CULTIVATION AND TOPDRESSING SAND COLOR EFFECTS ON CREEPING BENTGRASS GOLF GREENS

By

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To the Faculty of Washington State University:

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CULTIVATION AND TOPDRESSING SAND COLOR EFFECTS

ON BENTGRASS GOLF GREENS

Abstract

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Field studies were conducted at two locations in Pullman, WA, over two growing seasons (2008 and 2009) to determine the effects of cultivation method, cultivation timing, and topdressing sand color on thatch-mat management, golf green surface injury, and golf green surface quality of a ‘T-1’ creeping bentgrass (*Agrostis stolonifera* L.) golf green.

The field study at the Palouse Ridge Golf Club evaluated six cultivation methods and two topdressing materials for their ability to manage thatch-mat accumulation and minimize injury to the golf green. Cultivation treatments included core removal, venting, vertical mowing, and combination treatments in conjunction with black sand (BS) topdressing and tan sand (TS) topdressing and an untreated control (UTC). Within a cultivation method, BS resulted in fewer days injured when compared to TS. Black sand also improved turfgrass quality and color over TS. Cultivation methods with more severe injury resulted in a greater decrease in turfgrass quality. Vertical mowing resulted in the greatest thatch-mat layer, while the UTC had the least; however, the thatch-mat organic matter content was inversely related to thatch-mat depth with the UTC being greatest and vertical mowing being least. Cultivation method had no impact on ball roll distance (BRD), but BRD measured before cultivation was greater than after cultivation.

The field study at the WSU Turfgrass and Agronomy Research Center investigated the effects on the number of days to recovery after aeration and on turfgrass quality and color of core aeration applied at 9 or 11(2008 or 2009) dates using two types of topdressing sand. In the spring, mid-May aeration resulted in the fewest days to recovery. In the fall, mid-August to mid-September aeration was quickest to recover. Black sand resulted in fewer days to recover than TS in the fall. Additionally, BS improved turfgrass quality and color, especially in the spring and fall. Black sand also increased soil temperature within an aeration date over TS.

Selecting the appropriate cultivation method and timing with BS topdressing in spring and fall can minimize injury while managing thatch-mat and maintaining acceptable golf green quality.

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Dedication

This thesis is dedicated to my wife, Kara. I could not have done it were it not for your love, support, and encouragement.

LITERATURE REVIEW

Creeping Bentgrass

Creeping bentgrass (*Agrostis stolonifera* L.) is the primary turfgrass species used on high quality golf greens in the temperate regions of the world (Christians, 2004). Newer cultivars of creeping bentgrass have been developed with upright growth habit, high shoot density, fine texture, and good recuperative potential to achieve a uniform, high quality putting surface (Fraser, 1998; Landry and Schlossberg, 2001; Sifers et al., 2001; Stier and Hollman, 2003; Toubakaris and McCarty, 2000). While these newer cultivars of creeping bentgrass produce a higher quality putting surface, the dense growth habit of these plants may require more intense management regimes. Sifers et al. (2001) reported that bentgrass cultivars with high shoot density had the highest thatch-mat depth and the highest shoot-thatch-mat dry weight. This would suggest that over time these bentgrass cultivars may require a lower height of cut and more intense cultivation and topdressing practices to properly control biomass and thatch-mat accumulation (Landry and Schlossberg, 2001; Sifers et al., 2001).

Thatch-Mat

Thatch has been defined as an intermingled organic layer of dead and living shoots, stems, and roots that develops between the zone of green vegetation and the soil surface (Beard, 1973; Shildrick, 1985). Thatch is mainly formed from periodically sloughed roots, stolons, rhizomes, stubble, and mature leaf sheaths and blades (Engel, 1954; Wilson, 1953). When conditions allow surface organic debris to accumulate faster than it is decomposed, thatch is formed. Hurto et al. (1980) describes thatch development as any climatic, edaphic, or biotic factor that stimulates excessive plant growth or inhibits the decomposition of organic material. Soil fauna, primarily fungi and bacteria, are responsible for the degradation of thatch (Beard, 1973; Engel, 1954; Hurto et al., 1980; Martin and Beard, 1975; Shildrick, 1985).

Mat is a tightly intermingled layer of soil and thatch that forms when thatch is slow to decompose following sand topdressing (Beard, 1973; Beard, 1980; Turgeon, 2008; Williams and McCarty, 2005). It is often difficult to distinguish between the thatch and mat layers; therefore, they are commonly referred to as a thatch-mat layer. Soil conditions, which favor fungi and bacteria, such as adequate oxygen availability, low soil pH, and adequate soil moisture and temperature will result in a decrease in thatch (Engel, 1954; Martin and Beard, 1975; Shildrick, 1985). A moderate thatch-mat layer is desirable, as it provides cushion, improved wear tolerance, is less susceptibility to soil compaction, and has surface resiliency (Beard, 2002; Hurto et al., 1980; Wilson, 1953). Excess thatch-mat, however, may result in increased disease and insect problems, localized dry spots, excessive water holding capacity, increased puffiness, footprinting, slower putting green speed, increased injury due to environmental stress, and a susceptibility for mower scalping (Beard, 2002; Engel, 1954; Hurto et al., 1980; Shildrick, 1985; Wilson, 1953).

Golf Green Quality

This leads to the question, what makes a championship golf green? In general terms, a green should be firm and true. In 1947, the USGA defined an ideal golf green surface as being: “Firm to avoid footprinting and should be resilient so that a properly played shot will hold, but should be sufficiently solid so that a poorly-played shot will roll over. The surface should be smooth and true as a billiard table. Density of the turf should be so great that individual grass blades are crowded to a true vertical position. Graininess, sponge or mat destroy accuracy and the fun in golf (Anonymous, 1947, p. 1).” Wilson (1953, p. 25-26) addresses this question by saying: “The golfer is entitled to uniform putting conditions. Graininess, ball scars, slow putting, scuffing, foot printing, and slow healing cannot, therefore, be tolerated. All of these hindrances to enjoyable golf are directly or indirectly influenced by mat build-up. The golfer, further, is entitled to a reward for a properly made approach shot. A spongy cushion of mat will not hold a proper shot under dry conditions. When it is thoroughly saturated, such a green will hold even the poorest shots, thus placing no reward on the accuracy and skill which is part of the game.” Lemons (2008, p. 1), quoting from the September 1967 USGA Green Section Record, says that: “Championship greens should be fast and uniformly paced, firm but resilient. They should place a premium on well-executed shots, while exacting a penalty for less precise shots.”

Components of golf green quality include absence of grain, firmness, smoothness, resiliency, and uniformity (Beard, 2002). Putting speed refers to ball roll distance, not velocity, and is widely used and commonly accepted as a method to describe golf green playability (Salaiz et al., 1995). All factors except resiliency have an effect on putting green speed and trueness (Salaiz et al., 1995). The ‘Stimpmeter’ was developed by the United States Golf Association in 1978 to measure ball roll distance or green speed (Hoos, 1982). Stimpmeter methodology has been created to try to minimize measurement inaccuracies (Beard, 2002; Hoos, 1982; Radko, 1980). Researchers have reported a general decrease in ball roll distance following cultivation practices (Karcher et al., 2000; McCarty et al., 2007; Salaiz et al., 1995)

Cultivation and Topdressing

Mechanical cultivation and topdressing are commonly used methods to manage thatch-mat and improve golf green quality. Core aeration and vertical mowing physically remove thatch. Additionally, core aeration may also provide benefits such as reduced surface compaction, improved water infiltration rates, and increased surface aeration and rooting (Brauen et al., 1999; Carrow et al., 1987; Ledeboer and Skogley, 1967; McCarty et al., 2007; Murphy et al., 1993; Shildrick, 1985; White and Dickens, 1984). McCarty et al. (2007) noted that four core cultivations per year maintained the organic matter (OM) content of the thatch-mat layer at pre-study levels and reduced the thatch-mat depth by 10% compared to topdressing alone. In addition, water infiltration rates for core cultivation treatments increased from 130 to 169% compared to the untreated control (UTC), without a reduction in turfgrass quality to below acceptable levels. White and Dickens (1984) found no difference between semiannual or monthly core cultivation in total OM or thatch levels using 6.4-cm-diameter tines, 7 cm deep, on 5 cm centers. They also stated that cultivation frequency did not affect turfgrass quality, but monthly cultivation reduced turfgrass scalping. Smith (1979) determined twice yearly and monthly core cultivation with 1.25-cm-diam. hollow tines at 5 cm depth slightly diminished thatch thickness; however, monthly cultivation did not result in additional benefits compared to semi-yearly cultivation. The major disadvantage associated with core cultivation is the disruption caused to the golf green surface (Skorulski, 1998). Typically, the severity of disruption is related to the length of time to recovery. Stated another way, larger tines result in longer recovery. In addition, small diameter tines with close spacing can remove as much OM as larger diameter tines on wider spacing

(Hartwiger and O'Brien, 2001; Landreth et al., 2007; Murphy and Rieke, 1990). The disadvantage with smaller core holes is it can be difficult to work topdressing sand into the holes following cultivation.

Salaiz et al. (1995) found that light vertical mowing enhanced putting green speed by increasing surface smoothness and controlling turfgrass grain. McCarty et al. (2007) reported vertical mowing had no detrimental effect on turfgrass quality, but ball roll distance was decreased by 6% 7 d after treatment compared to the UTC. It was also noted that vertical mowing increased water infiltration by 54% compared to the untreated control. Boesch and Mitkowski (2007) found that velvet bentgrass (*Agrostis canina* L.), in general, was completely recovered from injury 3 to 4 weeks after vertical mowing.

Venting is a cultivation method used to increase soil oxygen content and assist gas exchange without removing OM while causing minimal surface disruption (Brame, 1999; Fontanier and Steinke, 2008; Piller, 2006; Schmid et al., 2008; Wolff, 2008). Adequate levels of soil oxygen help aerobic soil microbes to decompose OM and enhance root health and growth (Bunnell and McCarty, 1999; Chong et al., 2004; Green et al., 2001).

It has been recognized that topdressing is an effective practice for controlling thatch by improving the microenvironment for thatch decomposition (Ledeboer and Skogley, 1967). Others suggest that OM reduction from topdressing is due to thatch-mat dilution (Couillard et al., 1997; Rieke, 1994). There is inconsistency within the literature on topdressing effects on thatch-mat levels (McCarty et al., 2007; Rieke, 1994; Smith, 1979). Eggens (1980) found topdressing alone to be effective in controlling thatch in ‘Penncross’ creeping bentgrass. Carrow et al. (1987) found that one or two topdressing applications reduced thatch in 'Tifway' bermudagrass (*Cynodon dactylon* L.) by 44 and 62%, respectively. Both White and Dickens (1984) and Callahan et al. (1998) found that increasing the number of annual topdressing sand applications decreased thatch. McCarty et al. (2007) found that topdressing sand alone failed to control thatch-mat accumulation or improve water infiltration; however, turfgrass quality and water infiltration on treatments receiving topdressing sand was excellent. In addition, topdressing sand alone maintained OM content at pre-study levels. Dunn et al. (1995) observed that mat OM was greater with no topdressing compared to topdressing on 'Meyer' zoysiagrass (*Zoysia japonica* Steud.). Different thatch measurement methods, such as thatch thickness, percentage OM, actual OM, or volumetric OM could explain some of the discrepancies in thatch control studies (Couillard et al., 1997).

Dark Color Topdressing and Soil Warming

Different methods have been utilized to delay fall dormancy or improve spring green-up on turfgrass. Golf courses in South Florida have used a charcoal-sand topdressing mix in the winter to enhance turf color and quality (Foy, 1990). It has been noted that there is little nutrient value in charcoal, but a marked deepening of turfgrass color follows application (Anonymous, 1980). However, the Green Section of the U.S. Golf Association in1926 reported no beneficial results from the use of charcoal as topdressing and that the best that can be said is that it does no harm (Anonymous, 1926). Street et al. (2007) compared the effect of crumb rubber, green sand, 'Milorganite', and a polyethylene 'Evergreen Turf Cover' on fall color retention and spring green-up of a bermudagrass sports field. They found that the use of an Evergreen Turf Cover resulted in the most rapid spring green-up and the best fall color retention, with soil temperatures

1.7 to 2.0^{0}C higher than the UTC. In addition, Milorganite provided higher soil temperatures than the other treatments with the exception of the Evergreen Turf Cover, but resulted in an unacceptable playing surface. Research by Taylor (2001) found that both spring soil and surface temperatures on creeping bentgrass golf greens increased when topdressed in late fall with dark-colored topdressing sand and enhanced turfgrass color and growth in the spring. The color effect was attributed in part to reduced winter desiccation and higher soil temperature. Recently, black sand (BS) has been used in place of charcoal or Milorganite as a topdressing material to delay fall dormancy, reduce winter damage, and improve spring green-up. Hamilton (2003) noted that BS applied at both 19,529 kg ha^{-1} and 39,058 kg ha^{-1} resulted in acceptable turfgrass color and increased surface temperature when applied in either fall or spring. At The Pennsylvania State University, researchers found when comparing BS topdressing to white polyethylene turf covers there was no difference in turfgrass color ratings; however, the BS treatment resulted in 29% more tillering (Hamilton and Raley, 2004). Golob et al. (2008) noted BS treatments had higher soil temperatures compared to tan sand (TS) and polyethylene covers in a creeping bentrgrass late fall grow-in study. When comparing TS topdressing, BS topdressing, or no topdressing, Bigelow et al. (2005) found that late season topdressing resulted in improved visual green-up rates for either sand at applications ≥ 14,700 kg ha^{-1} with the greatest affect occurring at 19,600 kg ha^{-1}. Black sand at 19,600 kg ha^{-1} resulted in improved green-up ratings compared to the UTC at all three rating dates, however, the TS treatment showed improvement in green-up only at the first rating date.

