BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Achieving sustainable turfgrass management

Edited by Professor Michael Fidanza, Pennsylvania State University, USA

E-CHAPTER FROM THIS BOOK

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SCIENCE PUBLISHING

Advances in managing organic matter in turfgrass ecosystems

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1 Introduction

Beard (1973) defined thatch as a layer of dead and living stems and roots that accumulates between the green vegetation and soil surface (Fig. 1). Thatch has high lignin content and is composed of stems and nodes that do not readily decay (Ledeboer and Skogley, 1967). Thatch accumulation is a common problem in turfgrass ecosystems because such surface organic matter (OM) is resistant to decomposition. Many factors contribute to excessive thatch accumulation, including rapid and dense growth of the turfgrass species, excessive fertility and irrigation, and infrequent cultivation programs. Excessive thatch can be detrimental and cause desiccation and hydrophobicity during dry conditions, thus enhancing turfgrass drought stress. Water repellency was observed to be more severe with high OM soil in turf and more difficult to alleviate by using wetting agents (Barton and Colmer, 2011a,b). On the opposite extreme, thatch can also retain excess water, thereby restricting air exchange in the root zone during wet periods. Sampling of 24 golf course putting greens in New Zealand found surface infiltration rates declined as OM content increased (Glasgow et al., 2005). Early research demonstrated that thatch layer limits initial or early-time infiltration rate but not steady-state infiltration rate because thatch has a larger pore size than the underlying soil profile (Hurto et al., 1980; Taylor and Blake, 1982). Similarly, Liang

http://dx.doi.org/10.19103/AS.2022.0110.14

Chapter taken from: Fidanza, M. (ed.), *Achieving sustainable turfgrass management*, pp. 451–468, Burleigh Dodds Science Publishing, Cambridge, UK, 2023, (ISBN: 978 1 80146 019 4; www.bdspublishing.com).

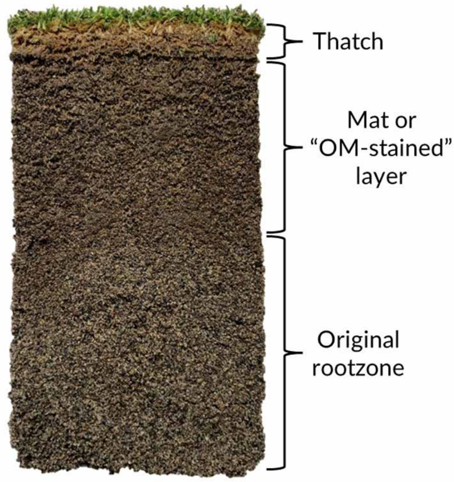

Figure 1 A putting green soil profile showing turfgrass, thatch, mat layer and the original rootzone.

et al. (2017) calculated early to intermediate infiltration rates (before approaching a constant infiltration rate) with a simulated rainfall method and reported that thatch held water, reduced runoff, and delayed infiltration. Furthermore, an examination of the physical properties of different sports turf root zone mixes indicated that saturated hydraulic conductivity (K_{sat}) was not affected by OM content but rather by pore size distribution (McCoy, 1992).

Although OM may not have a direct relationship with K_{sat}, OM can have an indirect effect by decreasing large pore spaces in the root zone. Large pores are an important factor influencing K_{sat}. As putting greens mature over the years OM will accumulate, which will decrease infiltration rates due to reductions in air-filled root zone porosity (Lewis et al., 2010; McClellan et al., 2009). Many researchers have shown evidence to support that decreases in air-filled porosity in sand root zones often result in decreased infiltration (Gibbs et al., 2000; Lewis et al., 2010; McCoy, 1992; Ok et al., 2003). Management practices such as sand topdressing and core cultivation introduce sand particles into the soil profile creating more pore spaces among OM. Measuring infiltration rates at five tensions from −5.5 to −0.5 cm, Wang et al. (2021) suggested that sand topdressing treatments increased K_{sat} by creating relatively larger pore spaces. Core cultivation physically removes thatch and plant tissue, and large amounts of sand are backfilled; therefore, a significant increase in infiltration was often observed, but the effects on OM reduction were inconsistent (McCarty et al., 2005, 2007; Schmid et al., 2014; Sidhu et al., 2014). This is likely because core cultivation is also very effective at promoting new growth/biomass.

