 0.10 mg cm^{-1} min^{-1} at 5 and 15 cm soil depths were 26 and 14 hours, respectively. To reach 0.20 mg cm^{-1} min^{-1} required 45 and 41 hours for 5 and 15 cm depths, respectively.

2. Penetration Resistance (Figures 5,6)

Soil compaction increased bulk density from 1.48 to 1.60 g/100 cm^3 soil, decreased total pore space from 41.7 to 39.0%, and reduced aeration porosity (-0.01 MPa) from 18.5 to 12.8% on the Cecil sandy loam used in this study.

Penetrometer resistance, as measured by cone resistance, revealed that compaction increased resistance in the surface 10 cm. At 2 cm depth, compaction resulted in a 28% increase in resistance relative to the uncompacted control. Except for the deep drill aerifier, all cultivation methods reduced resistance with hollow-tine coring most effectively. A slight trend was observed for the hollow-tine and shattercore (solid tine) procedures to increase cone resistance from 2.5 to 5.0 cm depths.

Rooting responses (discussed later) seem to indicate that mechanical resistance to root growth was more important than low soil oxygen status in inhibiting root growth. In previous studies on cool-season grasses, low soil oxygen appeared to be the primary limiting factor. Two possible reasons for differences are a) this soil is a sandy loam to sandy clay loam, while in other studies, silt loams were used, and b) the irrigation regime for bermudagrass (irrigated when 15 cm deep probe read -0.40 MPa) allowed considerably more soil drying than the irrigation regimes of -0.07 to -0.10 MPa common on cool-season grasses.

B. <u>ROOT RESPONSES</u> (Tables 13-16)

Root samples taken in Aug. 1987 demonstrated that soil compaction decreased root length density (RLD) by 20, 77, and 64% in the 0-10, 11-20, 21-60 cm zones, respectively, for Tifway bermudagrass -- a grass with very good compaction tolerance relative to other turfgrasses.

Surface RLD values are difficult to interpret since low soil oxygen can stimulate adventitious rooting in the surface which does not help the plant during drought periods. Regardless of any treatment differences, the RLD's were very high. Agronomic crops generally have RLD values of 0.1 to 6.0 versus the 34 to 54 range we observed.

More important is RLD differences in the 21-60 cm zone and to a lesser extent in the 11-20 cm depth. All cultivation methods except shattercoring improved deep rooting in the 21-60 cm zone relative to the compacted control. Shattercoring caused roots to proliferate in the 11-20 cm zone but declined at 21-60 cm.

Root weight data were similar to the RLD trends. However, observation of the root weights of the two controls reveal that at 11-20 cm, the compacted check had higher root weight but lower RLD. This suggests that the compacted check roots were larger and less fibrous in response to the higher mechanical resistance to rooting.

Root data from June 1988 indicated higher RLD in the surface for the compacted check compared to the uncompacted control. Perhaps this is a result of adventitious root development which could disappear (due to surface root deterioration) over the course of a summer. Again, the surface RLD's were all high. Deep rooting was reduced by 31% by compaction. Rooting in the 21-60 cm zone was enhanced by Aerway slicer (53%), hollow-tine (35%), and deep drill aerification (31%) relative to the compacted control, while shattercoring reduced deep rooting (significant at $P<0.15$).

C. <u>WATER EXTRACTION AND ET</u> (Tables 17-20)

In a compacted soil, enhanced water extraction from any depth by the roots in response to cultivation treatment would be viewed as beneficial. Water extraction data obtained during a dry-down in August 1987 demonstrated higher water uptake from the surface 0-10 cm by the non-compacted control versus the compacted control. Hollow-tine coring improved surface water extraction by 46% over the compacted control and 20% in the 11-20 cm zone. Only deep drill aerifier improved water uptake from the deepest zone. In terms of overall water uptake (0-60 cm = ET), deep drill and hollow-tine operations enhanced water use by 18 and 16%, respectively, compared to the compacted control.

Water use data in May and June 1988 exhibited many of the same trends but differences were not always significant at LSD (.10). The non-compacted check exhibited better uptake from the surface zone. Hollow-tine coring improved uptake from the 11-20 cm depth (mid-May, late June), deepest zone in early June, and total water use in late May-early June. Hollow-tine, deep drill and Aerway slicer consistently caused the higher water extraction but differences were not significant at 10% level. Perhaps as data is analyzed over all time periods in 1988, these may prove significant.