Turfgrass Recuperative Potential

Optimal top growth for creeping bentgrass is between 16 and 24°C (Schmidt and Blaser, 1967). Hawes and Decker (1977) found clipping yield to be a good indicator of the healing potential of creeping bentgrass and that as soil temperature increased clipping yields increased. Increasing N rates increases shoot growth (Beard, 1973; Hawes and Decker, 1977; Madison, 1962; Markland and Roberts, 1969) and N uptake by roots also increases with temperature up to the optimal range (Xu and Huang, 2006; Younis et al., 1965). Related to this, N mineralization and immobilization due to soil microbial activity increases with temperature (Agehara and Warncke, 2005; Terry et al., 1981; Wang et al, 2003). Urea hydrolysis and urease activity are both positively influenced by soil temperature and moisture (Moyo et al., 1989; Sadeghi et al., 1988; Sahrawat, 1984). Another factor affecting turfgrass growth is soil temperature. Root growth can occur at 1.6°C; generally, top growth begins when soil temperatures are > 10°C in cool-season grasses (Beard, 1973; Hanson and Juska, 1961). Low soil temperatures slow root uptake of N (Madison, 1960; Parks and Fischer, 1958).

Many consider an indirect method for measuring plant's ability to recover from injury is by measuring the total nonstructural carbohydrate (TNC) levels of turfgrass (Beard, 1973; Busso et al., 1990; Sheffer et al., 1979). One indicator of the effect of various management practices on plant vigor is to measure the quantity of TNC (White, 1973). Narra et al. (2004) found that different mowing heights resulted in differences in TNC for creeping bentgrass and that all mowing heights tested had seasonal changes in TNC. Total nonstructural carbohydrate levels started decreasing in mid-July with the lowest content in August, while there was an increase in TNC in September with the highest amount seen in October and November. Fu and Dernoeden (2009) reported shoot respiration and photosynthetic rates were not affected by core aerating creeping bentgrass greens; however, they did note a decrease in root TNC in July followed by an increase in leaf and root TNC in September.

Objectives

In the Intermountain Pacific Northwest the turfgrass growing season is relatively short, typically mid-March through mid-October. In order to avoid injuring putting surfaces during the peak of the short golf season, turfgrass managers often postpone disruptive cultivation methods. This may lead to cultivation practices occurring when growing conditions are sub-optimal. The objectives of this research were to determine what time of year resulted in the shortest recovery time from green cultivation injury, what cultivation methods were least disruptive yet resulted in a desirable playing surface for greens, and finally, determine what effect the use of BS topdressing had on recovery time from cultivation and golf green quality when compared to TS topdressing.

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CHAPTER I

CULTIVATION METHOD AND TOPDRESSING SAND COLOR EFFECTS ON INJURY, QUALITY, AND THATCH-MAT OF A CREEPING BENTGRASS GOLF GREEN

ABSTRACT

Cultivation and topdressing are commonly used methods to manage thatch-mat on creeping bentgrass (*Agrostis stolonifera* L.) golf greens. Disruption caused by these practices reduces the quality of the golf green playing surface. This study investigated the ability of various cultivation and topdressing practices to minimize thatch-mat accumulation while causing minimal surface disruption on a 'T-1' creeping bentgrass golf green. The cultivation treatments included core removal with large tines (CRL), venting (VT), vertical mowing (VM), core removal with large tines plus venting (CRL + VT), and core removal with large or small tines plus vertical mowing (CRL + VM; CRS + VM). Topdressing treatments used black sand (BS) and tan sand (TS). In 2008, CRS + VM had the fewest days injured and maintained acceptable turfgrass quality; VM had the most days injured, but turfgrass quality was not negatively affected. The CRL treatment showed an intermediate number of days injured; however, turfgrass quality was negatively affected by this cultivation method. Overall, BS treatments had a lower percentage of days injured compared to TS. In 2009, CRS + VM again was one of the least injured treatments. For both years, quality was consistently higher with BS compared to TS within a cultivation treatment. VM plus BS had the highest soil temperature and thatch-mat depth compared to the untreated control (UTC). Sand type did not influence thatch-mat depth. Vertical mowing had the greatest thatch-mat depth while UTC had the least, all other treatments were intermediate. The thatch-mat organic matter content was inversely related to the thatch-mat depth. In 2008, all but the VM with TS had the same infiltration rates. Vertical mowing had the slowest infiltration in 2009; notably, the VT with BS infiltration rate only decreased by 5% from one year to the next, which was the smallest decrease of any treatment. VM with BS consistently had the highest turfgrass color and all BS treatments ranked as good as or better than TS. Cultivation and topdressing sand had no influence on ball roll distance; however, ball roll distance did decrease after cultivation treatments compared with measurements taken before cultivation. Based on the current study, CRS + VM was the cultivation method that had relatively low percentage of injured days, managed OM, and had excellent turfgrass quality and color when topdressed with BS.

Abbreviations: TS, tan sand; BS, black sand; CRL, core removal large tines; VT, venting; VM, vertical mowing; CRL + VT, core removal large tines plus venting; CRL + VM, core removal large tines plus vertical mowing; CRS + VM, core removal small tines plus vertical mowing; UTC, untreated control; OC, organic carbon; LOI, loss on ignition; OM, organic matter.

INTRODUCTION

High quality putting greens grown in temperate climates are primarily creeping bentgrass (*Agrostis stolonifera* L.) (Christians, 2004). Newer cultivars of creeping bentgrass with upright growth habit, high shoot density, fine texture, and good recuperative potential have been developed for their desired ability to form a uniform, high quality putting surface (Fraser, 1998; Landry and Schlossberg, 2001; Sifers et al., 2001; Toubakaris and McCarty, 2000). Although these newer cultivars provide exceptional putting surfaces their dense growth habit requires more intensive management regimes. Over time, these bentgrass cultivars may require a lower height of cut and more intense cultivation and topdressing practices to properly control biomass and thatch-mat accumulation (Landry and Schlossberg, 2001; Sifers et al., 2001).

Thatch is a combined organic layer of dead and living shoots, stems, and roots accumulated between the zone of green vegetation and the soil surface (Beard, 2002; Shildrick, 1985). A sufficient thatch layer is desirable because it provides cushion, improved wear tolerance, reduced susceptibility to soil compaction, and surface resiliency (Beard, 2002; Hurto et al., 1980; Wilson, 1953). Excess thatch, however, may result in increased disease and insect problems, localized dry spots, excessive water holding capacity, increased puffiness, footprinting, slower putting, an increase of injury due to environmental stress, and a tendency for mower scalping (Beard, 2002; Engle, 1954; Hurto et al., 1980; Shildrick, 1985; Wilson, 1953). Mat is a tightly intermingled layer of soil and thatch that forms when thatch is slow to decompose following sand topdressing (Beard, 1973; Beard, 1980; Turgeon, 2008; Williams and McCarty, 2005). It is often difficult to distinguish between the thatch and mat layers and together they are commonly referred to as a thatch-mat layer.

Mechanical cultivation and topdressing are commonly used to manage thatch-mat and improve putting green quality. Core aeration is often beneficial, since it physically removes thatch, reduces surface compaction, improves water infiltration rates, and increases surface aeration and rooting (Brauen et al., 1999; Carrow et al., 1987; Ledeboer and Skogley, 1967; McCarty et al., 2007; Murphy et al., 1993; Shildrick, 1985; White and Dickens, 1984). However, Skorulski (1998) stated that disruption to the golf green surface is the major disadvantage associated with core aeration. Salaiz et al. (1995) found that light vertical mowing enhanced putting green speed by increasing surface smoothness and controlling turfgrass grain. McCarty et al. (2007) reported vertical mowing had no detrimental effect on turfgrass quality, but did show that ball roll distance was decreased by 6% 7 d after treatment compared with the untreated control. Venting has been shown to increase soil oxygen content and assist gas exchange without removing organic matter or causing excessive surface disruption (Brame, 1999; Fontanier and Steinke, 2008; Schmid et al., 2008; Piller, 2006; Wolff, 2008). Topdressing has been recognized as an effective practice for managing thatch by either improving the microenvironment for thatch decomposition or thatch dilution; however, it is likely a combination of the two (Couillard et al., 1997; Ledeboer and Skogley, 1967; Rieke, 1994).

Historically, different topdressing media have been utilized to delay fall dormancy or improve spring green-up of turfgrasses. Charcoal and sand topdressing mix has been used to enhance turf color and quality during the winter (Foy, 1990). More recently, black sand has been used in place of charcoal or 'Milorganite' as topdressing to delay fall dormancy, reduce winter damage, and improve spring green-up. Hamilton (2003) noted that black sand resulted in acceptable turf color and increased surface temperature when applied in either fall or spring.

The Intermountain Pacific Northwest has a relatively short growing season, typically mid-March through mid-October. As a result many turfgrass managers avoid disruptive cultivation methods during the peak of an already short golf season. The objective of this study was to determine the least disruptive cultivation method in combination with sand topdressing that maintains OM at acceptable levels and result in an acceptable playing surface.

MATERIALS AND METHODS

Experimental Area

A field study was conducted at the Palouse Ridge Golf Club at Washington State University, Pullman, WA over two growing seasons (2008 and 2009). The experimental area was a practice green constructed according to California green specifications (Beard, 1973; Christians, 2004). The green was seeded June 2007 with 'T-1' creeping bentgrass and the golf course practice facility opened for play June 2008. The green was maintained by golf course maintenance staff. It was mowed 4 to 6 times per week at a height of cut of 2.8 mm and irrigation was applied to avoid drought stress while maintaining a firm playing surface. Yearly fertilizer applications provided 150 kg N ha^{-1}, 32 kg P ha^{-1}, and 21 kg K ha^{-1}. The total study area was 12.2 × 15.9 m. Experimental units were 1.22 × 1.52 m arranged in a split block with four randomized complete blocks.

Treatments

The topdressing and cultivation treatments evaluated were a 2 x 7 factorial of topdressing sand type and cultivation method with 4 replications (Table 1.1). The topdressing sand, tan topdressing sand (TS) (Atlas Sand and Rock, Lewiston, ID), or black topdressing sand (BS) (Grass Roots Agronomics Inc., Emmett, ID), was applied immediately following cultivation using a drop spreader (Model 30, Gandy Company, Owatonna, MN). The topdressing sand was applied at a rate dependent on cultivation method (Table 1.1). Particle size distribution of the TS and BS met USGA specifications (Table 1.2). The cultivation treatments were: untreated control (UTC), core removal large tine (CRL), venting (VT), vertical mowing (VM), CRL + VT, CRL + VM, and core removal small tine (CRS) + VM. The UTC received no topdressing sand and no cultivation.

Core Removal

Core removal with large tines was accomplished with 12.7-mm-diameter side eject hollow tines (R&R Products Inc., Tucson, AZ) on a core cultivator (Model GreensAire 24, Ryan, Inc., Barrington, IL) with a tine depth of 76.2 mm on 50 mm centers. Core removal with small tines had 6.4-mm-diameter tines on 25.4 mm centers. Cores were removed from the surface and then topdressing sand was applied. Topdressing sand for CRL treatments was applied at 39,074 kg ha^{-1} TS for the TS treatments and 19,483 kg ha^{-1} TS brushed in followed by 19,483 kg ha^{-1} BS for the BS treatments. Topdressing sand for CRS was applied at 19,483 kg ha^{-1} TS for the TS treatments and 9,795 kg ha^{-1} TS applied and brushed in followed by 9,795 kg ha^{-1} BS for the BS treatments. Black sand treatments were a combination of BS and TS in order to reduce cost and duplicate how BS is commonly used on golf courses. Topdressing sand was brushed into aeration holes using a hand push broom.

Core removal with large tines treatments were applied on 12 May, 18 June, 4 Sept., and 3 Oct. 2008, and 15 May and 4 Sept. 2009.

Venting

Venting was performed using a planetary gear shatter knife cultivator (model HD 50 Tow, PlanetAir Turf Products LLC, Owatonna, MN) with 3-mm-width tines to a depth of 100 mm on 50 mm centers. Venting treatments were applied every 3 wk beginning on 15 May ± 3 d and continuing through 22 Sept. 2008 and 28 Aug. 2009. Topdressing sand was applied following cultivation at 9,795 kg ha^{-1} for both TS and BS treatments and was brushed in using a hand push broom.

Vertical Mowing

Vertical mowing was done with a triplex greens mower (model Greens King IV, Jacobsen, Charlotte, NC) with 1-mm-wide blades spaced at 20 mm and cutting 5 mm deep to remove organic matter (OM) down to the soil level. In 2008, VM treatments were applied weekly beginning on 12 May and continuing through 26 September. Topdressing sand was applied following cultivation at a rate of 9,795 kg ha^{-1} for both TS and BS treatments. The topdressing sand was brushed in using a hand push broom.

With weekly VM, treatments did not always fully recover before the next treatment was applied. Therefore, in order to allow treatments to fully recover between applications, the 2009 VM treatments were applied every 3 wk beginning on 15 May and continuing through 28 August. Topdressing sand was applied the same in both years.

Core Removal plus Venting

Core removal with large tines was combined with VT into one treatment, CRL + VT. Cores were removed in the spring only on 15 May ± 3 d. When the aeration holes fully recovered VT treatments were applied every 3 wk beginning 28 May ± 3 d continuing until 22 Sept. 2008 and 28 Aug. 2009.

