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Factors Affecting Creeping Bentgrass Quality of Three Different Putting Green Construction Methods

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FACTORS AFFECTING CREEPING BENTGRASS QUALITY OF THREE DIFFERENT PUTTING GREEN CONSTRUCTION METHODS

By

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ABSTRACT

FACTORS AFFECTING CREEPING BENTGRASS QUALITY OF THREE DIFFERENT PUTTING GREEN CONSTRUCTION METHODS

By

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Two studies were initiated in 1996 to evaluate the long-term response of three different putting green root zones (circa 1993) to various management inputs. The three root zones were an 80:20 (sand:peat v/v) mixture built to United States Golf Association (USGA) recommendations, an 80:10:10 (sand:soil:peat v/v/v) mixture built with subsurface drainage tile, and an unammended sandy clay loam textured (58% sand, 20.5% silt, 21.5% clay) "push-up" style green. A rolling factor was included as a split plot across the three construction methods/soil types. The two studies were conducted on these plots as split plots across the rolling factor. The first study examined the effects of plant growth regulators (PGR's) (trinexapac-ethyl and flurprimidol) on putting green speed and creeping bentgrass quality. PGR's did show differences in ball roll distance between 6 and 14 days after application. Rolling three times per week consistently increased ball roll distance. The application of flurprimidol adversely affected turfgrass color. Dollar spot (*Sclerotinia homoeocarpa*) incidence was reduced when rolling was applied. The second study investigated use of crumb rubber as a topdressing amendment into putting green collars. The greatest

depth of crumb rubber (9.5mm) produced both the highest color and quality ratings. *Poa annua* percentages were lowest in 9.5mm topdressing depth.

To my parents, Michael and Evelyn, whose love, support and gift of life have made all this possible.

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BRD = Ball Roll Distance

PGR = Plant Growth Regulator

INTRODUCTION

The putting green is the focus of most golf courses in terms of playability. Therefore, construction and maintenance have long been primary topics for discussion and research. The United States Golf Association (USGA) has made recommendations for putting green construction since 1960 (USGA Green Section Staff, 1960). The USGA method has proven effective over the years though other methods have been used (Beard, 1982). There has been little research reported of comparisons of USGA specification putting greens to other putting green construction methods because of the difficulty in the experimental design and replication necessary to draw valid statistical conclusions (Lodge et. al., 1991; Lodge and Lawson, 1993). Another reason for doing this work is that many golf courses have differently constructed putting greens. There has been work evaluating management practices on greens regarding almost all phases of putting green management, however there are no comparisons of management practices during the post grow-in stage (3-7 years after establishment) regarding different root zone mixes.

The practice of rolling putting greens has been in place for almost a century (Anonymous, 1954). Before the implementation of modern putting green cultural practices, improved turfgrass varieties and sophisticated mowing equipment, superintendents included rolling in their management regimes to improve putting conditions (Hartwiger, 1996). As the negative effects of compaction became more prevalent (Beard, 1973) many superintendents omitted rolling from their management regimes for fear of turf loss from soil compaction.

In recent years rolling has returned to management practices of many superintendents around the United States. With the proliferation of high sand content greens and the introduction of lightweight greens rollers, the practice of rolling has become a viable alternative for superintendents who have experienced continued pressure to produce smoother, faster, and more consistent putting surfaces (Hartwiger, 1996). Research has shown that rolling increases ball roll distance for up to 48hrs after rolling (Hamilton et al, 1994). Hartwiger et al (1994) found that rolling with a lightweight greens roller four times per week reduced putting green quality after one year on both USGA and native soils. The long term effects of rolling on different soil types, however, needs to be determined.

Plant growth regulators (PGR's) which include gibberellic acid biosynthesis inhibitors are known to decrease cell elongation (Kaufmann, 1986) and clipping yields (Dernoeden, 1984; Diesburg and Christians, 1989). Other known effects of PGR's are darker green color and increased turfgrass density with occasional temporary phytotoxic responses (Dernoeden, 1984; Watschke 1981). With the reduced clipping production as a result of PGR applications, there is a potential for increased ball roll distance (BRD). The effects of PGR's on BRD have been examined and results between the different studies were inconclusive with regard to their effects on BRD. Increased BRD was observed with the application of PGR's by Branham (1991) and Rogers et. al. (1992) while no differences were recorded by Rogers et. al. (1993) and Yelverton (1998). These research projects examined PGR's effects on BRD on putting greens with only one soil type. No research has been conducted examining the response of different soil types to the application of PGR's and therefore warrants the investigation of this problem.

The putting green collar has long been an area of concern for golf course superintendents (Anonymous, 1954; Dernoeden, 1994). Due to traffic patterns from putting green mowers and on many putting greens, limited entry and exit points to the putting green, collars are often subject to intensive wear that is difficult to manage. Topdressing crumb rubber has proven to be an effective method for improving quality on high trafficked turfgrass stands maintained above 16mm (Rogers et. al. 1998). Topdressing crumb rubber into putting green collars, however, has not been investigated.

As a result, two main objectives exist to test the responses of the three most commonly utilized putting green root zone mixes; USGA, 80:10:10, and native soil and their response to rolling.

The two main objectives were:

1) To determine the effects of two PGR's and a control on ball roll distance and putting green quality as effected by three putting green root zones and frequent lightweight rolling.

2) To determine the effects of topdressing crumb rubber into putting greens collars as influenced by three putting green root zones and frequent lightweight rolling.

General Materials and Methods

Both studies were conducted on the same set of research plots and were managed simultaneously. Therefore the management practices presented below cover each chapter. Specific materials and methods for the respective studies are presented at the beginning of each chapter.

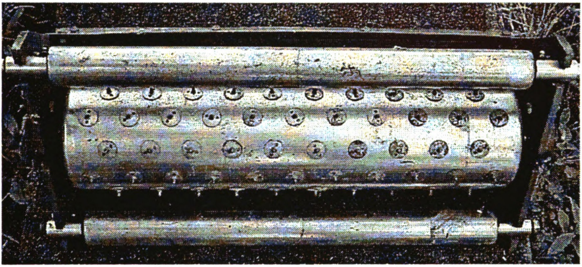
The research was conducted on a 1337m^2 (36.6m x 36.6m) putting green at the Hancock Turfgrass Research Center from May 1996 to October 1997. The putting green was constructed in the summer of 1992 and seeded with Penncross creeping bentgrass (*Agrostis palustris*) in spring 1993. The plots were constructed with the purpose of comparing three different putting green construction methods and their response to various maintenance inputs. Each root zone plot was 12.2m x 12.2m and was arranged in a randomized complete block design replicated three times. The three construction methods consisted of: an 80:20 (sand:peat v/v) (99.2% sand + 0.8% silt + clay) (Table 48, Appendix) mixture built to USGA putting green construction recommendations; an 80:10:10 (sand:soil:peat v/v/v) (98.8% sand + 1.2% silt + clay) (Table 49, Appendix) mixture built with subsurface tile drainage; and an unamended sandy clay loam (58% sand, 20.5% silt, 21.5% clay) "push-up" style green. Each construction method plot (12.2m x 12.2m) was arranged in a randomized complete block design and replicated three times. These construction methods were chosen based on the popularity of their use in putting greens constructed in Michigan and around the United States. Since the construction of the plots in 1992 sand topdressing was applied to all plots at 2-3 week intervals at a rate of 0.8mm per application in conjunction with the growth rate of the grass. By the end of the study (1997) a layer of sand accumulated on the greens totaling 26mm. Each construction method plot has individual irrigation control and was irrigated on an as needed basis.

A rolling factor was split over each root zone plot to compare its effects on the three different root zones. Rolling was applied with an Olathe (Olathe Manufacturing Inc., Industrial Airport, KS.) lightweight greens roller three times per week (Monday, Wednesday, Friday) immediately after the plots were mowed.

The putting green plots were mowed six days per week throughout each season at a height of 3.8mm with a Toro GM1000 (Bloomingdale, MN). The putting green collar plots were mowed three days per week (Monday, Wednesday, Friday) at a height of 9.5mm with a Ransomes Greenspro 22. Nitrogen was applied on a monthly basis at a rate of 49 kg/ ha/ month.

In the interest of simulating the foot traffic normally subjected to putting greens, a traffic simulator was constructed. A Toro Greensmaster 3000 (Bloomingdale, MN) triplex greens mower was fitted with rollers in place of the cutting units with metal golf shoe spikes mounted on the rollers to apply the traffic (Figure 1). Traffic was applied by making two passes five times per week over the plots to simulate foot traffic the foot traffic of 150 rounds of golf within a 60cm diameter of the golf hole. This calibration was made by counting the number of foot steps taken by golfers in that area, counting the number of spikes on the bottom of typical golf shoes, and associating that with the number of spikes which contact the ground from the traffic simulator.

Figure 1. Photograph of roller mounted with metal golf spikes. The roller is inserted on a Toro Greensmaster 3000 (Bloomingdale, MN) in place of the cutting units.



Chapter 1

THE EFFECTS OF PLANT GROWTH REGULATORS AND ROLLING ON THREE PUTTING GREEN CONSTRUCTION METHODS

Specific Materials and Methods

The experimental design was a 3 x 2 x 3 split split randomized complete block design. Three construction methods/soil types consisted of the main effects with a rolling factor split over the construction methods. A plant growth regulator factor was then split over the rolling factor. PGR plots measured 1.1m x 4.3m.

The plant growth regulators (PGR's) used were foliar absorbed trinexapac-ethyl (Primo) and root absorbed flurprimidol (Cutless). When the study began PGR's were not labeled for putting green use. Both PGR's were applied at 40% of the label rate, trinexapac-ethyl at 0.318L ha^{-1} and flurprimidol at 0.673kg ha^{-1}. Applications were made at five-week intervals in both years of the study beginning at the growing season and ending in September of each year of the study, 1996 and 1997. Plots were sprayed with a hand-held boom sprayer at a carrier volume of 897L ha^{-1}.

Data Collection

Ball roll distance (BRD) measurements were recorded three days per week on Mondays, Wednesdays, and Fridays for five weeks after each PGR application during both years of the study. BRD measurements were recorded with a Stimpmeter by taking three measurements in two directions for a total of six measurements per plot.

Turfgrass color and quality ratings were recorded during both years of the study. Ratings were recorded when differences in color were apparent. Overall color and quality were rated on a scale from 1-9; 1 = poor, 9 = excellent, and 6 = acceptable.

Disease ratings were recorded when disease outbreaks occurred during both years of the study. Diseases recorded were; dollar spot (*Sclerotinia homoeocarpa*) on 24-Jun and 2-Aug in 1996, microdochium patch (*Microdochium nivale*) on 14-Apr-97, and yellow tuft (*Scleropthera macrospora*) on 8-Aug-97. Dollar spot and microdochium patch were recorded according to the number of spots occurring in each plot. Yellow tuft was visually rated on a scale from 0 – 100%.

Thatch depth (mm) was recorded in 1996. Three samples were taken with a 2.54cm diameter soil probe from each plot measuring the longest visible root and averaged. Depth was recorded in millimeters. Thatch weight was recorded in 1997. Three samples were taken from each plot and averaged. Thatch samples were weighed, ashed at 500°C for five hours and then reweighed.

Root length was recorded in August of 1996. Three samples were taken from each plot and averaged. Root weight was recorded in October of 1996 and 1997. Three samples were collected from each plot at four depths; 0-2.5cm, 2.5-5.0cm, 5-10cm, and 10-15cm. Root were separated from the soil by the hydropneumatic eluriation system (Smucker et al, 1982). Roots were dried then weighed, ashed at 500°C for five hours and then reweighed. Samples were ashed to reduce variability from the presence of organic matter silt and clay (Willard and McClure 1932).

Surface hardness, which was measured by evaluating impact absorption, was collected in June 1997 using the Clegg Impact Soil Tester (Lafayette Instruments Co., Lafayette, IN) and the 2.25kg hammer. An average of three measurements was recorded as transmitted to a hand-held read-out box. The hammer was dropped randomly through the plot from a height of 0.46m (Rogers and Waddington, 1990).

Clipping yields were recorded in July 1996 and 1997. The area of the clippings removed was 1.75m^2. The plots were allowed to grow for two days prior to clipping removal. Clippings were collected, dried for 24 hours at 60°C, and weighed.

Data were analyzed using SAS analysis of variance procedures for a 3-by-2-by-3 factorial experiment in a randomized complete block, split-slpit plot design with three replications. The three PGR treatments were split into the rolled and not rolled plots.

Results and Discussion

Ball Roll Distance

Significant treatment effects from 1996 and 1997 are shown in Tables 1 and 2 respectively, with all three applications of PGR's from each year represented in both tables. Ball roll distance in soil types showed significant

Table 1. Mean squares and significance of treatment effects on ball roll distance on putting greens at the Hancock Turfgrass Research Center, East Lansing, MI, 1996.