D. SHOOT RESPONSES (Figures 7, 8)

In August 1987, compaction reduced clipping yields by 40% and in May-June 1988 by 21% relative to the uncompacted check. In 1987, all cultivation methods tended to improve clipping yield except for the Ryan slicer. The Ryan slicer decreased clipping yield in 1988 but all other cultivation procedures caused similar clipping production.

Verdure revealed trends but these were not significant at LSD (.10) in most cases. The only significant difference was higher verdure for the deep drill treatment relative to the compacted control.

Table 12.

<u>Treatments</u>:

Treatment		Description			Soil brought to the Surface
Cultivation	Soil Compacted	Depth	Spacing	Size	
		--------inches------			
1. None, not compacted	No	-	-	-	No
2. None, compacted	Yes	-	-	-	No
3. Deep drill aerofier Floyd McKay	Yes	10	5	5/8	Yes
4. Aerway slicer	Yes	6	7	1/3x4	No
5. Hollow tine core, Ryan	Yes	3	2	5/8	Yes
6. Scattercoring, Ryan	Yes	3	2	5/8	No
7. Ryan slicer	Yes	6	6	1/4x4	No

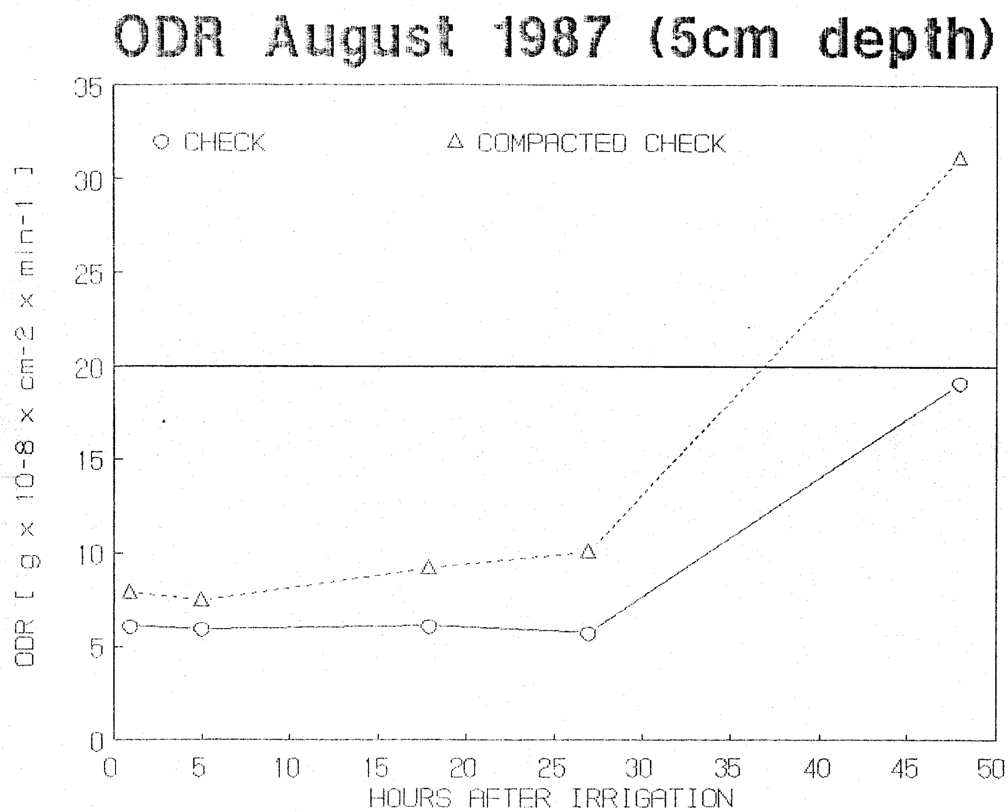
ODR August 1987 (5cm depth)
CHECK
COMPACTED CHECK
ODR [g x 10-8 x cm-2 x min-1]
HOURS AFTER IRRIGATION
0
5
10
15
20
25
30
35
40
45
50

FIG 1

ODR August 1987 (5cm depth)

