Received: 13 December 2021 | Accepted: 16 March 2022

DOI: 10.1002/cft2.20163

Crop, Forage & Turfgrass Management

RESEARCH

Applied Turfgrass Science

Benchmarking putting green organic matter in eastern Pennsylvania

Douglas T. Linde[1] | Andrew D. Mitchell[2] | Brendan Hannan[2]

[1]Plant Science Dep., Delaware Valley Univ., 700 E. Butler Ave., Doylestown, PA 18901, USA

[2]New Zealand Sports Turf Institute, PO Box 347, Palmerston North 4440, New Zealand

Correspondence
Douglas T. Linde, Plant Science Dep., Delaware Valley Univ., 700 E. Butler Ave., Doylestown, PA 18901, USA
Email: douglas.linde@delval.edu

Assigned to Associate Editor Rebecca Grubbs.

Abstract

Despite significant changes in sand introduction to putting greens the past 15 years, putting greens in eastern Pennsylvania are still vulnerable to excessive levels of organic matter (OM) which can lead to catastrophic turf loss. The objective was to benchmark current trends in OM and sand introduction on putting greens in eastern Pennsylvania along with N rate, core aeration frequency, soil moisture, firmness, trueness, budget, percentage bentgrass cover and construction method. From 74 courses, 221 greens were sampled for %OM at four depths. The average %OM in the top 0 to 1 inches was 2.8% and ranged from 0.6 to 10.8%, while the average in the 1-to-2-inch depth was 1.8% (0.5–5.9% range). The average sand introduction rate was 15 ft^3 sand 1,000 ft^{-2} yr^{-1} (range = 1–67) and the average N rate was 2.4 lb N 1,000 ft^{-2} yr^{-1} (range = 0.5–4.5). Seventy percent of greens were cored aerated two times per year. Correlations were weak between %OM in the 0-to-1-inch depth and sand rate ($r = -.33$), N rate (–0.11), and core aeration frequency (–0.18). These weak correlations were surprising and counterintuitive yet not uncommon for a benchmarking study of this nature. Higher budget courses do more sand introduction and core aeration and have greens that are truer, drier, firmer, lower in OM and use less N than lower budget courses. Superintendents can compare their greens to others in similar categories and use the results to help justify more resources and/or maintenance practices.

1 | BACKGROUND ON PUTTING GREEN ORGANIC MATTER

Research conducted between 2000 and 2011 has shown various benefits of regular application of sand to putting greens (Carrow, 2003; Ervin & Nichols, 2011; Hempfling et al., 2017; Landreth et al., 2007; Schmid, Gaussoin, & Gaussoin, 2014; Schmid, Gaussoin, Shearman, et al., 2014). Benefits include increased surface firmness, increased green speed, increased infiltration, organic matter (OM) reduction, and disease reduction. That research along with the introduction of kiln-dried sand and the increased prevalence of the "firm and fast" philosophy of managing greens in the past 15 years has resulted in superintendents introducing sand more frequently into their putting green root zones through backfilling aeration holes and grooves, injection, drill and fill cultivation, and topdressing. However, not all courses can afford to implement these practices. These courses are more vulnerable to excessive levels of OM in putting greens which can, in severe cases,

Abbreviations: LOI, loss on ignition; NZSTI, New Zealand Sports Turf Institute; OM, organic matter; USGA, United States Golf Association.

TABLE A Useful conversions

To convert Column 1 to Column 2, multiply by	Column 1 suggested unit	Column 2 SI unit
0.304	foot, ft	meter, m
2.54	inch	centimeter, cm (10^{-2} m)
0.405	acre	hectare, ha
0.405×10^3	acre	square meter, sq m
0.929	1,000 square feet	square meter, sq m
454	pound, lb	gram, g

Core Ideas

- Higher budget golf courses do more sand introduction and core aeration.
- Higher budget golf courses have greens that are truer, drier, firmer, lower in organic matter and use less N.
- Seventy percent of putting greens had organic matter levels less than the standard recommendation of 3-4%.
- The top inch of the greens had the highest organic matter which averaged 2.8% and ranged from 0.6 to 10.8%.
- Superintendents can use the results to justify more resources and/or maintenance practices.

lead to rapid turf decline and even death during periods of high temperature and high moisture (Carrow, 2003; Landreth et al., 2007; Moeller & Lowe, 2016). Golf courses in the eastern region of Pennsylvania are prone to this type of catastrophic turf loss on greens and in 2016 at least two courses experienced it (D. Linde, personal communication, 1 Oct. 2016). Conversely, there have been reports from a U.S. Golf Association (USGA) agronomist and superintendents from eastern Pennsylvania (D. Linde, personal communication, 1 Dec. 2015) that some superintendents may be introducing too much sand which is leading to other problems such as surface instability and poor moisture and nutrient retention.

A common recommendation since approximately 2004 is to keep the %OM in the upper rootzone of the putting green below 3–4% by affecting 15–20% of the surface each year with core aeration and incorporating 40–50 ft^3 of sand 1,000 ft^{-2} yr^{-1} (Moeller & Lowe, 2016; O'Brien & Hartwiger, 2003). The authors stated that OM levels above 4% are cause for concern. However, taking a scientific approach to managing OM can be frustrating because of variables that affect OM data such as sampling and laboratory methods (Moeller & Lowe, 2016; Vermeulen & Hartwiger, 2005). Today, there still is no standard sampling and laboratory method for testing OM in putting greens and is one reason why OM data has much variability.