		Application #1 (14-June)					
Source of Variation	df	7 DAT	10DAT	12 DAT	14 DAT	17 DAT	24 DAT
Replication	2	321	1343	450 **	2280	116	137
Soil, S	2	24	1164	93	236	147	462
Error (a)	4	62	747	58	510	139	332
Roll, R	1	10581 ***	6542 ***	13296 ***	2120 **	4914 ***	2275
S x R	2	377	220	440	231	673	413
Error (b)	6	155	142	58	216	244	739
PGR, P	2	1069 ***	666 ***	306 **	52	325	110
S x P	4	55	57	96	113	42	255
R x P	2	615 ***	88	537 ***	33	5	16
S x R x P	4	20	70	17	192	111	199
Error (c)	#	77	88	81	139	133	110
CV (%)		3.46	3.74	3.17	4.21	3.82	3.58

		Application #2 (20-July)					
Source of Variation	df	3 DAT	6 DAT	9 DAT	12 DAT	16 DAT	20 DAT
Replication	2	1127 **	2606	407	9277 ***	57774	5260 ***
Soil, S	2	549	296	102	422	60261	894 **
Error (a)	4	106	483	371	159	62727	68
Roll, R	1	16533 ***	6677 ***	968	968	147522	24452 ***
S x R	2	920	1115	188	559	82867	707
Error (b)	6	362	374	301	226	69612	333
PGR, P	2	53	166	110	53	60518	155
S x P	4	90	73	206	53	61379	89
R x P	2	88	796	78	122	61379	306
S x R x P	4	311	31	153	56	59951	68
Error (c)	#	208	306	204	112	63600	186
CV (%)		4.72	5.19	4.75	3.1	72.48	4.47

		Application #3 (31-Aug)					
Source of Variation	df	10 DAT	11 DAT	13 DAT	23 DAT	25 DAT	32 DAT
Replication	2	2377	276	376	166	254	290
Soil, S	2	238	142	399	1454 **	2017 **	598
Error (a)	4	1302	169	65	141	168	175
Roll, R	1	3043 ***	5031 ***	3518 **	5031 ***	1933 **	2908
S x R	2	279	327	263	130	111	356
Error (b)	6	134	270	262	67	223	775
PGR, P	2	75	350 **	104	1	168	52
S x P	4	15	23	158	204	45	89
R x P	2	69	652 ***	29	103	170	95
S x R x P	4	129	28	204	122	97	38
Error (c)	#	71	93	159	107	123	194
CV (%)		2.75	3.03	3.85	3.23	3.37	4.34

***, ** denotes statistical significance at $P < 0.01, 0.05$ respectively

Table 2. Mean squares and significance of treatment effects on ball roll distance on putting greens at the Hancock Turfgrass Research Center, East Lansing, MI, 1997.

		Application #1 (28-May)					
Source of Variation	df	7 DAT	11 DAT	16 DAT	21 DAT	26 DAT	35 DAT
Replication	2	832	2704 ***	2782 **	2628 **	1144	1651 ***
Soil, S	2	1583 **	188	490	287	430	169
Error (a)	4	127	109	206	355	393	45
Roll, R	1	9340 ***	4798 ***	2355 **	12728 ***	5149 ***	892 ***
S x R	2	1010	1506	791	85	862	812 ***
Error (b)	6	610	337	276	707	325	333
PGR, P	2	958 ***	1303 ***	561 **	306 **	220	22
S x P	4	209	103	344	131	114	56
R x P	2	13 **	482 **	140	63	39	1
S x R x P	4	272	230	184	174	220	18
Error (c)	24	87	171	164	82	220	113
CV (%)		3.1	4.0	4.0	2.7	5.9	3.5

		Application #2 (4-July)					
Source of Variation	df	7 DAT	10 DAT	14 DAT	19 DAT	26 DAT	28 DAT
Replication	2	1687 **	1825	389	172	1404 **	107
Soil, S	2	520	641	1396	824	499	669
Error (a)	4	230	346	230	768	80	229
Roll, R	1	11810 ***	18622 ***	661	13682 ***	6081 ***	14072 ***
S x R	2	944 **	391	44	56	74	153
Error (b)	6	112	251	271	94	388	694
PGR, P	2	604 **	1265 **	835 **	38	485 **	400 ***
S x P	4	98	199	43	56	53	35
R x P	2	246	65	149	193	250	33
S x R x P	4	197	119	120	33	73	45
Error (c)	24	155	256	162	118	111	60
CV (%)		3.7	5.1	3.8	3.8	3.1	2.3

		Application #3 (14-Aug)					
Source of Variation	df	11 DAT	13 DAT	15 DAT	20 DAT	22 DAT	38 DAT
Replication	2	147	350	29	746 **	143	93
Soil, S	2	605	38	439	987 ***	112	1154
Error (a)	4	373	397	629	57	940	184
Roll, R	1	11720 ***	24974 ***	1619 **	135	3871 ***	2355 ***
S x R	2	242	837 **	575	31	322	683 **
Error (b)	6	194	120	226	697	183	69
PGR, P	2	703 **	1859 ***	178	215	341	90
S x P	4	23	270 **	141	114	218	23
R x P	2	289	2	240	149	90	10
S x R x P	4	49	161	73	122	145	163
Error (c)	24	154	89	174	72	192	123
CV (%)		4.5	3.2	3.9	2.7	4.1	3.4

***, ** denotes statistical significance at $P < 0.01$, 0.05 respectively

differences five times through both years of the study. When these differences were recorded, the native soil had significantly lower BRD than the USGA soil (Tables 3 and 4). Rolling consistently showed significant increased ball roll distance throughout both years of the study (Tables 3 and 4). This increased BRD of rolled putting greens have been reported in previous studies (Hamilton et al, 1994, Nikolai et. al., 1997).

Differences between PGR's were present from 7 to 16 days after treatment (DAT) except for application #2 in 1996 where no differences were apparent between PGR's (Tables 3 and 4). 28 days after treatment of application #2 and 20 DAT of application #3 in 1997 showed that flurprimidol had significantly lower BRD than the check plots. A rebound effect has been suggested in previous research where a flush of growth may occur after the effects of the PGR have dimished (Calhoun, 1996).

Though interactions among all main effects were sporadic, ones of interest and relevance are presented. In 1996 interactions occurred between rolling and plant growth regulators (PGR) 6 to 12 days after treatment (DAT) of applications #1 and #3. This interaction was also recorded 11DAT of application #1 of 1997 (Table 5). When rolling was applied, flurprimidol and trinexapac-ethyl were significantly higher than the check while PGR's did not have this effect in plots that were not rolled. This interaction may indicate a potential benefit for superintendents looking to improve putting green speed without lowering mowing heights.

Table 3. Main effects of construction type, rolling and plant growth regulator (PGR) on ball roll distance in centimeters on putting greens at the Hancock Turfgrass Research Center, East Lansing, MI, 1996.

	centimeters																	
	14-Jun (Application #1)						20-Jul (Application #2)						31-Aug (Application #3)					
Soil Type	7 DAT	10 DAT	12 DAT	14 DAT	17 DAT	24 DAT	3 DAT	6 DAT	9 DAT	12 DAT	16 DAT	20 DAT	10 DAT	11 DAT	13 DAT	23 DAT	25 DAT	32 DAT
USGA	255	260	286	281	300	297	309	335	304	346	316	314a	309	320	329	329a	341a	328
80:10:10	253	245	281	276	299	290	309	335	299	337	313	302b	303	317	322	321ab	324b	317
Native	253	249	284	283	305	287	299	342	301	340	311	302b	308	314	331	311b	322b	319
Significance†	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	**	- NS -	- NS -	- NS -	**	**	- NS -
Rolling																		
Rolled	268	262	300	286	311	298	323	348	306	345	332	327	314	329	335	330	335	329
Not rolled	240	240	268	274	292	285	288	326	297	337	296	284	299	308	319	311	323	314
Significance	***	***	- NS -	**	***	- NS -	- NS -	***	- NS -	- NS -	- NS -	***	***	***	***	***	**	- NS -
PGR																		
Trinexapac-ethyl	253b	252a	288a	282	305	291	307	336	302	343	313	306	309	317ab	328	320	332	321
Flurprimidol	262a	257a	285ab	278	297	290	306	341	304	342	313	302	307	323a	328	321	328	320
Check	246c	245b	280b	280	303	294	303	335	298	339	315	308	304	314b	324	321	326	323
Significance†	***	***	**	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	***	- NS -	- NS -	- NS -	- NS -

***, ** denotes statistical significance at P < 0.01, 0.05 respectively; NS = Not Significant

† Within each column, treatment means not sharing a letter are significantly different at a = 0.05

Table 4. Main effects of construction type, rolling and plant growth regulator (PGR) on ball roll distance in centimeters on putting greens at the Hancock Turfgrass Research Center, East Lansing, MI, 1997.

	centimeters																	
	28-May (Application #1)						4-Jul (Application #2)						14-Aug (Application #3					
Soil Type	7 DAT	11 DAT	16 DAT	21 DAT	26 DAT	35 DAT	7 DAT	10 DAT	14 DAT	19 DAT	26 DAT	28 DAT	11 DAT	13 DAT	15 DAT	20 DAT	22 DAT	38 DAT
USGA	308a	328	326	335	311	304	343	324	343	294	345	341	281	294	342	327a	338	333
80:10:10	293b	332	324	329	302	301	335	316	334	282	339	333	269	293	333	314b	342	320
Native	290b	325	316	327	302	298	333	312	325	282	335	329	274	296	341	314b	337	318
Significance†	**	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	***	- NS -	- NS -
Rolling																		
Rolled	310	338	329	346	315	305	352	335	338	302	350	350	289	316	344	320	348	330
Not rolled	284	319	315	315	295	297	323	299	331	270	329	318	260	273	334	316	331	317
Significance	***	***	**	***	***	***	***	***	- NS -	***	***	***	***	***	**	- NS -	***	***
PGR																		
Trinexapac-ethyl	305a	324b	323ab	328b	301	300	341a	317ab	332b	287	344a	334a	272b	293b	336	316	344	321
Flurprimidol	293b	338a	327a	335a	307	302	340a	325a	342a	284	336b	329b	281a	305a	342	317	337	325
Check	292b	323b	316b	327b	306	301	331b	309b	329b	286	339ab	338a	270b	285c	337	322	337	324
Significance†	***	***	**	**	- NS -	- NS -	**	**	**	- NS -	**	***	**	***	- NS -	- NS -	- NS -	- NS -

***, ** denotes statistical significance at P < 0.01, 0.05 respectively; NS = Not Significant

† Within each column, treatment means not sharing a letter are significantly different at a = 0.05

Table 5. Rolling by plant growth regulator (PGR) means on ball roll distance in centimeters on putting greens at the Hancock Turfgrass Research Center.

	1996			1997
	7 DAT	12 DAT	11 DAT	11 DAT
Rolled/Trinexapac-ethyl	274a	309a	332a	339a
Rolled/Flurprimidol	274a	300b	334a	329ab
Rolled/check	255b	290c	317b	329ab
Not Rolled/Trinexapac-ethyl	233c	266d	303c	332ab
Not Rolled/ Flurprimidol	249b	270d	311bc	318b
Not rolled/check	237c	269d	311bc	324ab
Significance†	***	***	***	**

***, ** denotes statistical significance at $P < 0.01$, 0.05 respectively

† Within each column, treatment means not sharing a letter are significantly different at a = 0.05

Table 6. Soil by plant growth regulator (PGR) means for PGR treatments on ball roll distance in centimeters on putting greens at the Hancock Turfgrass Research Center, 1997.

	27-Aug
USGA/ Trinexapac-ethyl	294bcd
USGA/ Flurprimidol	312a
USGA/check	278e
80:10:10/ Trinexapac-ethyl	289cef
80:10:10/ Flurprimidol	301abd
80:10:10/Check	290bcde
Native/ Trinexapac-ethyl	297abcd
Native/ Flurprimidol	303abc
Native/check	288def
Significance†	**

** denotes statistical significance at $P < 0.05$

† Within each column, treatment means not sharing a letter are significantly different at a = 0.05

Table 7. Soil by roll means on ball roll distance in centimeters on putting greens at the Hancock Turfgrass Research Center.

	2-Jul	11-Jul	22-Sep
USGA/roll	302bc	357ab	343a
USGA/not rolled	305ab	330cd	322bc
80:10:10/rolled	313a	358a	330ab
80:10:10/not rolled	290d	313e	310c
Native/rolled	300bc	342bc	317bc
Native/not rolled	296cd	325de	318bc
Significance†	***	**	**

***, ** denotes statistical significance at $P < 0.01$, 0.05 respectively

† Within each column, treatment means not sharing a letter are significantly different at a = 0.05

A soil-by-PGR interaction was observed 13DAT of application #3 in 1997 (Table 6). Flurprimidol showed significantly higher BRD than trinexapac-ethyl and check plots on USGA and 80:10:10 greens. Being that this was the only significant interaction between soil and PGR, superintendents can be confident in using PGR's will not cause different effects in different soils.