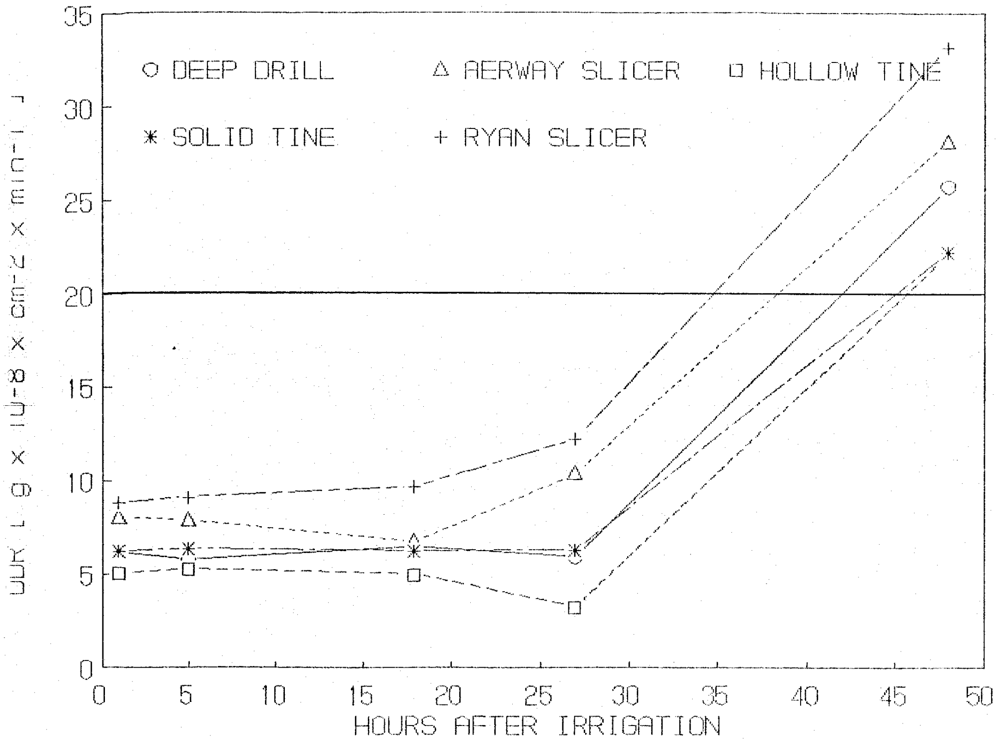

FIG 2

ODR August 1987 (15cm depth)