From 2006 to 2008, Schmid, Gaussoin, & Gaussoin (2014) conducted a benchmarking study of OM and cultural practices on 308 putting greens from 104 golf courses from 15 states, not including Pennsylvania. Since that survey, there has been significant changes in sand introduction to putting greens. In 2013, a similar benchmarking study was conducted by the New Zealand Sports Turf Institute (NZSTI) on 150 putting greens from 52 courses across New Zealand (D. Linde and B. Hannan, personal communication, 24 Dec. 2015). Although data from that study have not been published, that study was part inspiration for the current study. Since 2004, the NZSTI has conducted multiple putting green benchmarking studies across New Zealand (Linde, 2005; Linde et al., 2011; Linde et al., 2017).

Despite significant changes in sand introduction to putting greens the past 15 years, golf courses in eastern Pennsylvania are still vulnerable to excessive levels of OM which can, in severe cases, lead to catastrophic turf loss. In addition, there are anecdotal reports that too much sand introduction can lead to other problems. The objective of this study was to benchmark current trends in OM and sand introduction on putting greens in eastern Pennsylvania along with other variables that may influence OM including N rate, core aeration frequency, soil moisture, firmness, trueness, budget, percentage bentgrass cover, and construction method. From this study, superintendents will have more insight on the ideal range for OM and can see how their greens and practices compare to the benchmarked greens. In addition, superintendents can use the data to justify funds for additional materials and equipment, to justify more or less surface-disrupting practices, and to have more confidence in making a change in their management practices.

2 | HOW WERE GREENS BENCHMARKED

From 2016 to 2021, putting greens were sampled by the same scientist primarily between July and mid-August of each year. This time period was chosen because during that period greens in eastern Pennsylvania are most susceptible to catastrophic turf loss due to high OM and sand introduction is minimal. One goal of sampling was to sample greens from a wide variety of operating budgets, construction methods, and grass species composition. Another goal was to sample greens from courses of members of the Philadelphia Association of Golf Course Superintendents (PAGCS) and the Pocono Turfgrass Association (PTA) which supported the study.

Three greens from each course were sampled for OM. For most courses, greens were selected by the superintendent and included what they thought were their best, average, and worst performing greens. Eight core samples, each 0.75 inches in diameter, were taken from each green with a “T-style” core sampler. Sample locations were across the entire green at least 12 ft apart as to include eight sections of the green. While in the core sampler, each core was sliced with a knife into four sections based on the depth from the surface (0–1 inch from the surface, 1–2 inches, 2–3 inches, and 3–4 inches). The verdure was removed from the top section using a knife and cutting board. All thatch and mat were left on the core. Each section was composited by depth into the appropriate sample bag so that eight subsamples of each depth were in each bag. Each green, therefore, had four composited samples (by sampling depth) that were air-dried and then sent to Penn State University's Agricultural Analytical Lab to be tested for percentage soil OM by the loss on ignition (LOI) test (Schulte & Hoskins, 2011). Before conducting the LOI test, samples were prepared according to the standard protocol for all soils which included drying at 37 ^{0}C, disaggregation (breaking up soil clumps) using a stainless steel hammer mill, and then passing each sample through a 0.08-inch (2-mm) sieve (no. 10) (J. Spargo, Penn State lab manager, personal communication, September 2018). The LOI test was conducted on the material passing the 0.08-inch (2-mm) sieve.

Immediately after collecting core samples from a green, surface firmness and moisture content were measured about 1 inch from each sample location. One drop of a 5 lb (2.25 kg) Clegg hammer was used to measure surface firmness. A Field-Scout TDR 150 (Spectrum) soil moisture meter with 3-inch probes was used to measure soil moisture. Surface trueness was assessed using the bobble test as described by Linde et al. (2017). For the bobble test, at least three balls at a minimum of three locations on the green were rolled about 8 ft from the evaluator's hand. The amount of ball bobbles and snaking in the last 3 ft of roll were visually observed and given a rating between 1 and 10 where 1 = many bobbles and much snaking, 5 = some bobbles and snaking, 9 = 1 bobble or snake, and 10 = no bobbles or snaking. A bobble was defined as a vertical deviation of the ball while it rolled. Snaking was defined as a lateral deviation of the ball from its intended path. To get an estimate of the grass composition of each green, percentage creeping bentgrass cover for the entire green was visually estimated. Putting greens in eastern Pennsylvania contain two grass species, creeping bentgrass (*Agrostis stolonifera* L.) and annual bluegrass (*Poa annua* L.). If a green was not 100% bentgrass, then the remainder of the green was annual bluegrass. Other data such as core cultivation frequency (corings per year), green acreage, sand introduced per year, N per year, sand dustings per year, construction method and operating budget category were collected through communication with the superintendent. Construction methods included USGA specification, California-style, and sand-capped. Sand-capped greens were those built with native soil and then topdressed with a predominantly sand mixture over many years that resulted in the top 3–6 inches of the green consisting of a sand-based soil. Superintendents chose which category their annual 18-hole maintenance operating budget fell (<US$500,000; $500,000–$1,000,000; or >$1,000,000).

3 | RESULTS AND DISCUSSION

A total of 74 courses (221 greens) were tested from 2016 to 2021. Of the 74 courses, 64 (86%) had superintendents that were members of the PAGCS and the PTA. Most courses were within 60 mi of Philadelphia or Scranton, PA. Comparisons were made using descriptive statistics and correlation coefficients using SPSS software. Pearson's correlation coefficients were calculated for all variables with numerical data and Spearman's correlation coefficients were calculated for variables with categorical data (Budget). A series of separate multivariate regressions were conducted to investigate the combined effects of management practices (sand rate, N rate, corings, moisture) on each quality metric (firmness, moisture, trueness, %OM 0–1 inch). Only variables that had significant correlations with each other were included in each regression model.

