Grass Research

REVIEW

Open Access

https://doi.org/10.48130/grares-0024-0028
Grass Research **2025**, 5: e003

Sand topdressing: the history, current knowledge, and new perspectives of its role in organic matter management

Ruying Wang[1*], James W. Hempfling[2] and James A. Murphy[3]

[1] *Department of Horticulture, Oregon State University, 4017 Agriculture and Life Sciences Building, Corvallis, OR 97331, USA*
[2] *Envu Turf & Ornamentals North America, 5000 CentreGreen Way, Suite 400, Cary, NC 27513, USA*
[3] *Department of Plant Biology, Rutgers University, 59 Dudley Road, New Brunswick, NJ 08901, USA*
* Corresponding author, E-mail: ruying.wang@oregonstate.edu

Abstract

Sand topdressing is the practice of applying a thin layer of sand to the surface of a turf. The history of sand topdressing dates back over a century on the Old Course at St. Andrews, Scotland. Sand topdressing is critical for improving root zone physical properties, supporting healthy root systems, and alleviating compaction stresses at the soil surface of highly trafficked turfs. A primary benefit of using non-amended sand for topdressing is to avoid adding additional organic matter when the management objective is to prevent excessive organic matter (thatch) accumulation. However, there is a long-running debate about whether topdressing alone is sufficient for organic matter control. The documentation of organic matter accumulation is limited. Multiple years are often needed for sufficient organic matter to accumulate and enable the detection of differences among topdressing treatments. In a three-year case study on an annual bluegrass (*Poa annua*) putting green turf, our data suggest that topdressing sand decreases organic matter content on a mass basis by diluting thatch and forming a mat layer. The growth of healthy turfgrass can contribute greatly to organic matter accumulation at the surface of the soil profile. Thus, a successful topdressing program needs consistent applications to match the growth pattern of turfgrass for the local climate. A more comprehensive understanding of organic matter build-up and its subsequent role in soil and plant health is needed. Cultural management solely based on thresholds of organic matter content in turfgrass systems does not acknowledge that other evaluations such as layering, root health, water infiltration, and surface firmness need to be carefully considered before implementing cultivation management practices to reduce organic matter.

Citation: Wang R, Hempfling JW, Murphy JA. 2025. Sand topdressing: the history, current knowledge, and new perspectives of its role in organic matter management. *Grass Research* 5: e003 https://doi.org/10.48130/grares-0024-0028

The history of topdressing

The practice of topdressing is believed to have been invented by Old Tom Morris (1821–1908), pioneer of the game of golf and greenskeeper at St. Andrews Golf Course in Scotland[1]. In fact, Old Tom Morris was thought to have discovered the benefits of topdressing accidentally when he spilled a wheelbarrow of sand on a putting green and noted the increased quality of that green thereafter[2]. In those days, topdressing was applied using wheelbarrows and shovels, and applications were uneven, time-consuming, and laborious[3].

In the literature, a wide range of units for topdressing rates were reported, such as weights or volumes per unit area or the depth of topdressing on the turf surface. In this review, all topdressing rates were converted to L·m^{-2} using Table 1, and a topdressing rate converter with the interactive conversion feature was provided in Supplementary Table S1. Piper & Oakley were among the first to publish recommendations for topdressing in the United States, citing the benefits of 'sanding' clayey soil greens a few times per season at a rate of 1.65 L·m^{-2} to improve surface characteristics and provide winter protection[4]. Shortly after, agronomists from the US Golf Association Green Section noted that heavy, infrequent applications of compost topdressing could be replaced by more lighter-rate applications as often as every seven days[5]. The material used for topdressing varied greatly from location to location, but the majority of superintendents during this time were using a mix of sand, finer-textured soil, and organic matter[6,7]. Regardless of the material used, most topdressing practices were suspended during the late-1930s and 1940s due to shortages in labor, equipment, and materials caused by the Second World War[6]. The advent of the mechanical aerifier during the late-1940s also led to reduced topdressing because many managers incorporated soil removed during coring instead of topdressing[6]. Although some scientists encouraged the use of frequent topdressing at 10- to 14-d intervals at rates of 1.65 L·m^{-2}[8], putting greens were generally topdressed twice per year at most before the mid-1970s[9].

The trend of frequent sand topdressing during the second half of the 20th century can be attributed primarily to research initiated by Dr. John Madison and coworkers at the University of California at Davis during the late-1950s. Similar to Old Tom Morris, Dr. Madison observed the benefits of sand topdressing accidentally when sand from a nearby pile blew onto the corner of a research field and enhanced the quality of the affected plots. Madison et al. promoted the use of a sand-only topdressing medium because it was cheaper, easier to apply, and provided better protection from the heavy traffic caused by increased play during the 1960s compared to sand-soil-peat mixes[10]. The authors recommended applying sand at a rate of 0.91 L·m^{-2} every 21 d to avoid creating alternating layers of sand and thatch. The advent of the first mechanized topdresser in the 1960s made topdressing at these rates and frequencies practicable for superintendents, leading to the widespread adoption of the practice by the late-1970s[3,9,11].

In the late 1970s, Hall warned against using sand-only materials for topdressing because of the potential to produce excessive water infiltration, excessive nutrient leaching, lower microbial activity, hydrophobic drying, lower water availability, and susceptibility to layering[12]. However, proponents of a sand-only topdressing medium considered adding more organic matter to be illogical

Table 1. Sand topdressing rate unit conversions.