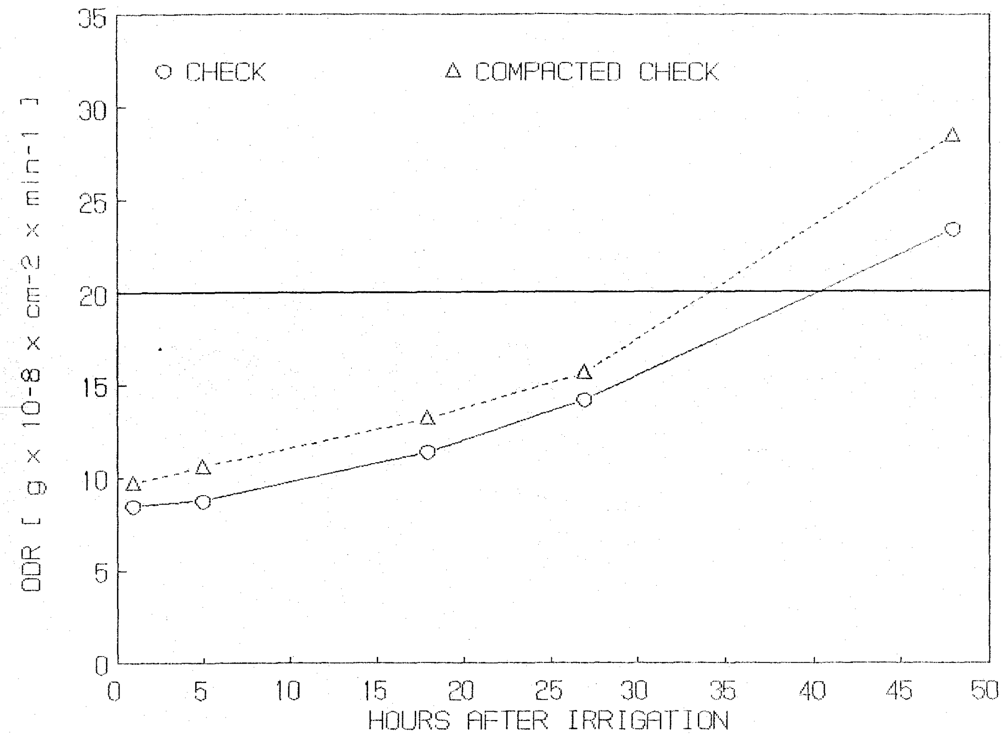

FIG3

ODR August 1987 (15 cm depth)