3.1 | Comparing data with averages and ranges

Table 1 lists the descriptive statistics by three categories–all greens, operating budget, and construction method. In general, greens were sampled from a wide variety of operating budgets, construction methods, and percentage creeping bentgrass (see “*n*” values in Table 1 which represents number greens in each category). A good use of Table 1 is for superintendents to see how their greens compare to others in similar categories. For example, one superintendent that participated in the study had been aggressively introducing sand into his greens the past few years and asked if he may be doing too much. Plus, he was getting pressure from members to cut back on the amount of surface disruption. The superintendent compared the data from three of his greens to the summary data and decided to cut back on the amount of cultivation and sanding for the next season. Caution should be taken when making comparisons because values are not absolutes and benchmarking studies like this one have much inherent variability.

The 0-to-1-inch depth had the highest %OM for all categories except sand-capped (Table 1 and Figure 1). The average %OM in the top 0–1-inch for the 221 greens was 2.8% with a range from 0.6 to 10.8%. In their putting green OM study,

TABLE 1 Descriptive statistics by putting green category for 221 putting greens from 74 eastern Pennsylvania golf courses from 2016 to 2021

		Firmness	Moisture content		Percentage organic matter by depth, inches						
Category[a] (*n*)	Trueness[b]	Gmax	VWC %	Bentgrass	0–1	1–2	2–3	3–4	Annual sand rate[c]	Annual N rate	Corings yr^{-1}
				%					ft^3 sand 1,000 ft^{-2}	lb N 1,000 ft^{-2}	
All greens (221)											
Avg.	7.3	62	25	65	2.85	1.84	1.51	1.66	15	2.4	1.7
Min.	4.0	43	8	1	0.60	0.46	0.00	0.00	1	0.5	0.0
Max.	9.0	88	45	100	10.80	5.90	6.37	7.44	67	4.5	4.0
Budget 1 (85)											
Avg.	6.6	58	29	58	3.66	2.18	1.82	1.91	10	2.6	1.4
Min.	4.0	43	14	1	1.09	0.49	0.13	0.00	1	1.5	0.0
Max.	9.0	80	44	99	10.80	4.90	6.37	7.19	31	4.5	2.0
Budget 2 (79)											
Avg.	7.2	63	23	63	2.40	1.63	1.26	1.39	15	2.5	1.8
Min.	5.0	47	12	5	0.60	0.46	0.00	0.00	6	0.8	0.0
Max.	9.0	83	45	100	6.87	4.74	4.46	4.66	34	4.5	2.0
Budget 3 (57)											
Avg.	8.4	68	20	77	2.26	1.64	1.40	1.67	22	2.1	2.1
Min.	6.0	54	8	10	0.90	0.50	0.15	0.06	7	0.5	2.0
Max.	9.0	88	32	100	6.27	5.90	4.81	7.44	67	4.5	4.0
California (26)											
Avg.	7.4	62	21	83	1.92	1.27	0.49	0.27	11	2.7	1.9
Min.	6.0	49	12	50	1.09	0.70	0.00	0.00	7	0.5	0.0
Max.	9.0	78	30	99	2.87	2.03	1.34	0.50	15	4.5	2.0
Sand-capped (91)											
Avg.	7.1	61	28	48	3.25	2.24	2.47	3.26	16	2.2	1.6
Min.	4.0	43	13	1	1.20	1.00	0.80	0.60	1	0.7	1.0
Max.	9.0	82	45	100	10.80	5.90	6.37	7.44	67	4.5	2.0
USGA (104)											
Avg.	7.4	63	23	75	2.73	1.64	0.93	0.62	15	2.5	1.7
Min.	5.0	43	8	10	0.60	0.46	0.13	0.00	2	0.8	0.0
Max.	9.0	88	40	100	10.40	4.90	4.18	2.80	67	4.5	4.0

Note. *n*, number of greens; VWC, volumetric water content.

[a]Budget 1 = Operating budget <US$500,000 yr^{-1}, Budget 2 = $500,000–1 million yr^{-1}, Budget 3 = >$1 million yr^{-1}.

[b]Visual rating (1–10) of amount of bobbling as balls rolled across green (1 = many bobbles, 10 = no bobbles).

[c]Includes all sand and sand-based materials broadcasted and injected into greens.