1 L·m^{-2} equals [ab]	
3.28	ft^3·1,000 ft^{-2}
24.5	gal·1,000 ft^{-2}
1.54	kg·m^{-2}
0.122	yd^3·1,000 ft^{-2}
328	lbs·1,000 ft^{-2}
7.15	tons·acre^{-1}
16.0	tonnes·ha^{-1}
0.0394	depth (inch)
0.100	depth (cm)
10.0	m^3·ha^{-1}

[a] All conversions from volume to weight are made under the assumption that one cubic foot of sand weighs 100 lbs. [b] All conversions from volume to depth are made under the assumption that one liter of dry sand spread across one square meter is 0.1 cm in depth.

because a primary benefit of topdressing is to prevent excessive organic matter (thatch) accumulation[9,13]. This debate continued into the mid-1990s, but today an overwhelming majority of superintendents use a sand-only medium for topdressing for the same reasons provided by Madison et al.[10]: sand is cheaper, easier to apply, resistant to compaction, and free of organic matter[9,13].

Today the most common topdressing program involves light-rate, frequent applications of sand on putting greens. Topdressing has become as routine as fertilization[13]. Modern mechanized topdressers and material handlers allow for precise and accurate topdressing applications to 18 greens in less than an hour[3]. Additionally, modern equipment can apply sand at very low rates, allowing managers to topdress more frequently. O'Brien & Hartwiger reported that 0.15, 0.60, and 1.2 L·m^{-2} are considered light, moderate, and heavy rates of sand topdressing, respectively[14]; and topdressing is now applied as often as every seven days on golf course putting greens[3].

Modern sand topdressing programs

The recognized objectives and benefits of a modern topdressing program includes providing a smooth, firm putting green surface; increased shoot density; reduced thatch accumulation; protection against winter injury; and better movement of air, water, nutrients, and roots into the soil[9,11,15,16]. Larger, elongated, and healthy crowns of annual bluegrass (*Poa annua*) have been observed and documented from topdressing treatments compared to non-topdressed turf[17]. Thus, benefits from topdressing are commonly attributed to developing a sand (mat) layer that buries and protects crowns from biotic and abiotic stress. Additionally, the impact of a good topdressing program on playability (i.e., ball roll distance) and putting green performance under anthracnose disease (caused by *Colletotrichum cereale*) becomes even greater under stressful conditions of lower mowing or lower N fertilization[18]. However, the mechanisms of how topdressing improves turfgrass health have not been clearly described.

The primary considerations for developing a topdressing program are the material, timing, frequency, rate, and method used for topdressing[19]. Labor, material, and equipment expenditures must be allowed for a successful topdressing program; flawed programs can cause permanent damage that may require expensive reconstruction[7,15,20].

Light, frequent topdressing during mid-summer is often supplemented with higher-rate topdressing applied alone or in conjunction with cultivation events during the spring and autumn when play is minimal[14]. Frequent, ultra-light (< 0.15 L·m^{-2}) topdressing every 7–14 d with sand is commonly practiced in the golf industry to achieve acceptable playing conditions and minimize interference with mowing throughout the summer. Daily mowing removes unincorporated particles on the turf surface, creating excessive wear on the bed knives and reels for mowers. However, lower rates of topdressing have to be applied more frequently to achieve the same total amount of topdressing per year, otherwise, the objectives for topdressing will not be accomplished[21]. The target quantity of sand needed to achieve the benefits of a sound topdressing program is often unclear[14]. Based on the annual bluegrass performance under anthracnose disease, Wang et al. determined that increasing annual topdressing linearly reduced anthracnose up to 6 L·m^{-2}·yr^{-1} for the Northeastern US climate[22], however, other regions that have longer growing seasons for annual bluegrass may require greater annual sand topdressing rates. Once a consistent topdressing program is implemented, it also increases water infiltration[23−25].

Many attributes of modern putting greens make it more challenging to apply topdressing. Putting green turfs are maintained at low mowing heights with low fertilizer and plant growth regulation to restrict upright growth; newer cultivars of cool- and warm-season turfgrasses developed for putting greens have much greater shoot density compared to older cultivars, which can prevent the incorporation of topdressing sand[21,26]. Particle size distributions and chemical compositions can vary greatly among sands[7], so it is recommended that only sands that meet the United States Golf Association (USGA) specifications for putting green root zone mix be used for topdressing[27]. As a general rule, the texture of a topdressing material should be the same or coarser than the texture of the underlying soil[20]. However, when sand topdressing is applied at high rates in the summer, it becomes more difficult to be incorporated into the turf canopy resulting in excess sand on the putting green surface[23,28,29]. Using finer-textured sands has become a logical solution. The need to topdress larger areas on golf courses such as fairways and the lower cost of sand that does not meet the USGA specifications also facilitated the research to examine the effects, positive or negative, of using finer-textured sands for topdressing[23,29−31]. Topdressing velvet bentgrass (*Agrostis canina*) putting green turf with medium-coarse and medium-fine sands was shown to increase saturated hydraulic conductivity regardless of sand size and rate[23]. Even though research has shown that using sands that are finer than the USGA specifications had no noticeable short-term (< 4 years) negative effects on putting greens, the sands used in both studies were finer than the USGA recommendations but still predominately medium-sized (0.25–0.50 mm) sand particles[23,29]. The questions of what the limit of fineness is for topdressing sand and what the long-term effects of finer sands are on turf quality and physical properties need further investigation.

Sand topdressing for thatch management

Beard defined thatch as a layer of dead and living stems and roots that accumulated between the green vegetation and soil surface[32]. Mat is defined by Beard as an organic layer intermixed with topdressing material[32]. Moderate thatch thickness can provide surface resiliency, wear tolerance, and a buffer to soil temperature extremes[32]. However, excessive thatch can be detrimental and cause desiccation and hydrophobicity during dry conditions thus intensifying drought stress. On the opposite extreme, thatch can also retain excessive water thereby restricting air exchange in the root zone during wet periods. Excess thatch accumulation can restrict root growth into the underlying soil[33]. As a result, restricted root growth and elevated crowns predispose thatchy turfs to drought and heat stresses as well as scalping from mowing. Excessive thatch can also harbor insects and disease organisms[34−36], deprive oxygen and nutrients in the root zone[37], and reduce turf quality and playability on golf and sports turfs. Ultradwarf bermudagrass (*Cynodon dactylon* × *C. transvaalensis*) as an example has a strong tendency to accumulate organic matter within the surface zone, excessive organic matter accumulation cause adverse soil physical conditions that can lead to secondary stresses, such as limited rooting depth, inhibition of nutrient and water uptake, and root rot diseases[37]. Many factors contribute to excessive thatch accumulation including rapid and dense growth of the grass species, excessive fertility and irrigation, and infrequent cultivation programs.