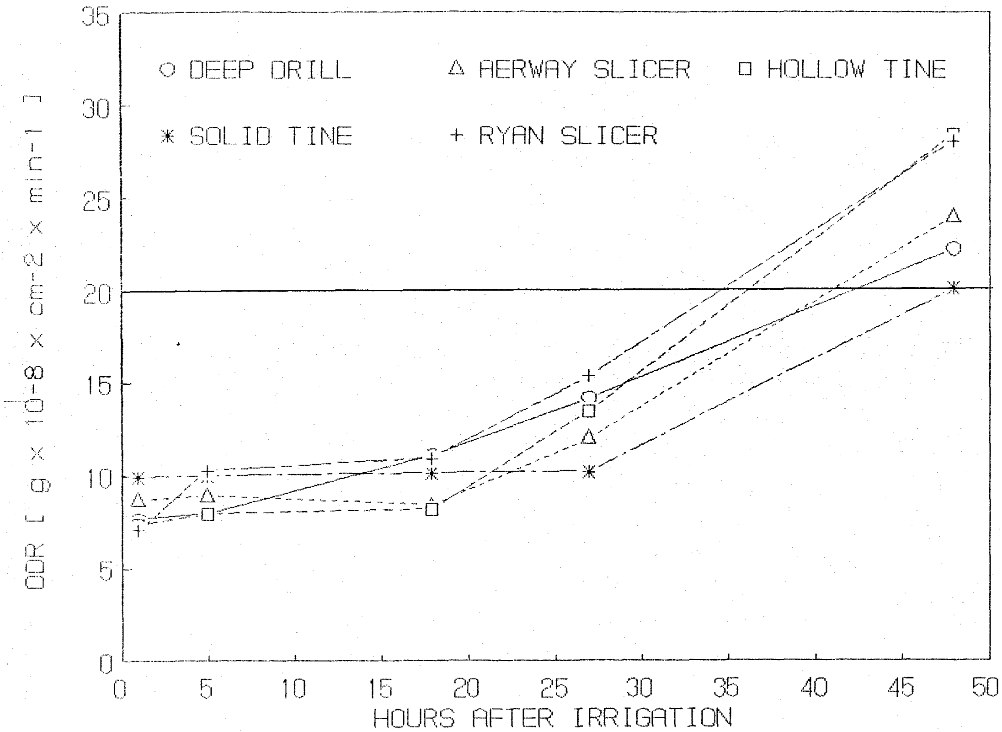

FIG 4

CONE RESISTANCE

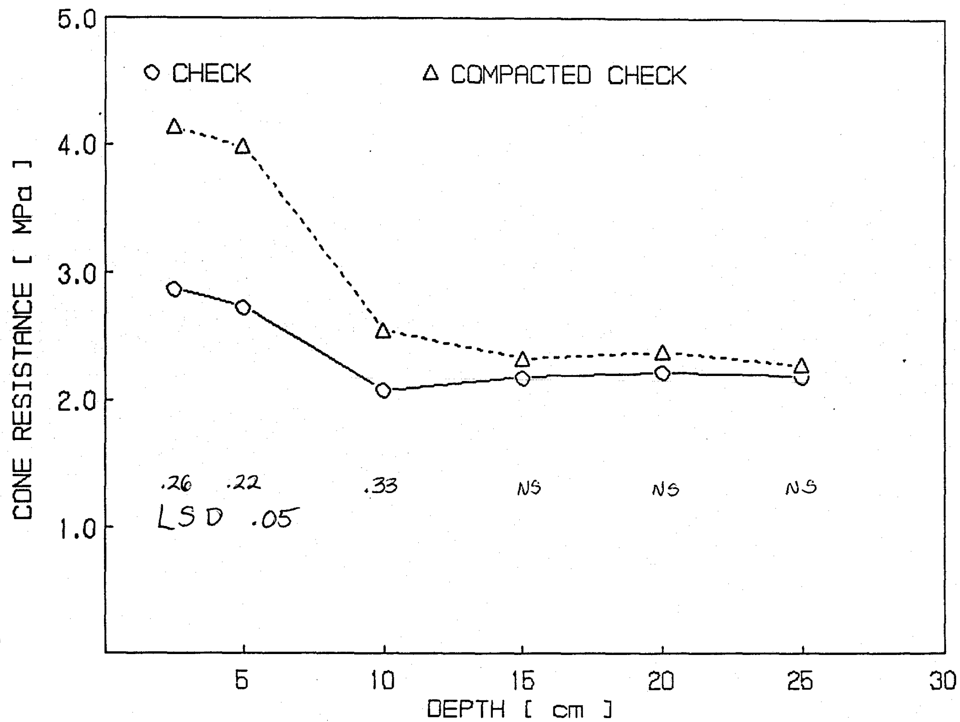

FIG 5

CONE RESISTANCE

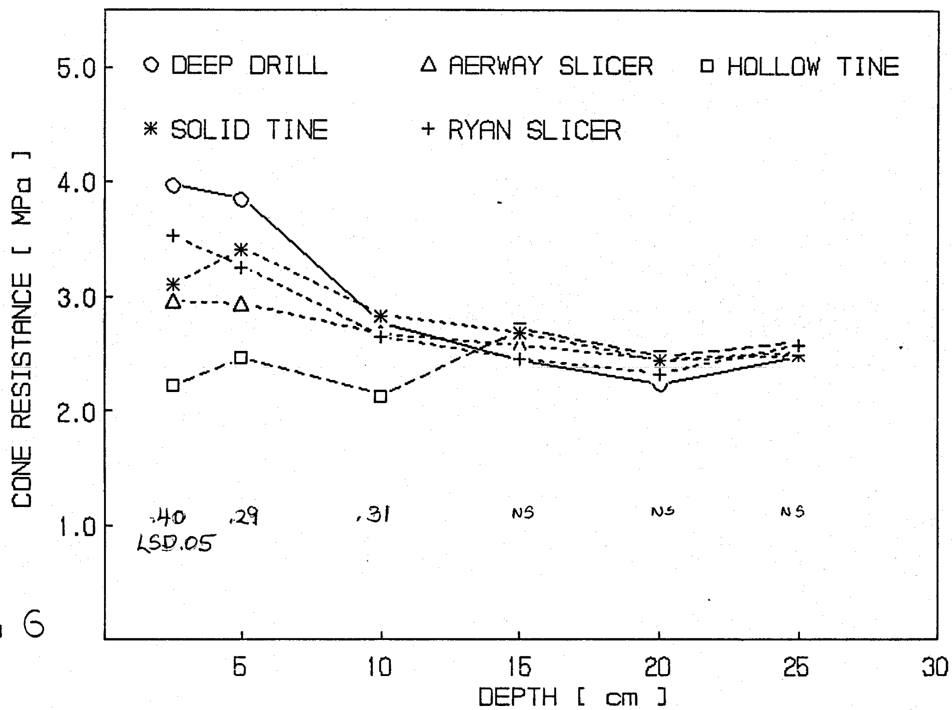

FIG 6

Table 13.

Root length density (August 1987)

Treatment		Root length density by depth			Total root length
Cultivation	Compaction	0-10 cm	11-20 cm	21-60 cm	0-60 cm
		----------cm cm^{-3}	-----------		---cm cm^{-2}--
None	No	44.0H	16.6H	5.5H	826
None	Yes	35.4†	3.8	2.0	472
Deep Drill	Yes	42.6H	3.7	3.1H	587
Aerway Slicer	Yes	42.3H	2.8L	4.4H	627
Hollow Tine	Yes	33.8	3.4	2.4H	468
Shattercore	Yes	38.1H	8.3H	1.7L	532
Ryan Slicer	Yes	53.7H	3.3	2.6H	674

†Based on LSD (.05) compared to the compacted check: H=higher; L=lower

Table 14.