Soil-by-roll interactions were observed on three dates in 1997 (Table 7). On 2-Jul the 80:10:10 soil produced higher BRD when rolled while the USGA and Native soils did not show this effect. On 11-Jul and 22-Sep, both the USGA and 80:10:10 soils produced significantly higher BRD when rolled than the native greens. This interaction was not observed in 1996. These interactions indicate that high sand content root zones may produce higher BRD when rolling is applied while native soil greens do not produce higher BRD.

Color

Significant treatment effects on putting green color ratings are shown in Table 8. No differences in color were recorded between soil types in 1996 though differences were observed in 1997 (Table 9). At the beginning of the 1997 season on 4-Jun the native greens had significantly darker color than the USGA and 80:10:10 greens. At the end of the season, on 23 Aug and 5 Sep, the USGA greens showed higher color ratings than the native and 80:10:10 greens. As was observed by Hartwiger (1996), rolling consistently produced decreased turfgrass color though both years of the study (Table 9). When differences in color were apparent between PGR's, flurprimidol caused lower color ratings below that of

Table 8. Mean squares and significance of treatment effects on color ratings on putting greens at the Hancock Turfgrass Research Center, East Lansing, M

Source of Variation	df	1996			1997					
		29-Jul	10-Sep	18-Sep	3-Jun	4-Jun	19-Jun	25-Jun	7-Jul	10-Jul
Replication	2	2.17	0.40	0.73	0.31	1.56	0.02	0.60	1.68	0.20
Soil, S	2	0.62	0.01	0.80	0.89	1.39	1.87	0.06	1.13	0.23
Error (a)	4	0.77	0.50	0.42	0.50	0.24	0.63	1.19	0.51	0.41
Roll, R	1	3.89 **	0.20	3.89 **	0.04	0.17	0.23	0.04	2.67	2.67
S x R	2	0.70	0.50	0.07	0.18	0.17	0.78	0.17	0.10	0.10
Error (b)	6	0.38	0.40	0.43	0.59	0.75	0.22	0.07	0.63	0.70
PGR, P	2	6.70 ***	6.80 ***	6.25 ***	7.14 ***	9.18 ***	3.75 ***	0.51 ***	5.17 ***	5.17 ***
S x P	4	0.13	0.07	0.05	0.77	0.59	0.28	0.17	0.35 *	0.34
R x P	2	0.06	0.04	0.06	0.04	0.01	0.23	0.01	0.06	0.18
S x R x P	4	0.03	0.04	0.01	0.56	0.49	0.95	0.03	0.34	0.13
Error (c)	24	0.12	0.30	0.19	0.38	0.51	0.49	0.08	0.16	0.22
CV (%)		4.98	8.00	6.51	10.13	11.70	11.08	3.70	5.85	7.15

Source of Variation	df	1997							
		11-Jul	13-Jul	14-Jul	20-Jul	22-Jul	31-Jul	23-Aug	5-Sep
Replication	2	0.13	0.13	0.43	0.89	0.62	2.79	0.69	2.18
Soil, S	2	0.24	0.96	0.60	4.24	0.37	2.10	10.84 ***	4.50
Error (a)	4	0.44	0.98	0.53	2.24	1.12	2.95	0.48	0.85
Roll, R	1	2.45 **	1.85	5.67 ***	0.23	0.02	2.89	15.57	28.89 **
S x R	2	0.57	0.30	0.62	0.96	0.45	0.17	2.59	2.74
Error (b)	6	0.37	0.50	0.25	1.75	0.43	1.93	2.81	3.65
PGR, P	2	7.64 ***	12.87 ***	15.26 ***	5.41 ***	4.45 ***	0.26	17.24 ***	3.29 ***
S x P	4	0.25	0.51	0.57	0.55	0.07	0.03	0.93	0.25
R x P	2	0.00	0.62	0.31	0.13	0.03	0.20	1.41	0.92 **
S x R x P	4	0.19	0.29	0.21	0.62	0.30	0.06	0.11	0.02
Error (c)	24	0.21	0.24	0.31	0.36	0.16	0.11	0.51	0.26
CV (%)		6.97	7.31	8.50	9.07	5.92	4.99	11.75	8.26

***, ** denotes statistical significance at $P < 0.01$, 0.05 respectively

Table 9. Effects of construction type, rolling, plant growth regulator (PGR) treatments on color ratings on putting greens at the Hancock Turfgrass Research Center, East Lansing, MI

	1996			1997			
				App. #1 (28-May)			
Soil Type	29-Jul	10-Sep	18-Sep	3-Jun	4-Jun	19-Jun	25-Jun
USGA	6.7	7	6.6	5.9	5.8	6.2	7.7
80:10:10	6.9	7.1	6.6	6.1	6.1	6.1	7.8
Native	7.1	7.1	7	6.3	6:4	6.7	7.6
Significance†	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -
Rolling							
Rolled	6.6	7	6.5	6.1	6.1	6.4	7.7
Not rolled	7.2	7.1	7	6.1	6.2	6.3	7.7
Significance	**	- NS -	**	- NS -	- NS -	- NS -	- NS -
Plant Growth Regulator							
Trinexapac-ethyl	7.2a	7.7a	7.1a	6.3a	6.4a	6.5a	7.8a
Flurprimidol	6.2b	6.5c	6.1b	5.4b	5.3b	5.8b	7.5b
Check	7.3a	7.0b	7.0a	6.6a	6.7a	6.7a	7.8a
Significance†	***	***	***	***	***	***	***

	1997							
	App. #2 (4-Jul)						App. #3 (14-Aug)	
Soil Type	7-Jul	10-Jul	11-Jul	13-Jul	14-Jul	20-Jul	23-Aug	5-Sep
USGA	6.8	6.8	6.5	6.6	6.3	6.2	6.9a	6.6
80:10:10	6.5	6.6	6.6	6.7	6.6	6.5	5.9b	5.6
Native	7	6.5	6.8	7	6.7	7.1	5.4b	6.1
Significance†	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	***	- NS -
Rolling								
Rolled	6.6	6.4	6.4	6.6	6.2	6.5	5.5	5.4
Not rolled	7	6.9	6.8	6.9	6.9	6.7	6.6	6.9
Significance	- NS -	- NS -	**	- NS -	***	- NS -	- NS -	**
Plant Growth Regulator								
Trinexapac-ethyl	7.0a	6.8a	6.8a	7.1a	6.8b	6.9a	6.6a	6.5a
Flurprimidol	6.2b	6.0b	5.9b	5.8b	5.5c	6.0b	4.9b	5.7b
Check	7.2a	7.1a	7.1a	7.4a	7.3a	7.0a	6.7a	6.3a
Significance†	***	***	***	***	***	***	***	***

***, ** denotes statistical significance at P < 0.01, 0.05 respectively; NS = Not Significant

† Within each column, treatment means not sharing a letter are significantly different at a = 0.05

‡ Color was evaluated on a 1-9 scale, 1=brown/dead turf and 9=dark green

the trinexapac-ethyl and check plots. Trinexapac-ethyl did not adversely affect color.

The only significant interaction recorded during both years of the study was between rolling and PGR's (Table 10). 22 DAT of application #3 of 1997 a roll-by-plant growth regulator interaction occurred. When not rolled, trinexapac-ethyl treated plots had significantly higher color than all other plots and rolled flurprimidol plots had significantly lower color than all other plots.

Quality

Significant treatment effects on putting green quality ratings are shown in Table 11. Quality ratings were taken when visual differences were apparent, therefore two ratings were taken each year. No quality differences were recorded among the three soil types during either year of the study (Table 12). Rolling did not show differences in quality except for 3-Jun 1997 where rolled plots had higher quality than not rolled plots. Due to color being a major influence in the determination of quality, results in PGR quality ratings reflect the results that were observed in color ratings on the same dates. Flurprimidol significantly decreased quality ratings below trinexapac-ethyl and check plots.

Two interactions regarding quality were recorded. A soil-by-roll interaction was recorded on 10-Sep-96 (Table 13). When rolling was applied, no significant differences were detected between soil types while the USGA plots had significantly lower quality when rolling was not applied. A soil-by-PGR interaction was recorded on 3 Jun 1997 (Table 13). No significant differences were shown

Table 10. Roll by plant growth regulator interaction for color ratings on putting greens at the Hancock Turfgrass Research Center, East Lansing, MI 1997. ‡

	5-Sep
Rolled/Trinexapac-ethyl	5.6 b
Rolled/Flurprimidol	4.8 c
Rolled/check	5.8 b
Not Rolled/Trinexapac-ethyl	7.4 a
Not Rolled/ Flurprimidol	6.5 b
Not rolled/check	6.7 b
Significance†	**

** denotes statistical significance at P < 0.05

† Treatment means not sharing a letter are significantly different at a = 0.05

‡ Color was evaluated on a 1-9 scale, 1=brown/dead turf and 9=dark green

Table 11. Mean squares and significance of treatment effects on quality ratings on putting greens at the Hancock Turfgrass Research Center, East Lansing, MI.

		Quality			
		1996		1997	
		29-Jul	10-Sep	3-Jun	7-Jul
Source of Variation	df				
Replication	2	0.13	0.02	1.03	0.02
Soil, S	2	0.96	1.19	2.20	0.48
Error (a)	4	0.83	1.21	2.24	0.20
Roll, R	1	1.04	0.07	2.04	0.02
S x R	2	0.06	2.25 ***	1.10	0.09
Error (b)	6	0.47	0.19	0.41	0.34
PGR, P	2	1.35 ***	2.07 ***	1.20 ***	0.37 ***
S x P	4	0.18	0.35	0.70 ***	0.07
R x P	2	0.00	0.07	0.26	0.09
S x R x P	4	0.12	0.05	0.19	0.09
Error (c)	24	0.14	0.30	0.15	0.06
CV (%)		5.30	7.90	6.32	3.55

*** denotes statistical significance at $P < 0.01$

Table 12. Effects of construction type, rolling, plant growth regulator (PGR) treatments on quality ratings on putting greens at the Hancock Turfgrass Research Center, East Lansing, MI. ‡

	1996		1997	
Soil Type	29-Jul	10-Sep	3-Jun	7-Jul
USGA	6.7	6.6	5.7	7.0
80:10:10	7.0	7.0	6.0	6.7
Native	7.1	7.1	6.4	7.0
Significance	- NS -	- NS -	- NS -	- NS -
Rolling				
rolled	6.8	6.9	6.2	6.9
Not rolled	7.1	6.9	5.9	6.9
Significance	- NS -	- NS -	**	- NS -
PGR				
Trinexapac-ethyl	7.1a	7.3a	6.2a	6.9a
Flurprimidol	6.6b	6.6b	5.8b	6.8b
check	7.1a	6.8b	6.2a	7.0a
Significance†	***	***	***	***

***, ** denotes statistical significance at P < 0.01, 0.05 respectively; NS = Not Significant

† Within each column, treatment means not sharing a letter are significantly different at a = 0.05

‡ Color was evaluated on a 1-9 scale, 1=brown/dead turf and 9=dark green

Table 13. Quality ratings for the significant soil-by-roll and soil-by-PGR interactions on putting greens at the Hancock Turfgrass Research Center, East Lansing, MI. ‡

	Soil-by-roll interaction			Soil-by-PGR interaction		
	10-Sep-96			3-Jun-97		
Soil Type	Rolled	Not Rolled	Soil Type	Trinexapac-ethyl	Flurprimidol	Check
USGA	7.1a	6.2b	USGA	5.8abc	5.4bd	6.0ac
80:10:10	6.8ab	7.2a	80:10:10	6.4ab	5.3cd	6.3ab
Native	6.9ab	7.2a	Native	6.3abc	6.5ab	6.4abc
Significance†	***		Significance†		***	

*** denotes statistical significance at $P < 0.01$

† Within each column and between each row, treatment means not sharing a letter are significantly different at a = 0.05

‡ Color was evaluated on a 1-9 scale, 1=brown/dead turf and 9=dark green

between PGR's in the native soil plots while flurprimidol caused lower quality in the USGA and 80:10:10 plots.

Root Weight

Significant treatment effects for both years of the study are shown in Table 14. The main effect of soil type produced only one significant difference in 1996 and none in 1997. USGA soils showed the greatest root weight in the 0-15cm sampling depth in 1996(Table 15). Rolling did not cause a difference in root weight for either year of the study. Trinexapac-ethyl produced more roots than flurprimidol at the 5-10cm depth. As shown in Table 14, no significant main effects or interactions were recorded in 1997.

Despite the lack of differences between main effects there were several significant interactions in 1996. A soil-by-roll interaction was recorded at the 0-2.5cm depth where the 80:10:10 soil types produced significantly higher root weights when rolling was applied (Table 16).