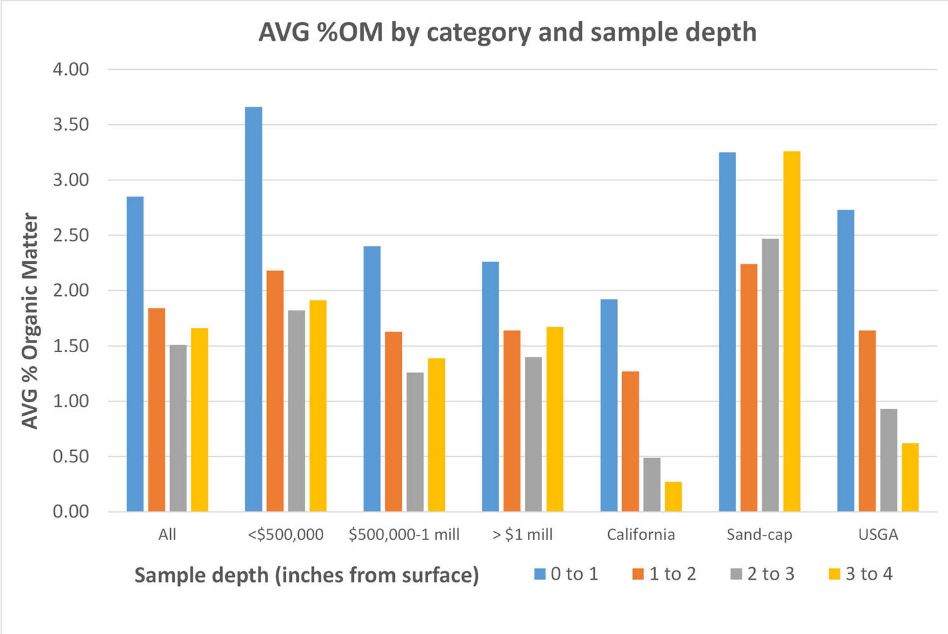

FIGURE 1 Percent organic matter by category and sample depth for 221 putting greens in eastern Pennsylvania sampled from 2016 to 2021

McAuliffe et al. (2005) sampled 173 sand-based greens from 28 New Zealand golf courses and found the average %OM was 8.2, 4.7, 3.3, and 3.2% for the 0-to-20-mm, 20-to-40-mm, 40-to-60-mm and 60-to-80-mm depths, respectively. In their 2006–2008 benchmarking study, Schmid, Gaussoin, & Gaussoin (2014) reported the average %OM from 308 greens across the United States was 3.1% with a range from 1.2 to 8.4%. Their results were similar to the current study despite some differences in the sampling method. Schmid, Gaussoin, & Gaussoin (2014) took three 0.75-inch diam. core samples from three greens per course. The verdure was removed, and each sample contained the soil from 0 to 3 inches below the verdure.

To provide further insight into sampling and lab method influence on OM values, eight samples from two eastern Pennsylvania golf courses were split and sent to both the Penn State Agricultural Analytical Lab and the NZSTI lab in 2018. The %OM results from the NZSTI lab were on average 3.3 times higher than results from the Penn State lab. Although the NZSTI sampling method was similar to the current study, the lab preparation of the samples was not. The samples tested by the NZSTI were not sieved to 0.08 inches (2 mm) while the samples tested by Penn State were sieved. Sieving removed some of the undecomposed root mass and thatch. Therefore, sieving was the presumed reason why the NZSTI values were so much higher. From these results, caution should be taken when comparing OM values for putting greens between studies unless sampling and testing methods were identical. Researchers and superintendents should be consistent in their sampling method and use one lab for testing. In addition, the results are evidence that a standardized sampling and testing method for putting green OM is needed.

Sand-capped greens had much higher OM levels in the 2-to-3- and 3-to-4-inch depths compared with California and USGA greens (Table 1 and Figure 1). The greens in the sand-capped category typically were constructed with native soil before 1970, had 3–5 inches of topdressing gradually applied over many years on top of the original soil which had a much finer soil texture such as a silt loam or clay loam. Also, today's 3-to-4-inch depth in one of those sand-capped greens at one time was the 0-to-1-inch depth. The results of the agronomic practices from previous years were buried deeper each year. One common agronomic practice between 1970 and 1990 was topdressing with a "dirty sand" such as a 6:2:2 (sand/soil/peat) mixture (Zontek, 1980). Since the 1990s, pure sand has become the most common material used for topdressing. In contrast, most of the USGA and California greens in this study were built after 1980 and, starting at the 2-to-3-inch depth, the %OM became low and similar to levels in a new sand-based green (Table 1).

3.2 | Comparing data with correlations

Although useful, making comparisons between variables solely on the averages without statistical procedures can lead to false conclusions. Therefore, correlation statistics were used to provide more insight on comparisons between variables (Tables 2 and 3). Table 2 lists correlations for various comparisons with an emphasis on the %OM in the 0-to-1-inch depth. That depth is most critical to playability,

TABLE 2 Select correlations for putting greens from 74 eastern Pennsylvania golf courses from 2016 to 2021

Comparison	Correlation statistics		
	n	*r*[a]	*p* value[b]
Firmness vs. trueness	221	.38	.001
Firmness vs. moisture	221	−.52	.001
Firmness vs. sand rate yr^{-1}	215	.17	.014
Firmness vs. N rate yr^{-1}	215	−.16	.023
Firmness vs. %OM[c] 0–1 inch	221	−.32	.001
Firmness vs. %OM 1–2 inches	221	−.10	.135
Firmness vs. %OM 2–3 inches	221	−.03	.632
Firmness vs. %OM 3–4 inches	221	−.00	.970
Moisture vs. sand rate yr^{-1}	215	−.18	.007
Moisture vs. trueness	221	−.47	.001
%OM 0–1 inch vs. trueness	221	−.42	.001
%OM 0–1 inch vs. firmness	221	−.32	.001
%OM 0–1 inch vs. moisture	221	.47	.001
%OM 0–1 inch vs. %bentgrass cover	221	−.20	.004
%OM 0–1 inch vs. %OM 1–2 inch	221	.65	.001
%OM 1–2 inch vs. %OM 2–3 inch	221	.71	.001
%OM 2-3-inch vs. %OM 3–4 inch	221	.84	.001
%OM 0–1 inch vs. sand rate yr^{-1}	215	−.33	.001
%OM 0–1 inch vs. N rate yr^{-1}	215	−.11	.097
%OM 0–1 inch vs. corings yr^{-1}	221	−.18	.007

[a]Pearson's correlation coefficient *r*.
[b]Two-tailed significance test statistic.
[c]Percentage organic matter by depth from surface in inches.