Core Removal plus Vertical Mowing

Core removal with large tines and CRS were combined with VM into two treatments, CRL + VM and CRS + VM. Cores were removed in the spring and fall on 15 May ± 3 d and 1 September ± 3 d. When the spring aeration holes fully recovered VM treatments were applied every 3 wk beginning 28 May ± 3 d until the fall aeration was performed.

Treatment Parameters

Treatment effects evaluated as visual injury, turfgrass quality, soil temperature, thatch-mat depth, thatch-mat and soil OM content, and water infiltration. Turfgrass color and ball roll distance were recorded in 2009 only.

Visual Injury

Visual injury was rated on a scale of 1 to 9; 9 was no detectable disruption from cultivation and 1 was over 95% of plot area injured from cultivation treatment. Visual injury was rated semi-weekly from May to September. In 2008, aeration core hole diameter was measured along with visual injury using a digital caliper (Carrera Precision, Max Tool, La Verne, CA). Five measurements were taken per plot. The core holes measured were randomly selected to provide a representative sample. Visual injury ratings were negatively correlated ($R^2 = .88$) with core hole diameter measurements and therefore core hole diameter measurements were not collected in 2009 (Proctor, 2009). Visual injury data was used to determine the percentage of days treatments had less than a 9 visual injury rating.

Turfgrass Quality

Turfgrass quality was visually rated based on color, shoot density, and uniformity of stand on a scale of 1 to 9; 9 was ideal, dark green uniform turf, 6 was minimum acceptable quality, and 1 was dead turf. Turfgrass quality ratings were recorded semi-weekly from May to September.

Soil Temperature

In 2008, soil temperature was recorded weekly at a 7.5-cm-depth with a digital thermometer (Spectrum Technologies Inc., East-Plainfield, IL). One reading from the center of each plot was taken. The thermometer was never placed in an aeration core hole. The 7.5 cm depth was based on data collected by Chapman (1994). The 2008 data collected showed statistically significant treatment differences; however, it was unclear if the differences detected were large enough to affect plant function. Therefore, in 2009, temperatures were recorded weekly at a 2.5-cm-depth in an attempt to detect greater treatment differences in soil temperature.

Thatch-Mat Depth and Organic Matter Content

Thatch-mat depth and OM content were determined from 4 soil cores per plot (19-mm-diam. core and 102-mm-depth) collected on 17 Oct. 2008 and 26 Sept. 2009. Roots and soil below the thatch-mat layer and verdure above the thatch-mat layer were removed. Thatch-mat depth was measured on the uncompressed soil cores at two points (McCarty et al., 2007; Smith, 1979). The two thatch-mat depths were averaged for each treatment prior to statistical analysis. The thatch-mat cores were air dried and ground for 5 to 7 s using a coffee grinder (model F203, Krups, Millville, NJ) until homogenized. As the blades on the coffee grinder wore down, grinding time was increased so that the samples remained uniform. When this was no longer possible due to the condition of the coffee grinder blade, a new coffee grinder was used. In 2008, 1 subsample from each treatment was analyzed for organic carbon (OC) using a LECO C and N analyzer (Model TruSpec CN, LECO Corp., St. Joseph, MI). Due to the high cost of analysis for OC, the

2008 and the 2009 samples were analyzed using the loss on ignition (LOI) method to determine the OM content (%). Samples were homogenized using the same method describe above. The samples were oven dried at 105°C for 24 h. Three gram (±1 g) oven dry thatch-mat subsamples were placed in oven dry crucibles and heated at 600°C for 2h in a muffle furnace. The ashed weight minus the oven dry weight of the subsample was used to determine LOI. The LOI method was adapted from Dunn et al. (1995), Ledeboer and Skogley (1967), and Nelson (1996).

Soil OM content was determined using the root and soil portion of the same four cores collected for thatch-mat analysis. The soil cores were processed and analyzed for OC (2008) and LOI (2008 and 2009) using the methods described above.

Water Infiltration

Infiltration rates were measured using a double ring infiltrometer (model IN5-W, Turf-Tec International Inc., Tallahassee, Fl). The outside ring diameter was 30 cm and the inner ring was 15 cm × 10 cm tall. The infiltrometer was randomly placed in each plot and inserted 5 cm into the soil. Water was poured into the inner ring until both rings were full. After drainage initiation (90 s per plot), the rings were refilled and the time for the water to vacate the inner ring was measured and converted to cm h^{-1}. Water in the outer ring was kept at a constant head. One measurement per plot was taken 17 Oct. 2008 and 26 Sept. 2009.

Turfgrass Color

A chlorophyll meter (Field Scout CM 1000 NDVI Meter, Spectrum Technologies Inc., East-Plainfield, IL) was used in 2008 to record chlorophyll index values to quantify turfgrass color. The index values were consistently lower for BS treatments compared to

TS treatments. This was inconsistent with visual observations; therefore, visual turfgrass color ratings were taken in 2009. Turfgrass color was visually rated on a scale of 1 to 9; 9 was ideal, dark green turf, 6 was minimum acceptable green color, and 1 was brown turf. Turfgrass color ratings were recorded semi-weekly from May to October.

Ball Roll Distance

Ball roll distance was determined with a modified United States Golf Association 'Stimpmeter' (Gaussoin et al., 1995). The mean distance of three golf balls rolled directly downslope and then rerolled upslope was measured for each plot. The effect of slope on ball roll distance was eliminated by using a corrected green speed equation (Brede, 1991). Ball roll distance was measured semi-monthly in 2009 from June to August with one measurement being taken just prior to cultivation and the second measurement being taken just following cultivation.

Statistical Analysis

The two-factor study was a split-block (strip plot) experimental design arranged in 4 randomized complete blocks (Kuehl, 2000). Each block consisted of 2 topdressing whole plots, 6 cultivation and 1 UTC whole plots stripped across each other. Subplots were made up of whole plot intersections and measured 1.22 × 1.52 m. Analysis of variance were performed to determine the main and interaction effects of the two-factors using the general linear model procedure (SAS Institute, 2003). Means separation was performed using the LSMEANS test with $\alpha = 0.05$.

RESULTS AND DISCUSSION

Visual Injury

In 2008, the CRS + VM and CRL treatments had the least number of days injured excluding the UTC (Fig. 1.1). The VM treatment had the highest number of days injured. The severity of cultivation had a greater influence, when compared to frequency of cultivation, on the number of days injured per growing season. This can be seen when comparing the number of days injured with turfgrass quality; although the weekly applied VM treatment was frequently injured it did not result in a large decrease in turfgrass quality (Table 1.3). However, CRL was applied only 4 times per year, yet each treatment resulted in a greater decrease in turfgrass quality because the injury from each treatment was more severe. Carrow et al. (1987) reported that core aeration of 'Tifway' bermudagrass (*Cynodon dactylon* L.) turf twice per year with cores returned reduced turf shoot density (quality); however, when only aerated once per year turf density remained the same or improved. The BS treatments had fewer number of days injured than TS in 2008.

During year 2 (2009), the VM and CRS + VM treatments had the fewest number of days injured (Figure 1.2). All CRL treatments had the highest number of days injured and were not different from one another. The VM treatment was applied every 3 wk in 2009, which resulted in fewer days injured as the treatments recovered from injury before the next treatment was applied, instead of an accumulation of injury as seen in 2008. There was no effect of topdressing sand type in 2009.

In both years, CRS + VM had relatively few number of days injured compared to the other treatments. Although CRL and CRS impact the same surface area, as noted by

Hartwiger and O'Brien (2001), the smaller core holes from CRS recover more quickly. Landreth et al. (2007) also found that aeration using 6.4-mm-diam. hollow tines recovered more quickly than 1.3-cm-diam. hollow tines.

Turfgrass Quality

Both years (2008 and 2009) within cultivation treatments BS was generally higher in turfgrass quality than TS (Tables 1.3 and 1.4). In 2008, all treatments had acceptable quality (> 6.0) with the exception of the VT treatments in August and the CRL treatments applied in September. Karcher et al. (2001) also noted a decrease in turfgrass quality from hollow tine cultivation on a creeping bentgrass green while core cultivation holes were still obvious. The VM with BS treatment had excellent quality May through July and the CRS + VM had excellent quality in May and Sept. McCarty et al. (2007) found that neither vertical mowing nor core cultivation resulted in unacceptable turfgrass quality, although there was a slight decrease in quality following core cultivation. Salaiz et al. (1995) reported an increase in quality over time following vertical mowing on a creeping bentgrass green.

In 2009, the VM with BS had the highest quality across all months followed by CRS + VM with BS (Table 1.4). As already noted in the current study, vertical mowing did not result in unacceptable turfgrass quality; however, Carrow et al. (1987), Boesch and Mitkowski (2007), and White and Dickens (1984) all report that vertical mowing caused a decrease in quality following application. In May, the only treatments with acceptable turfgrass quality were VT with BS, CRS + VM with BS, VM with BS and TS, and the UTC (Table 1.4). One explanation for the low quality ratings was the CRL caused severe injury, which resulted in an extended recovery period following spring cultivations. While there were significant differences in turfgrass quality, it should be noted that visual turfgrass quality differences were recorded in increments of 0.5. Therefore, differences less than 0.5 may not be visually detectable.

Soil Temperature

Generally, in both 2008 and 2009, the VM with BS had the highest soil temperature, while the UTC had the lowest soil temperature (Tables 1.5 and 1.6). Additionally, BS always had a higher soil temperature than TS within a given cultivation treatment. Bigelow et al. (2005) observed only minor (0 to 0.75^{o}C) temperature differences between topdressed and non-topdressed plots and did not find that sand type made a difference in soil temperature. Golob et al. (2008) reported higher soil temperatures from BS treatments when compared to TS and polyethylene turf cover treatments on a late fall creeping bentgrass grow-in study. Hamilton (2003) reported an increase in surface temperatures from dark-colored topdressing sand when compared to white topdressing and the UTC on a 60:40% creeping bentgrass annual bluegrass (*Poa annua* L.) golf green. Street et al. (2007) recorded soil temperatures at a 5-cm-depth on bermudagrass for treatments with a polyethylene 'Evergreen Turf Cover', green sand topdressing, crumb rubber, and 'Milorganite'. The Evergreen Turf Cover resulted in 1.7 to 2.0^{o}C higher temperatures than the UTC and the topdressing treatments had soil temperatures that averaged 0.34 to 0.67^{o}C higher than the UTC. Carrow et al. (1987) noted that coring twice per year with cores returned resulted in better spring color compared to the UTC. They suggested that this was due to an increased exposure of the soil to solar radiation, which would have a warming effect on the dormant turfgrass. In addition, they found that vertical mowing twice a year resulted in enhanced early spring turfgrass color, and that topdressing significantly improved turf color in the spring with both responses attributed to higher surface soil temperatures. It is somewhat unclear if the temperature differences in the current study, though statistically significant, were large enough to have a biological impact on turfgrass growth. The results from the current study and others suggest that dark-colored topdressing materials resulted in improved turfgrass color and quality in which soil temperature may play a role (Anonymous, 1980; Bigelow, 2005; Carrow, 1987; Foy, 1990; Hamilton, 2003; Street, 2007; Taylor 2001).

Thatch-Mat Depth and Organic Matter Content

There was no difference in thatch-mat depth between sand types. Vertical mowing had the greatest thatch-mat depth, while the UTC had the least (Table 1.7). All other cultivation treatments were intermediate. Thatch-mat depth significantly increased from 2008 to 2009. The change in thatch-mat depth for the VM treatment was due to the frequent sand topdressing that was applied weekly in 2008 and every 3 wk in 2009. White and Dickens (1984) also found that frequent topdressing increased thatch-mat depth. They attributed, as was also seen in the current study, the increase to a dilution of the OM within the profile rather than to a direct increase in OM production. This would also explain the smallest thatch depth measurement for the UTC. Since no sand topdressing was applied to the UTC, only a thatch layer was present and the increased depth could be recognized as an accumulation of OM. McCarty et al. (2007) observed an increase in thatch-mat depth of 12 and 15%, respectively, with a biological thatch control agent or topdressing alone compared with the UTC. Dunn et al. (1995) found no difference in mat depth for aeration or topdressing treatments when compared to no treatment; however, a decrease in the percentage of OM was noted among topdressing treatments.

Thatch-mat depth and thatch-mat OM content were inversely related. The UTC had 71% higher OM content than VM. This difference was due to a dilution effect from sand topdressing and has been observed by other researchers (Couillard et al., 1997; Rieke, 1994). All other cultivation treatments did not differ. McCarty (2007) reported a 28% difference in OM between the UTC and the vertical mowed treatment on a creeping bentgrass green; all other treatments remained at pre-study levels. Many researchers have reported a reduction in thatch on various grass species using different cultivation methods (Brauen et al., 1999; Carrow et al., 1987; Dunn et al., 1995; Landreth et al., 2007; McCarty et al., 2007; White and Dickens, 1984).

The current study also showed a decrease in thatch-mat OM content from cultivation when compared to the UTC (Table 1.8). Beard (1973) stated that topdressing is one of the more effective methods to control thatch because it creates a microenvironment that encouraged microbial degradation of thatch. This is in agreement with Ledeboer and Skogley (1967) who also recognize topdressing aids in the decomposition of thatch. White and Dickens (1984) and Carrow et al. (1987) also report topdressing as an effective means of thatch control. It is not clear to what degree topdressing or cultivation had on thatch reduction in the current study, nevertheless there seems to be a synergistic effect between the two that results in a net reduction in OM content when compared to the UTC.

There was a decrease in OM content from year 1 to year 2 by about one-third. It is uncertain why all cultivation treatments decreased in OM; however, similar results were seen by Vanini et al. (2003). Even though there was a decrease from one year to the next, the trends between cultivation treatments remained the same, as there was no year × cultivation interaction.