Thatch is often quantified as thatch thickness (compressed or uncompressed) and organic matter content measured by weight loss-on-ignition in turfgrass research[19,38]. Soil organic matter plays a critical role in soil health, carbon stocks, and crop productivity[39]. The formation of soil organic matter is governed by plant litter decomposition[40,41]. Both above- and below-ground biomass production of turfgrass contributed to organic matter accumulation in turfgrass–soil ecosystems[42]. However, in turfgrass management, organic matter has been associated with negative effects of thatch on other root zone physical properties. Soil organic matter also serves as a repository for nutrients and contributes significantly to carbon sequestration capacity and atmospheric CO_2 mitigation[43,44]. Soil organic matter dynamics and carbon sequestration capacity have received limited research in turfgrass systems[42].

Some researchers have found that topdressing did not reduce organic matter production; instead, it diluted thatch and formed a mat layer[25,35,45−48]. Others noted topdressing contributed to thatch degradation as well as dilution[33,49]. In the literature, different methods of evaluating thatch in cool- and warm-season turfgrasses can yield contrasting results[38,50,51]. Some researchers observed that frequent topdressing[25,45,52,53] as well as seasonal high-rate topdressing[53−55] with sand or a high sand-content soil mixture can reduce thatch calculated as the percentage of organic matter by weight. Increasing the number of sand applications on putting greens was found to reduce the compressed thickness of thatch[35,56]. Espevig et al. reported that increasing the application rate of topdressing sand from 0.5 to 1 $L \cdot m^{-2}$ applied every two weeks on velvet bentgrass putting greens reduced organic matter content as measured by loss-on-ignition[49]. However, Stier & Hollman indicated that topdressing every two weeks at 0.2 $L \cdot m^{-2}$ or monthly at 0.4 $L \cdot m^{-2}$ with sand on creeping bentgrass (*A. stolonifera*) and creeping bluegrass (*P. annua* var. *reptans*) putting greens did not facilitate thatch decomposition as measured by the compressed thickness of thatch[46].

Topdressing rates should be based on the amount of sand required to fill the thatch, and the frequency of application should match the rate of thatch–verdure accumulation[10,15,57]. Light, frequent topdressing reduces the production of alternate sand/thatch layers if matched with the rate of thatch accumulation and minimizes interruption to play caused by excess sand on the putting surface[3,9,10,13,14,58−61]. The extent to which benefits from topdressing are achieved depends upon the frequency of application and the annual amount of sand applied to a putting green[57]. O'Brien & Hartwiger[14] outlined strategies to apply 12.2 to 15.2 $L \cdot m^{-2}$ of sand per year, a sufficient annual amount to maintain the concentration of organic matter below a threshold of 40 $g \cdot kg^{-1}$ (4%)[62]. The authors suggested applying 4.3 to 13.4 $L \cdot m^{-2}$ of the annual sand amount as surface topdressing and the rest as back-fill after cultivation[14].

A case study on an annual bluegrass putting green

A monostand of annual bluegrass was established in Sept. 2002 in North Brunswick, NJ, USA. A topdressing trial was conducted from autumn 2010 to 2013 to study the effect of sand topdressing on anthracnose disease of an annual bluegrass putting green turf[22]. Prior to this study, the field was renovated in 2008 with heavy topdressing and core aeration and routinely topdressed afterward with medium-coarse sand conforming to the USGA guidelines[27] across the entire field. Field maintenance and experimental design were previously described by Wang et al.[22]. This three-year field study was a 3 × 3 × 3 factorial of autumn, spring, and summer topdressing in a randomized complete block design with four replications. Autumn and spring topdressing were applied at 0, 1.2, or 2.4 $L \cdot m^{-2} \cdot yr^{-1}$, and 0, 0.6, or 1.2 $L \cdot m^{-2} \cdot yr^{-1}$ of sand was applied during summer. Core cultivation was not applied during the study. Each of the 27 treatment combinations from the 3 × 3 × 3 factorial design was applied to the same plot location, generating a range of topdressing sand quantities from 0 to 18 $L \cdot m^{-2}$ over three growing seasons (0–6 $L \cdot m^{-2} \cdot yr^{-1}$).

Soil samplings are destructive and can interfere with other measurements within the same experiment, such as soil water content and infiltration; therefore, they are often only taken at the conclusion of the study. Samples of the mat layer (an organic layer intermixed with topdressing sand) that had developed in response to topdressing treatments were taken at the conclusion of this study. Four 32-mm diameter (approximately 70-mm deep) cores were collected from each plot. A distinct thick sand layer in the soil profile from a previous field renovation (heavy topdressing and core aeration) in 2008 was observed to be consistent across the entire field and was used as a reference to measure mat layer depth corresponding to the three years of sand topdressing treatment applications in this case study (Fig. 1). After renovation, the light sand topdressing program applied to the field was insufficient to prevent the development of an excessive thatch layer before the initiation of this study. Mat layer samples were separated at the interface of the heavy sand layer and the thatch layer (as shown in Fig. 1). Uncompressed thatch–mat depth was measured at three equidistant points for each soil core. Verdure was removed from each core, and organic matter content was determined using the loss on ignition at 360 °C (ASTM Standard F1647-02a) for 12 h. Organic matter accumulation ($kg \cdot m^{-2}$) was calculated as the weight difference of a sample between 105 and 360 °C divided by the turf surface area of the sample. Samples in this study had varying depths in response to topdressing sand added to the root zone profile, thus both mat layer depth and organic matter content contributed to the organic matter