TABLE 3 Correlations between golf course operating budget category and various variables for 221 putting greens from 74 golf courses in eastern Pennsylvania from 2016 to 2021

Comparison	Correlation statistics		
	n	ρ[a]	*p* value[b]
Budget[c] vs. trueness	221	.55	.001
Budget vs. firmness	221	.43	.001
Budget vs. moisture	221	−.47	.001
Budget vs. % bentgrass cover	221	.28	.001
Budget vs. %OM[d] 0 to 1-inch	221	−.38	.001
Budget vs. %OM 1 to 2-inch	221	−.26	.001
Budget vs. %OM 2 to 3-inch	221	−.12	.070
Budget vs. %OM 3 to 4-inch	221	−.03	.691
Budget vs. sand rate yr^{-1}	215	.49	.001
Budget vs. N rate yr^{-1}	215	−.14	.041
Budget vs. corings yr^{-1}	221	.52	.001

[a]Spearman's correlation coefficient ρ.
[b]Two-tailed significance test statistic.
[c]Operating budget was split into three categories: <US$500,000 yr^{-1}, $500,000–1 million yr^{-1}, >$1 million yr^{-1}.
[d]Percentage organic matter by depth from surface in inches.

receives the highest management intensity, and is where the majority of new OM is deposited. Correlations between firmness and %OM are strongest for the 0-to-1-inch depth then gradually get weaker as depth increases. This would be expected since most OM is in the 0-to-1-inch depth and one drop of the 5 lb Clegg hammer is meant to measure surface firmness.

Figure 2 shows the percentage creeping bentgrass cover of the greens sampled in various categories. Putting greens in eastern Pennsylvania contain two grass species, creeping bentgrass and annual bluegrass. In Figure 2, if a green had 70% creeping bentgrass cover then it had 30% annual bluegrass as well. The correlation (−0.20) between %OM in the 0-to-1-inch depth and percentage bentgrass cover (Table 2) was weak and inverse.

The correlations in Table 2 were very strong for %OM of adjacent depths. For example, the correlation between the %OM in the 2-to-3-inch depth and the %OM in the 3-to-4-inch depth was 0.84. Despite the strong correlation, the relationship between adjacent depths does not have much practical implication or management consequences.

Trueness and moisture had moderate correlations with %OM in the 0-to-1-inch depth while sand rate, N rate, and corings had weak correlations with %OM at that depth. These weak correlations were surprising because they were counterintuitive to the common belief that more core aeration and sand introduction will decrease OM and more N will increase OM. To further investigate these and other significant correlations, multivariate regression was conducted.

3.3 | Comparing data with regression

Table 4 lists the series of separate multivariate regressions that were conducted to investigate the combined effects of management practices on each quality metric (firmness, moisture, trueness, %OM 0–1 inch). Only variables that had significant correlations with each metric (dependent variable) were used in building the regression models. Values of R^2 for the four models ranged from 0.22 to 0.29, which indicates that the regression models only did a fair job at explaining their respective dependent variable. From the regressions, it was found that %OM 0–1 inch significantly predicted moisture, moisture and N rate significantly predicted firmness, sand rate and moisture significantly predicted %OM 0–1 inch, and N rate and moisture significantly predicted trueness.

3.4 | Nature of benchmarking

The nature of a golf course benchmarking study lends itself to much variability and makes it more difficult to show strong correlations and R^2, especially for variables that can widely

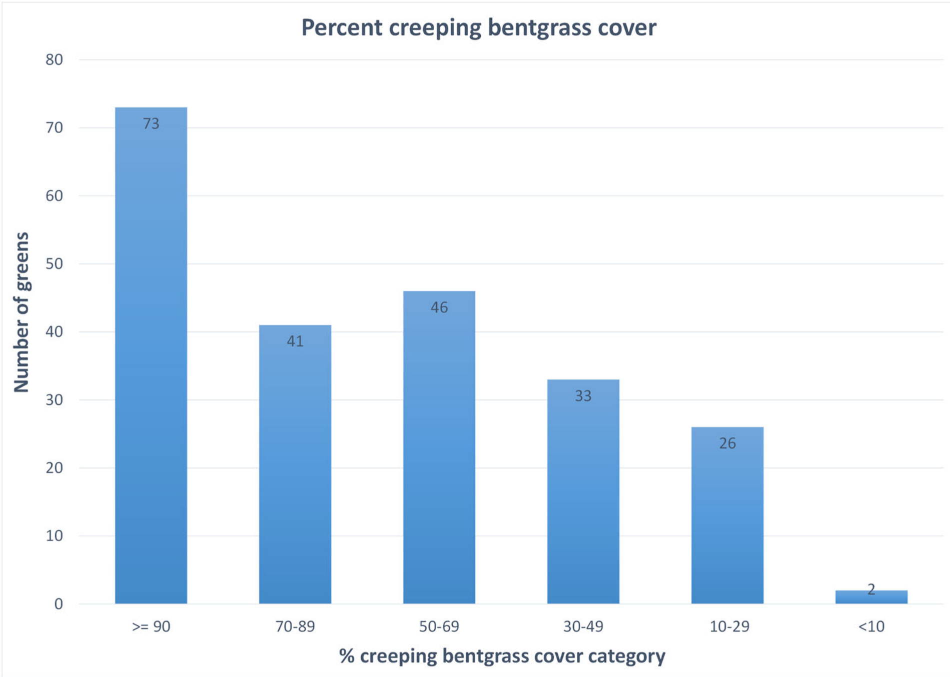

FIGURE 2 Percent creeping bentgrass cover category for 221 putting greens in eastern Pennsylvania from 2016 to 2021

