Field Sampling Warm-season Putting Greens for Thatch-mat Depth and Organic Matter Content

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SUMMARY. **Thatch-mat and organic matter (OM) accumulation near the putting green soil surface impacts soil physical properties and turf performance. Excessive thatch and OM can encumber infiltration of water and oxygen into the soil profile and slow drainage of excess water away from the putting surface. Proper sampling of thatch-mat depths and OM contents is vital for management of putting green turf; therefore, a study was performed in Knoxville, TN, to derive proper sampling procedures of these important parameters using 'TifEagle' and 'Champion' bermudagrass (*Cynodon dactylon* × *C. transvaalensis*), 'SeaDwarf' seashore paspalum (*Paspalum vaginatum*), and 'Diamond' zoysiagrass (*Zoysia matrella*). 'TifEagle' and 'Champion' accumulated thatch-mat to a greater depth than 'SeaDwarf' and 'Diamond'. However, 'SeaDwarf' had a higher OM content than 'Diamond' and both had higher OM contents than 'TifEagle' and 'Champion'. Data generated from sampling procedures indicate that previous studies often undersampled plots for thatch-mat depth; however, previous sampling procedures have not traditionally undersampled plots for OM. Data in this study provide a range of confidence and minimum detectable difference levels which may allow future researchers to more accurately sample 'TifEagle', 'Champion', 'SeaDwarf', and 'Diamond' putting green plots for thatch-mat depth and OM content.**

Organic matter accumulation near the soil surface of putting greens is of concern to turf managers because of its effects on soil physical properties that can influence turf performance. Soil OM is composed primarily of dead and sloughed plant tissues that are most resistant to decay, along with soil microbial biomass (Waddington, 1992; Wolf et al., 1994). In turfgrass systems, OM is often divided into thatch and mat layers (McCarty, 2001). Thatch is a tightly intermingled layer of living and dead tissue that develops between the verdure and the soil surface (Beard, 1980). Thatch includes horizontal stems, nodes, crown tissue, periodically sloughed roots, intact fibrous roots, and vascular strands of stem and leaf sheaths (Engel, 1954; Hurto et al., 1980; Roberts and Bredakis, 1960). The mat layer is the layer below the thatch in which the OM of the thatch is intermixed with soil (Carrow et al., 1987). Thatch and mat accumulate because their constituents have high lignin content relative to other components of OM, such as leaf tissue, and slow microbial degradation of the cellulosic structures comprising this layer (Ledeboer and Skogley, 1967). Meinhold et al. (1973) found that leaf matter in clippings did not add to thatch dry weight, but did influence depth and thickness of the thatch layer, suggesting that leaf matter is degraded more quickly than root or stem tissues, but is still an important constituent of soil OM.

The depth of the organic layer and the density of that layer in the upper 2.5 cm of the root zone can have both positive and negative effects on turf performance (Carrow et al., 1987; Neylan, 1994; Waddington et al., 1974). Moderate amounts of surface OM are beneficial for putting greens (Carrow, 2004). Surface OM can cushion turf crowns against foot traffic and incoming golf shots, reduce ammonia volatilization, and slow the leaching of pesticides into groundwater (Horst et al., 1996; McCarty and Miller, 2002; Petrovic, 1990; Snyder and Cisar, 1995; Vermeulen and Hartwiger, 2005). However, thatch depths exceeding 13 mm can be considered excessive (Christians, 1998; McCarty and Miller, 2002). Large amounts of OM can encumber infiltration of water into the soil profile, slow drainage of excess water away from the putting surface, and plug soil pores, which may decrease the infiltration of oxygen into the soil profile (Carrow, 2000; Harris, 1978; Murray and Juska, 1977). Accumulated OM is also associated with reduced tolerance to cold temperatures, increased disease and insect incidence, and possible reduced pesticide efficacy (Cornman, 1952; Miller, 1965; Musser, 1960; Sprague, 1945; Thompson, 1967; White, 1962). Additionally, excessive OM accumulation near the putting surface may result in soft playing surfaces, which are not desirable for golf and may lead to mower scalping (Barton et al., 2009; Carrow, 2001; Hurto et al., 1980).