Data was collected for the OM content of the soil below the thatch-mat layer but there was no difference between treatments or years.

Water Infiltration

All 2008 treatments did not differ from the UTC except for VM with TS (Table 1.9). In 2009, VM with TS again had the slowest infiltration rate. In general, there was a decrease in water infiltration rates from year 1 to year 2. Notably, the VT with BS treatment had the smallest decrease in infiltration (5%) from 2008 to 2009, compared to the UTC, which decreased by about 25%. McCarty et al. (2007) reported a general decrease in water infiltration rates over time on a bentgrass green. They also noted that core cultivation resulted in the greatest increase in infiltration followed by vertical mowing and topdressing, which did not improve infiltration compared to the UTC.

Turfgrass Color

Initially (2008), chlorophyll index was recorded to quantify turfgrass color; however, the results were not in agreement with visual observations. The BS treatments consistently had a lower chlorophyll index even though they visually appeared darker green than the TS treatments. Since the chlorophyll index is based on reflectance, it was thought that the BS reduced reflectance, and thus influenced the index values. Similar results were also reported by Bigelow et al. (2005).

The following year (2009), turfgrass color was visually rated instead of chlorophyll index measurements to try and quantify the apparent differences between BS and TS plots. Black sand treatments were always greater than or equal to TS treatments, and VM treatments were always highest among BS (Table 1.10). Hamilton (2003) observed that BS topdressing had a higher color rating compared to the UTC when applied in either the spring or fall. Bigelow et al. (2005) reported that topdressing sand improved visual spring green-up ratings on a creeping bentgrass green compared to the UTC. In addition, BS topdressing maintained higher color ratings further into the spring than TS topdressing. No color difference was noted by Hamilton and Raley (2004) between BS topdressing and a polyethylene turf cover on a newly established ‘L-93’ creeping bentgrass green. Taylor (2001) found that early spring color on late-fall topdressed greens was significantly better when dark-colored topdressing material was used compared to light-colored topdressing sand or no topdressing. Taylor (2001) speculated that enhanced spring green-up was due to a combination of reduced desiccation and higher temperature effects. In the current study, it was difficult to determine what affect BS had on turfgrass color ratings. A difference in turfgrass color was noticeable immediately following BS application. This initial affect was likely due to the BS creating a contrast with the green turf making it appear darker. However, as the turf canopy grew and the BS was covered, there was still a noticeable darker green color. It was hypothesized that an increase in soil temperature due to the BS resulted in increased microbial activity and plant metabolic functions. A nutrient analysis was done for both topdressing sands to determine if the turfgrass color response was due to a nutrient increase from the sand; however, there was an insignificant amount of plant available nutrients in both sands to affect a turfgrass color response (Appendix Table I).

Ball Roll Distance

There was no difference in ball roll distance between cultivation treatments; however, the ball roll distance after cultivation was significantly less when compared to before cultivation measurements (Table 1.11). Others have also reported a decrease in ball roll distance following cultivation (Karcher et al., 2000; McCarty et al., 2007; Salaiz et al., 1995)

CONCLUSIONS

Black sand topdressing had a positive effect on increasing turfgrass quality and color. These benefits were most noticeable in the spring and fall. In terms of managing OM accumulation, topdressing frequency had a greater effect than cultivation method as VM had the least OM concentration yet was topdressed the most frequently. The severity of surface disruption to golf greens was influenced by cultivation method as well as frequency. Vertical mowing every 3 wk proved to be the least injurious treatment the second year. The most disruptive cultivation methods were the CRL treatments, which were injured up to 50% of the time. Overall, CRS + VM ranked high in turfgrass quality and color with little injury while maintaining consistent OM content and water infiltration rates throughout the study.

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Table 1.1. Topdressing sand, sand rate, tine depth, diameter, and spacing for aeration and topdressing treatments on a T-1 creeping bentgrass golf green.

Cultivation† Sand	Sand rate	Depth	Diameter-width	Spacing
	kg ha^{-1}	----------	mm	----------
CRL+VT		76 + 100	12.7 + 3.2	50
TS	39,074 + 9,795			
BS	19,483TS;19,483BS + 9,795BS			
VT		100	3.2	50
TS	9,795			
BS	9,795			
CRL		76	12.7	50
TS	39,074			
BS	19,483TS;19,483BS			
CRL+VM		76 + 5	12.7 + 1	50 + 20
TS	39,074 + 9,795			
BS	19,483TS;19,483BS + 9,795BS			
CRS+VM		76 + 5	6.4 + 1	25 + 20
TS	19,483 + 9,795			
BS	9,795TS;9,795BS + 9,795BS			
VM		5	1	20
TS	9,795			
BS	9,795			
UTC				
None				
None				

† CRL = core removal large tine, VT = venting, CRS = core removal small tine, VM = vertical mowing, UTC = untreated control, TS = tan sand topdressing, BS = black sand topdressing.

Table 1.2. Particle size distribution of topdressing sand used on a T-1 creeping bentgrass golf green.

Topdressing sand	Soil separation (%)					
	Sand 2.0-0.05	Silt 0.05-0.002	Clay <0.002			
	-------------------mm------------------					
Tan	96.1	2.0	1.9			
Black	99.5	< 1.0	< 1.0			
	Sieve fraction sand particle diameter (% retained)					
	Gravel 2.0	V. Course 1.0	Course 0.5	Medium 0.25	Fine 0.15	V. Fine 0.05
	---------------------------------------mm--------------------------------					
Tan	0.0	2.0	10.7	61.3	16.5	5.5
Black	0.0	0.0	22.5	61.6	12.5	2.9

Table 1.3. Turfgrass quality for cultivation and sand topdressing treatments on a T-1 creeping bentgrass golf green, 2008.

Cultivation†	May‡		June		July		Aug.		Sept.	
	Sand§									
Treatment	TS	BS	TS	BS	TS	BS	TS	BS	TS	BS
	Quality¶									
CRL+VT	6.1d	6.4c	6.4d	6.7bc	6.0e	6.2d	5.7e	5.9d	6.1e	6.8b
VT	6.6c	6.9b	6.5cd	6.7bc	6.0e	6.2d	5.7e	5.9d	6.2de	6.8b
CRL	6.0d	6.5c	6.6cd	6.6cd	6.3cd	6.4c	6.2c	6.3bc	5.1g	5.7f
CRL+VM	6.0d	6.4c	6.6cd	6.9ab	6.4c	6.7b	6.2c	6.4ab	5.7f	6.2de
CRS+VM	6.5c	7.0ab	6.6cd	6.9ab	6.4c	6.6b	6.2c	6.4ab	6.3d	7.0a
VM	6.0d	6.8b	6.6cd	7.0a	6.4c	6.9a	6.0d	6.5a	5.8f	6.6c
UTC	6.8b	7.2a	6.9ab	6.9ab	6.3cd	6.3cd	6.2c	6.2c	6.3d	6.3d

† CRL = core removal large tine, VT = venting, CRS = core removal small tine, VM = vertical mowing, UTC = untreated control.
‡ Means within a month followed by the same letter are not significantly different ($P \leq 0.05$).
§ TS = tan sand, BS = black sand.
¶ Quality rated on a scale of 1 to 9; 9 = green healthy turf, ≥ 6 = acceptable turf quality, 1= dead turf.

Table 1.4. Turfgrass quality for cultivation and sand topdressing treatments on a T-1 creeping bentgrass golf green, 2009.

Cultivation†	May‡		June		July		Aug.		Sept.	
	Sand§									
Treatment	TS	BS	TS	BS	TS	BS	TS	BS	TS	BS
	Quality¶									
CRL+VT	3.4f	5.3d	5.9e	6.2d	6.0h	6.4def	5.9e	6.6bc	6.8d	6.9d
VT	5.7c	5.1d	5.9e	6.1de	6.1gh	6.3e	6.0e	6.6bc	6.8d	6.9d
CRL	3.4f	4.9de	5.7e	6.1de	6.2fgh	6.2fg	6.3d	6.3d	5.8h	6.2g
CRL+VM	3.5f	5.1d	6.1de	6.3cd	6.5de	7.0b	6.6bc	7.4a	5.9h	6.4f
CRS+VM	4.6e	6.4b	6.6b	6.9b	6.6cd	7.0b	6.5bcd	7.4a	6.9d	7.4c
VM	5.9c	7.0a	6.9bc	7.3a	6.8bc	7.4a	6.7b	7.5a	7.8b	8.0a
UTC	5.8c	6.0c	6.4c	6.4c	6.3efg	6.4def	6.4cd	6.5bcd	6.6e	6.6e

† CRL = core removal large tine, VT = venting, CRS = core removal small tine, VM = vertical mowing, UTC = untreated control.
‡ Means within a month followed by the same letter are not significantly different ($P \leq 0.05$).
§ TS = tan sand, BS = black sand.
¶ Quality rated on a scale of 1 to 9; 9 = green healthy turf, ≥ 6 = acceptable turf quality, 1 = dead turf.

Table 1.5. Soil temperature at 7.5 cm depth for cultivation and sand topdressing treatments on a T-1 creeping bentgrass golf green, 2008.

	May‡		June		July		Aug.		Sept.	
Cultivation†	Sand§									
Treatment	TS	BS	TS	BS	TS	BS	TS	BS	TS	BS
	°C									
CRL+VT	14.1a	14.2a	13.6e	13.8cd	17.8ef	18.0cd	18.2de	18.5c	18.0ef	18.3d
VT	14.0a	14.1a	13.6e	13.8cd	17.8ef	18.0cd	18.3d	18.5c	17.9f	18.3d
CRL	14.0a	14.3a	13.6e	13.8cd	17.8ef	17.9de	18.1ef	18.1ef	18.9b	18.3d
CRL+VM	14.1a	14.3a	13.7de	13.9bc	17.9de	18.1bc	18.3d	18.6bc	18.1e	18.4cd
CRS+VM	14.1a	14.2a	13.7de	14.0ab	17.9de	18.2b	18.3d	18.6bc	18.0ef	18.4cd
VM	14.2a	14.5a	13.9bc	14.1a	18.2b	18.5a	18.7b	19.1a	18.5c	19.1a
UTC	14.1a	14.2a	13.6e	13.7de	17.7f	17.7f	18.0f	18.0f	17.4g	17.5g

† CRL = core removal large tine, VT = venting, CRS = core removal small tine, VM = vertical mowing, UTC = untreated control.
‡ Means within a month followed by the same letter are not significantly different ($P \leq 0.05$).
§ TS = tan sand, BS = black sand.

Table 1.6. Soil Temperature at 2.5 cm depth for cultivation and sand topdressing treatments on a T-1 creeping bentgrass golf green, 2009.

	May‡		June		July		Aug.		Sept.	
Cultivation†	Sand§									
Treatment	TS	BS	TS	BS	TS	BS	TS	BS	TS	BS
	°C									
CRL+VT	25.2	26.4a	26.7d	27.3bcd	23.9e	24.6bc	29.2d	30.3a	20.7f	21.0cd
VT	24.7	25.1a	27.2c	28.3a	23.9e	24.7ab	29.2d	30.2a	20.8ef	21.1c
CRL	24.9	24.7a	26.5f	26.9cdef	23.4f	23.5f	28.4f	28.3f	20.9d	21.3b
CRL+VM	25.3	26.6a	26.9c	27.4bc	24.0de	24.6b	29.1d	30.0b	21.1c	21.5a
CRS+VM	25.0	24.7a	26.6e	27.0cdef	24.0de	24.6b	28.8e	29.9c	20.9d	21.5a
VM	25.6	26.4a	27.1c	27.9ab	24.3cd	25.0a	29.3d	30.2a	20.8ef	20.9de
UTC	24.1	24.3a	25.8g	25.7g	22.9g	22.8g	27.4g	27.5g	20.0g	20.1g

† CRL = core removal large tine, VT = venting, CRS = core removal small tine, VM = vertical mowing, UTC = untreated control.
‡ Means within a month followed by the same letter are not significantly different by ($P \leq 0.05$).
§ TS = tan sand, BS = black sand.

Table 1.7. Thatch-mat depth for cultivation and sand topdressing treatments on a T-1 creeping bentgrass golf green, 2008 and 2009.

Treatment	Thatch-mat Depth‡
Cultivation†	mm
CRL+VT	18.74b
VT	19.32b
CRL	17.65b
CRL+VM	19.09b
CRS+VM	19.01b
VM	23.08a
UTC	13.18c
Year	
2008	16.72b
2009	20.45a

† CRL = core removal large tine, VT = venting, CRS = core removal small tine, VM = vertical mowing, UTC = untreated control

‡ Means within a column followed by the same letter are not significantly different ($P \leq 0.05$).

Table 1.8. Thatch-mat organic matter content for cultivation and sand topdressing treatments on a T-1 creeping bentgrass golf green, 2008 and 2009.

Treatment	2008‡	2009
Cultivation†	----------g kg^{-1}----------	
CRL+VT	75.24bc	47.94bc
VT	80.89b	49.48bc
CRL	88.26b	59.06b
CRL+VM	79.83b	47.41bc
CRS+VM	78.18b	52.94b
VM	52.89c	35.88c
UTC	151.89a	140.02a
Sand		
Tan	89.25a	64.36a
Black	84.23b	59.27a

† CRL = core removal large tine, VT = venting, CRS = core removal small tine, VM = vertical mowing, UTC = untreated control

‡ Means within a column followed by the same letter are not significantly different ($P \leq 0.05$).

Table 1.9. Water infiltration for cultivation and sand topdressing treatments on a T-1 creeping bentgrass golf green, 2008 and 2009.