TABLE 4 Results from multivariate regressions for putting greens from 74 eastern Pennsylvania golf courses from 2016 to 2021

	Dependent variable							
	Moisture		Firmness		%OM 0–1 inch		Trueness	
Independent variable	B[a]	SE_B	B	SE_B	B	SE_B	B	SE_B
Constant	20.46***	1.87	81.48***	2.90	2.51*	1.06	7.96***	0.92
%OM 0–1 inch	2.08***	0.30	−0.24	0.42				
Sand rate yr^{-1}	−0.02	0.05	0.01	0.05	−0.04***	0.01	0.01	0.01
Moisture			−0.58***	0.08	0.08***	0.01	−0.06***	0.01
Firmness					−0.01	0.01	0.01	0.01
Corings yr^{-1}	−0.67	0.77			−0.21	0.16	0.15	0.12
Nitrogen rate yr^{-1}			−1.88***	0.58			−0.20*	0.81
R^2	0.22		0.28		0.29		0.26	
N	215		212		215		212	

[a]B, unstandardized coefficient.

*and ***, significant at the α = .05 and .001 levels, respectively.

vary during the season such as firmness, moisture content, and trueness. A one-time measure of these variables may not be representative of their typical levels throughout the growing season. Some possible sources of variability for this study included time and day of testing, rainfall or irrigation before testing, time since last cultivation or topdressing, sample preparation, time since mowing or rolling, age of the green, management practices, grass species, and soil composition. As a result, some findings can be counterintuitive. For example, a putting green that is high in OM near the surface, gets minimal coring and topdressing, and retains moisture like a sponge typically is soft and bumpy. However, there are times during the season that such a green will be firm and smooth, especially during dry-down periods and shortly after rolling. Typically, the most statistically robust and valid method to compare variables or treatments is to conduct a plot study with a carefully planned statistical design and analysis that attempt to limit variability. Therefore, when interpreting data for a benchmarking study, it's important to focus on general trends and obvious patterns in the data.

In a 2004 putting green benchmarking study in which 150 greens were sampled from 50 courses in New Zealand,

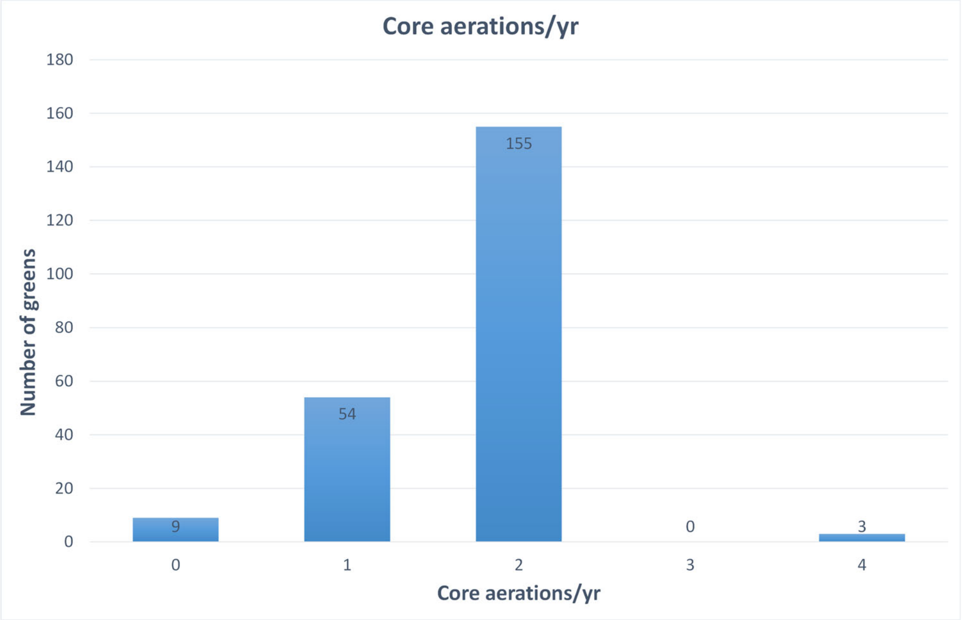

FIGURE 3 Core aerations per year for 221 putting greens in eastern Pennsylvania from 2016 to 2021

Linde et al. (2011) also found lower than expected R^2 values. For example, they reported an R^2 value of .44 between moisture and firmness data and stated that the relatively low R^2 was mainly due to inherent variability caused by turf variety, verdure, thatch, mat, soil texture, and soil bulk density. They concluded that the potential variability caused by these factors made putting green firmness and moisture comparisons between golf courses less useful.

In their golf green benchmarking study, Schmid, Gaussoin, & Gaussoin (2014) conducted multivariate regressions on variables that had significant correlations to OM. Their final regression model had an R^2 of .572 with bentgrass cultivar, topdressing frequency, cultivation frequency, and putting green age being the significant predictors in the model. They commented that their model's R^2 value of .572 was indicative of the complex parameters involved. However, they were able to identify several management practices–including sand topdressing and soil cultivation–that significantly affected OM.