The 5-10cm sampling depth produced three significant interactions in 1996. A soil-by-PGR interaction (Table 17) showed that within the 80:10:10 plots trinexapac-ethyl produced more roots than the flurprimidol and check plots. Both the USGA and native soils exhibited no differences in root mass between PGR's. A roll-by-PGR interaction was also recorded at the 5-10cm depth in 1996 (Table 18). When rolling was applied, trinexapac-ethyl produced more roots than both the flurprimidol and check plots. In the not-rolled plots there were no differences in root weights between PGR's.

Table 14. Mean squares and significance of treatments on root mass on putting greens at the Hancock Turfgrass Research Center, East Lansing, MI.

		1996				
		.... depth				
		0-2.5cm	2.5-5cm	5-10cm	10-15cm	0-15cm
Source of Variation	df					
Replication	2	0.05000	0.00400	0.00200	0.00100	0.10800
Soil, S	2	0.01000	0.00200	0.01000	0.00700	0.06900 ***
Error (a)	4	0.00700	0.00100	0.00600	0.00200	0.00300
Roll, R	1	0.03000	0.00010	0.00070	0.00300	0.00300
S x R	2	0.04000 **	0.00100	0.00010	0.00100	0.03600
Error (b)	6	0.00500	0.00040	0.00090	0.00200	0.00900
PGR, P	2	0.00400	0.00100	0.00400 **	0.00200	0.01500
S x P	4	0.00500	0.00100	0.00400 ***	0.00070	0.00600
R x P	2	0.00050	0.00010	0.00400 **	0.00020	0.00020
S x R x P	4	0.00400	0.00300 **	0.00500 ***	0.00020	0.00400
Error (c)	24	0.00600	0.00080	0.00080	0.00100	0.00500
CV (%)		27.1	33.2	38.9	194.4	15.6

		1997				
		.... depth				
		0-2.5cm	2.5-5cm	5-10cm	10-15cm	0-15cm
Source of Variation	df					
Replication	2	0.00070	0.00210	0.00040	0.00020	0.00100
Soil, S	2	0.00340	0.00360	0.00040	0.00040	0.01400
Error (a)	4	0.00510	0.00130	0.00010	0.00006	0.01200
Roll, R	1	0.00030	0.00320	0.00010	0.00007	0.00009
S x R	2	0.00840	0.00230	0.00020	0.00030	0.00300
Error (b)	6	0.00190	0.00190	0.00030	0.00008	0.00500
PGR, P	2	0.00110	0.00070	0.00000	0.00020	0.00200
S x P	4	0.00370	0.00110	0.00020	0.00006	0.00500
R x P	2	0.00420	0.00190	0.00010	0.00006	0.00800
S x R x P	4	0.00240	0.00110	0.00020	0.00010	0.00200
Error (c)	24	0.00200	0.00160	0.00020	0.00007	0.00300
CV (%)		31.3	83.2	46.6	71.8	25.7

***, ** denotes statistical significance at at $P < 0.01, 0.05$ respectively

Table 15. Effects of construction type, rolling, plant growth (PGR) regulator treatments of 19 on root weights in grams on putting greens at the Hancock Turfgrass Research Center.

	grams/mm^3				
Soil Type	0-2.5cm	2.5-5cm	5-10cm	10-15cm	0-15cm
USGA	3.7	1.2	2.5	1.0	19.5a
80:10:10	3.1	1.0	1.7	0.5	15.1b
Native	3.6	1.0	1.2	0.0	16.5b
Significance†	- NS -	- NS -	- NS -	- NS -	***
Rolling					
Rolled	3.7	1.1	1.7	0.2	17.3
Not rolled	3.2	1.1	2.0	0.7	16.9
Significance	- NS -	- NS -	- NS -	- NS -	- NS -
PGR					
Trinexapac-ethyl	3.6	1.1	2.2a	0.7	18.4
Flurprimidol	3.4	1.0	1.5b	0.2	16.5
Check	3.3	1.1	1.7ab	0.5	16.5
Significance†	- NS -	- NS -	**	- NS -	- NS -

***, ** denotes statistical significance at $P < 0.01$, 0.05 respectively; NS = Not Significant

† Within each column, treatment means not sharing a letter are significantly different at a = 0

Table 16. Soil by rolling interaction for root weights (grams/mm^3) on putting greens at the Ha Turfgrass Research Center, East Lansing, MI.

	1996	
	0-2.5cm depth	
Soil type	Rolled	Not Rolled
USGA	4.0a	3.3ab
80:10:10	3.8a	2.3b
Native	3.3ab	3.9a
Significance†	**	

** denotes statistical significance at $P < 0.05$

† Within each column and between each row, treatment means not sharing a letter are significantly different at a = 0.05

Table 17. Soil by plant growth regulator interaction for root weights from 5.0-10.0cm depth on putting greens at the Hancock Turfgrass Research Center, East Lansing, MI, 1996.

	grams/mm^3
	5.0-10cm depth
USGA/ trinexapac-ethyl	2.5ab
USGA/ flurprimidol	2.5ab
USGA/check	2.5ab
80:10:10/ trinexapac-ethyl	2.9a
80:10:10/ flurprimidol	0.7c
80:10:10/Check	1.7bc
Native/ trinexapac-ethyl	1.2bc
Native/ flurprimidol	1.2bc
Native/check	1.2bc
Significance†	***

*** denotes statistical significance at $P < 0.01$

† Treatment means not sharing a letter are significantly different at a = 0.05

Table 18. Roll by plant growth regulator interaction for root weights (grams) from 5.0-10.0cm depth on putting greens at the Hancock Turfgrass Research Center, East Lansing, MI, 1996.

	grams/mm^3
	5.0-10.0cm depth
Rolled/Trinexapac-ethyl	2.5a
Rolled/Flurprimidol	1.0c
Rolled/check	1.7bc
Not Rolled/Trinexapac-ethyl	2.0ab
Not Rolled/ Flurprimidol	2.0ab
Not rolled/check	2.0ab
Significance†	**

** denotes statistical significance at $P < 0.05$

† Treatment means not sharing a letter are significantly different at a = 0.05

Table 19. Soil by roll by plant growth regulator interaction for root weights (grams/mm^3) from putting greens at the Hancock Turfgrass Research Center, East Lansing, MI, 1996.

	depth	
	2.5-5.0cm	5.0-10.0cm
USGA /rolled/trinexapac-ethyl	1.23 a	2.45 abc
USGA /rolled/flurprimidol	1.23 a	2.45 abc
USGA /rolled/check	1.23 a	2.45 abc
USGA /not rolled/trinexapac-ethyl	1.23 a	2.45 abc
USGA /not rolled/flurprimidol	1.23 a	2.45 abc
USGA /not rolled/check	1.23 a	2.45 abc
80:10:10/rolled/trinexapac-ethyl	1.23 a	3.19 a
80:10:10/rolled/flurprimidol	1.23 a	0.74 cd
80:10:10/rolled/check	0.86 ab	0.74 cd
80:10:10/not rolled/trinexapac-ethyl	1.23 a	2.45 ab
80:10:10/not rolled/flurprimidol	0.37 b	0.74 cd
80:10:10/not rolled/check	0.86 ab	2.45 ab
Native/rolled/trinexapac-ethyl	1.23 a	1.72 abc
Native/rolled/flurprimidol	0.37 b	0.00 d
Native/rolled/check	1.23 a	1.72 abc
Native/not rolled/trinexapac-ethyl	0.86 ab	0.74 bd
Native/not rolled/flurprimidol	1.23 a	2.45 ac
Native/not rolled/check	1.23 a	0.74 bd
Significance†	**	***

***, ** denotes statistical significance at $P < 0.01, 0.05$

† Within each column, treatment means not sharing a letter are significantly different at a = 0.05

The final interaction at the 5-10cm sampling depth was between soil, rolling and PGR's (Table 19). This three-way interaction showed that the USGA soil had no differences in root weight regardless of rolling or PGR applications. In the native greens, flurprimidol produced significantly fewer roots in both rolled and not rolled plots when compared to the 80:10:10 and USGA root zones. In the 80:10:10 soil, flurprimidol produced significantly fewer roots than trinexapac-ethyl in both rolled and not-rolled plots. There was also a three-way interaction at the 0-2.5cm sampling depth. This interaction was also influenced by the application of flurprimidol. In the USGA soil there were no differences among PGR or rolling treatments. In the 80:10:10 soil, flurprimidol treatments produced significantly less roots in the not-rolled plots. In the native soil the response was reversed. Flurprimidol produced significantly fewer roots when rolled.

Also worth noting is the potential for error in the collection of data for root weights. This may explain the lack of differences shown in 1997. Skogley and Sawyer (1992) noted the potential for loss of roots due to the laborious task of separating roots from soil.

Turfgrass responses

Other information regarding turfgrass responses were recorded on a periodic basis. Significant treatment effects for dollar spot (Sclerotinia homeocarpa) counts, clipping weights, microdochium patch (Microdochium nivale) counts, and cutworm damage counts are presented in Table 20. Yellow tuft (*Scleropthera macrospora*) incidence showed no significant differences and

Table 20. Mean squares and significant treatments for dollar spot counts, clipping weights, microdochium patch counts and cutworm damage counts on putting greens at the Hancock Turfgrass Research Center, East Lansing, MI.

		Dollar Spot			Clipping weights		Microdochium patch	Cutworm Damage
Source of Variation	df	24-Jun-96	2-Aug-96	25-Jun-97	8-Aug-96	21-Jul-97	14-Apr-97	5-Aug-96
Replication	2	10.3	46.3	988.7	5.1	2.6	561.6	514.5
Soil, S	2	1337.8 ***	85.6	1718.1	1.1	9.4 **	1044.9	264.5
Error (a)	4	54.8	42.5	423.0	2.1	0.9	1026.2	150.9
Roll, R	1	1310.3 ***	5.4 **	1462.2	0.0	0.4 **	22.7	988.2 **
S x R	2	404.5 **	5.9 **	528.2	1.3	0.4 **	225.5	211.7
Error (b)	6	50.5	0.8	343.5	0.6	0.1	196.2	145.8
PGR, P	2	25.6	6.7	20.1	0.2	0.3 **	29.6	45.9
S x P	4	27.0	2.6	51.9	0.1	0.1	17.1	11.6
R x P	2	4.6	7.4	46.8	0.2	0.6 ***	35.2	21.6
S x R x P	4	11.5	7.9	14.2	1.3	0.1	29.6	10.1
Error (c)	24	64.7	9.2	80.0	0.8	0.1	198.2	28.6
CV (%)		104.4	212.8	73.5	16.9	16.0	30.7	45.3

***, ** denotes statistical significance at $P < 0.01, 0.05$ respectively

Table 21. Main effects of construction type, rolling, plant growth regulator treatments on dollar spot c cutworm damage, and root length on putting greens at the Hancock Turfgrass Research Center.

	Dollar Spot spots/m^2		Clipping Weights grams	Cutworm Damage holes/m^2
Soil Type	24-Jun-96	2-Aug-96	21-Jul-97	5-Aug-96
USGA	3.74a	0.87	1.35b	3.6
80:10:10	1.10b	0	1.69b	2.1
Native	0.22b	0	2.74a	2.1
Significance†	***	- NS -	**	- NS -
Rolling				
Rolled	0.66	0.22	1.84	1.6
Not rolled	2.86	0.44	2.02	3.5
Significance	***	**	**	**
PGR				
Trinexapac-ethyl	1.76	0.22	1.9ab	2.3
Flurprimidol	1.98	0.44	1.8b	2.5
check	1.32	0.22	2.08a	3.0
Significance†	- NS -	- NS -	**	- NS -

***, ** denotes statistical significance at $P < 0.01, 0.05$ respectively; NS = Not Significant

† Within each column, treatment means not sharing a letter are significantly different at a = 0.05

therefore will not be discussed. USGA soils had significantly more dollar spots on 24 Jun 1996 than the 80:10:10 and native soil plots (Table 21). Rolling produced significantly less dollar spots than not-rolled plots during all data collection dates. PGR's did not effect dollar spot incidence. In 1996 two soil-by-roll interactions occurred (Table 22). On both 24-Jun and 2-Aug rolling significantly reduced dollar spot incidence on USGA plots. On 24-Jun the 80:10:10 soil also showed significantly less dollar spot incidence when rolling was applied. The reduction of dollar spot as a result of rolling has been shown in previous research (Nikolai et. al., 1997) and suggests a substantial benefit to superintendents looking to reduce dollar spot incidence on sand-based putting greens.

Main effects produced no differences in clipping weights on 8-Aug-96 (Table 20). On 21-Jul-97 the main effects of soil type and rolling showed significant differences in clipping weights but will not be discussed because a soil-by-roll interaction was also observed. Clipping weights showed a soil-by-roll interaction (Table 22) where the sand-based plots had no differences between rolled and not-rolled plots while the native soil produced more clippings when rolling was applied.