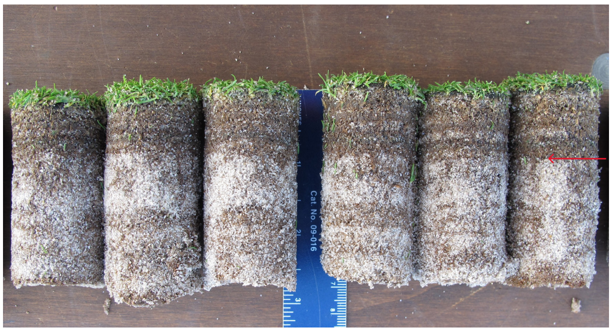

Fig. 1 Soil cores from an annual bluegrass putting green were evaluated from the zone below the green leaf canopy to the distinct interface between the thatch and sand layer indicated by the red arrow.

accumulation values. The organic matter accumulation has the same units as soil organic carbon stock and can be converted to soil organic carbon.

Regression analyses were performed using Statistical Analysis System software v. 9.3 (SAS Institute Inc., Cary, NC, USA) to describe the relationship between organic matter data and sand topdressing quantities. Data were also subjected to analysis of variance (ANOVA) with the General Linear Model procedure in SAS. Means were separated by Fisher's protected least significant difference test at the 0.05 probability level. Orthogonal polynomial contrasts were performed to test whether the organic matter response to increasing topdressing rate for a main effect was linear or quadratic.

Mat layer depth and organic matter content (weight loss-on-ignition) were measured at the conclusion of our study to allow adequate accumulation of sand. Other studies have indicated that topdressing effects on organic matter content required more than two years of treatment to be measurable[25,45].

A mat layer developed in this study ranging from 11 to 31 mm in response to topdressing treatments (Fig. 2a), and the organic matter content of the mat layer ranged from 45 to 191 g·kg^{-1} (Fig. 2b). The highest rate of topdressing produced the lowest organic matter content, which was slightly greater than the organic matter content threshold of 40 g·kg^{-1} proposed by O'Brien & Hartwiger[14]. Please note that the current study used a variable depth sampling method to best capture the effects of sand topdressing. Therefore, extremely high organic matter contents were identified from non-topdressed plots that had shallow depths of 11–14 mm (Fig. 2a & b) and indicated that, without topdressing, organic matter accumulated rapidly at the soil surface. Organic matter content data from non-topdressed plots were excluded from the regression analysis, because they were identified as outliers using the method previously reported by Motulsky & Brown[63] and were also highly variable across replications (Fig. 2b). The high organic matter content near the soil surface is not uncommon on golf courses. Carley et al. sampled a large number of creeping bentgrass greens in North Carolina, USA, and found the organic matter of mature putting greens (> 5 years old) generally exceeded the critical level of 40 g·kg^{-1} in the top 2.5 cm[64]. Glasgow et al. sampled many golf greens throughout New Zealand and also reported a high mean organic matter content of 82 g·kg^{-1} in the top 2 cm depth[65].

Increasing the annual topdressing rate significantly increased mat layer depth linearly (Fig. 2a). In contrast, the organic matter content was explained by a quadratic model (Fig. 2b). Within the 0–18 L·m^{-2} cumulative sand quantities over three years we studied, the model indicated that 18 L·m^{-2} of topdressing resulted in the lowest organic matter content (Fig. 2b). Increasing sand quantities was beneficial for reducing organic matter content. However, the derivatives of the estimated quadratic equation became less negative as the cumulative quantity of sand applied increased, suggesting that the reduction in organic matter content was less effective as the sand quantity increased. Whether the reduction in organic matter content will plateau beyond our highest rate of 18 L·m^{-2}·yr^{-1} applied in three years (6 L·m^{-2}·yr^{-1}) remains unknown. Considering topdressing is such a costly practice and is disruptive to play, turf managers would be less likely to apply quantities of sand topdressing beyond the highest annual rate (6 L·m^{-2}) used in our study on annual bluegrass putting greens in the Northeast region of the USA. Other regions without snow cover could have a longer growing season for annual bluegrass putting greens and, as a result, would require greater amounts of sand topdressing annually.

Across all treatments, an average of 6.54 kg·m^{-2} organic matter was accumulated over ~4 years (the reference line for sampling was deemed to be about a year before the study; Fig. 1). Assuming that soil organic carbon comprises 58% of soil organic matter mass[43], an average of 3.8 kg C m^{-2} was accumulated over ~4 years with varying mat layer depths of 11 to 31 mm. This estimated organic carbon stock aligns within the range reported from other putting green research as summarized by a meta-analysis[66]. However, the current study only measured organic matter content at the surface (11–31 mm) which can exhibit variability due to seasonal plant growth and litter decomposition as well as potential changes in vertical distribution over time; therefore, organic matter at the soil surface is not truly indicative of the entire soil carbon pool for turfgrass. More importantly, our data clearly indicated that sand topdressing was effective at building up a mat layer which created additional soil substrate contributing to the turfgrass–soil carbon pool. Soil volume increases upward by adding topdressing sand, which needs to be