Root weights (August 1987) Cultivation Study

Treatment		Root weight by depth			Total root weight
Cultivation	Compaction	0-10 cm	11-20 cm	21-60 cm	0-60 cm
		---------mg/100 cm^3---------			g/100 cm^2
None	No	781H	551L	67H	16.0
None	Yes	611†	614	25	13.3
Deep Drill	Yes	756H	607	38H	15.2
Aerway Slicer	Yes	752H	538L	54H	15.1
Hollow Tine	Yes	600	428L	29	11.4
Shattercore	Yes	676	555L	21	13.2
Ryan Slicer	Yes	954H	510L	32	15.9

†Based on LSD (.05) compared to the compacted check; H=higher; L=lower

Table 15.

Root length density (June 1988) Cultivation Study

Treatment		Root length density by depth			Total root length
Cultivation	Compaction	0-10 cm	11-20 cm	21-60 cm	0-60 cm
		----------cm cm^{-3}	----------	----------	---cm cm^{-2}--
None	No	12.58L	3.75	1.18H	212
None	Yes	15.21†	4.11	0.81	225
Deep Drill	Yes	12.54L	4.50	1.06H	214
Aerway Slicer	Yes	12.63L	3.46	1.24H	209
Hollow Tine	Yes	17.18	3.03L	1.09H	246
Shattercore	Yes	14.70	3.51	0.61	206
Ryan Slicer	Yes	10.89L	4.24	0.84	183

†Based on LSD (.05) compared to the compacted check: H=higher; L=lower

Table 16.

Root weights (June 1988) Cultivation Study

Treatment		Root weight by depth			Total root weight
Cultivation	Compaction	0-10 cm	11-20 cm	21-60 cm	0-60 cm
		---------mg/100 cm^3---------			g/100 cm^2
None	No	423L†	76	23	5.9
None	Yes	548	83	20	7.1
Deep Drill	Yes	503	94H	24	6.9
Aerway Slicer	Yes	452L	76	27H	6.4
Hollow Tine	Yes	521	65L	24	6.8
Shattercore	Yes	558	67L	17	6.9
Ryan Slicer	Yes	473L	82	20	6.4

†Based on LSD (.05) compared to the compacted check.

Table 17.

Water extraction (14-24 August 1987)   Cultivation Study

Treatment		Water extraction by depth			
Cultivation	Compaction	0-10 cm	11-20 cm	21-60 cm	0-60 cm(ET)
		-------------------cm of water-------------			
None	No	1.46H	1.03	1.51	3.99
None	Yes	1.16[†]	.93	1.65	3.74
Deep Drill	Yes	1.28	1.03	2.12H	4.42H
Aerway Slicer	Yes	1.27	1.01	1.77	4.05
Hollow Tine	Yes	1.69H	1.12H	1.52	4.33H
Shattercore	Yes	1.38	1.07	1.45	3.90
Ryan Slicer	Yes	1.10	.92	1.47	3.48

[†]Based on LSD (.05) compared to the compacted check; H=higher; L=lower

Table 18.

Water extraction (11-24 May 1988) Cultivation Study

Treatment		Water extraction by depth			
Cultivation	Compaction	0-10 cm	11-20 cm	21-60 cm	0-60 cm(ET)
		----------------cm of water--------------			
None	No	1.88H	1.10	1.77	4.76
None	Yes	1.56†	.98	1.67	4.21
Deep Drill	Yes	1.52	1.00	2.45	4.97
Aerway Slicer	Yes	1.71	1.00	2.40	5.10
Hollow Tine	Yes	1.73	1.22H	1.71	4.65
Shattercore	Yes	1.85	.86	1.74	4.45
Ryan Slicer	Yes	1.57	.96	1.19	3.72

†Based on LSD (.05) compared to the compacted check; H=higher; L=lower

Table 19.