Organic matter is often assessed as the depth of the thatch-mat layer, as well as some measure of OM content (Callahan et al., 1998; Waddington, 1992). Thatch-mat depth can be measured by several methods, although no industry-wide standard exists for this measurement (Waddington, 1992). Thatch-mat depth has been physically measured both before and after compressing the sample with various weights (Beard, 1976; Callahan et al., 1997; Engel and Alderfer, 1967; McWhirter and Ward, 1976; Volk, 1972; Waddington, 1992). Compressing

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1.1209	lb/acre	$kg \cdot ha^{-1}$	0.8922
33.9057	$oz/yard^2$	$g \cdot m^{-2}$	0.0295
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

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the sample is often used to correct for differences in thatch density and can also correct for the thatch stretching that can occur when samples are removed from the soil (Waddington, 1992). However, compression can understate the amount of thatch-mat present in samples that have a loose arrangement of thatch (Waddington, 1992). Previous research has found both compressed and uncompressed thatch thickness to be correlated to thatch dry weights, suggesting that thatch compression may not be necessary in assessing thatch depth (NE-57 Technical Research Committee, 1977).

Organic matter content is often measured using dry combustion, wet chemical oxidation, or weight loss on ignition (Combs and Nathan, 1998; Kimble et al., 2001; Nelson and Sommers, 1982). The dry combustion method is used primarily for assessing soil organic carbon content and involves measuring carbon dioxide (CO_2) evolved from oxidizing samples at high temperatures, which requires costly equipment (Konen et al., 2002). Wet chemical oxidation (Walkley and Black, 1934), often referred to as the Walkley–Black procedure, has long been the standard for measuring OM concentration in soils, but may overstate OM because of the oxidation of materials other than true OM and involves hazardous materials (Miyazawa et al., 2000). Weight loss on ignition is the most common method of assessing OM content in turfgrass systems and involves oxidizing samples at moderate to high temperatures, with the weight loss after ignition being proportional to the amount of OM in the sample (Combs and Nathan, 1998; Waddington, 1992). The weight loss on ignition method has produced OM values that correlate well with OM values obtained by the Walkley–Black method, is less costly than other methods, and has been adopted by the American Society for Testing and Materials (ASTM) for use in testing OM content in soils for turfgrass use (ASTM, 2002, 2007).

Although many options exist for assessing thatch-mat and OM in turfgrass systems, preferred sampling procedures do not currently exist. The objective of this study was to determine optimum sample sizes required to estimate thatch-mat depth and OM content in ‘TifEagle’ and ‘Champion’ ultradwarf bermudagrass, ‘SeaDwarf’ seashore paspalum, and ‘Diamond’ zoysiagrass with a predetermined degree of accuracy and confidence.

Materials and methods

Experimental area. This study was conducted in Apr. 2010 on a putting green comprised of 90% sand and 10% reed sedge peat (v/v) at the University of Tennessee East Tennessee Research and Education Center in Knoxville, TN (lat. 35.96° N, long. 83.92° W, elevation 276 m above sea level). Sand texture was 15.6% coarse sand (0.5–1.0 mm), 73% medium sand (0.25–0.50 mm), and 11.4% fine sand (0.15–0.25 mm). ‘TifEagle’ and ‘Champion’ bermudagrass, ‘SeaDwarf’ seashore paspalum, and ‘Diamond’ zoysiagrass were established in 1 × 4-m plots from washed sod in July 2008 in a randomized complete block design with three replications, in which the cultivar was the treatment factor. Beginning in July 2008 and continuing throughout the study, granular nitrogen (N) and potassium (K) were applied to the bermudagrass and seashore paspalum cultivars at 24.4 and 12.2 $kg\cdot ha^{-1}$, respectively, in March and September, then at 48.0 and 36.6 $kg\cdot ha^{-1}$, respectively, each month from April through August. Granular phosphorus (P) was applied at 29.3 $kg\cdot ha^{-1}$ in March and August, then at 9.8 $kg\cdot ha^{-1}$ each month from April through July. For ‘Diamond’ zoysiagrass, granular N and K were applied at 12.2 and 6.1 $kg\cdot ha^{-1}$, respectively, in March and September, then at 24.0 and 18.3 $kg\cdot ha^{-1}$, respectively, each month from April through August. Granular P was applied at 14.6 $kg\cdot ha^{-1}$ in March and August, then at 4.9 $kg\cdot ha^{-1}$ each month from April through July. Because each cultivar was fertilized in accordance with recommendations, ‘Diamond’ received a different fertility regime than ‘TifEagle’, ‘Champion’, and ‘SeaDwarf’ (McCarty, 2001; Qian and Engelke, 1999). Plots were maintained as a putting green and were mowed six times per week at 1/8 inch with a triplex greens mower (Jacobsen Greens King IV; Textron, Charlotte, NC). Plots were irrigated to supplement natural rainfall and avoid drought. Plots were topdressed at a rate of 550 $g\cdot m^{-2}$, using sand from the same source and of the same size analysis as that used for construction, without reed sedge peat, on 14-d intervals during periods of active growth. Plots were also aerated in May 2009 with a hollow-tine aerator using 1/2-inch-diameter tines at 2 × 2-inch spacing. After aeration, cores were removed and holes were filled with sand.