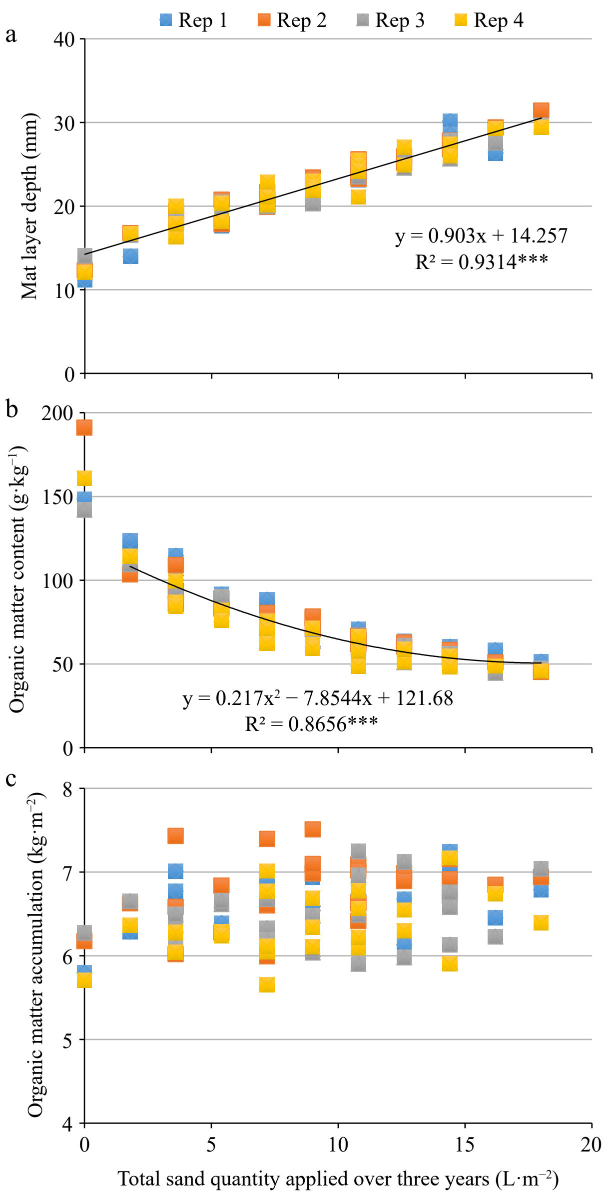

Fig. 2 Relating organic matter of an annual bluegrass putting green to the cumulative quantities (L·m^{-2}) of sand applied as topdressing over three years. Data from all four replications were used for regression analysis. (a) Mat layer depth increases linearly with sand quantity. (b) Organic matter content based on loss-on-ignition method has a quadratic relationship with sand quantity. (c) Organic matter accumulation per unit area does not have a strong relationship with sand quantity.

taken into consideration when calculating soil carbon accumulation. The commonly used fixed depth method for soil carbon accounting is subject to errors due to the changes in the volume of soil within the profile[67]. An equivalent soil mass method has been implemented in calculating soil carbon in turfgrass systems[66]. Standard methods for sampling and evaluating soil carbon need to be established in turfgrass systems to account for effects of topdressing, a routine practice on golf courses and sports fields in modern turfgrass management.

The relationship between organic matter accumulation (kg·m^{-2}) and total topdressing sand quantity was not clear and varied by replications in the current study (Fig. 2c & Table 2). This could suggest that increases in topdressing quantity did not promote the decomposing of organic matter or the decomposing of organic matter was canceled out by the overall better growth and greater biomass production of the turf promoted by topdressing. A study on creeping bentgrass and zoysiagrass (*Zoysia japonica*) fairways showed that thatch microbial activities were highly correlated with thatch moisture, but not thatch organic matter content[68]. Turf with high organic content is known to retain more water[34], and sand topdressing has been shown to reduce the water content in the zone modified by topdressing[23,29]. However, the effect of sand topdressing on microbial decomposing is still unclear. The practice of sand topdressing does not involve physically removing organic matter, and there is no strong evidence that adding sand promotes the decomposition of thatch. Nevertheless, our data strongly supported other research on both cool- and warm-season turfgrasses that topdressing decreases organic matter content by diluting thatch and forming a mat layer[25,35,45–48].

Further ANOVA analysis suggested that increasing spring and summer topdressing rates increased the organic matter accumulation per unit area as a linear response, whereas, autumn topdressing did not affect organic matter accumulation (Table 2). The significant main effects of spring and summer sand topdressing suggested that topdressing in spring and summer increased organic matter accumulation as a result of promoting annual bluegrass growth (Table 2). In contrast, annual bluegrass exhibits slow growth or winter dormancy during late autumn and winter months in the Northeast region of the USA, thus there was less potential for autumn topdressing to promote annual bluegrass growth and organic matter accumulation. This study provided evidence that sand topdressing promoted growth and organic matter accumulation on an annual bluegrass putting green, and further research is warranted to fully elucidate the mechanism of plant growth and organic matter accumulation responses to sand topdressing and other cultivation practices.

Sand topdressing positively affected root zone physical properties needed for a high-functioning playing surface[23,37,52]. Increasing rates of topdressing decreased surface water retention[23,29] and organic matter content. However, inconsistent topdressing programs can be detrimental to putting greens. Due to the factorial experiment design of this study, layering was observed with the high rate of spring or autumn topdressing only treatments (Fig. 3). In practice, these treatments should be avoided since layering in the soil can impede water infiltration[69] and root growth, thus can lead to turf failure over the long run[12]. Future research should also focus on identifying sand topdressing programs for a wide range of turfgrass species that will match turfgrass growth in different climates. Particularly, many new warm-season turfgrass varieties could require aggressive topdressing for their vigorous summer growth[14,37].

The ability of soil to store carbon plays a critical role in mitigating CO_2 emissions and global warming. Carley et al. reported rapid organic matter accumulation on putting greens and unraveled implications for carbon sequestration[64]. Sand topdressing in turfgrass systems is unique in the sense that it buries organic matter and builds up a mat layer. This vertical increase in soil volume can contribute to soil carbon sequestration in turfgrass systems, however, an appropriate method for quantifying soil carbon must be established. Furthermore, the misconception of organic matter in

Table 2. Organic matter accumulation response to the main effects of autumn, spring, and summer topdressing rate measured at the conclusion of the three-year study on an annual bluegrass turf mowed at 2.8 mm in North Brunswick, NJ, USA.