Water extraction (25 May-6 June 1988) Cultivation Study

Treatment		Water extraction by depth			
Cultivation	Compaction	0-10 cm	11-20 cm	21-60 cm	0-60 cm(ET)
		cm of water			
None	No	1.07H	.61	2.28	3.96
None	Yes	.64†	.40	1.99	3.03
Deep Drill	Yes	.99	.74H	2.15	3.87
Aerway Slicer	Yes	.71	.46	2.40	3.57
Hollow Tine	Yes	1.03	.62	3.12H	4.78H
Shattercore	Yes	1.04H	.54	2.29	3.87
Ryan Slicer	Yes	.61	.45	2.01	3.07

†Based on LSD (.05) compared to the compacted check; H=higher; L=lower

Table 20.

Water extraction (15-28 June 1988) Cultivation Study

Treatment		Water extraction by depth			
Cultivation	Compaction	0-10 cm	11-20 cm	21-60 cm	0-60 cm(ET)
		cm of water			
None	No	1.72H	1.01	1.61	4.35
None	Yes	1.55†	1.04	1.73	4.32
Deep Drill	Yes	1.63	1.04	2.13	4.81
Aerway Slicer	Yes	1.62	1.07	1.99	4.68
Hollow Tine	Yes	1.65	1.18H	1.59	4.42
Shattercore	Yes	1.67	1.00	1.67	4.34
Ryan Slicer	Yes	1.41	1.02	1.65	4.08

†Based on LSD (.05) compared to the compacted check; H=higher; L=lower

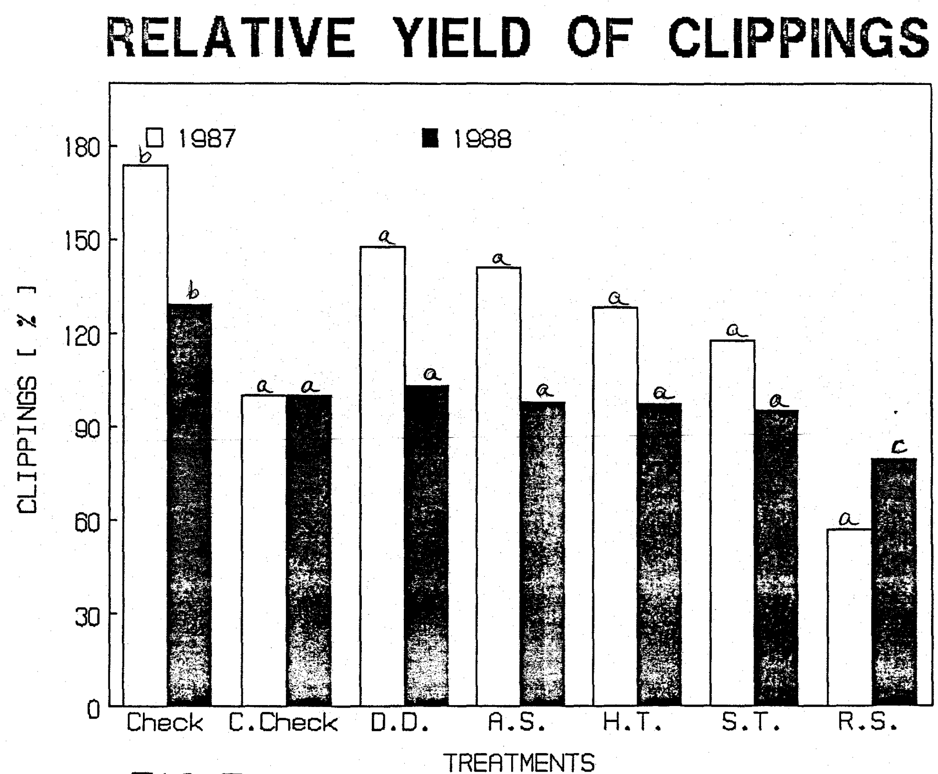
RELATIVE YIELD OF CLIPPINGS
1987
1988
CLIPPINGS [%]
0
30
60
90
120
150
180
b
b
a
a
a
a
a
a
a
a
a
a
a
c
Check
C.Check
D.D.
A.S.
H.T.
S.T.
R.S.
TREATMENTS