Sampling procedure and measurements. A simple random sampling procedure was generated for 25 x–y coordinate points in each plot (SAS version 9.1; SAS Institute, Cary, NC) to capture as much variation across the plots as possible. One soil core was extracted at each sampling point using a 10-cm-diameter cup cutter, comprising a total sampling area of 4.9% of the plot area. Uncompressed thatch-mat depth was determined by measuring the depth of the thatch-mat layer from the soil surface for each sample using a ruler (Callahan et al., 1998). Each soil core was then used for assessment of OM content. Organic matter content was determined using the weight loss on ignition method (Carrow et al., 1987; McCarty et al., 2005). The verdure was removed from each soil core and the top 1 inch of the core was used for analysis. The samples were oven-dried at 105 °C for 24 h, weighed, then ashed at 600 °C for 6 h, in a modification of the ASTM D2974–07a procedure (N.W. Hummel, personal communication). The ashes were then weighed and the difference between pre- and postashing weight was used to find the total OM present as a percent of the sample.

Data analysis. A one-way analysis of variance [ANOVA ($P \leq 0.05$)] was performed using the mixed model procedure in SAS statistical software (version 9.1) to determine the effect of cultivar on thatch-mat depth and OM content. When cultivation treatment main effects were significant, means were separated using Fisher’s protected least significant difference test ($\alpha = 0.05$).

Means, variances, and standard deviations were calculated for ‘TifEagle’, ‘Champion’, ‘SeaDwarf’, and ‘Diamond’. The sample sizes needed to detect differences between means at different detectable levels were calculated from the following equation: $n = \{2\ [z_{(1\text{-}\alpha/2)} + z_{\text{power}}] \times \sigma^2\}/d^2$, where n = estimated number of samples, $z_{(1-\alpha/2)}$ = z value from 1 – desired alpha level, z_{power} = z value of desired power level, σ^2 = residual sample variance, and d = minimum detectable difference [MDD (Cochran and Cox, 1957; Tugel et al., 2008)].

Results

Thatch-mat depth and OM content differed among warm-season putting green cultivars (Table 1). 'TifEagle' and 'Champion' accumulated thatch-mat deeper in the soil profile (26.9 and 27.6 mm, respectively) than both 'SeaDwarf' and 'Diamond' (22.4 and 23.3 mm, respectively) (Table 2). 'TifEagle' and 'Champion' thatch-mat depth in this study exceeded those reported by Hollingwsorth et al. (2005) and White et al. (2004), where thatch-mat depths for 'TifEagle' and 'Champion' were between 17 and 20 mm. The larger thatch accumulation in this study may be the result of management practices that differed from the previous studies. Plots were aerated and vertical mowed by Hollingsworth et al. (2005) and White et al. (2004), but plots were only aerated once per year in this study and did not receive any vertical mowing. However, Baldwin et al. (2009) found 'Champion' to accumulate 36 mm of thatch-mat depth when grown in full sun, but only accumulate 28 mm of thatch-mat depth when grown in shade, while aerating twice per year without vertical mowing. Kopec et al. (2004) reported less thatch-mat (ranging between 12 and 16 mm) for 'Sea Isle 1' seashore paspalum mowed at 12.2 mm and 15.4 mm than this study found for 'SeaDwarf' mowed at 1/8 inch (3.2 mm). Thatch-mat accumulation for Sea Isle 1 was lower than 'SeaDwarf' possibly because 'SeaDwarf' is a more aggressive biomass producer and the lower mowing height for 'SeaDwarf' stimulated more lateral growth than the higher mowing heights for 'Sea Isle 1', encouraging more thatch production.