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2 Monitoring and measuring organic matter in turfgrass

Historically, researchers have quantified OM accumulation and/or reduction by measuring thatch thickness and OM content by combustion. However, with the increased frequency and quantity of topdressing applied to golf course putting greens and fairways, it has become very difficult to measure a thatch layer due to the mixing of sand or soil with thatch that produces a mat layer (Carrow et al., 1987). As a result, recent studies have focused on OM combustion, or loss on ignition (LOI), to quantify OM changes over time. Despite having numerous laboratory methods for determining OM in soils (Carrow et al., 1987; Nelson and Sommers, 1996), and putting green and sports turf root zone mixes (ASTM F1647-02, 2002), there is a lack of standardized sampling procedures for OM sampling in turf. Various sampling methods have been documented in the literature, including differing soil probe diameter size, soil sampling depth, whether the soil samples are stratified, and if the verdure is removed. Consequently, comparing results from OM studies is difficult due to nonuniformity in OM sampling/collection and measurement technique.

A summary of research papers related to OM management and their soil sampling methods is listed in Table 1. The diameter of soil cores used for OM analysis and the number of samples collected per plot vary greatly in the turfgrass literature. Most of these studies collected between two and five soil samples per plot (Barton et al., 2009; Carrow et al., 1987; Dunn et al., 1995; Espevig et al., 2012; Fu et al., 2009; McCarty et al., 2005; Murphy et al., 1993; Schmid et al., 2014; Stier and Hollman, 2003; Wang, 2015). Kauffman et al. (2013) conducted a field trial in which they investigated the effect of sample size (number per plot) on thatch/mat depth and OM content of four warm-season grasses. Results from this trial indicate that the number of samples required to detect a difference ($P = 0.05$) of 3 mm in thatch depth ranged from 10 to 13, depending on species/cultivar. Moreover, the number of samples required to detect a 0.5% change in OM content ranged from 3 to 17 samples. The discrepancy between the number of soil samples collected per plot in previous OM studies and the estimated number of samples required to detect a 0.5% OM content change might explain why few studies have been able to consistently detect differences in OM content. It should also be noted that Kauffman et al. (2013) used a 100-mm diameter soil core, which is larger than most of the previous studies investigating OM content. Although extensive research has been carried out on OM in turfgrass, no previous study has investigated the impact of soil core diameter on OM content, particularly with respect to cultivation treatments. It is important that soil core diameter is sufficiently large enough to capture variations in OM, while not being too disruptive to the turfgrass surface. Future research is needed to investigate the impact of soil core diameter samples on OM content measurement.

Table 1 A summary of research papers related to organic matter management and their soil sampling methods in the turfgrass science literature

Reference	Year	Sample diameter (mm)	Sample depth (mm)	Number of samples per plot
Carrow et al.	1987	54	Variable – thatch or mat layer	2
Murphy et al.	1993	50	Variable – thatch/mat layer	5
Dunn et al.	1995	100	Variable – mat layer	5
Stier and Hollman	2003	25	50	3
Glasgow et al.	2005	25 or 50	80	NS[a]
McCarty et al.	2005	19	51	2
Barton et al.	2009	70	0–50	2
Fu et al.	2009	25	80	2
McClellan et al.	2009	25	152	NS
Fontanier et al.	2011	NS	13–89	NS
Espevig et al.	2012	24	Variable – mat layer	2
Kauffman et al.	2013	100	25	25
Schmid et al.	2014	19	76	2
Fidanza et al.	2017	19	Variable – thatch and OM-'stained' layer	8

[a]NS, not stated.