There was also a roll-by-PGR interaction for clipping weights (Table 23). When rolling was applied, the check plots produced significantly more clippings than both trinexapac-ethyl and flurprimidol. No differences were recorded when PGR's were applied to not-rolled plots.

As shown in Table 20, no differences were recorded in microdochium patch incidence from 14-Apr-97. Cutworm damage counts showed that rolling

Table 22. Soil by roll interaction means for dollar spot counts and clipping weights on putting greens at the Hancock Turfgrass Research Center, East Lansing, MI.

	Dollar spot interactions		Clipping weight interaction
	dollar spots/m2		$g * m^{-2} * d^{-1}$
	24-Jun-96	2-Aug-96	21-Jul-97
USGA/roll	1.63 c	0.66 b	1.41 c
USGA/not rolled	6.02 a	1.08 a	1.29 c
80:10:10/rolled	0.09 c	0.00 ab	1.66 c
80:10:10/not rolled	1.93 b	0.07 ab	1.73 c
Native/rolled	0.09 bc	0.07 ab	2.99 a
Native/not rolled	0.37 bc	0.00 ab	2.49 b
Significance†	**	**	**

** denotes statistical significance at $P < 0.05$

† Within each column, treatment means not sharing a letter are significantly different at a = 0.05

Table 23. Roll by plant growth regulator interaction for clipping weights at the Hancock Turfgrass Res Center, East Lansing, MI, 21-July, 1997.

	Clipping Weights (g * m-2 * d-1)
Rolled/Trinexapac-ethyl	1.8b
Rolled/Flurprimidol	1.9b
Rolled/check	2.4a
Not Rolled/Trinexapac-ethyl	1.9b
Not Rolled/ Flurprimidol	1.7b
Not rolled/check	1.8b
Significance†	***

*** denotes statistical significance at $P < 0.01$

† Treatment means not sharing a letter are significantly different at a = 0.05

resulted in significantly less damage than not-rolled plots (Table 21).

Soil Responses

Thatch weights, root length, and Clegg impact absorption (Gmax) values were also recorded. Mean squares for significant treatment effects are presented in Table 24. Thatch weight and root length data produced no interactions or main effect significance and therefore will not be discussed. Clegg impact absorption values produced significant differences between the main effects of rolling and soil types. A soil-by-roll interaction was recorded for Clegg impact absorption on 23-Jun-97 (Table 25). When rolling was applied, the native soil produced a significantly higher G_{max} than the sand-based plots. There were no differences in G_{max} values between soil types when rolling was not applied.

Conclusions

When significant differences in BRD between soil types were recorded, which was five times through both seasons, the native soil had less BRD than the other soil types. A connection can be attributed to clipping yields. On one date when clipping weights were recorded, the native soil showed significantly greater clippings than the sand-based soils. The lower BRD measurements in the native soil may be attributed to the increased shoot growth. As has been shown in other research, (Hamilton et al, 1994, Nikolai et. al., 1997) rolling consistently increased BRD through both seasons. Regarding the effects of PGR's on

Table 24. Means squares and significance of treatments for dollar spot counts, clipping weights, cutworm damage counts, root length, snowmold, thatch weight and peak deceleration on putting greens at the Hancock Turfgrass Research Center, East Lansing, MI, 1996.

Source of Variation	df	Thatch Weight 16-Jun	Clegg 23-Jun	root length 8-Aug
Replication	2	2.1	4.8	53939.1 **
Soil, S	2	36.5	597.0 **	13013.7
Error (a)	4	2.1	66.9	4245.9
Roll, R	1	0.2	1759.0 ***	7969.2
S x R	2	13.5	197.8 ***	184.6
Error (b)	6	8.7	18.5	1479.4
PGR, P	2	0.0	14.3	991.2
S x P	4	9.6	3.6	1296.3
R x P	2	1.2	4.1	312.9
S x R x P	4	1.9	21.6	457.2
Error (c)	24	4.6	7.4	949.9
CV (%)		10.6	3.7	16.9

***, ** denotes statistical significance at $P < 0.01$, 0.05 respectively

Table 25. Soil by roll interactions for peak deceleration (G_{max}) on putting greens at the Hancock Turfgrass Research Center, 1997.

	Peak deceleration interaction	
	23-Jun	
	G_{max}	
Soil Type	Rolled	Not Rolled
USGA	73.8bc	66.7d
80:10:10	76.6b	68.4cd
Native	90.7a	71.7bcd
Significance	***	

*** denotes statistical significance at $P < 0.01$

† Within each column and between each row, treatment means not sharing a letter are significantly different at $\alpha = 0.05$

BRD through both seasons. Regarding the effects of PGR's on rolling, differences appeared in the window of 7 to 16 days after application except for the second application in 1996. When these differences were recorded, the check plot had less BRD than either trinexapac-ethyl or flurprimidol or both, though one PGR in particular was not consistently greater than the check. A connection can be made to clipping weights for PGR applications as well. On 21-Jul-97 clipping weights in the check plots were significantly greater than both PGR's which would account for the lower BRD in the check plots.

There were six PGR applications made during the study (three each year). Of those six, four showed a roll-by-PGR interaction between 6 and 12 DAT. Both PGR's had significantly higher BRD than check plots when rolling was applied. This result may provide a valuable alternative for superintendents looking to improve putting green speeds without reducing mowing heights.

The most important findings with regard to color and quality ratings were the effects from PGR's. When color differences became apparent after the PGR applications, flurprimidol consistently reduced both color and quality below that of trinexapac-ethyl and the check. Rolling periodically had an adverse effect on color though no reduction in quality resulted.

Dollar spot incidence was reduced when rolling was applied to USGA soils for both data collections in 1996. Though this was not seen in 1997, Nikolai et. al. (1997) showed the reduction of dollar spot from rolling as well. This shows that rolling can be an asset to superintendents for not only increasing putting green speeds, but also reducing dollar spot incidence.

Nikolai and Karcher (1999) found that when putting green speeds are high (above 270cm BRD), most golfers are not able to detect differences in putting green speeds that differ by 30cm. Though statistically significant differences involving PGR's were recorded in this study, the increased BRD averaged 10cm. This implies that though increases were recorded, they would not be detectable by the golfer.

Since the inception of the study in 1996 the use of PGR's by superintendents on putting greens has changed. When the study began, PGR's were not labeled for putting green use and few superintendents were using them. There are many superintendents who now apply PGR's to their putting greens on a weekly basis throughout the growing season (Rogers, Vargas, and Crum, 1999). Since the window of effect from the PGR's is one to two weeks after application, this has become a more useful practice than the methods used in this study. Future projects may benefit from examining the practice of weekly applications that produce a more consistent reduction in growth.

Chapter 2

The Effects Of Topdressing With Crumb Rubber On Creeping Bentgrass Quality On Putting Greens Collars Constructed With Three Different Soil Types

Specific Materials and Methods

There were four topdressing treatments applied to the putting green collars; 3.2mm crumb rubber, 9.6mm crumb rubber, 3.2mm crumb rubber mixed with 3.2mm sand, and sand alone. The particle size of the crumb rubber was 2.00/0.84mm. Particle size analysis of crumb rubber is shown in Table 50. In the interest of reducing potential heat stress to the turfgrass plant from excessive rubber on the surface, the rubber was applied at 1.6mm increments every week starting 23-May-96. The final rate of 9.6mm crumb rubber was achieved on 24-Jun-96, six weeks after the initial application and the point of data collection. Both treatments containing sand received continual sand topdressing applications through both years of the study. The collars were mowed three days per week at 9.5mm. Traffic simulation was applied by making six passes five days per week which was three times the rate applied to the putting greens. The collars received more traffic to simulate the more intensively trafficked collar areas that superintendents often have difficulty maintaining. All other management practices are outlined in the general materials and methods section.

quality were rated on a scale from 1-9; 1 = poor, 9 = excellent, and 6 = acceptable.

Impact absorption was collected in June 1997 using the Clegg Impact Soil Tester (Lafayette Instruments Co., Lafayette, IN) and the 2.25kg hammer. An average of three measurements was recorded as transmitted to a hand-held read-out box. The hammer was dropped randomly through the plot from a height of 0.46m (Rogers and Waddington, 1990).

Shear resistance was recorded with the Eijkelkamp Shearvane Type 1B (Henderson, 1986). The values recorded (Nm) were an average of three measurements.

Disease ratings were recorded when disease outbreaks occurred during both years of the study. Diseases recorded were; dollar spot (Sclerotinia homoeocarpa), microdochium patch (Microdochium nivale), and yellow tuft (Scleropthera macrospora). Dollar spot and microdochium patch were recorded according to the number of spots occurring in each plot. Yellow tuft was visually rated on a scale from 0 – 100%.

Poa annua invasion ratings were recorded on 5-Oct-96, 16-Oct-96, 28-May-97, and 10-Oct-97. Ratings were visually recorded on a scale from 0-100%.

Surface and soil temperatures (2.54cm depth) were recorded with a Barnant 115 Thermocouple Thermometer (Barnant Co., Barrington, IL) on 4-Jun-96 and 10-Jul-97 respectively. Three temperature measurements were taken randomly for each treatment and averaged.

Thatch depth was recorded on 16-Jun-96. Three samples were removed from each plot, measured in millimeters, and then averaged. Thatch weight was recorded on 16-Jun-97 (Skogely and Sawyer, 1992). Three samples were taken from each plot. The area of the probe was 4.9cm. Verdure and soil were removed from the sample and weighed. Samples were then ashed at 500°C for five hours, reweighed and then averaged. Crumb rubber was present in the thatch layer when measurements were taken and therefore may have affected the results.

Results were analyzed using the SAS analysis of variance and least significant difference (LSD) test for a 3-by-2-by-4 factorial experiment in a randomized complete block split-split plot design with three replications. The four topdressing treatments were split into the rolling treatments and the rolling treatments were split into the three soil types.

Results and Discussion

Color

Mean squares and significant treatment effects are shown in Table 26 for 1996 and 1997. The 1996 season showed no differences in color among soil types. On 14-Apr, the first color rating of the 1997 season, the 80:10:10 and native soil plots had significantly darker green color than the USGA plots (Table 27). On 19-Jun-97 both of the sand based greens showed significantly darker green color than the native soil. Rolling treatments showed inferior color to not-rolled plots in both seasons. Topdressing with crumb rubber has proven effective in improving the color of turfgrass stands (Rogers et al, 1998). In both of years of the study, topdressing treatments with crumb rubber showed darker green color than plots with no crumb rubber application (Table 27).

Table 26. Mean squares and significance of treatment effects for color ratings of putting green collars at the Hancock Turfgrass Research Center, East Lansing, MI.

		1996				
Source of Variation	df	28-Jun	18-Jul	5-Sep	18-Sep	16-Oct
Replication	2	0.045	0.135	0.097	1.399	2.931
Soil, S	2	0.045	0.010	0.056	0.181	0.337
Error (a)	4	0.545	0.083	0.159	0.556	2.133
Roll, R	1	0.125	2.720 ***	3.780 ***	8.000 ***	3.781
S x R	2	0.198	0.337	0.292	0.292	4.760
Error (b)	6	0.247	0.142	0.215	0.205	1.079
Topdressing Treatment, T	3	2.857 ***	0.639	1.707 ***	0.097	0.902
S x T	6	0.207	0.149	0.203	0.153	0.443
R x T	3	0.245	0.231	0.068	0.009	0.947
S x R x T	6	0.360	0.068	0.190	0.356	0.385
Error (c)	36	0.164	0.241	0.135	0.188	0.397
CV (%)		5.780	7.377	5.280	6.270	8.886

		1997				
Source of Variation	df	14-Apr	19-Jun	7-Jul	14-Jul	31-Jul
Replication	2	0.847 **	1.073 ***	0.420	0.056	0.010
Soil, S	2	0.597 **	0.948 ***	0.420	0.389	1.344
Error (a)	4	0.076	0.052	0.441	0.649	1.557
Roll, R	1	0.000	1.837 ***	9.031 ***	4.753 **	0.281
S x R	2	0.792	0.462 **	0.385	0.514	0.823
Error (b)	6	0.278	0.087	0.392	0.583	0.653
Topdressing Treatment, T	3	0.093	0.300	1.716 ***	0.550 **	0.161
S x T	6	0.023	0.216	0.383	0.588 ***	0.140
R x T	3	0.111	0.291	0.531	0.031	0.050
S x R x T	6	0.069	0.749	0.497	0.083	0.119
Error (c)	36	0.065	0.378	0.237	0.175	0.097
CV (%)		4.263	9.257	7.050	6.357	4.634

***, ** denotes statistical significance at $P < 0.01, 0.05$ respectively

Table 27. Main effects of construction type, rolling, and the topdressing treatments on color ratings on putting green collars at the Hancock Turfgrass Research Center. ‡

	1996					1997				
Soil Type	28-Jun	18-Jul	5-Sep	18-Sep	16-Oct	14-Apr	19-Jun	7-Jul	14-Jul	31-Jul
USGA	7.0	6.7	6.9	6.8	7.1	5.8b	6.8a	6.8	6.4	6.6
80:10:10	7.0	6.7	6.9	6.9	7.2	6.0a	6.8a	6.8	6.6	6.6
Native	7.0	6.6	7.0	7.0	7.0	6.1a	6.4b	7.1	6.7	7.0
Significance†	- NS -	- NS -	- NS -	- NS -	- NS -	**	***	- NS -	- NS -	- NS -
Rolling										
Rolled	7.0	6.5	6.7	6.6	6.9	6.0	6.5	6.6	6.3	6.7
Rot rolled	7.0	6.9	7.2	7.2	7.3	6.0	6.8	7.3	6.8	6.8
Significance	- NS -	***	***	***	- NS -	- NS -	***	***	**	- NS -
Topdressing Amendments										
3.2mm rubber	6.8b	6.8	7.1b	6.9	7.2	5.9	6.8	6.9a	6.8a	6.9
9.5mm rubber	7.6a	6.9	7.4a	7.0	7.3	5.9	6.5	7.3a	6.6ab	6.7
3.2mm rubber & 3.2mm Sand	6.8b	6.6	6.8c	6.9	6.9	6.0	6.7	6.9a	6.6ab	6.7
Sand§	6.8b	6.4	6.7c	6.8	6.9	6.0	6.6	6.5b	6.3b	6.6
Significance†	***	- NS -	***	-NS -	- NS -	- NS -	- NS -	***	**	- NS -

***, ** denotes statistical significance at $P < 0.01, 0.05$ respectively; NS = Not Significant

† Within each column treatment means not sharing a letter are significantly different at a = 0.05

‡ Color was evaluated on a 1 - 9 scale, 1= brown/dead and 9= dark green.