	2008‡		2009	
Cultivation†	Sand§			
	TS	BS	TS	BS
Treatment				
	cm h^{-1}			
CRL+VT	66b	78a	47de	65ab
VT	75ab	83a	46de	71a
CRL	78a	82a	50cde	69a
CRL+VM	72ab	82a	52cd	68a
CRS+VM	78a	72ab	42e	63a
VM	55c	72ab	27f	52cd
UTC	81a	82a	67a	58bc

† CRL = core removal large tine, VT = venting, CRS = core removal small tine, VM = vertical mowing, UTC = untreated control.
‡ Means within a year followed by the same letter are not significantly different ($P \leq 0.05$).
§ TS = tan sand, BS = black sand.

Table 1.10. Turfgrass color for cultivation and sand topdressing treatments on a T-1 creeping bentgrass golf green, 2009.

	May‡		June		July		Aug.		Sept.	
Cultivation†	Sand§									
	TS	BS	TS	BS	TS	BS	TS	BS	TS	BS
Treatment										
	Color¶									
CRL+VT	4.6h	7.0c	6.4f	7.2cd	6.4d	7.9b	6.2f	7.8c	7.0ef	7.4cd
VT	5.9f	6.5de	6.7ef	7.7b	6.5d	7.9b	6.3ef	7.9bc	7.0ef	7.5c
CRL	4.3h	6.8cd	6.2g	6.9de	6.8c	6.8c	6.6de	6.6de	6.8f	7.9b
CRL+VM	4.6h	7.2bc	6.7ef	7.3c	6.9c	8.3a	6.7d	8.2ab	7.0ef	8.1ab
CRS+VM	5.2g	7.5ab	7.1cd	7.7b	6.9c	8.2a	6.7d	8.2ab	7.2de	8.2a
VM	6.1ef	7.8a	7.3d	8.2a	7.0c	8.4a	6.8d	8.3a	7.9b	8.2a
UTC	6.0f	6.3ef	6.9de	7.0cde	6.8c	7.0c	6.7d	6.8d	7.2de	7.2de

† CRL = core removal large tine, VT = venting, CRS = core removal small tine, VM = vertical mowing, UTC = untreated control.
‡ Means within a month followed by the same letter are not significantly different ($P \leq 0.05$).
§ TS = tan sand, BS = black sand.
¶ Color rated on a scale of 1 to 9; 9 = ideal, dark turf, 6 = minimum acceptable color, and 1 = brown turf.

Table 1.11. Ball roll distance for cultivation and sand topdressing treatments on a T-1 creeping bentgrass golf green, 2008 and 2009.

Treatment	Ball Roll Distance‡
Cultivation†	cm
CRL+VT	232a
VT	226a
CRL	224a
CRL+VM	223a
CRS+VM	219a
VM	217a
UTC	208a
Time§	
Before	224a
After	218b

† CRL= Core removal large tine, VT = Venting, CRS = Core removal small tine, VM = Vertical mowing, UTC = Untreated control.
‡Means within a column followed by the same letter are not significantly different ($P \leq 0.05$).
§ Before = ball roll measured before cultivation treatment, after = ball roll measured after cultivation treatment

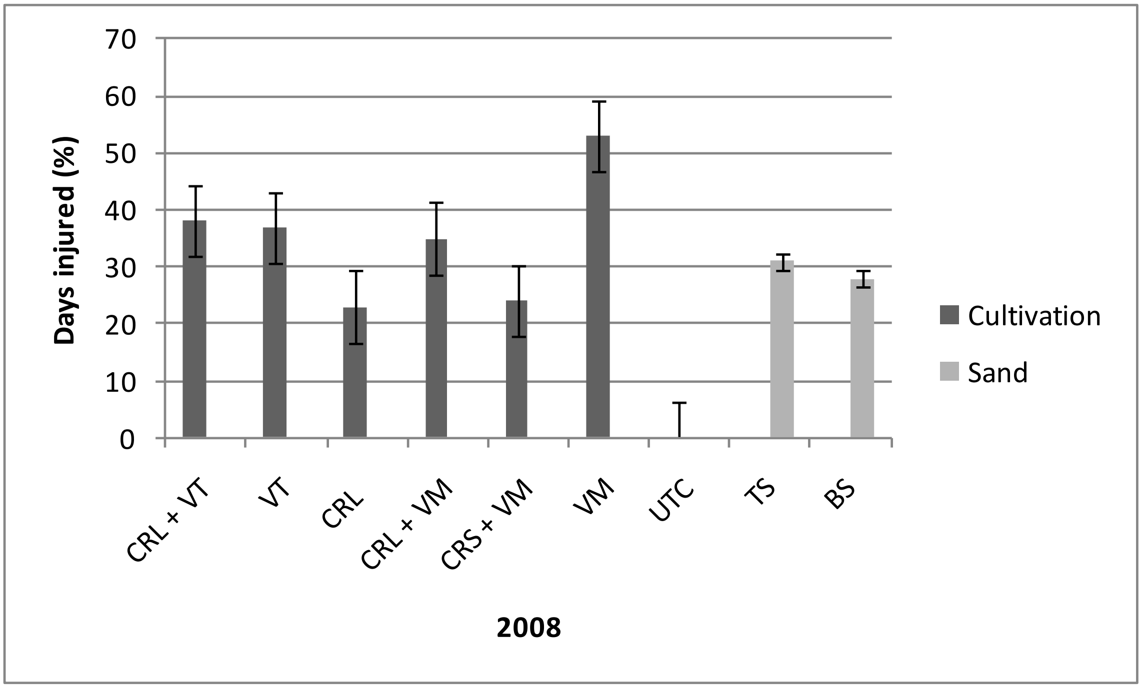

Fig. 1.1. Percentage of days injured for core removal with large tines (CRL), core removal with small tines (CRS), venting (VT), vertical mowing (VM), black sand (BS), tan sand (TS), and untreated control (UTC) treatments on a T-1 creeping bentgrass golf green, 2008. Bars are ± SE.

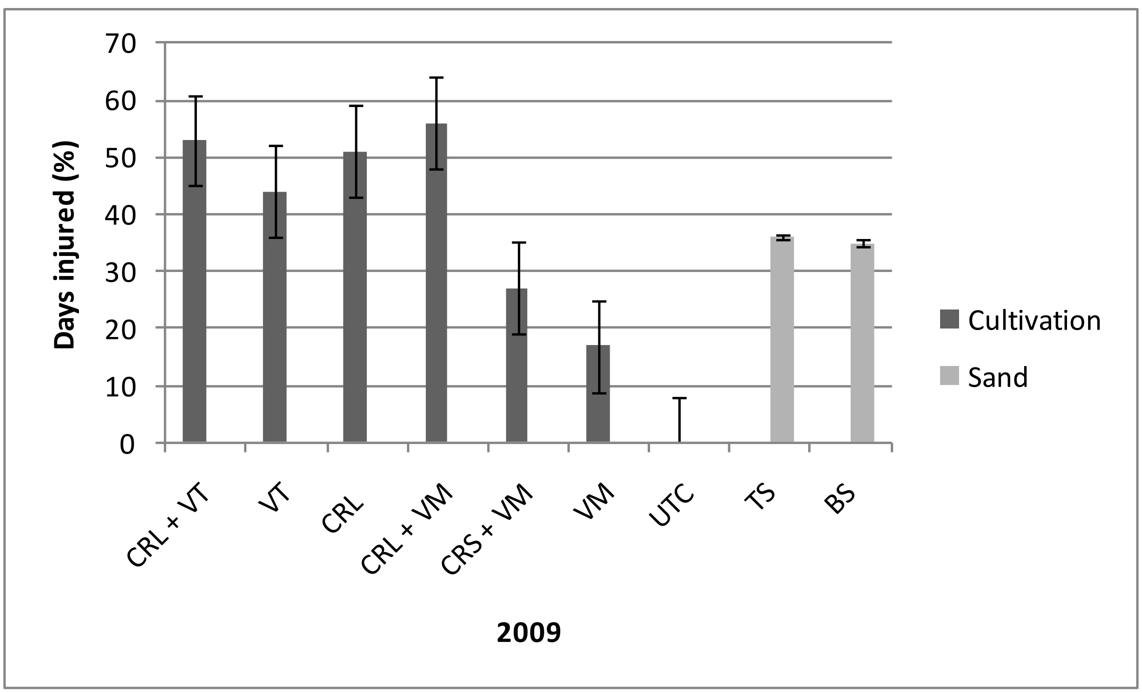

Fig. 1.2. Percentage of days injured for core removal with large tines (CRL), core removal with small tines (CRS), venting (VT), vertical mowing (VM), black sand (BS), tan sand (TS), and untreated control (UTC) treatments on a T-1 creeping bentgrass golf green, 2009. Bars are ± SE.

CHAPTER II

GOLF GREEN RECOVERY AS AFFECTED BY AERATION TIMING AND TOPDRESSING SAND COLOR

ABSTRACT

Newer cultivars of creeping bentgrass (*Agrostis stolonifera* L.) provide an exceptional golf green putting surface, but their dense aggressive growth habit, if unmanaged, can result in the accumulation of a thatch-mat layer. Core aeration, a common cultivation method used to manage thatch-mat, causes surface disruption and decreases the turfgrass quality and playability. Multiple aeration dates, beginning 15 April and continuing through 15 September, and two topdressing sand types, tan sand (TS) and black sand (BS), were used to determine the time of year that resulted in the fewest days to recovery (DTR) on an established 'T-1' creeping bentgrass golf green. The early spring dates were the slowest to recover both years (2008 and 2009). The quickest recovery from aeration in the spring was mid-May both years. In the fall, the fewest DTR from aeration were mid-August to mid-September. Black sand topdressing had as much as a 36% decrease in the number of DTR compared to TS; however, this was not true for all aeration dates and years. Black sand had higher soil temperatures compared to TS within an aeration application date. Turfgrass quality was up to 25% greater in the spring when BS was used compared to TS. Black sand also had higher turfgrass quality ratings in the fall. There was never a decrease of quality below acceptable levels (≥6.0) in the summer months, even among the BS treatments. Turfgrass color significantly improved from BS topdressing with the most noticeable difference in the spring and fall.

Abbreviations: TS, tan sand; BS, black sand; DTR, days to recovery; TNC total nonstructural carbohydrates;

INTRODUCTION

The newer varieties of creeping bentgrass (*Agrostis stolonifera* L.), such as 'T-1', 'L-93', and the A and G series bentgrasses were selected for their upright growth habit, high shoot density, fine texture, and good recuperative potential that results in a uniform, high quality putting surface (Fraser, 1998; Landry and Schlossberg, 2001; Sifers et al., 2001; Stier and Hollman, 2003; Toubakaris and McCarty, 2000). The dense and aggressive growth habit of these cultivars may require more intense cultivation and topdressing practices to adequately manage biomass and thatch-mat accumulation (Landry and Schlossberg, 2001; Sifers et al., 2001).

Core aeration is commonly used to minimize thatch-mat accumulation, while also providing reduced surface compaction, improved water infiltration, and increase surface aeration and rooting on golf greens (Brauen et al., 1999; Carrow et al., 1987; Ledeboer and Skogley, 1967; McCarty et al., 2007; Murphy et al., 1993; Shildrick, 1985; White and Dickens, 1984). Skorulski (1998) stated that disruption to the golf green surface is the major disadvantage associated with core aeration. The more severe the disruption, the longer recovery takes. In addition to severity, which typically is related to the size of core aeration tine used, the recuperative potential of turfgrass can affect the time needed to recover.

Recuperative potential is the ability of turfgrass to recover from injury through vegetative growth (Beard, 1973). The rate of recuperation is a function of the growth rate and severity of injury, and has been closely associated with clipping yields and N fertilizer rates (Beard, 1973; Hawes and Decker, 1977). Soil temperature is one factor that affects turfgrass growth. In cool-season grasses root growth can occur at 1.6°C although, leaf growth does not begin until soil temperatures are > 10°C (Beard, 1973; Hanson and Juska, 1961). Soil temperature also influences root uptake of N, which is slowed by low soil temperatures (Madison, 1960; Parks and Fischer, 1958). In addition, rates of N mineralization and immobilization, urea hydrolysis, and urease activity increase with soil temperature (Agehara and Warncke, 2005; Terry et al., 1981; Wang et al., 2003)

Dark-colored topdressing material has been used in the spring and fall to enhance spring green-up or delay fall dormancy by increasing soil temperatures (Anonymous 1980; Foy, 1990; Taylor, 2001). More recently, black sand topdressing has been used in the fall and spring and has shown increased soil temperature, tillering, and clipping yield (Bigelow et al., 2005; Hamilton, 2003; Hamilton and Raley, 2004; Street et al., 2007).

In the Intermountain Pacific Northwest, cool-season turfgrasses are typically growing from April through September. With such a short growing season, timing of disruptive aeration practices, which reduces golf green playability, can be difficult. The objective of this study was to determine the time of year that results in the quickest recovery time from core aeration and if black sand topdressing has an effect on time to recovery.

MATERIALS AND METHODS

Experimental Area

Research was conducted from April 2008 to September 2009 at the Washington State University Turfgrass and Agronomy Research Center, in Pullman, WA, on a creeping bentgrass research putting green. The putting green was constructed according to United States Golf Association putting green specifications and planted with T-1 creeping bentgrass in May 2005 (USGA Green Section Staff, 1993). The area was mowed five times weekly at a 3.3-mm-height of cut with clippings collected. Irrigation was applied to prevent water stress. Granular fertilizer applications were made spring and fall totaling 58.6 kg N ha^{-1}, 10.25 kg P ha^{-1}, and 78.1 kg K ha^{-1} y^{-1}. Foliar fertilizer was applied every 14 d, 15 May through 1 October, totaling 170.9 kg N ha^{-1} N, 84.0 kg P ha^{-1}, and 90.3 kg K ha^{-1} y^{-1}. To prevent localized dry spot, a soil surfactant (TriCure AD, Mitchell Products, Millville, NJ) was applied monthly at 12 L ha^{-1}, May through September during 2008 and 2009.