Source of variation	Organic matter accumulation
Replication	***
Autumn topdressing (AU)	NS[a]
Linear	NS
Quadratic	NS
Spring topdressing (SP)	***
Linear	***
Quadratic	NS
Summer topdressing (SU)	***
Linear	***
Quadratic	NS
AU × SP	NS
AU × SU	NS
SP × SU	NS
AU × SP × SU	NS
CV, %	5.0
Main effects	kg·m^{-2}
Autumn topdressing[b]	
0 L·m^{-2}·yr^{-1}	6.5
1.2 L·m^{-2}·yr^{-1}	6.6
2.4 L·m^{-2}·yr^{-1}	6.5
Spring topdressing[c]	
0 L·m^{-2}·yr^{-1}	6.4
1.2 L·m^{-2}·yr^{-1}	6.5
2.4 L·m^{-2}·yr^{-1}	6.7
Summer topdressing[d]	
0 L·m^{-2}·yr^{-1}	6.4
0.6 L·m^{-2}·yr^{-1}	6.6
1.2 L·m^{-2}·yr^{-1}	6.7

*** Significant at the 0.001 probability level. [a] NS, nonsignificant. [b] The total autumn topdressing was applied as two split applications on 22 Oct., 9 Nov. 2010; 21 Oct., 4 Nov. 2011; and 18 Oct., 6 Nov. 2012. Data for means were pooled across other factor levels. [c] The total spring topdressing was applied as two split applications on 21 Apr., 5 May 2011; 20 Apr., 4 May 2012; and 20 Apr., 3 May 2013. Data for means were pooled across other factor levels. [d] Summer topdressing was applied at 0, 0.075, and 0.15 L·m^{-2} every two weeks from 7 June to 13 Sept. 2011, 8 June to 14 Sept. 2012, and 12 June to 13 Sept. 2013. Data for means were pooled across other factor levels.

Fig. 3 Layering observed from 2.4 L·m^{-2}·yr^{-1} autumn and spring only treatments at the conclusion of a three-year sand topdressing study on an annual bluegrass turf mowed at 2.8 mm.

turfgrass needs to be revised, as it can be managed to support healthy root systems and contribute to capturing and storing carbon. In many cases, cultivation practices would temporarily decrease organic matter content, but they also promote new vigorous growth through positive modifications of the soil environment, ultimately contributing to new additions to organic matter near the soil surface.

New technologies for quick organic matter quantification are needed. Developing standardized approaches to quantify layering in the root zone is as important as measuring organic matter content. Digital image analysis and other sensor scanning technologies[70] could be new directions for evaluating organic matter. Particularly, the development of machine learning and computer vision would empower digital image analysis for evaluating organic matter and assist us in providing recommendations for turf managers.

Conclusions

Sand topdressing has been a routine practice on golf courses and sports fields. This review provides new perspectives on organic matter management. The organic matter in the soil contributes greatly to the soil carbon pools and has become a key focus for mitigating carbon emissions globally. A more comprehensive understanding of organic matter and its role in soil and plant health is needed to ease the fear of organic matter build-up. Cultural management solely based on thresholds of organic matter content in turfgrass systems needs to be avoided. Other evaluations such as layering, root health, water infiltration, and surface firmness need to be carefully considered before implementing cultivation management practices to reduce organic matter.

Author contributions

The authors confirm contribution to the paper as follows: study conception and design: Wang R, Hempfling JW, Murphy JA; data collection: Wang R; analysis and interpretation of results: Wang R; draft manuscript preparation: Wang R, Hempfling JW; funding acquisition: Murphy JA. All authors reviewed the results and approved the final version of the manuscript.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Acknowledgments

The case study presented in this review paper was supported by the USDA National Institute of Food and Agriculture Hatch Multistate project 0206183 through the New Jersey Agricultural Experiment Station, Hatch Multistate project NJ12294. Additional support was provided by the Rutgers Center for Turfgrass Science, United States Golf Association, Golf Course Superintendents Association of America, Golf Course Superintendents Association of New Jersey, Tri-State Research Foundation, and New Jersey Turfgrass Foundation. The authors would also like to thank T. J. Lawson and Bruce B. Clarke for their assistance with the research.

Conflict of interest

The authors declare that they have no conflict of interest.

Supplementary information accompanies this paper at (https://www.maxapress.com/article/doi/10.48130/grares-0024-0028)

Dates

Received 29 October 2024; Revised 10 December 2024; Accepted 17 December 2024; Published online 23 January 2025