§ Sand was topdressed everythree weeks

No significant interactions below $P < 0.05$ were recorded in 1996. Two interactions were recorded in 1997 for color ratings. On 14-Jul a soil-by-topdressing interaction (Table 28) showed that the 9.5mm crumb rubber topdressing treatment had significantly lower color rating on USGA soil than the other two soil types. The soil-by-roll interaction on 19-Jul-97 showed that color in the 80:10:10 and native soils declined significantly while rolling did not adversely effect the USGA soil.

Quality

Significant treatment effects for quality ratings are presented in Table 28. Due to color being a primary factor in the rating or quality, results for the main effects of soil type and rolling were similar to those recorded for quality. No differences in quality were recorded among soil types through both years of the study (Table 29). Rolling consistently decreased quality except on 22-Jul where rolling caused higher ratings in quality. Density is one factor in rating for quality. With a reduction in quality and therefore a potentially less dense turf, *Poa annua* may have an opportunity to establish in the open canopy.

On 28-Jun-96, four days after the final application of crumb rubber, the 9.5mm plots showed lower quality than all other topdressing treatments (Table 30). This may be attributed to the presence of rubber near the turfgrass surface and thus increasing temperatures to the point that quality was adversely affected. Vanini (1995) noted temperature increases due to the presence of crumb rubber.

Table 28. Color ratings for the significant soil-by-roll and soil-by-topdressing treatment interactions on putting green collars at the Hancock Turfgrass Research Center, East Lansing, MI. ‡

	Soil-by-roll interaction		Soil-by-topdressing treatment interaction			
	19-Jun-97		14-Jul-97			
Soil	Rolled	Not-Rolled	3.2mm rubber	9.5mm rubber	3.2mm sand & 3.2mm rubber	Sand§
USGA	6.8ab	6.8ab	6.8abc	6.0e	6.7abcd	6.3de
80:10:10	6.5b	7.0a	6.8abcd	6.9ab	6.3cde	6.4cde
Native	6.2c	6.7b	6.7abcd	6.9ac	6.8acd	6.3be
Significance†	**		***			

***, ** denotes statistical significance at $P < 0.01, 0.05$

† Within each interaction table treatment means not sharing a letter are significantly different at a = 0.05

‡ Color was evaluated on a 1 - 9 scale, 1= brown/dead and 9= dark green.

§ Sand was topdressed everythree weeks

Table 29. Mean squares and significance of treatment effects on quality of putting greens collars at the Hancock Turfgrass Research Centerl, East Lansing, MI.

		1996			
Source of Variation	df	28-Jun	18-Jul	1-Oct	16-Oct
Replication	2	1.01	0.39	1.26	3.43
Soil, S	2	1.09	0.97	0.32	0.38
Error (a)	4	0.68	0.67	1.97	2.97
Roll, R	1	0.68	5.56 ***	36.13 ***	15.59 ***
S x R	2	0.17	0.63	0.20	0.11
Error (b)	6	0.14	0.24	1.29	0.67
Topdressing Treatme	3	2.76 ***	0.64 ***	3.52 ***	4.03 ***
S x T	6	0.18	0.05	0.58	0.24
R x T	3	0.16	0.25	0.32	0.79
S x R x T	6	0.17	0.16	0.17	0.28
Error (c)	36	0.13	0.12	0.41	0.30
CV (%)		5.34	5.21	9.62	7.83

		1997			
Source of Variation	df	7-Jul	14-Jul	22-Jul	31-Jul
Replication	2	0.69	2.06	4.75	0.36
Soil, S	2	0.68	1.72	3.23	3.38
Error (a)	4	0.25	2.09	1.73	2.15
Roll, R	1	18.00 ***	12.92 ***	11.28 ***	5.84
S x R	2	0.29	0.01	0.03	2.65
Error (b)	6	0.51	0.29	0.71	1.16
Topdressing Treatme	3	1.45 ***	1.35 **	1.55 ***	1.66 ***
S x T	6	0.05	0.40	0.20	0.45
R x T	3	0.07	0.06	0.33	0.08
S x R x T	6	0.52 **	0.32	0.19	0.67
Error (c)	36	0.19	0.52	0.26	0.37
CV (%)		6.31	11.07	55.91	9.19

***, ** denotes statistical significance at $P < 0.01$, 0.05 respectively

Table 30.. Main effects of construction type, rolling, and the topdressing treatments on quality ratings on putting green collars at the Hancock Turfgrass Research Center, East Lansing, MI. ‡

	1996				1997					
	28-Jun	18-Jul	1-Oct	16-Oct	14-Apr	19-Jun	7-Jul	14-Jul	22-Jul	31-Jul
Soil Type										
USGA	6.4	6.7	6.6	6.8	5.3	6.2	7	6.8	6.5	6.4
80:10:10	6.8	6.6	6.8	7	5.5	6	6.7	6.4	5.8	6.5
Native	6.8	7	6.6	7.1	6.1	5.7	7	6.3	6.3	7.1
Significance	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -	- NS -
Rolling										
Rolled	6.6	6.5	6	6.5	5.5	5.7	6.4	6.1	6.6	6.3
Not Rolled	6.8	7	7.4	7.4	5.7	6.2	7.4	6.9	5.8	6.9
Significance	- NS -	***	***	***	- NS -	- NS -	***	***	***	- NS -
Topdressing Amendments										
3.2mm rubber	7.0a	6.9ab	6.8b	7.0b	5.4	6.1	7.0a	6.5	6.1b	6.8a
9.5mm rubber	6.1b	6.9a	7.3a	7.6a	5.7	6.1	7.2a	6.9	6.6a	6.9a
3.2mm rubber & 3.2mm Sand	6.8a	6.7bc	6.4bc	6.6c	5.8	5.9	6.6b	6.5	6.0b	6.6ab
Sand§	6.8a	6.5c	6.3c	6.6c	5.5	5.8	6.6b	6.2	5.9b	6.2b
Significance†	***	***	***	***	- NS -	- NS -	***	- NS -	***	***

*** denotes statistical significance at $P < 0.01$; NS = Not Significant

† Within each column treatment means not sharing a letter are significantly different at $\alpha = 0.05$

‡ Quality was evaluated on a 1-9 scale, 1= dead turf/bare soil and 9= dark green, dense, uniform turf.

§ Sand was topdressed everythree weeks

After the crumb rubber moved below the surface and into the crown area of the plant, quality ratings increased. On all other dates that quality was significant, the 9.5mm plots showed better quality than the sand treatment and often was better than all other treatments.

A three way, soil-by-roll-by-topdressing treatment interaction was recorded on 7-Jul-97 (Table 31). Regarding the 9.5mm rubber topdressing treatment, the USGA soil showed no differences between rolled and not-rolled plots. The other two soil types (80:10:10 and native) however, showed that rolling significantly decreased quality. Also, the highest quality ratings came from 9.5mm topdressing treatments that were rolled in both 80:10:10 and native soils.

Poa annua

Poa annua is an aggressive species known to invade close cut, irrigated, intensively maintained turfgrass stands within a period of 3 to 5 years after establishment (Beard, 1973). Hartwiger et al (1994) found that rolling four times per week reduced putting green quality after one year. This decrease in quality could lead to decreased density and therefore an opening in the turfgrass canopy to allow *Poa annua* room for invasion.

Treatment effects and significance for *Poa annua* invasion ratings are shown in Table 32. Both rolling and topdressing treatments showed significant differences in *Poa annua* ratings. Rolling caused increased *Poa annua* over plots that were not rolled on all data collection dates. Plots receiving 9.5mm crumb rubber had significantly less *Poa annua* than plots receiving only sand topdressing (Table 33).

Table 31. Soil by roll by topdressing treatment interaction for quality ratings on putting green collars at the Hancock Turfgrass Research Center, 1997.‡

	7-Jul
USGA/rolled/3.2mm rubber	6.5 eghi
USGA/rolled/9.5mm rubber	7.2 bcdef
USGA/rolled/3.2mm rubber & 3.2mm sand	6.5 eghi
USGA/rolled/sand§	6.0 ij
USGA/not rolled/3.2mm rubber	7.7 abc
USGA/not rolled/9.5mm rubber	7.3 bcdef
USGA/not rolled/3.2mm rubber & 3.2mm sand	7.2 bcdef
USGA/not rolled/sand§	7.3 bcdef
80:10:10/rolled/3.2mm rubber	6.3 gij
80:10:10/rolled/9.5mm rubber	6.3 gij
80:10:10/rolled/3.2mm rubber & 3.2mm sand	5.7 j
80:10:10/rolled/sand§	5.8 ij
80:10:10/not rolled/3.2mm rubber	7.3 bcd
80:10:10/not rolled/9.5mm rubber	7.8 ab
80:10:10/not rolled/3.2mm rubber & 3.2mm sand	7.2 bcdefg
80:10:10/not rolled/sand§	6.8 defgh
Native/rolled/3.2mm rubber	6.8 defgh
Native/rolled/9.5mm rubber	6.3 hij
Native/rolled/3.2mm rubber & 3.2mm sand	6.3 hij
Native/rolled/sand§	6.5 fghi
Native/not rolled/3.2mm rubber	7.3 bcdf
Native/not rolled/9.5mm rubber	8.2 a
Native/not rolled/3.2mm rubber & 3.2mm sand	7.0 cdefgh
Native/not rolled/sand§	7.2 bcdefh
Significance†	**

** denotes statistical significance at $P < 0.05$

† Treatment means not sharing a letter are significantly different at a = 0.05

‡ Quality was evaluated on a 1-9 scale, 1= dead turf/bare soil and 9= dark green, dense, uniform turf.

§ Sand was topdressed every three weeks

Table 32. Mean squares and significance of treatment effects on *Poa annua* invasion putting green collars at the Hancock Turfgrass Research Center, East Lansing, MI

		Poa annua			
		1996		1997	
		16-Oct	5-Oct	28-May	10-Oct
Source of Variation	df				
Replication	2	500	369	550	972
Soil, S	2	462	420	918	764
Error (a)	4	208	196	468	484
Roll, R	1	2965 ***	2901 ***	5513 ***	5548 **
S x R	2	28	12	14	480
Error (b)	6	72	103	167	448
Topdressing Treatment, T	3	257 ***	288 ***	500 ***	961 ***
S x T	6	48	52	61	88
R x T	3	64	71 **	145 **	139
S x R x T	6	110	49	110	175
Error (c)	36	57	23	50	172
CV (%)		41	33	33	48

***, ** denotes statistical significance at $P < 0.01, 0.05$ respectively

Table 33. Effects of construction type, rolling, and the topdressing treatments on *Poa annua* invasion ratings on putting green collars at the Hancock Turfgrass Research Center, East Lansing, MI.