3.5 | Core aerations

The number of core aerations (corings) per year are listed in Figure 3 and Table 1. The majority (70%) of greens were core aerated twice per year. Of the 63 greens that received 0 or 1 corings per year, 48 (76%) were from budget category no. 1 (<$500,000 per year). Of the 57 greens in budget category no. 3, 54 (95%) were core aerated twice per year and 3 (5%) were done four times per year. The correlation between budget and corings was 0.52 (Table 3). Therefore, the amount of corings increased with budget.

Sand dustings were defined as light topdressings of sand as opposed to a heavy topdressing after core aeration. Of the 221 greens, 136 (61%) greens received regular sand dustings while 85 (38%) did not. Of those 85 greens that did not get dustings, 49 (58%) were from budget category no. 1. Also, 54 of 57 (95%) greens in budget category no. 3 received regular sand dustings. The results from the number of corings and dustings are not surprising in that courses with the higher budgets are doing the most coring and dusting. In addition, the averages in Table 1 and correlations in Table 3 show some relationship trends such as higher budget courses have greens that are truer, drier, firmer, lower in OM, use less N, and introduce more sand than lower budget courses. This data can be useful by superintendents to help get more resources or justify their maintenance practices.

3.6 | Is there an ideal percentage organic matter?

This study did provide some insight on the ideal range of OM in an eastern Pennsylvania putting green. Only 42 (19%) of the 221 greens had %OM levels in the 0-to-1-inch depth ≥4% and only 67 (30%) had levels ≥3%. Therefore, most greens (154; 70%) had OM levels less than the USGA's standard recommendation of 3–4% in the upper rootzone (Moeller & Lowe, 2016). However, as stated by Moeller and Lowe, there are instances in which some putting greens might perform well at one level of OM while others experience problems. Organic matter lab data should not be the sole factor guiding management programs (Moeller & Lowe, 2016).

3.7 | How much sand was introduced?

Unfortunately, there is not a consistent term used by authors to represent sand applied to a putting green. The most common terms are topdressing and sand topdressing. In addition, some authors do not indicate whether their definition of topdressing includes sand addition by all methods or just topdressing. For this study, the term sand introduction was used instead of topdressing. Today, topdressing is one of various methods to introduce sand into a putting green. The others include backfilling aeration holes and grooves, injection, and drill and fill cultivation. In addition, most superintendents are using 100% sand for these procedures.

The average sand introduction rate was 15 ft^3 sand 1,000 ft^{-2} yr^{-1} with a range from 1 to 67 (Table 1). Only 6 of 221 greens (two courses) had rates greater than the 40–50 ft^3 sand 1,000 ft^{-2} yr^{-1} recommendation by the USGA originally stated in 2004. A more recent recommendation published by the USGA is 25–35 ft^3 sand 1,000 ft^{-2} yr^{-1} (Whitlark & Thompson, 2019) which included sand additions from all methods. Only 21 greens (seven courses) had rates >25 ft^3. In 2005, Vermeulen and Hartwiger reported the results of a USGA topdressing study that surveyed 10 or more superintendents of well-maintained golf courses within each USGA regional office. They reported an average of 16 ft^3 topdressing 1,000 ft^{-2} yr^{-1} (range = 7–26) for the Mid-Atlantic regional office based in eastern Pennsylvania and an average of 27 ft^3 topdressing 1,000 ft^{-2} yr^{-1} (range = 14–51) for the Mid-Atlantic regional office based in western Pennsylvania. The average sand introduction rate for budget category no. 3 ("well-maintained" courses) in the current study was 21 ft^3 sand 1,000 ft^{-2} yr^{-1} with a range from 7 to 67. Schmid, Gaussoin, & Gaussoin (2014) reported that greens receiving an annual sand topdressing rate of at least 20 ft^3 topdressing 1,000 ft^{-2} yr^{-1} were consistently <3.3% OM. Even after comparing the results from these studies, there still is no optimal sand rate per year that can be recommended. Optimal rates of sand depend on the quality of the growing environment (growth rate) and the length of the growing season (Whitlark & Thompson, 2019). A common recommendation today is to match the sand rate with the growth rate in order to dilute the OM (Whitlark & Thompson, 2019). The sand introduction data from this study do provide some general insight to superintendents especially in eastern Pennsylvania.

3.8 | Could too much sand be introduced?

To provide more insight on whether eastern Pennsylvania superintendents could be introducing too much sand into greens, data from 20% (44) of the greens with the lowest OM in the 0-to-1-inch depth were analyzed more closely. The green with the lowest %OM (0.6%) in the 0-to-1-inch depth was a 9-month-old USGA green. The 44 greens had <1.8%OM in the 0-to-1-inch depth. Of those 44 greens, 10 were from budget category no. 1, 18 from category no. 2, and 16 from category no. 3. In addition, 25 of the 44 greens (57%) received regular dustings. The construction categories of the 44 greens were 26 (59%) USGA greens, 9 (20%) sand-capped, and 9 (20%) California-style. The average sand introduced for the 44 greens was 18 ft^3 sand 1,000 ft^{-2} yr^{-1} while the average for all greens was 15 ft^3 sand 1,000 ft^{-2} yr^{-1}. The average N applied was 2.5 lb N 1,000 ft^{-2} yr^{-1} for the 44 greens and 2.4 lb N 1,000 ft^{-2} yr^{-1} for all greens. The average firmness was slightly higher (65 gmax) than for all greens (62 gmax) and the average moisture content was drier (21%) than for all greens (25%). From analyzing 20% of the greens with the lowest %OM in the 0-to-1-inch depth, it is difficult to conclude whether some superintendents could be introducing too much sand. To date, there is still only anecdotal reports from superintendents and consultants that introducing too much sand might lead to symptoms of poor moisture and nutrient retention and surface instability. This study did provide one such report that applying too much sand can lead to poor moisture retention. The superintendent at one course tested in this study had been aggressively introducing sand into the greens the past few years and reported the highest sand rate in the study of 67 ft^3 sand 1,000 ft^{-2} yr^{-1}. The OM levels for the three greens tested were very low for mature greens and ranged from 1 to 1.2%. During the next year, the superintendent reported that various greens had symptoms of doughtiness shortly after rainfall and was considering ways to improve moisture retention. Therefore, until there is more research on the effects of high rates of sand introduction, superintendents that do high amounts of cultivation and sand introduction should be aware of the associated symptoms.