Treatments

In 2008, the study area measured 7.3 × 15.9 m. Individual plots (experimental units) were 1.22 × 1.22 m arranged in a split-plot design with 4 randomized complete blocks. The aeration date and sand topdressing treatments were a 2 × 12 factorial of topdressing sand and aeration date. Both tan sand (TS) topdressing (Atlas Sand and Rock, Lewiston, ID) and black sand (BS) topdressing (Grass Roots Agronomics Inc., Emmett, ID) were applied immediately following aeration using a drop spreader (model 30, Gandy Company, Owatonna, MN). Aeration dates were 15 April, 1 May, 15 May, 1 June, 15 June, 1 July, 15 August, 1 September, and 15 September.

In 2009, the study area measured 8.5 × 15.9 m. Two aeration dates, 15 July, and 1 August, were added to the 2008 treatment dates; everything else remained the same from 2008 to 2009. One week prior to each aeration date, each corresponding sand treatment received 293 kg ha^{-1} fertilizer (10-4-16) (Micro 10, BEST Fertilizer, Lathrop, CA).

Aeration was accomplished with a core cultivator (model GreensAire 24, Ryan, division of Textron Inc., Charlotte, NC) using 1.27-cm-diameter side eject hollow tines (R&R Products Inc., Tucson, AZ) and a tine depth of 7.62 cm on 5 cm centers. Ejected cores were removed from the surface and topdressing sand was applied. Tan sand topdressing treatments were applied at 39,059 kg ha^{-1}. Black sand topdressing treatments were a combination of BS and TS in order to reduce cost and duplicate how BS is commonly used by golf course superintendents on golf courses. Black sand topdressing treatments received TS at 19,530 kg ha^{-1} brushed in followed by BS at 19,530 kg ha^{-1}. The topdressing sand was brushed into aeration holes using a hand push broom.

Treatment Parameters

Experimental units were evaluated in 2008 and 2009 for data collected on visual injury, turfgrass quality, soil temperature, and turfgrass color (2009 only). Data was collected until all plots within an aeration date were fully recovered from injury.

Visual Injury

Visual injury was rated on a scale of 1 to 9; 9 was no detectable disruption from cultivation and 1 was maximum injury from cultivation treatment. Visual injury was rated semi-weekly. In 2008, aeration core hole diameter was measured along with visual injury using a digital caliper (Carrera Precision, Max Tool, La Verne, CA). Five measurements were recorded per plot. The core holes measured were randomly selected to provide a representative sample. Visual injury ratings were negatively correlated (R^2 = .88) with core hole diameter measurements and, therefore, core hole diameter measurements were not collected in 2009 (Fig. 2.1). Visual injury data was used to determine the days required for aeration treatments to recover.

Turfgrass Quality

Turfgrass quality was visually rated based on color, shoot density, and uniformity of stand on a scale of 1 to 9; 9 was ideal, dark green uniform turf, 6 was minimum acceptable quality, and 1 was dead turf. Turfgrass quality ratings were recorded semi-weekly.

Soil Temperature

In 2008, soil temperature was recorded semi-weekly at a 7.5 cm depth with a digital thermometer (Spectrum Technologies Inc., East-Plainfield, IL). One reading from the center of each plot was taken. The thermometer was never placed in an aeration core hole. The 7.5-cm-depth was determined from data collected by Chapman (1994). The 2008 data collected showed statistically significant treatment differences; however, it was unclear if the differences detected were large enough to affect plant function. Therefore, in 2009, temperatures were recorded semi-weekly at a 2.5-cm-depth in an attempt to detect greater differences in soil temperature due to treatments.

Turfgrass Color

A chlorophyll meter (Field Scout CM 1000 NDVI Meter, Spectrum Technologies Inc., East-Plainfield, IL) was used in 2008 to record chlorophyll index values to quantify turfgrass color. The chlorophyll index values were consistently lower for BS treatments compared to TS treatments. This was inconsistent with visual observations and was also reported by Bigelow et al. (2005); therefore, chlorophyll index was not measured in 2009. Turfgrass color was visually rated on a scale of 1 to 9; 9 was ideal, dark green turf, 6 was minimum acceptable green color, and 1 was brown turf. Turfgrass color ratings were recorded semi-weekly during 2009.

Statistical Analysis

The two-factor study was a split-plot randomized complete block experimental design with 4 replications (Kuehl, 2000). Each block consisted of 9 or 11 (9 in 2008, 11 in 2009) whole plots with 2 subplots. The subplots measured 1.22 × 1.22 m. The whole plot treatment factor was aeration date and the subplot treatment factor was topdressing sand type. Analysis of variance was performed to determine the main and interaction effects of the two factors using the general linear model procedure (SAS Institute, 2003). Means separation was performed using the LSMEANS test with $\alpha = 0.05$.

RESULTS AND DISCUSSION

Visual Injury

The highest number of days to recovery (DTR) occurred in the spring for both 2008 and 2009 (Figure 2.2 and 2.3). There was a decrease in the number of DTR from the 1 May aeration date to the 15 May aeration date for both years. Sand types did not differ in 2008, except for both June aeration dates and both September aeration dates when BS had fewer DTR than TS (Figure 2.2). In 2008, DTR steadily decreased from the 15 May to 15 August aeration date, which had the fewest DTR. In 2009, DTR remained at about 15 d from the 15 May until 1 August aeration dates for BS treatments. Beginning 15 August the BS treatments decreased in DTR until the 15 September aeration date (Figure 2.3). The 15 September with BS treatment had the fewest number of days to recover in 2009.

There are likely many factors that influenced the number of DTR. Creeping bentgrass exhibits optimal top growth between 16 and 24°C (Schmidt and Blaser, 1967). Hawes and Decker (1977) found clipping yield to be a good indicator of the healing potential of creeping bentgrass. They reported that as soil temperature increased clipping yields increased. Although clipping yields were not measured in the current study, it was hypothesized that as soil temperatures increased, clipping yields, or turfgrass healing potential, would also increase. One reason for this hypothesis was DTR decreased as soil temperature increased in the spring and fall (Fig. 2.4 and 2.5). Additionally, it has been noted that increasing N rates increased shoot growth (Beard, 1973; Hawes and Decker, 1977; Madison, 1962; Markland and Roberts, 1969). Nitrogen uptake by roots increases with soil temperature up to the optimal range (Xu and Huang, 2006; Younis et al., 1965). Related to this, N mineralization and immobilization due to soil microbial activity increases with temperature (Agehara and Warncke, 2005; Terry et al., 1981; Wang et al, 2003); and urea hydrolysis and urease activity are both positively influenced by soil temperature and moisture (Moyo et al., 1989; Sadeghi et al., 1988; Sahrawat, 1984). This would suggest that as soil temperature increased from spring into summer, organic matter would be mineralized supplying the plant with N to increase shoot growth and recovery potential. This is one possible explanation to why DTR decreased as soil temperature increased.

Total nonstructural carbohydrate (TNC) levels of turfgrass have been considered an indirect method to measure a plant's physiological status, or ability to recover from injury. (Beard, 1973; Busso et al., 1990; Sheffer et al., 1979). Measuring the quantity of TNC, which represents a source of energy, can be an indicator of the effect of various management practices on plant vigor (White, 1973). Narra et al. (2004) found that different mowing heights showed differences in TNC on bentgrass and that there were significant seasonal changes in TNC for all mowing heights. They also found TNC started decreasing in mid-July with the lowest content in August, while there was an increase in TNC in September with the highest amount seen in October and November. Fu and Dernoeden (2009) reported no effect of core aerating on bentgrass greens for root and shoot respiration and photosynthetic rates. However, they did note a decrease in root TNC in July followed by an increase in leaf and root TNC in September. The current study did not examine treatment effects on TNC content, but it is hypothesized that this may also help determine the most effective time of year to core aerate as it relates to turfgrass recuperative potential.

Soil Temperature

Soil temperature differences were more dramatic in 2009 compared to 2008 because temperatures were measured at 2.5 cm instead of 7.5 cm, however, the overall trends remained the similar (Fig. 2.4 and 2.5). In both years there was a significant increase in temperature between the 1 May and the 15 May aeration dates. This appeared to relate to the decrease in DTR seen between those two dates (Fig. 2.2 and 2.3). Soil temperatures were highest in the summer months, as was expected, and decreased by the 15 September aeration date. Sand type resulted in soil temperature differences both years with BS being higher than TS. This was especially noticeable at the 15 September date when the BS treatments recovered faster than the TS treatments (Fig. 2.4 and 2.5). In the summer months, when soil temperatures were within the plants optimum growth range the temperature increase from BS did not have an affect; however, when soil temperature began to cool in the fall the increase in soil temperature from BS resulted in faster recovery compared to TS.

Hawes and Decker (1977) also noted an increase in plant growth due to artificially increased soil temperature, most notably when the uncontrolled temperature was sub-optimal. Bigelow et al. (2005) found only minor increases in surface and soil temperature from late-March to early-April when topdressing was applied and found that BS did not increase temperature over tan sand. This is similar to what was seen in the current study, namely topdressing sand did not have an effect on recovery early in the spring.

Turfgrass Quality

Sand type resulted in turfgrass quality differences in the spring and fall for both 2008 and 2009 (Figures 2.6 and 2.7). Black sand had as much as a 25% increase in quality over TS. In general, BS had higher quality ratings than TS. In 2008, there was a decrease in turfgrass quality during the summer; however, in 2009, turfgrass quality was highest in the summer, most notably in July.

Turfgrass Color

Turfgrass color is one component of turfgrass quality. In 2008, an attempt to quantify turfgrass color was made using a chlorophyll meter to measure chlorophyll index. It was observed that all BS treatments had visually darker green color than the TS treatments; however, the chlorophyll meter consistently recorded lower chlorophyll index readings for BS treatments. Since the chlorophyll index is based on reflectance, it was thought that the BS reduced reflectance, thus, influencing the index values. Similar results have also been reported by Bigelow et al. (2005). Because of the dramatic difference in color visually noted in 2008, it was decided to collect visual turfgrass color ratings in addition to quality ratings in 2009.

There was a 25% increase in turfgrass color ratings due to BS at the 15 April aeration date (Fig. 2.8). This was the largest difference in color between the two sand types. Within each rating date, BS had a higher color rating than TS. Other research has also shown dark-colored topdressing materials to improve turfgrass color ratings over light colored material or no topdressing (Bigelow et al., 2005; Hamilton, 2003; Hamilton and Raley, 2004; Street et al., 2007; Taylor, 2001). The improvement in turfgrass color from the use of BS was the most dramatic effect seen from the use of BS. Initially it was thought that there may be a fertility response from the BS, but a nutrient analysis showed an insignificant amount of plant available nutrients in either TS or BS (Appendix Table I).

CONCLUSIONS

The timing of aeration had an effect on DTR for the bentgrass golf green. Based on the current study, in order to minimize DTR the best time of year to core aerate in Pullman, WA, would be mid-May in the spring and mid-August to mid-September in the fall. If aeration were to occur later in the fall, BS topdressing was able to reduce the number of DTR compared to using TS. In addition, BS topdressing showed an increase in turfgrass quality and color, especially in the spring and fall. It has been suggested that BS application in the summer would result in turfgrass burning due to excess temperature (Hamilton and Raley, 2004). In the current study, BS did not result in a decrease in turfgrass quality due to burning, although when temperatures rose above 32°C, localized dry spots did appear in both BS and TS treatments. Nevertheless, because minimum temperatures were relatively low compared to maximum temperatures (Appendix Table II), there was no cumulative injury effect due to high temperature resulting in an overall decrease in turfgrass quality as is often seen in the southeast United States. Further research could be done to elucidate the color response due to BS. It is still unclear what causes the deepening of turfgrass color.

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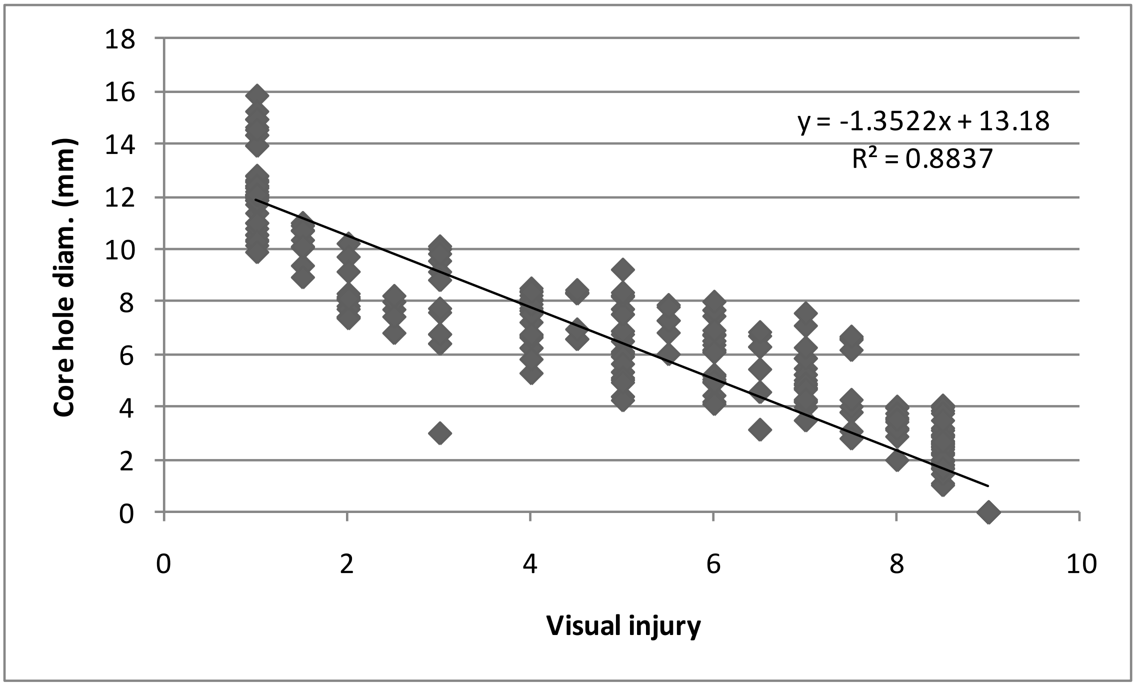

Fig. 2.1. Core hole diam. measurements correlated with visual injury ratings on core aeration and topdressing treatments at WSU Turfgrass and Agronomy Research Center, at Pullman, WA, 2008. Visual injury was rated on a scale of 1 to 9; 9 was no detectable disruption from cultivation and 1 was over 95% of plot area injured from cultivation treatment.