Soil sampling depth for OM content in turfgrass research has varied greatly (Table 1). Several researchers have used a fixed soil core depth for OM samples and analyzed the entire soil sample minus the verdure (Barton et al., 2009; Fontanier et al., 2011; McCarty et al., 2005, 2007; Schmid et al., 2014; Stier and Hollman, 2003). While other researchers have also used a fixed soil core depth but stratified the soil core into specific depth increments prior to combusting the sample (Glasgow et al., 2005; McClellan et al., 2009; Windows and Bechelet, 2012). McClellan et al. (2009) divided the soil cores in their study into 0–76 mm and 76–152 mm increments, whereas Glasgow et al. (2005) and Windows and Bechelet (2012) both stratified their samples into 20-mm increments (0–20, 20–40, 40–60, and 60–80 mm). Other researchers have relied on variable depth sampling for OM based on the depth of the thatch/mat region (Carrow et al., 1987; Dunn et al., 1995; Espevig et al., 2012; Fidanza et al., 2017; Murphy et al., 1993; Wang, 2015). Early research by Carrow et al. (1987) looking at the effect of fertility and cultivation on Bermuda grass limited soil sampling to only the thatch region of the soil profile. The authors of this trial noted that it was difficult to make comparisons between treatments that received topdressing or core aeration (with cores returned) and all other treatments since those treatments form a mat layer, thus significantly reducing thatch. With increased frequencies and quantities of sand topdressing applied to putting greens and fairways, some studies have focused sampling depth on the mat or thatch/mat layer (Dunn et al., 1995; Espevig et al., 2012; Murphy et al., 1993; Wang, 2015). A recent study by Fidanza et al. (2017) stratified soil samples into three layers, verdure/thatch, OM-'stained' layer, and original root zone. The authors found that as the Bermuda grass putting greens aged, the depth of the OM-'stained' layer increased, but the OM level remained consistent and relatively low. In contrast, the depth of the thatch layer was relatively consistent, and the OM level fluctuated greatly throughout the season, which was attributed to the cultivation program.

Combustion temperature for measuring OM content using the LOI method also varies considerably in the turfgrass literature. In studies referenced previously, combustion temperature ranged from 440°C (Glasgow et al., 2005; Schmid et al., 2014) to 550°C (Espevig et al., 2012; Fidanza et al., 2017; Fu et al., 2009) to 600°C (Barton et al., 2009; Carrow et al., 1987; Dunn et al., 1995; Kauffman et al., 2013; Murphy et al., 1993; Stier and Hollman, 2003), and even up to 700°C (McCarty et al., 2005). To date, no published research has evaluated the effect of combustion temperature on OM content measurements in turfgrass. In general, researchers have used higher combustion temperatures for soils or thatch samples that have high OM to ensure complete combustion of OM (ASTM, 2020) or to reduce the time required to completely combust a sample. However, heating a soil sample to temperatures ≥1000°C could result in elevated OM measurements due to the combustion of carbonate C from $CaCO_3$, especially in calcareous soil. Rabenhorst (1988) determined that the appropriate combustion temperature for determining organic carbon (OM) content for a calcareous soil was 575°C, whereas carbonate C from $CaCO_3$ was combusted when samples were heated to 1000°C. Because of this, the authors recommend heating soil samples to a maximum of 575°C for the measurement of OM content using LOI in turfgrass.

To date, all previous studies investigating OM content in turfgrass have removed the verdure, or living green plant tissue above the soil surface, prior to laboratory analysis (Barton et al., 2009; Carrow et al., 1987; Dunn et al., 1995; Espevig et al., 2012; Fidanza et al., 2017; Fontanier et al., 2011; Fu et al., 2009; Glasgow et al., 2005; Kauffman et al., 2013; McCarty et al., 2005; McClellan et al., 2009; Murphy et al., 1993; Schmid et al., 2014; Stier and Hollman, 2003; Wang, 2015). However recently, researchers have suggested leaving the verdure intact for OM sampling (Woods, 2019). Subjective removal of verdure and loss of soil material during the verdure removal process may reduce the accuracy and precision of the measurement; however, to date, no study has addressed the implication of verdure removal.