4 | RECOMMENDATIONS

From this putting green benchmarking study, superintendents in eastern Pennsylvania should have more insight on the ideal range for OM, sand introduction, N, core aerations, and dustings. They can compare their greens to others in similar categories and use the results to help justify more or fewer resources and/or maintenance practices. In addition, if superintendents suspect OM may be an issue on their greens, they should have them tested at least once per year for OM. Due to the variability associated with OM data, it is critical to be consistent with sampling method and use the same lab for testing.

ACKNOWLEDGMENTS

Thanks to the Philadelphia Association of Golf Course Superintendents and the Pocono Turfgrass Association for helping fund the study and for the golf course superintendents that gave access to their golf course.

AUTHOR CONTRIBUTIONS

Douglas T. Linde: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Writing – original draft; Writing – review & editing. **Brendan Hannan:** Conceptualization; Methodology. **Andrew D. Mitchell:** Conceptualization; Methodology.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ORCID

Douglas T. Linde https://orcid.org/0000-0002-4201-2451

REFERENCES

Carrow, R. N. (2003). Surface organic matter in bentgrass greens. *USGA Turfgrass and Environmental Research Online*, *2*(17), 1–12.

Ervin, E., & Nichols, A. (2011). Organic matter dilution programs for sand-based putting greens. *USGA Turfgrass and Environmental Research Online*, *10*(8), 1–6.

Hempfling, J. W., Schmid, C. J., Wang, R., Clarke, B. B., & Murphy, J. A. (2017). Best management practices effects on anthracnose disease of annual bluegrass. *Crop Science*, *57*(2), 602–610. https://doi.org/10.2135/cropsci2016.06.0492

O'Brien, P., & Hartwiger, C. (2003). Aeration and topdressing for the 21st century. *USGA Green Section Record*, *41*(2), 1–7.

Landreth, J., Karcher, D., & Richardson, M. (2007). Cultivating to manage organic matter in sand-based putting greens. *USGA Turfgrass and Environmental Research Online*, *6*(19), 1–7.

Linde, D. (2005). Assessing golf course conditions in New Zealand. *Golf Course Management*, *73*(2), 110–113.

Linde, D. T., Mitchell, A. D., & Hannan, B. (2017). Comparing three methods to measure putting green trueness. *International Turfgrass Society Research Journal*, *13*, 1–11. https://doi.org/10.2134/itsrj2016.05.0332

Linde, D. T., Stowell, L. J., Gelernter, W., & Mcauliffe, K. (2011). Monitoring and managing putting green firmness on golf courses. *Applied Turfgrass Science*, https://doi.org/10.1094/ATS-2011-0126-01-RS

McAuliffe, K., Glasgow, A., Gibbs, R., & Liu, C. (2005). An investigation of organic matter levels in New Zealand golf greens. *International Turfgrass Society Research Journal*, *10*, 1078–1084.

Moeller, A., & Lowe, T. (2016). Managing organic matter in putting greens. *USGA Green Section Record*, *54*(21), 1–7.

Schmid, C. J., Gaussoin, R. E., & Gaussoin, S. A. (2014). Organic matter concentration of creeping bentgrass putting greens in the continental U.S. and resident management impact. *Applied Turfgrass Science*, *11*(1), 1–2.

Schmid, C. J., Gaussoin, R. E., Shearman, R. C., Mamo, M., & Wortmann, C. S. (2014). Cultivation effects on organic matter concentration and infiltration rates of two creeping bentgrass (*Agrostis stolonifera* L.) putting greens. *Applied Turfgrass Science*, *11*(1), 1–7.

Schulte, E. E., & Hoskins, B. (2011). Recommended soil organic matter tests. pp. 63–74. In J. T. Sims & A. Wolf (Eds.), *Recommended soil testing procedures for the northeastern United States* (Northeast Regional Bulletin 493, 3rd ed.). Agricultural Experiment Station, University of Delaware.

Vermeulen, P., & Hartwiger, C. (2005). Strategies for organic matter control. *USGA Green Section Record*, *43*(3), 18–19.

Whitlark, B., & Thompson, C. (2019). Light and frequent topdressing programs. *USGA Green Section Record*, *57*(9).

Zontek, S. (1980). Topdressing putting greens: A panel discussion. *USGA Green Section Record*, p. 23–25.

How to cite this article: Linde, D. T., Mitchell, A. D., & Hannan, B. (2022). Benchmarking putting green organic matter in eastern Pennsylvania. *Crop, Forage & Turfgrass Management*, *8,* e20163. https://doi.org/10.1002/cft2.20163