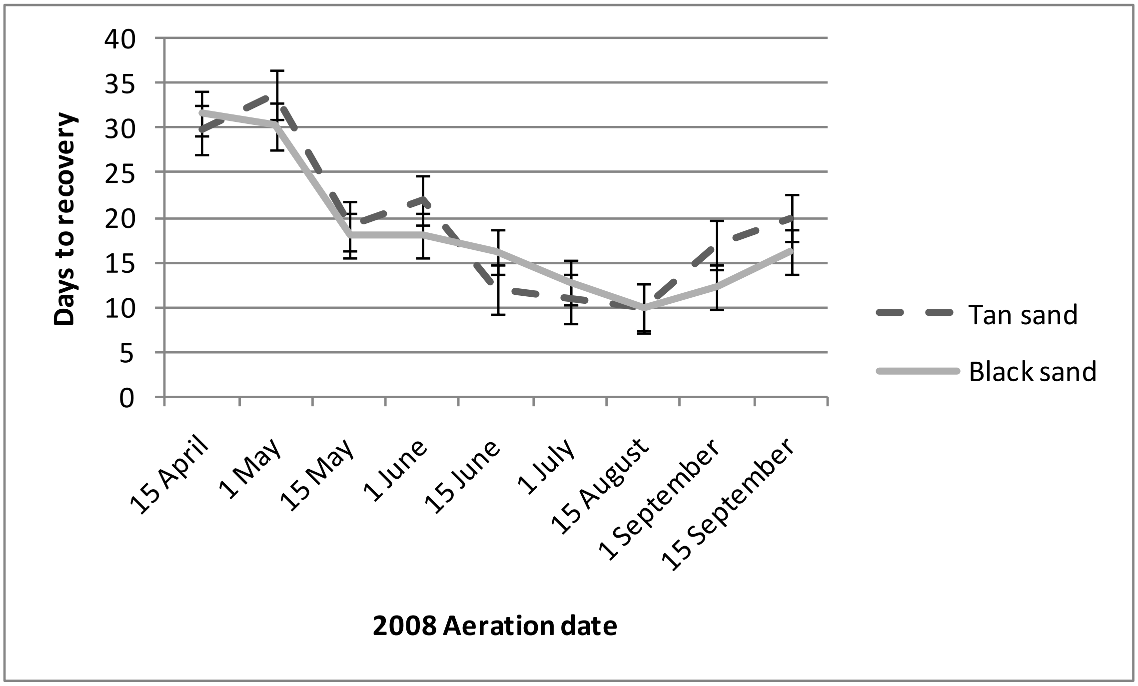

Fig. 2.2. Days to recovery for core aeration treatments at multiple dates using tan sand and black sand as topdressing on a T-1 creeping bentgrass green at the WSU Turfgrass and Agronomy Research Center, at Pullman, WA, 2008. Bars are ± SE.

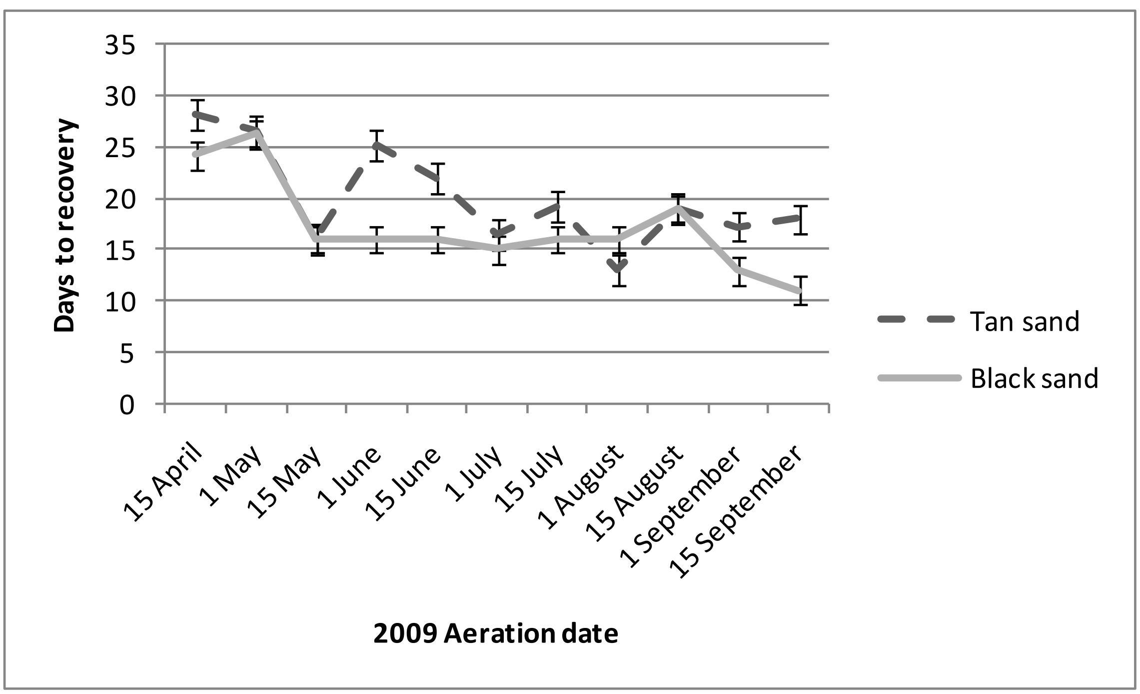

Fig. 2.3. Days to recovery for core aeration treatments at multiple dates using tan sand and black sand as topdressing on a T-1 creeping bentgrass green at the WSU Turfgrass and Agronomy Research Center, at Pullman, WA, 2009. Bars are ± SE.

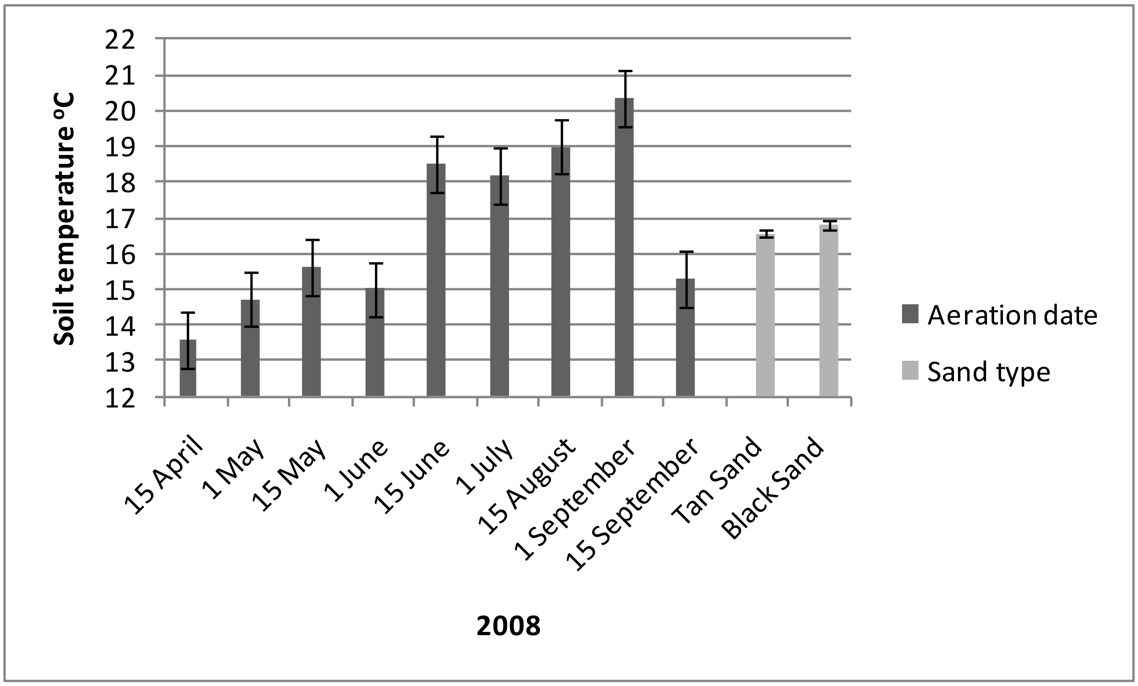

Fig. 2.4. Soil temperature at 7.5 cm depth for core aeration treatments at multiple dates using tan sand and black sand as topdressing on a T-1 creeping bentgrass green at the WSU Turfgrass and Agronomy Research Center, at Pullman, WA, 2008. Bars are ± SE.

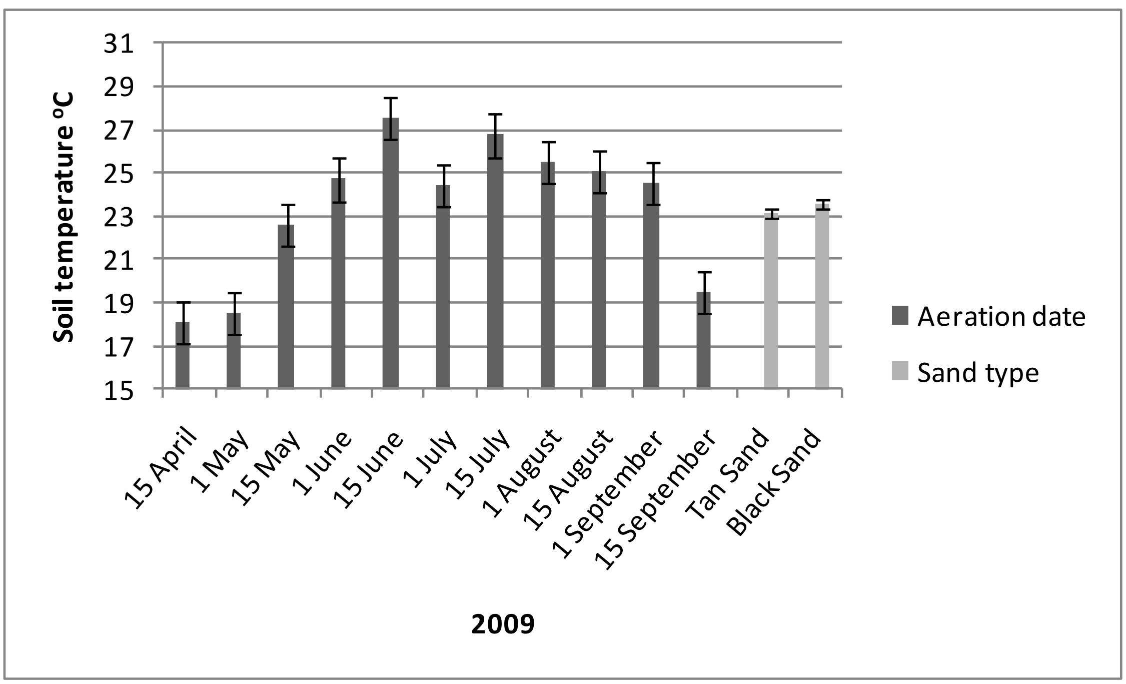

Fig. 2.5. Soil temperature at 2.5 cm depth for core aeration treatments at multiple dates using tan sand and black sand as topdressing on a T-1 creeping bentgrass green at the WSU Turfgrass and Agronomy Research Center, at Pullman, WA, 2009. Bars are ± SE.