	Poa annua %			
	1996		1997	
Soil Type	5-Oct	16-Oct	28-May	10-Oct
USGA	9.7	13.7	14.3	20.5
80:10:10	17.5	22.3	25.8	30.2
Native	16.3	19.4	24.2	30.4
Significance†	- NS -	- NS -	- NS -	- NS -
Rolling				
Rolled	20.8	24.9	30.2	35.8
Not Rolled	8.1	12	12.7	18.3
Significance	***	***	***	**
Topdressing Amendments				
3.2mm Rubber	15.8a	20.0a	23.1ab	25.9ab
9.5mm Rubber	8.7b	12.9b	14.5c	17.3b
3.2mm Rubber & 3.2mm Sand	15.7a	19.6b	20.9b	30.8a
Sand‡	17.8a	21.3b	27.1a	34.2a
Significance†	***	***	***	***

***, ** denotes statistical significance at $P < 0.01, 0.05$ respectively; NS = Not Significant

† Within each column treatment means not sharing a letter are significantly different at a = 0.05

‡ Sand was topdressed every three weeks.

Table 34. Roll by topdressing treatment interaction for *Poa annua* invasion ratings on putting green collars at the Hancock Turfgrass Research Center, East Lansing, MI.

	Poa annua %			
	5-Oct-96		28-May-97	
Topdressing Amendments	Rolled	Not-Rolled	Rolled	Not-Rolled
3.2mm Rubber	22.8a	8.9bc	33.7ab	12.6de
9.5mm Rubber	12.2b	5.1c	20.9cd	8.1e
3.2mm Rubber & 3.2mm Sand	23.9a	7.4bc	27.2bc	14.7de
Sand‡	24.4a	11.1b	38.9a	15.3d
Significance†	**		**	

** denotes statistical significance at $P < 0.05$

† Within each column and between each row, means not sharing a letter are significantly different at a = 0.05

‡ Sand was topdressed every three weeks.

A roll-by-topdressing treatment interaction was recorded on 5-Oct-96 and 28-May-97. No other interactions were recorded. On 5-Oct-96 the 9.5mm depth of crumb rubber had significantly less *Poa annua* than the other topdressing treatments when rolling was applied (Table 34). The 28-May-97 date showed that the 9.5mm depth of crumb rubber had significantly less *Poa annua* than the 3.2mm crumb rubber depth and the sand treatment. These results may be the result of crumb rubbers' ability to prevent compaction and therefore maintain turfgrass quality under trafficked situations (Rogers et al, 1998) thus not giving *Poa annua* the opportunity to invade the stand.

Shearvane

Mean squares and significant treatment effects of shearvane and peak deceleration values are given in Table 35. Shear resistance values were higher in 1997 than in 1996 for all main effects (Table 36). Vanini (1995) found that shear resistance values were different between the first and second years after crumb rubber was topdressed. In the first year of the study crumb rubber particles were still in and around the turf canopy and had not reached the soil surface. After a growing season, the crumb rubber particles had reached the soil surface and were simultaneously protecting the crown tissue area of the plant thus allowing for more resistance to shearing. Topdressing amendments did not show consistent shear resistance values though significant differences were observed at each data collection date. In 1996 on the first data collection date of 12-Aug, the 9.5mm crumb rubber depth had lower shear resistance values than

Table 35. Mean squares and significance of treatment effects of shearvane and clegg on putting green collars at the Hancock Turfgrass Research Center, East Lansing, MI.

		Shearvane			Clegg		
Source of Variation	df	12-Aug-96	18-Sep-96	5-Jun-97	24-Jul-96	7-May-97	25-Jun-97
Replication	2	11.7 **	5.2	1.1	518.4	235.3	530.2
Soil, S	2	20.0 **	17.9 **	31.4	570.1	219.3	199.3
Error (a)	4	1.5	1.4	6.5	417.3	119.8	181.4
Roll, R	1	10.3	14.2	2.6	1242.5 ***	365.0 **	627.2
S x R	2	20.4 **	17.2	2.0	428.1 **	7.2	61.8
Error (b)	6	2.5	4.4	6.4	72.4	29.1	143.9
Topdressing Treatment,	3	9.0 ***	3.0 **	14.0 ***	405.8 ***	217.9 ***	243.2 ***
S x T	6	1.0	0.6	1.6	48.2	21.2	18.8
R x T	3	0.2	0.3	1.4	62.9	13.3	8.6
S x R x T	6	1.1	1.4	0.7	21.2	12.2	7.9
Error (c)	#	0.6	0.8	1.5	31.0	24.3	18.4
CV (%)		6.4	7.2	6.5	8.2	7.0	6.5

***, ** denotes statistical significance at $P < 0.01, 0.05$ respectively

Table 36. Effects of construction type, rolling, and the topdressing treatments on shearvane resistance (Nm) and peak deceleration (G_{max}) on putting green collars at the Hancock Turfgrass Research Center, East Lansing, MI

	Shear resistance (Nm)			Peak Deceleration (G_{max})		
	1996		1997	1996	1997	
Soil Type	12-Aug	18-Sep	5-Jun	24-Jul	7-May	25-Jun
USGA	11.2b	11.2b	17.3	66.6	69.7	64.7
80:10:10	12.0b	12.0ab	18.8	64.1	70	63.9
Native	13.0a	12.9a	19.6	73.5	73.8	69.3
Significance†	**	**	- NS -	- NS -	- NS -	- NS -
Rolling						
rolled	11.7	11.6	18.8	72.2	72.7	68.9
not rolled	12.5	12.5	18.4	63.9	68.2	63
Significance	- NS -	- NS -	- NS -	***	**	- NS -
Topdressing Amendments						
3.2mm Rubber	13.0a	12.3ab	19.4a	70.0ab	71.8a	66.8b
9.5mm Rubber	11.3c	12.5a	19.0a	61.7c	65.3b	61.6c
3.2mm Rubber & 3.2mm Sand	11.8bc	11.6c	17.4b	67.7b	72.8a	65.1b
Sand‡	12.2b	11.8bc	18.6a	72.9a	72.0a	70.4a
Significance†	***	**	***	***	***	***

***, ** denotes statistical significance at $P < 0.01, 0.05$ respectively; NS = Not Significant

† Within each column treatment means not sharing a letter are significantly different at a = 0.05

‡ Sand was topdressed every three weeks.

Table 37. Soil by roll interaction for shearvane resistance (Nm) and peak deceleration (G_{max}) on putting green collars at the Hancock Turfgrass Research Center, East Lansing, MI, 1996.

	Shear Resistance (Nm)		Peak Deceleration (G_{max})	
	12-Aug		24-Jul	
Soil Type	Rolled	Not Rolled	Rolled	Not Rolled
USGA	10.3c	12.1b	70.5ab	62.6b
80:10:10	12.7ab	11.3bc	64.2b	64.1b
Native	12.1b	13.9a	82.0a	65.0b
Significance†	**		**	

** denotes statistical significance at $P < 0.05$

† Within each column and between each row, means not sharing a letter are significantly different at a = 0.05

the sand topdressed plots. Later in that year, on 18-Sep, the highest rate of crumb rubber of 9.5mm had significantly greater shear resistance than the sand topdressed plots. On 5-Jun-97 the rubber and sand mixed plots had significantly lower shear resistant than all other plots. The native soil produced significantly higher shear resistance values than the USGA soil for both dates in 1996. This was also seen in 1997 though the differences were not statistically significant. An interaction between rolling and soil type was recorded on 12 Aug 96 for shear resistance values (Table 37). This interaction showed that the USGA and native soils produced significantly lower shear resistance when rolled while the 80:10:10 did not show a difference between rolled and not-rolled plots.

Peak Deceleration

The main effect of soil type did not have an effect on surface hardness. Rolling produced a significantly harder surface (Table 36). Previous work by Rogers and Waddington in 1992 also showed that when surfaces were rolled and thus compacted, peak deceleration values were significantly higher than non-compacted plots. The depth of crumb rubber topdressing also affected surface hardness. The greatest depth of crumb rubber (9.5mm) showed significantly lower peak deceleration (G_{max}) values than other topdressing treatments. This result agrees with the findings of Rogers et al (1998) that showed that peak deceleration values decreased as crumb rubber topdressing depths increased, indicating a softer surface. Soil type and rolling produced a significant interaction with regards to surface hardness on 24-Jul-96 (Table 37). When rolled, the surface hardness of the native soil increased significantly while the sand-based soils were not affected by rolling.

Dollar Spot

Dollar spot counts were taken when disease outbreak was present. Dollar spot incidence showed significant differences in 1996 while no statistical significance was recorded in 1997. Significant treatment effects are given in Table 38. In both seasons, no significant differences in dollar spot incidence were observed between soil types. On the same plots where research was also being conducted at putting green heights, Nikolai et al (1998) found that USGA and 80:10:10 soils produced significantly more dollar spots than the native soil. The higher mowing height of the putting green collars may have affected the lack of differences in dollar spot incidence. In 1996, rolling significantly reduced dollar spot incidence over not rolled plots (Table 39). This reaction was not seen in 1997.

In 1996 significant soil-by-topdressing interactions were observed on both data collection dates (Table 40). In both interactions the 3.2mm crumb rubber depth produced significantly greater numbers of dollar spots in the USGA soil than the native soil. Other treatments did not have significant differences between the USGA and native soils.

Table 38. Mean squares and significance of treatment effects of dollar spot counts on putting green collars at the Hancock Turfgrass Research Center, East Lansing, MI.

		1996		1997	
Source of Variation	df	30-Aug	5-Sep	23-Jun	25-Jul
Replication	2	373.0	2823.5	1233.0	1163.4
Soil, S	2	191.2	539.4	203.4	158.4
Error (a)	4	185.4	660.9	277.6	351.6
Roll, R	1	3626.7 ***	7340.7 ***	0.2	0.1
S x R	2	26.4	187.1	757.4	691.7
Error (b)	6	68.7	232.3	299.5	302.0
Topdressing Treatment, T	3	59.9	135.9	40.8	38.0
S x T	6	182.7 **	408.6 ***	49.1	44.0
R x T	3	19.9	62.1	16.5	33.8
S x R x T	6	66.7	156.9	51.1	51.4
Error (c)	36	58.0	114.2	45.6	45.2
CV (%)		54.6	47.1	63.4	67.6

***, ** denotes statistical significance at *P* < 0.01, 0.05 respectively

Table 39. Main effects of construction type, rolling, and the topdressing treatments on dollar spot counts on putting green collars at the Hancock Turfgrass Research Center, East Lansing, MI 1996.

	dollar spots/m²	
Soil Type	30-Aug	5-Sep
USGA	10.8	17.7
80:10:10	7.4	13.3
Native	8.2	12.0
Significance†	- NS -	- NS -
Rolling		
Rolled	4.4	8.0
Not Rolled	13.4	20.8
Significance	***	***
Topdressing Amendments		
3.2mm Rubber	10.2	16.6
9.5mm Rubber	7.3	12.4
3.2mm Rubber & 3.2mm Sand	8.8	14.4
Sand‡	9.0	14.0
Significance†	- NS -	- NS -

*** denotes statistical significance at $P < 0.01$; NS = Not Significant

† Within each column treatment means not sharing a letter are significantly different at a = 0.05

‡ Sand was topdressed every three weeks.

Table 40. Soil by topdressing interaction on dollar spot counts on putting green collars at the Hancock Turfgrass Research Center, East Lansing, MI, 1996.

	30-Aug			5-Sep		
Topdressing Treatment	USGA	80:10:10	Native	USGA	80:10:10	Native
3.2mm Rubber	25.2a	15.2abcd	7.8d	40.0a	25.8abcd	12.8ce
9.5mm Rubber	9.8cd	11.7bcd	13.3bcd	15.2de	23.3abcd	20.2bcd
3.2mm Rubber & 3.2mm Sand	14.3bcd	8.7bcd	18.8abc	25.7bcd	16.7bcd	23.2abd
Sand‡	19.2ab	11.3bcd	17.0bcd	31.3abc	18.0bcd	17.0bcd
Significance†		**			***	

***, ** denotes statistical significance at $P < 0.01$, 0.05 respectively

† Within each column and between each row, means not sharing a letter are significantly different at a = 0.05

‡ Sand was topdressed every three weeks.

Root Mass

Mean squares and significant treatment effects are given in Table 41. Topdressing treatments at the 0-2.5cm and 0-15cm depths showed significant differences in root weights in 1996 and were not significant in 1997 (Tables 42 and 43). Sand topdressing produced more roots than 3.2mm of crumb rubber at the 0-2.5cm sampling depth in 1996. When combining all four sampling depths (0-15cm), sand topdressing produced significantly more roots than both the 3.2mm and 9.5mm depths. In 1997 the native soil produced more roots at the 2.5-5.0cm depth than the sand-based plots.