FIG 7

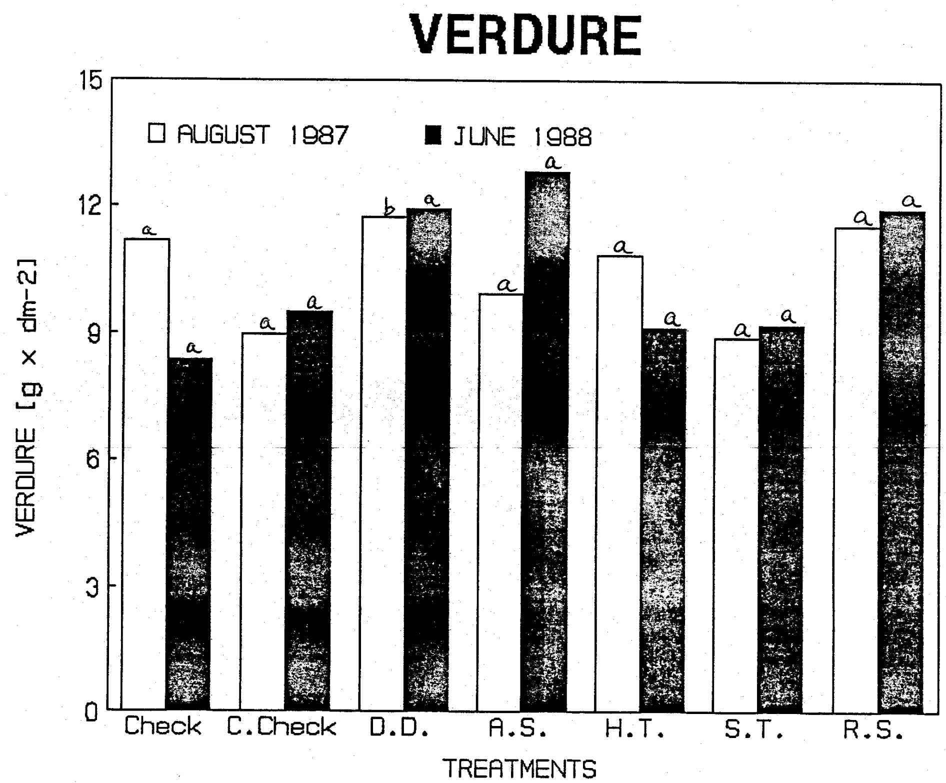
VERDURE
□ AUGUST 1987
■ JUNE 1988
VERDURE [g x dm-2]
15
12
9
6
3
0
a
a
a
a
b
a
a
a
a
a
a
a
a
a
Check
C.Check
D.D.
A.S.
H.T.
S.T.
R.S.
TREATMENTS

FIG 8

III. BUDGET

Expenditures to date have been very close to budget estimates with salaries of an Agricultural Technical II and temporary labor accounting for 95% of the expenditures.

IV. PUBLICITY

Several opportunities have occurred over the past year to discuss these two research projects to audiences concerned with water conservation in the turfgrass industry. In each instance, we have credited the USGA for their support and noted their overall goal of water conservation on turfgrasses. Talks and papers presented were:

National Conferences:

Carrow, R.N. 1988. Irrigation scheduling by infrared thermometry. Proc. 59th Int. Golf Course Supt. Conf. and Show. GCSAA Pub., Lawrence, KS. p. 6-7.

Carrow, R.N. and B.J. Johnson. 1988. Water use and growth of warm season turfgrasses under different irrigation regimes. Amer. Soc. of Agron. (ASA) Agron. Abstr. p. 149.

Wiecko, G., R.N. Carrow, K. Karnok, and B.J. Johnson. 1988. Turfgrass cultivation effects on growth and water/oxygen relations of bermudagrass. ASA Agron. Abstr. p. 157.

Regional or State Events

Carrow, R.N. 1988. Developing meaningful cultivation programs for golf courses. Univ. of Maryland Turf Conf., Baltimore, MD. Jan. 4-5.

Carrow, R.N. 1988. Managing compaction problems on the golf course. Western Penn. Turf Conf. and Trade Show. Pittsburg, PA. Feb. 23-25.

Carrow, R.N. 1988. Water use and growth of warm season grassese under different irrigation regimes. UGA/GTF Turf Field Day. Griffin, GA Aug. 3.

Carrow, R.N. 1988.
*Irrigation and stress sensing techniques,
*Compaction effects on soils and alleviation methods.
*Water use of bermuda and zoysia under different irrigation regimes.
Catcus and Pine GCSA Show. Phoenix, AZ. Sept. 13-15.