'SeaDwarf' accumulated more OM (7.0% by weight) than all cultivars (Table 2). 'Diamond' accumulated more OM than 'Champion' (5.1% vs. 4.4%), which accumulated more OM than 'TifEagle' (4.4% vs. 4.0%). Rowland et al. (2009) found similar OM values on 8-year-old 'TifEagle' and 'Champion' plots maintained similarly to the plots in this study. Although no previous studies have assessed OM or thatch-mat accumulation characteristics of seashore paspalum or 'Diamond' zoysiagrass, a study by Dunn et al. (1981) assessing 'Meyer' zoysiagrass (*Zoysia japonica*) reported thatch-mat depth accumulations between 19 and 39 mm when mowed at a 19-mm height, which mostly exceeded the thatch-mat depth found for 'Diamond', likely because of the higher mowing height of the 'Meyer'. The higher OM content for 'SeaDwarf' than 'TifEagle' and 'Champion' may be the result of the aggressive underground biomass production of 'SeaDwarf' and its large and prolific rhizomes (Duncan and Carrow, 2000). Although 'Diamond' zoysiagrass has a slower growth rate than 'TifEagle' or 'Champion', its tissues have more lignin than the bermudagrass cultivars (McCarty, 2001) and decompose more slowly.

Table 1. Analysis of variance for sources of variation of block, cultivar, and their interaction for thatch-mat depth and organic matter (OM) content on warm-season putting greens in Knoxville, TN.

Source	df	Thatch-mat depth	OM content
Block (B)	2	0.0125[z]	0.1102
Cultivar (C)[y]	3	0.0012	0.0001
B × C	6	0.0973	0.1354

[z] Probability value corresponding to ANOVA F statistic.

[y] 'TifEagle' bermduagrass, 'Champion' bermudagrass, 'SeaDwarf' seashore paspalum, 'Diamond' zoysiagrass.

Table 2. Sample means, variances, and standard deviations for thatch-mat depth and organic matter (OM) content of four warm-season putting green cultivars in Knoxville, TN.

	Thatch-mat depth (mm)[y]			OM content		
Cultivar[z]	Mean	Variance	SD	Mean	Variance	SD
TifEagle	26.9 b[x]	5.4	2.8	4.0 a	0.03	0.19
Champion	27.6 b	6.0	3.0	4.4 a	0.09	0.35
SeaDwarf	22.4 a	7.1	2.8	7.0 c	0.26	0.52
Diamond	23.3 a	5.5	2.3	5.1 b	0.09	0.32

[z] 'TifEagle' bermduagrass, 'Champion' bermudagrass, 'SeaDwarf' seashore paspalum, 'Diamond' zoysiagrass.

[y] 1 mm = 0.0394 inch.

[x] Means sharing the same letter are not significantly different according to Fisher's protected least significant difference test (α = 0.05).

ESTIMATING THATCH-MAT DEPTH SAMPLE NUMBER. The number of samples required to estimate thatch-mat depth varied among cultivars and was determined by desired confidence and MDD levels (Table 3). Although increased thatch-mat depth is linked to decreased water infiltration, slow drainage of excess water, decreased oxygen content in the soil atmosphere, reduced cold tolerance, and increased disease and insect incidences, the impact of specific thatch-mat depths on soil or plant characteristics is not well known and may be impacted by many environmental, soil textural, and plant management factors (Carrow, 2000; Cornman, 1952; Harris, 1978; Horst et al., 1996; Miller, 1965; Murray and Juska, 1977; Musser, 1960; Sprague, 1945; Taylor and Blake, 1982; Thompson, 1967; White, 1962). Thus, the confidence and MDD levels are variables best left to the discretion of the investigator, and can be altered based on knowledge of the study subject and the confidence level desired. Additionally, sampling sizes can be impacted by the time and expense incurred in collecting and processing the samples.

To be 95% confident that differences in thatch-mat depth of 'TifEagle' or 'Champion' putting green plots could be detected within 1 mm, 85 and 95 samples, respectively, would need to be extracted per plot (Table 3). However, as the MDD increases to 3 mm, only 11 samples per plot for each cultivar are needed at 95% confidence. Similarly, sample numbers increase or decrease as the desired confidence level increases or decreases and are displayed in Table 3 for 'TifEagle', 'Champion', 'SeaDwarf', and 'Diamond'. 'SeaDwarf' requires more samples than all other cultivars for each confidence and MDD level because thatch-mat depth was more variable across the population (Tables 2 and 3). Previous studies

Table 3. Number of samples required per plot to estimate thatch-mat depth means at specified minimum detectable differences (MDD) and indicated significance levels for 'TifEagle' bermudagrass, 'Champion' bermudagrass, 'SeaDwarf' seashore paspalum, and 'Diamond' zoysiagrass.