Interactions for root mass were observed at the 2.5-5.0cm and 0-15cm depths. In 1996 a soil-by-roll interaction at the 2.5-5.0cm depth showed that the USGA produced significantly fewer roots when rolling was applied while the 80:10:10 and native soils did not show decreases in rooting as a result of rolling(Table 44). In 1996 an interaction also occurred at the 0-15cm depth between soil and topdressing treatments(Table 44). The USGA soil produced significantly more roots under sand topdressing treatments than the crumb rubber. The third interaction involving rooting occurred in 1997 at the 0-15cm depth where the sand topdressing plots produced significantly more roots than the other topdressing treatments when rolling was not applied (Table 45). Under rolled conditions there were no differences between topdressing treatments. These findings are in contrast with those of Vanini (1995) who showed that as crumb rubber rates increased, rooting at the 0-5cm sampling depth increased

Table 41. Mean squares and significance of treatment effects of root mass measurements on putting green collars at the Hancock Turfgrass Research Center, East Lansing, MI.

		1996				
Source of Variation	df	0-2.5cm	2.5-5cm	5-10cm	10-15cm	0-15cm
Replication	2	49854.43	778.57	6744.41	630.03	65647.31
Soil, S	2	16164.91	232.79	873.58	582.98	30768.84
Error (a)	4	52904.37	1511.35	1203.05	512.16	49853.64
Roll, R	1	29589.34	106.58	59.04	643.81	20736.66
S x R	2	7196.49	3519.23 **	3729.27	842.65	49996.48
Error (b)	6	9498.97	523.84	923.71	450.60	15299.29
Topdressing Treatment, T	3	24854.18 **	948.68	601.51	132.24	40682.50 **
S x T	6	18637.99	178.95	1508.85	316.47	38348.25 **
R x T	3	427.93	172.49	489.62	168.15	1712.52
S x R x T	6	3102.54	59.91	348.56	238.30	4073.40
Error (c)	36	8011.20	405.44	714.02	150.13	14378.20
CV (%)		37.91	31.05	42.75	39.03	30.37

		1997				
Source of Variation	df	0-2.5cm	2.5-5cm	5-10cm	10-15cm	0-15cm
Replication	2	0.0345	0.0014	0.0002	0.0002	0.0680
Soil, S	2	0.0078	0.0044 **	0.0030	0.0003	0.0540
Error (a)	4	0.0196	0.0003	0.0001	0.0002	0.0240
Roll, R	1	0.0003	0.0008	0.0007	0.0005	0.0006
S x R	2	0.0124	0.0009	0.0023	0.0004	0.0350
Error (b)	6	0.0067	0.0009	0.0005	0.0001	0.0170
Topdressing Treatment, T	3	0.0152	0.0006	0.0002	0.0000	0.0310
S x T	6	0.0111	0.0005	0.0007	0.0001	0.0140
R x T	3	0.0193	0.0008	0.0004	0.0000	0.0410 **
S x R x T	6	0.0074	0.0003	0.0004	0.0000	0.0110
Error (c)	36	0.0098	0.0000	0.0002	0.0001	0.0111
CV (%)		49.67	41.25	36.10	44.81	38.99

** denotes statistical significance at $P < 0.05$

Table 42. Main effects of construction type, rolling, topdressing treatments on root weights on putting greens collars at the Hancock Turfgrass Research Center, East Lansing, MI 1996.

	grams/mm³				
	0-2.5cm	2.5-5cm	5-10cm	10-15cm	0-15cm
Soil Type					
USGA	3.2	0.8	1.7	0.9	15.7
80:10:10	2.5	0.8	1.5	0.6	13.1
Native	3.0	0.8	1.4	0.8	14.7
Significance	- NS -	- NS -	- NS -	- NS -	- NS -
Rolling					
Rolled	3.1	0.8	1.6	0.7	15.1
Not Rolled	2.6	0.8	1.5	0.8	13.9
Significance	- NS -	- NS -	- NS -	- NS -	- NS -
Topdressing Amendments					
3.2mm rubber	2.4b	0.8	1.4	0.8	12.8b
9.5mm rubber	2.7ab	0.7	1.5	0.7	13.4b
3.2mm rubber & 3.2mm Sand	3.1ab	0.9	1.5	0.7	15.3ab
Sand‡	3.4a	0.8	1.7	0.8	16.6a
Significance†	**	- NS -	- NS -	- NS -	**

**, * denotes statistical significance at $P < 0.05$, 0.10 respectively; NS = Not Significant

† Within each column treatment means not sharing a letter are significantly different at a = 0.05

‡ Sand was topdressed every three weeks.

Table 43. Main effects of construction type, rolling, topdressing treatments on root weights on putting greens collars at the Hancock Turfgrass Research Center, East Lansing, MI 1997.

	grams/mm³				
	0-2.5cm	2.5-5cm	5-10cm	10-15cm	0-15cm
Soil Type					
USGA	2.2	0.4b	0.8	0.4	8.6
80:10:10	2.4	0.6b	1.1	0.4	9.3
Native	2.8	0.8a	1.6	0.5	11.9
Significance	- NS -	**	- NS -	- NS -	- NS -
Rolling					
Rolled	2.4	0.5	1.1	0.4	10.1
Not rolled	2.4	0.6	1.3	0.5	9.8
Significance	- NS -	- NS -	- NS -	- NS -	- NS -
Topdressing Amendments					
3.2mm rubber	2.3	0.7	1.4	0.5	9.3
9.5mm rubber	2.1	0.5	1.1	0.4	9.0
3.2mm rubber & 3.2mm Sand	2.4	0.5	1.1	0.4	9.3
Sand‡	3.0	0.6	1.1	0.4	12.2
Significance†	- NS -	- NS -	- NS -	- NS -	- NS -

** denotes statistical significance at $P < 0.05$; NS = Not Significant

† Within each column treatment means not sharing a letter are significantly different at a = 0.05

‡ Sand was topdressed every three weeks.

Table 44. Root weight values (grams/mm^3) for the significant rolling-by-soil and soil-by- topdressing treatment interactions on putting green collars at the Hancock Turfgrass Research Center, East Lansing, MI, 1996.

	2.5-5cm depth		0 - 15 cm depth			
	b,ab,ab	a,ab,ab	Topdressing Treatments			
Soil Type	Rolled	Not Rolled	3.2mm rubber	9.5mm rubber	3.2mm rubber & 3.2mm Sand	Sand‡
USGA	0.6b	0.9a	13.5b	12.1b	14.8b	22.4a
80:10:10	0.9ab	0.6ab	12.4b	14.0b	13.6b	12.3b
Native	0.8ab	0.9ab	12.3b	14.1b	17.5ab	15.0b
Significance†	**			**		

** denotes statistical significance at $P < 0.05$

† Within each column and between each row, means not sharing a letter are significantly different at a = 0.05

‡ Sand was topdressed every three weeks.

Table 45. Roll-by-topdressing treatment interaction for root weights (grams/mm^3) on putting green collars at the Hancock Turfgrass Research Center, 1997.

	0 - 15 cm depth	
Topdressing Treatments	Roll	Not Rolled
3.2mm rubber	10.6ab	8.0b
9.5mm rubber	8.8b	9.1b
3.2mm rubber & 3.2mm Sand	10.8ab	7.7b
Sand‡	9.9b	14.5a
Significance†	**	

** denotes statistical significance at $P < 0.05$

† Within each column and between each row, means not sharing a letter are significantly different at a = 0.05

‡ Sand was topdressed every three weeks.

incrementally. In this study, sand topdressed plots caused the differences in both main effects and interactions.

Turfgrass Responses

Significant treatment effects of thatch depth, thatch weight, surface temperature, soil temperature, and microdochium patch counts are given in Table 46. No significant interactions were reported for these data. Thatch depth did produce significance for all main effects (Table 47). Thatch depth was greater in native soil than in USGA soil. Rolling significantly reduced thatch below that of not-rolled plots. Thatch depth was also significant for topdressing treatments where the greatest depth of crumb rubber produced the deepest thatch and the sand had shallower thatch than all other treatments. When measuring thatch depth the presence of the crumb rubber may have influenced measurements. Thatch weight measurements taken in 1997 produced significant differences among topdressing treatments. The 9.5mm crumb rubber treatment had significantly more thatch than the 3.2mm depth. Both topdressing treatments receiving sand topdressing produced significantly more thatch than the treatments with crumb rubber alone. When measurements were recorded, crumb rubber was present in the thatch, which may have effected the results. In the ashing process, which separates the organic matter from the soil particles, the crumb rubber was ashed and probably affected the final results since the weight of the rubber was included in the pre-ashing weight measurements.

Table 46. Mean squares and significance of treatment effects of thatch depth, thatch weight, soil on putting green collars at the Hancock Turfgrass Research Center, East Lansing, MI.

		Thatch Depth	Thatch Weight	Surface Temperature	oil Temperature	Snowmold
Source of Variation	df	16-Jun-96	16-Jun-97	4-Jun-96	10-Jul-97	14-Apr-97
Replication	2	52.7	81.0 **	3.8	286.2 ***	388.5
Soil, S	2	91.1 **	0.2	20.1	3.5	242.2
Error (a)	4	12.8	10.1	16.2	14.6	130.6
Roll, R	1	168.4 **	1.2	23.8	7.4	793.3 **
S x R	2	0.3	2.8	2.8	1.1	421.7
Error (b)	6	23.2	11.6	12.0	6.4	127.7
Topdressing Treatment, T	3	203.4 ***	172.2 ***	18.6	21.8 ***	11.1
S x T	6	11.5	4.0	2.5	0.4	10.6
R x T	3	13.3	9.3	1.1	0.7	28.4
S x R x T	6	4.3	0.9	9.2	0.3	25.3
Error (c)	36	5.0	7.8	5.6	0.9	28.7
CV (%)		12.7	13.0	2.9	1.2	51.2

***, ** denotes statistical significance at $P < 0.01, 0.05$

Table 47. Effects of construction type, rolling, and the topdressing treatments on thatch depth in millimeters on putting green collars at the Hancock Turfgrass Research Center, East Lansing, MI.

	Thatch Depth (mm)	Thatch Weight (mg)	Surface Temperature (°C)	Soil Temperature (°C)	Snowmold
Soil Type	16-Jun-96	16-Jun-97	4-Jun-96	10-Jul-97	14-Apr-97
USGA	15.7b	21.5	27.2	26.5	15.5
80:10:10	17.5ab	21.3	27.7	26.8	8.4
Native	19.6a	21.4	28.3	26.4	7.5
Significance†	**	- NS -	- NS -	- NS -	- NS -
Rolling					
Rolled	16.1	21.5	27.9	26.4	7.1
Not Rolled	19.1	21.3	28.6	26.8	13.8
Significance	**	- NS -	- NS -	- NS -	**
Topdressing Amendments					
3.2mm Rubber	16.1c	17.6c	27.2b	26.6b	11.1
9.5mm Rubber	22.0a	20.1b	29.1a	25.7c	9.8
3.2mm Rubber & 3.2mm Sand	18.1b	23.6a	28.1b	27.1ab	11.2
Sand‡	14.2d	24.2a	28.1b	26.8a	9.8
Significance†	***	***	**	***	- NS -

***, ** denotes statistical significance at $P < 0.01$, 0.05 respectively; NS = Not Significant

† Within each column treatment means not sharing a letter are significantly different at a = 0.05

‡ Sand was topdressed every three weeks.

Surface temperature measurements showed that the 9.5mm rubber depth had significantly higher temperatures than the other treatments. Soil temperatures showed that the 9.5mm depth had significantly lower temperatures than the other topdressing treatments. Microdochium patch counts were recorded on 14-Apr-97 and showed that rolling significantly reduced snowmold incidence when compared with not-rolled plots.

Conclusions

The USGA soil showed a decrease in color in the spring of 1997 while on 19-Jun-97 the native soil had significantly poorer color than the sand-based soils. Rolling caused a decrease in color and quality for both seasons. As was shown by Vanini (1995), topdressing with crumb rubber can improve turfgrass color. In the interaction between soil and topdressing treatments on 14-Jul-97, however, the highest rate of crumb rubber (9.5mm) did have significantly lower color ratings than the other topdressing treatments in the USGA soil. This interaction was only seen on this date.

Both rolling and topdressing treatments produced significant differences in quality. One of the primary factors in quality ratings is density. Since *Poa annua* has the ability to produce abundant, viable seed even at low cutting heights (Beard, 1973), a decrease in density could give *Poa annua* the opportunity to germinate and thrive. On all of the dates that *Poa annua* ratings were taken, the highest rate of crumb rubber (9.5mm) had significantly less *Poa annua* than the check plots. Hartwiger et al (1994) found that rolling decreased quality after one year. The practice of rolling also produced significantly more *Poa annua*. Two interactions between rolling and topdressing treatments showed that the highest rate of crumb rubber had significantly less *Poa annua* than all the other topdressing treatments in both rolled and not-rolled plots.

Surface hardness measurements confirmed the findings of Rogers et al (1998) where the highest rate of crumb rubber had the softest surface.

Being that the highest rate of crumb rubber produced the highest quality and the least amount of *Poa annua*, using crumb rubber on putting green collars is a viable option for superintendents looking to confront the problems associated with high traffic areas around putting greens.

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