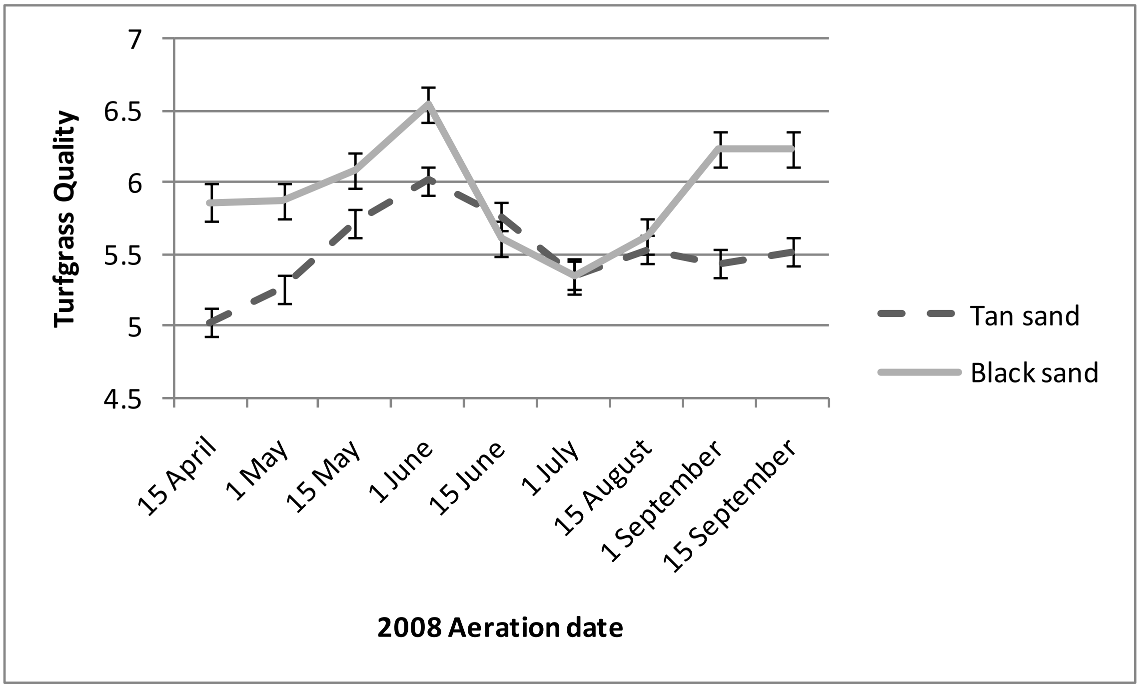

Fig. 2.6. Turfgrass quality rating for core aeration treatments at multiple dates using tan sand and black sand as topdressing on a T-1 creeping bentgrass green at the WSU Turfgrass and Agronomy Research Center, at Pullman, WA, 2008. Bars are ± SE. Turfgrass quality rated on a scale of 1 to 9; 9 = green healthy turf, ≥ 6 = acceptable turf quality, 1= dead turf.

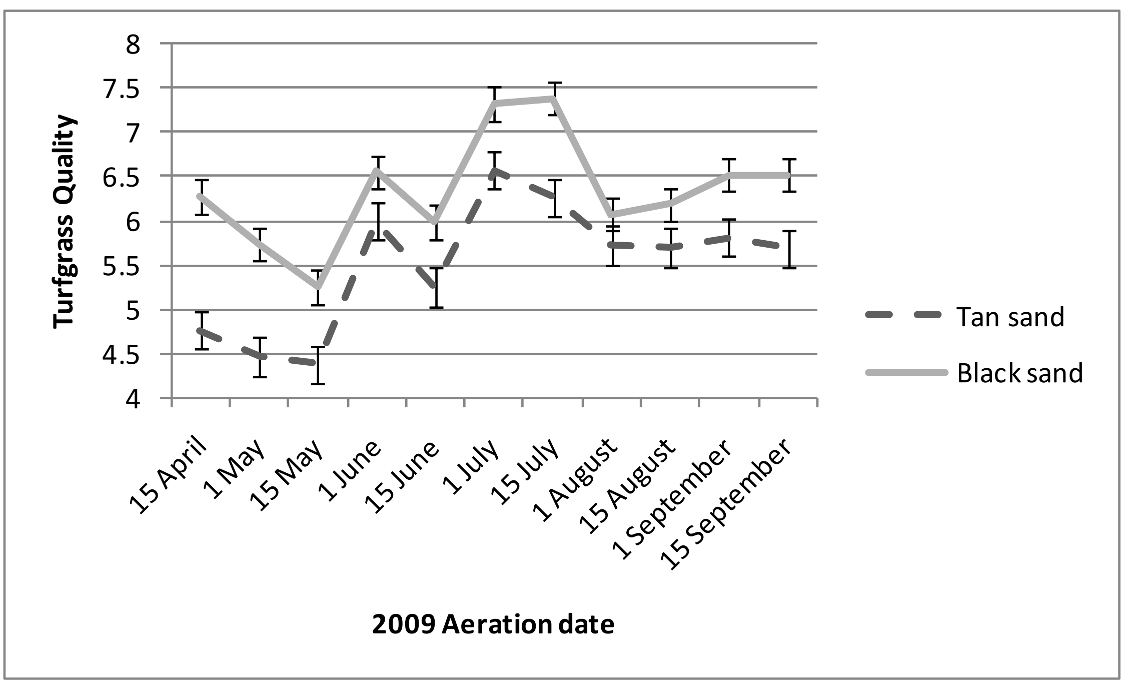

Fig. 2.7. Turfgrass quality rating for core aeration treatments at multiple dates using tan sand and black sand as topdressing on a T-1 creeping bentgrass green at the WSU Turfgrass and Agronomy Research Center, at Pullman, WA, 2009. Bars are ± SE. Turfgrass quality rated on a scale of 1 to 9; 9 = green healthy turf, ≥ 6 = acceptable turf quality, 1 = dead turf.

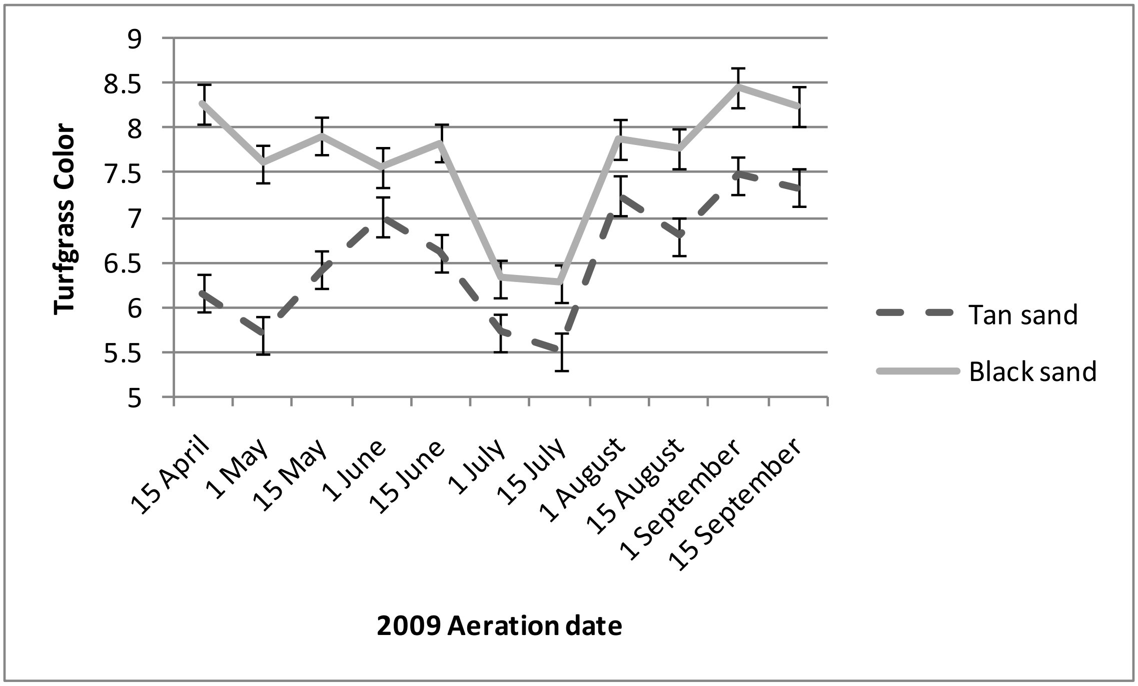

Figure 2.8. Turfgrass color rating for core aeration treatments at multiple dates using tan sand and black sand as topdressing on a T-1 creeping bentgrass green at the WSU Turfgrass and Agronomy Research Center, at Pullman, WA, 2009. Bars are ± SE. Turfgrass color rated on a scale of 1 to 9; 9 = ideal, dark turf, 6 = minimum acceptable color, and 1 = brown dead turf.

APPENDIX

Appendix Table I. Topdressing sand nutrient analysis for aeration and topdressing treatments on a T-1 creeping bentgrass golf green.

Topdressing	NO_3-N	P	K	Mg	Ca	Na
	ppm					
Tan	2	4	34	30	84	16
Black	2	1	69	316	1184	30
	Soil pH	Excess carbonate	Soluble salts			
			mmhos/cm			
Tan	7.5	L	0.09			
Black	8.7	M	0.15			
	Cation Exchange Capacity					
	K	Mg	Ca	Na	H	Total
	%					
Tan	10.5	30.2	50.8	8.4	0.0	0.8
Black	2.0	29.7	66.8	1.5	0.0	8.9

Appendix Table II. Mean temperature by month for Pullman, WA, 2008 and 2009.

Year		Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
		°C							
2008	Max.	11.5	19.3	21.9	28.6	28.6	24.1	17.2	9.7
	Min.	0.3	6.2	6.8	9.4	10.2	6.4	2.0	1.9
2009	Max.	13.1	19.0	23.2	28.8	29.0	26.8		
	Min.	1.4	5.3	8.5	10.2	11.9	7.8		

Appendix Table III. Analysis of variance by year for quality at the Palouse Ridge Golf Course, Pullman, WA.

	2008					2009				
	May	June	July	Aug.	Sept.	May	June	July	Aug.	Sept.
Cultivation (C)	***	*	***	***	***	***	***	***	***	***
Sand (S)	**	**	**	***	***	**	ns†	**	**	**
C x S	ns	*	***	***	***	***	ns	***	***	***

* $P \leq 0.05$.
** $P \leq 0.01$.
*** $P \leq 0.001$.
† ns $P > 0.05$.

Appendix Table IV. Analysis of variance by year for soil temperature at 2.5 cm and 7.5 cm for 2008 and 2009 respectively on a T-1 creeping bentgrass green at Palouse Ridge Golf Course, Pullman, WA.

	2008					2009				
	May	June	July	Aug.	Sept.	May	June	July	Aug.	Sept.
Cultivation (C)	ns†	ns	*	***	***	*	***	***	***	***
Sand (S)	*	**	*	**	**	ns	ns	ns	**	***
C x S	ns	ns	**	***	***	ns	ns	**	***	***

* $P \leq 0.05$.
** $P \leq 0.01$.
*** $P \leq 0.001$.
† ns $P > 0.05$.

Appendix Table V. Analysis of variance for thatch depth at the Palouse Ridge Golf Course, Pullman, WA.

	Thatch depth
Cultivation (C)	***
Sand (S)	ns†
C x S	ns
Year (Y)	***
C x Y	ns
S x Y	ns
C x S x Y	ns

*** $P \leq 0.001$.
† ns $P > 0.05$.

Appendix Table VI. Analysis of variance by year for thatch organic matter content at the Palouse Ridge Golf Course, Pullman, WA.

	2008	2009
Cultivation (C)	***	***
Sand (S)	*	ns
C x S	ns†	ns

* $P \leq 0.05$.
*** $P \leq 0.001$.
† ns $P > 0.05$.

Appendix Table VII. Analysis of variance by year for infiltration at the Palouse Ridge Golf Course, Pullman, WA.

	2008	2009
Cultivation (C)	ns†	ns
Sand (S)	ns	ns
C x S	*	**

* *P* ≤ 0.05.
** *P* ≤ 0.01.
† ns *P* > 0.05.

Appendix Table VIII. Analysis of variance for color at the Palouse Ridge Golf Course, Pullman, WA.

	2009				
	May	June	July	Aug.	Sept.
Cultivation (C)	***	*	***	***	***
Sand (S)	**	**	**	***	***
C x S	ns†	*	***	***	***

* *P* ≤ 0.05.
** *P* ≤ 0.01.
*** *P* ≤ 0.001.
† ns *P* > 0.05.

Appendix Table IX. Analysis of variance for ball roll distance at the Palouse Ridge Golf Course, Pullman, WA.

	Ball roll distance
Cultivation (C)	ns†
Time (T)	*
C x T	ns

* *P* ≤ 0.05.
† ns *P* > 0.05.

Appendix Table X. Analysis of variance by year for injury at the Palouse Ridge Golf Course, Pullman, WA.

	2008	2009
Cultivation (C)	***	***
Sand (S)	*	ns
C x S	ns†	ns

* *P* ≤ 0.05.
*** *P* ≤ 0.001.
† ns *P* > 0.05.

Appendix Table XI. Analysis of variance by year for soil organic matter content at the Palouse Ridge Golf Course, Pullman, WA.

	2008	2009
Cultivation (C)	ns†	ns
Sand (S)	ns	ns
C x S	ns	ns

* *P* ≤ 0.05.
** *P* ≤ 0.01.
*** *P* ≤ 0.001.
† ns *P* > 0.05.

Appendix Table XII. Analysis of variance by year for days to recovery on a T-1 creeping bentgrass green at the Turfgrass and Agronomy Research Center, Pullman, WA.

	2008	2009
Date (D)	***	***
Sand (S)	ns†	***
D x S	*	**

* $P \leq 0.05$.
** $P \leq 0.01$.
*** $P \leq 0.001$.
† ns $P > 0.05$.

Appendix Table XIII. Analysis of variance by year for soil temperature at 7.5 and 2.5 cm depth in 2008 and 2009 respectively on a T-1 creeping bentgrass green at the Turfgrass and Agronomy Research Center, Pullman, WA.

	2008	2009
Date (D)	***	***
Sand (S)	***	***
D x S	ns†	ns

*** $P \leq 0.001$.
† ns $P > 0.05$.

Appendix Table XIV. Analysis of variance by year for quality on a T-1 creeping bentgrass green at the Turfgrass and Agronomy Research Center, Pullman, WA.

	2008	2009
Date (D)	**	***
Sand (S)	***	***
D x S	***	***

** $P \leq 0.01$.
*** $P \leq 0.001$.

Appendix Table XV. Analysis of variance for color on a T-1 creeping bentgrass green at the Turfgrass and Agronomy Research Center, Pullman, WA.

	2009
Date (D)	***
Sand (S)	***
D x S	***

*** $P \leq 0.001$.