References

1. Labance B, Witteveen G. 2002. *Keepers of the green: a history of golf course management*. Chelsea, MI: Ann Arbor Press. 268 pp
2. Hurdzan MJ. 2004. *Golf greens: History, design, and construction*. Hoboken, NJ: John Wiley & Sons. 352 pp
3. Aylward L. 2010. How topdressing became an art: superintendents used to use wheelbarrows and shovels. How times have changed. *Golfdom* 66:38−40
4. Piper CV, Oakley RA. 1917. *Turf for golf courses*. New York: Macmillan
5. Green Section Staff. 1925. General treatment in the upkeep of greens. *The Bulletin of the United States Golf Association Green Section* 5:118
6. Bengeyfield WH. 1969. This year: Top-dress greens and see the difference. *USGA Green Section Record* 7:1−4
7. Carrow R. 1979. Topdressing: an essential management tool. *Golf Course Management* 47:26−32
8. Musser HB. 1950. *Turf management*. New York, NY: McGraw-Hill Book Company, Inc. 354 pp
9. Cooper R. 2004. Refining your putting green topdressing program. *North Carolina Turfgrass* 14:16−17
10. Madison JH, Paul JL, Davis WB. 1974. Alternative method of greens management. In *Proceedings of the Second International Turfgrass Research Conference*, ed. Roberts EC. US: American Society of Agronomy, Inc. and the Crop Science Society of America, Inc. pp. 429–37. doi: 10.2135/1974.proc2ndintlturfgrass.c65
11. Zontek SJ. 1979. Is sand topdressing right for you? *Golf Course Management* 47(6):15−21
12. Hall JR. 1978. Avoid the temptation of sand topdressing. *Mid-Atlantic Newsletter* 31:3−5
13. Hummel NW. 1995. Topdressing for success. *Cornell University Turfgrass Times* 5:8−9
14. O'Brien P, Hartwiger C. 2003. Aeration and topdressing for the 21st century: Two old concepts are linked together to offer up-to-date recommendations. *USGA Green Section Record* 41:1−7
15. Beard JB. 2002. *Turf management for golf courses*. Chelsea, MI: Ann Arbor Press. 793 pp
16. Kowalewski AR, Rogers JN III, Crum JR, Dunne JC. 2010. Sand topdressing applications improve shear strength and turfgrass density on trafficked athletic fields. *HortTechnology* 20:867−72
17. Inguagiato JC, Murphy JA, Clarke BB. 2012. Sand topdressing rate and interval effects on anthracnose severity of an annual bluegrass putting green. *Crop Science* 52:1406−15
18. Hempfling JW, Schmid CJ, Wang R, Clarke BB, Murphy JA. 2017. Best management practices effects on anthracnose disease of annual bluegrass. *Crop Science* 57:602−10
19. Gaussoin RE, Berndt WL, Dockrell CA, Drijber RA. 2013. Characterization, development, and management of organic matter in turfgrass systems. In *Turfgrass: Biology, Use, and Management*, eds Stier JC, Horgan BP, Bonos SA. US: American Society of Agronomy, Soil Science Society of America, Crop Science Society of America. Volume 56. pp. 425–56. doi: 10.2134/agronmonogr56.c12
20. Christians NE. 2011. *Fundamentals of turfgrass management*, 4th edition. Hoboken, NJ, USA: John Wiley & Sons. 359 pp
21. Murphy JA. 2012. The size of topdressing sand: does it matter? *USGA Green Section Record* 50: 1−4
22. Wang R, Hempfling JW, Clarke BB, Murphy JA. 2018. Seasonal and annual topdressing effects on anthracnose of annual bluegrass. *Agronomy Journal* 110:2130−35
23. Wang R, Murphy JA, Giménez D. 2021. Velvet bentgrass putting green quality, water retention, and infiltration as affected by topdressing sand size and rate. *Agronomy Journal* 113:3857−70