MDD (mm)[z]	Proportion of grand mean (%)[y]	Alpha level						
		0.001	0.005	0.01	0.05	0.1	0.15	0.2
		'TifEagle' bermudagrass samples						
1	3.7	187	144	127	85	67	57	49
2	7.4	47	34	32	22	17	15	13
3	11.2	21	16	15	11	8	7	6
4	14.9	12	9	8	6	5	4	4
5	18.6	8	6	6	4	3	3	2
		'Champion' bermudagrass samples						
1	3.6	206	167	141	95	75	63	55
2	7.2	53	41	36	24	19	16	14
3	10.9	23	18	16	11	9	7	7
4	14.5	19	11	9	6	5	4	4
5	18.2	9	7	6	4	3	3	3
		'SeaDwarf' seashore paspalum samples						
1	4.5	242	189	166	112	88	74	64
2	8.9	61	48	42	28	22	19	16
3	13.4	27	21	19	13	10	9	8
4	17.9	16	12	11	7	6	5	4
5	22.4	10	8	7	5	4	3	3
		'Diamond' zoysiagrass samples						
1	4.3	189	148	130	85	69	58	50
2	8.6	48	37	33	22	18	15	13
3	12.9	21	17	15	10	8	7	6
4	17.2	12	10	9	6	5	4	4
5	21.5	8	6	6	4	3	3	2

[z] 1 mm = 0.0394 inch.

[y] Percentage of grand mean represented by MDD.

have sampled at varying numbers, ranging from 3 to 10 samples per plot in 'Tifdwarf', 'Tifgreen', and 'Dothan' bermudagrass (Volk, 1972; White and Dickens, 1984), 'Meyer' zoysiagrass (Dunn et al., 1981), 'TifEagle' and 'Champion' ultradwarf bermudagrass, 'MS Supreme' and 'Floradwarf' bermudagrass (Baldwin et al., 2009; Hollingsworth et al., 2005). Thus, the studies assessing thatch-mat depth on ultradwarf bermudagrass putting green cultivars have been sampling at numbers that can only detect 3 to 5 mm of thatch-mat depth difference at 85% to 95% confidence. More samples are required from each plot to detect thatch-mat depth differences of less than 3 mm at 85% to 95% confidence.

ESTIMATING OM CONTENT SAMPLE NUMBER. Organic matter content was less variable than thatch-mat depth among cultivars (Table 2) and required fewer samples per plot to predict OM content for a particular percent of the population mean at a given confidence level (Table 4). Twenty-four samples are required to accurately and precisely estimate the OM content of a 'Diamond' zoysiagrass putting green plot within 4.9% of the population mean, which corresponds to a MDD of 0.25% OM content by weight, with 95% confidence (Table 4). However, 85 samples per plot are needed to estimate the thatch-mat depth within 4.3% of the population mean, corresponding to a MDD of 1 mm of thatch-mat depth, with 95% confidence (Table 3). Sample numbers increase or decrease as the desired confidence level increases or decreases and are displayed in Table 4 for 'TifEagle', 'Champion', 'SeaDwarf', and 'Diamond'. Sampling numbers were similar across cultivars; however, sampling numbers varied within each cultivar according to population mean and variance (Table 4). For example, 'SeaDwarf' requires more samples per plot than other cultivars to estimate OM content at each confidence level and each MDD level because its population mean was higher than the other cultivars and its variance was larger (Tables 2 and 4).

Although the influence of OM content varies with cultivar and various environmental and management factors, such as irrigation or rainfall amount or frequency, OM consistency, nitrogen fertility, aeration program, and soil texture, no studies have correlated particular OM content percentages and plant or soil responses. Although Murphy et al. (1993) suggested that OM exceeding 5% by weight would be detrimental to creeping bentgrass (*Agrostis stolonifera*) growth and Carrow (2000) suggested that excessive amounts of OM can encumber infiltration of water into the soil profile, slow drainage of excess water away from the putting surface, plug soil pores, and may decrease the infiltration of oxygen into the soil profile, no correlation has been made between particular OM content values and soil physical properties or plant physiological responses. Because OM content samples require a more lengthy and labor-intensive data collection and sample analysis procedure than thatch-mat depth samples, an investigator may select a larger MDD to decrease the required sample size. Similar to thatch-mat depth, the confidence level is left to the discretion of the investigator and can be altered based on knowledge of the study subject and the expense incurred during data collection and analysis.

Previous studies have sampled at varying numbers, ranging from two to five samples per plot in 'Providence' and 'A-1' creeping bentgrass (Fu et al., 2009; McCarty et al., 2007) and 'TifEagle', 'Champion', 'Tifdwarf', 'Floradwarf', and 'MiniVerde' bermudagrass (White et al., 2004). These sample numbers were able to detect mean OM content differences 0.5% to 1% OM content by weight with 90% to 95% confidence (Table 4). Thus, OM sampling procedures commonly used in previous literature were likely sufficient to detect meaningful OM content differences. Further research correlating specific OM content values to specific soil or plant responses can help to refine and guide MDD recommendations.

The size of the cores extracted for OM determination must also be considered when determining sample number. The equation to determine

Table 4. Number of samples required per plot to estimate organic matter (OM) content means at specified minimum detectable differences (MDD) and indicated significance levels for 'TifEagle' bermudagrass, 'Champion' bermudagrass, 'SeaDwarf' seashore paspalum, and 'Diamond' zoysiagrass.

MDD (%)[z]	Proportion of grand mean (%)[y]	Alpha level						
		0.001	0.005	0.01	0.05	0.1	0.15	0.2
'TifEagle' bermudagrass samples								
0.05	1.2	465	363	318	214	169	142	123
0.1	2.5	117	90	80	54	43	36	31
0.25	6.2	19	15	13	9	7	6	5
0.5	12.5	5	4	4	3	2	2	2
1.0	24.9	2	1	1	1	1	1	1
'Champion' bermudagrass samples								
0.05	1.1	1162	906	795	534	421	354	307
0.1	2.3	291	227	199	134	106	89	77
0.25	5.6	47	37	32	22	17	15	13
0.5	11.3	12	10	8	6	5	4	4
1.0	22.5	3	3	2	2	2	1	1
'SeaDwarf' seashore paspalum samples								
0.05	0.7	3593	2801	2458	1652	1301	1095	949
0.1	1.4	899	701	615	413	326	274	238
0.25	3.5	144	113	99	67	53	44	38
0.5	7.1	36	29	25	17	14	11	10
1.0	14.2	9	8	7	5	4	3	3
'Diamond' zoysiagrass samples								
0.05	1.0	1285	1002	879	591	465	392	339
0.1	2.0	322	251	220	148	117	98	85
0.25	4.9	52	41	36	24	19	16	14
0.5	9.9	13	11	9	6	5	4	4
1.0	19.8	4	3	3	2	2	1	1

[z] MDD of OM content by weight; 1 mm = 0.0394 inch.

[y] Percentage of grand mean represented by MDD.

sample number required per plot does not address the size of the individual sample extracted for OM determination. Larger samples will capture a larger proportion of the plot area than smaller samples. Thus, the number of samples required can vary indirectly with the area encompassed by each sample.

Discussion

Thatch-mat depth and OM content are important characteristics of putting greens and can be indicative of the relative health and performance of putting green soils. Thatch-mat depth and OM content differed among 'TifEagle' and 'Champion' bermudagrass, 'SeaDwarf' seashore paspalum, and 'Diamond' zoysiagrass. 'TifEagle' and 'Champion' accumulated thatch-mat to a deeper depth than both 'SeaDwarf' and 'Diamond'. However, 'SeaDwarf' had a higher OM content than 'Diamond' and both had higher OM contents than 'TifEagle' and 'Champion', suggesting that the ultradwarf bermudagrass cultivars generate less dense and more quickly decomposing underground biomass than 'SeaDwarf' and 'Diamond'. Thus, more aggressive thatch and OM management practices may be needed for 'SeaDwarf' and 'Diamond'.

Sampling procedures for determining thatch-mat depth and OM content are important, as well. This study found that sampling methods used in previous studies may have had MDD and confidence levels outside of the range the investigator intended for thatch-mat depth, but came close to intended ranges for OM content. The sampling numbers generated in this study provide a range of confidence levels and MDD levels to allow future researchers to take MDD and confidence level into consideration, along with time and expense of sample gathering and processing, when sampling 'TifEagle', 'Champion', 'SeaDwarf', and 'Diamond' putting green plots for thatch-mat depth and OM content. Future research correlating specific levels of thatch-mat depth and OM content to specific soil and plant responses could aid in determining an appropriate MDD level. Additionally, similar sampling studies could be performed for different cultivars and different evaluations to give additional accuracy and precision to turfgrass scientific measurements.

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