24. Anonymous. 1977. Sand topdressing plan boosts infiltration rates. *Golf Superintendent* 45:68
25. McCarty LB, Gregg MF, Toler JE, Camberato JJ, Hill HS. 2005. Minimizing thatch and mat development in a newly seeded creeping bentgrass golf green. *Crop Science* 45:1529−35
26. Kauffman JM, Sorochan JC, Brosnan JT. 2011. Brushing plus vibratory rolling enhances topdressing incorporation on ultradwarf bermudagrass putting greens. *Applied Turfgrass Science* 8:1−8
27. United States Golf Association. 2018. USGA recommendations for a method of putting green construction. Far Hills, NJ: USGA.
28. Hempfling JW, Clarke BB, Murphy JA. 2015. Anthracnose disease on annual bluegrass as influenced by spring and summer topdressing. *Crop Science* 55:437−43
29. Wang R, Hempfling JW, Clarke BB, Murphy JA. 2020. Sand size affects topdressing removed by mowing and anthracnose on annual bluegrass putting green turf. *HortScience* 55:237−43
30. Moeller AC. 2008. *Evaluation of putting green surface organic matter management programs*. Thesis. Purdue Univeristy, US
31. Taylor DH. 1986. Points of caution: sand size for topdressing golf greens. *Golf Course Management* 54:50,52,54,58,60,62
32. Beard JB. 1973. *Turfgrass: science and culture*. Englewood Cliffs, NJ: Prentice Hall. 658 pp
33. Ledeboer FB, Skogley CR. 1967. Investigations into the nature of thatch and methods for its decomposition. *Agronomy Journal* 59:320−23
34. Hurto KA, Turgeon AJ, Spomer LA. 1980. Physical characteristics of thatch as a turfgrass growing medium. *Agronomy Journal* 72:165−67
35. White RH, Dickens R. 1984. Thatch accumulation in bermudagrass as influenced by cultural practices. *Agronomy Journal* 76:19−22
36. Thompson WR, Ward CY. 1966. Prevent thatch accumulation of Tifgreen bermudagrass greens. *The Golf Superintendent* 34:20,38
37. Carrow RN. 2004. Surface organic matter in bermudagrass greens: a primary stress? *Golf Course Management* 72:102−05
38. Callahan LM, Sanders WL, Parham JM, Harper CA, Lester LD, et al. 1997. Comparative methods of measuring thatch on a creeping bentgrass green. *Crop Science* 37:230−34
39. Dalal RC, Allen DE, Chan KY, Singh BP. 2011. Soil organic matter, soil health and climate change. In *Soil Health and Climate Change*, eds Singh BP, Cowie AL, Chan KY. Berlin, Heidelberg: Springer. Vol 29. pp. 87−106 doi: 10.1007/978-3-642-20256-8_5
40. Cotrufo MF, Soong JL, Horton AJ, Campbell EE, Haddix ML, et al. 2015. Formation of soil organic matter via biochemical and physical pathways of litter mass loss. *Nature Geoscience* 8:776−79
41. Cotrufo MF, Wallenstein MD, Boot CM, Denef K, Paul E. 2013. The Microbial Efficiency-Matrix Stabilization (MEMS) framework integrates plant litter decomposition with soil organic matter stabilization: do labile plant inputs form stable soil organic matter? *Global Change Biology* 19:988−95
42. Wang R, Mattox CM, Phillips CL, Kowalewski AR. 2022. Carbon sequestration in turfgrass–soil systems. *Plants* 11:2478
43. Qian Y, Follett RF. 2002. Assessing soil carbon sequestration in turfgrass systems using long-term soil testing data. *Agronomy Journal* 94:930−35
44. Evers M, de Kroon H, Visser E, de Caluwe H. 2020. Carbon accumulation of cool season sports turfgrass species in distinctive soil layers. *Agronomy Journal* 112:3435−49
45. McCarty LB, Gregg MF, Toler JE. 2007. Thatch and mat management in an established creeping bentgrass golf green. *Agronomy Journal* 99:1530−37
46. Stier JC, Hollman AB. 2003. Cultivation and topdressing requirements for thatch management in A and G bentgrasses and creeping bluegrass. *HortScience* 38:1227−31
47. Vavrek RC. 1995. A successful topdressing program requires consistency, commitment, and communication. *USGA Green Section Record* 33:8−10
48. Rieke PE, McElroy MT, Lee D. 1988. Turfgrass soil research report: [I. Topdressing programs and nitrogen fertility]. *Proc. 58th Annual Michigan Turfgrass Conference, Michigan, 1988*. Michigan State University, East Lansing, MI. pp. 2−6
49. Espevig T, Molteberg B, Tronsmo AM, Tronsmo A, Aamlid TS. 2012. Thatch control in newly established velvet bentgrass putting greens in Scandinavia. *Crop Science* 52:371−82
50. Kauffman JM, Sorochan JC, Kopsell DA. 2013. Field sampling warm-season putting greens for thatch-mat depth and organic matter content. *HortTechnology* 23:369−75
51. Shaddox TW, Unruh JB. 2019. Correlating methods of measuring zoysiagrass thatch. *Crop Science* 59:792−99
52. Engel RE, Alderfer R. 1968. The effect of cultivation, topdressing, lime, nitrogen and wetting agent on thatch development in 1/4-inch bentgrass turf over a ten-year period. *Report on Turfgrass Research at Rutgers University*, Rutgers University, US. pp. 32−45
53. Rieke PE, McElroy MT, Lee D. 1988. Turfgrass soil research report: [II. Soil and peat as amendments for sand topdressing]. *Proc. 58th Annual Michigan Turfgrass Conference, Michigan, 1988*. East Lansing, MI: Michigan State University. pp. 4,6–8.
54. Barton L, Wan GGY, Buck RP, Colmer TD. 2009. Effectiveness of cultural thatch-mat controls for young and mature kikuyu turfgrass. *Agronomy Journal* 101:67−74
55. Carrow RN, Johnson BJ, Burns RE. 1987. Thatch and quality of Tifway bermudagrass turf in relation to fertility and cultivation. *Agronomy Journal* 79:524−30
56. Callahan LM, Sanders WL, Parham JM, Harper CA, Lester LD, et al. 1998. Cultural and chemical controls of thatch and their influence on rootzone nutrients in a bentgrass green. *Crop Science* 38:181−87
57. Beard JB. 1978. Topdressing overview. *Proc. 48th Annual Michigan Turfgrass Conference, 1978*. 7: 36−39
58. Cooper R, Skogley C. 1981. Putting green and sand/soil responses to sand topdressing. *USGA Green Section Record* 19:8−13
59. Davis WB. 1977. Sands and your putting green. *California Turfgrass Culture* 27:31−32
60. Fermanian TW, Haley JE, Burns RE. 1985. The effects of sand topdressing on a heavily thatched creeping bentgrass turf. *International Turfgrass Society Research Journal* 5:439−48
61. Zontek SJ. 1983. Mismanagement in topdressing greens. *Proc. 53rd Annual Michigan Turfgrass Conference, Michigan, 1983*. 12:82−84
62. Carrow RN. 2003. Surface organic matter in bentgrass greens. *USGA Turfgrass and Environmental Research Online* 2:1−12
63. Motulsky HJ, Brown RE. 2006. Detecting outliers when fitting data with nonlinear regression – a new method based on robust nonlinear regression and the false discovery rate. *BMC Bioinformatics* 7:123
64. Carley DS, Goodman D, Sermons S, Shi W, Bowman D, et al. 2011. Soil organic matter accumulation in creeping bentgrass greens: a chronosequence with implications for management and carbon sequestration. *Agronomy Journal* 103:604−10
65. Glasgow A, Gibbs R, McAuliffe K, Liu C. 2005. An investigation of organic matter levels in New Zealand golf greens. *International Turfgrass Society Research Journal* 10:1078−84
66. Phillips CL, Wang R, Mattox C, Trammell TLE, Young J, et al. 2023. High soil carbon sequestration rates persist several decades in turfgrass systems: a meta-analysis. *Science of The Total Environment* 858:159974
67. von Haden AC, Yang WH, DeLucia EH. 2020. Soils' dirty little secret: depth-based comparisons can be inadequate for quantifying changes in soil organic carbon and other mineral soil properties. *Global Change Biology* 26:3759−70
68. Mu Y, Carroll MJ. 2013. Thatch and soil microbial activity in recently cultivated turfgrass. *International Turfgrass Society Research Journal* 12:567−74
69. Miller DE, Gardner WH. 1962. Water infiltration into stratified soil. *Soil Science Society of America Journal* 26:115−19
70. Couillard A, Turgeon AJ, Shenk JS, Westerhaus MO. 1997. Near infrared reflectance spectroscopy for analysis of turf soil profiles. *Crop Science* 37:1554−59