Topdressing and aerification programs on creeping bentgrass fairways

by

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General Introduction

Golf course fairways are the area between the tee box and the putting green. Fairways are typically thought of as a reward for hitting a good tee shot because the golfer hits the next shot off a low mown, high quality turf. On a typical eighteen hole golf course, the fairways occupy from 10 to 14.5 hectares, while greens and tee boxes usually cover 2.4-3.3 hectares.

Several cool-season species are used as fairway turf. Cool-season grass species used for fairway turf include Kentucky bluegrass (*Poa pratensis* L.), perennial ryegrass (*Lolium perenne* L.), fine fescues (*Festuca spp.*), and creeping bentgrass (*Agrostis stolonifera* L.) (Christians, 2000). Creeping bentgrass is a highly stoloniferous turf species that is able to repair itself from damage and can be cut as low as 3.2 mm while still maintaining a dense turf stand (Christians, 2007). For these reasons, creeping bentgrass is the fairway species of choice for high budget golf operations in the northern region of the country.

Golf course fairways have many problems. One major problem is invasion by annual bluegrass (*Poa annua* L.). Annual bluegrass is a highly competitive grass that is able to crowd out the other turf species and potentially become the primary grass in the fairway (Christians, 2000). Fungal disease infection is another fairway problem. Diseases such as dollar spot (*Sclerotinia homeocarpa*), *Pythium* blight (*Pythium spp.*), and brown patch (*Rhizoctonia solani*) are able to attack a variety of fairway turf species (Christians, 2007). A third problem is thatch buildup. Thatch is an accumulation of living and dead grass leaves, stems, and green vegetation in a turf (Beard, 1973). Thatch causes many turf problems including increased disease and insect infestations, scalping, poor quality, localized dry spot, and limited rooting (Beard, 1973; Hurto et al., 1980).

A final problem associated with fairways is damage caused by soil compaction. Fairways are placed on natural soils, which often contain particle sizes that are susceptible to compaction. Compaction can directly affect turf quality by damaging roots (Murphy et al., 1993). It can also indirectly affect quality by increasing disease and weed incidence such as *Poa annua* (Clarke, 1996; Beard, 1973). In general, as soils are compacted, there is a decrease in air porosity while water holding capacity is not affected (Beard, 1973). As a soil becomes compacted, the percentage of large pores decreases resulting in reduced air and water movement (Beard, 1973). Traffic from mowers, sprayers, golfers, and golf carts compact fairway soils. This traffic usually compacts the top 5 to 7.5 cm in turf situations with the top 2.5 cm being the most severely compacted (Beard, 1973). Topdressing and aerification are two cultural practices that are used to reduce compaction and improve fairway turf quality.

Topdressing is the application of a layer of prepared soil mix to a turf surface (Carrow, 1979). Topdressing has been employed since the early days of greens keeping and originally was used to smooth the playing surface, control thatch, and supply nutrients to the turf (Fitts, 1925). Currently, topdressing is implemented in most greens programs and recently it has seen increased use on golf course fairways due to ever increasing turf quality expectations from golfers.

Multiple research projects have been completed on the benefits of topdressing (Stier et al., 2003; Fermanian et al., 1985; Christians et al., 1985; Madison et al., 1974). These reports state that topdressings positive effects are smoothing the playing surface, firming the turf, and enhancing thatch decomposition (Zontek, 2005; Callahan et al., 1998; Madison et al., 1974). The addition of sand to the thatch layer provides a better environment for microorganisms to decompose organic matter (Zontek, 2005; Fermanian et al., 1985). Topdressing also reduces winter damage (Christians et al., 1985), and topdressing used in conjunction with aerification can increase the recovery speed of the turf (Christians, 2007).

Sand is the material commonly recommended for topdressing (Obrien and Hartwiger, 2001). Research has shown that topdressing on putting greens, applied in small amounts, frequently throughout the growing season is beneficial for turf (Cooper and Skogley, 1981). The strategy of light, frequent applications of sand is less practical for fairways because of the large area to be covered.

How topdressing effects the winter freeze-thaw cycles is not fully understood. Winter freeze-thaw cycles alone may reduce soil compaction (Beard, 1973). Soils in the northern region of the United States undergo a freeze to a depth of 0.91 m (DeJong-Hughes, personal communication). The top 5.1 to 12.7 cm of soil undergoes more than one freeze-thaw cycle (DeJong-Hughes, personal communication). Freeze-thaw cycles have a major impact on soil formation and properties. Freeze-thaw cycles have been shown to reduce bulk density, a measure of compaction (Li et al., 2001; Unger, 1991). Topdressing may insulate the soil and reduce the beneficial effects of the winter freeze-thaw cycles. Soil texture can also affect the extent to which the freeze-thaw alters soil properties (Lehrsch et al., 1991). The addition of sand topdressing to a fairway will alter the texture of the underlying soil and also influence the extent to which the freeze-thaw cycles alter physical soil properties.

Aerification, like topdressing, is a cultural practice used on fairway turf. Aerification is a method of turf cultivation in which holes are created in the ground to a defined depth. It is one of a few ways to cultivate soil under a perennial turf cover without destroying the playing surface or killing the turf. Aerification is primarily used to reduce soil compaction and to improve drainage (Christians, 2007). Two types of aerification are used in the turf industry: solid tine and hollow tine core aerification (HTCA).

Solid tine aerification entails driving a spike into the ground and pulling it out. This method has two benefits over HTCA: less clean-up time following the treatment and less disruption to turf (Murphy et al., 1993). On the other hand, the two main drawbacks of solid tine aerification are the creation of a compacted zone at the bottom and side of the tine and there is no physical removal of thatch (Brauen et al., 1998).

The second method, HTCA, is accomplished by driving a hollow tine into the soil and pulling it out. Soil will eject from the top or the side of the tine leaving an open cylinder in the turf and a soil plug resting on top of the grass surface. Research on HTCA has shown mixed results when tested for its influence on soil and plant properties. Some studies have concluded HTCA increases water infiltration, while others have reported it decreases infiltration (McCarty et al., 2007; Waddington et al., 1974; Roberts, 1975). Other research has demonstrated that HTCA reduces soil bulk density (Murphy et al., 1993). In contrast, research has also shown HTCA increases bulk density below the zone of aerification (Brauen et al., 1998). HTCA research studies have shown improvement in plant rooting, while others studies have reported it either does not change root mass, or even decreases root mass (Murphy et al., 1993; Smith, 1979). Experimental results have demonstrated HTCA decreases penetration resistance in the zone of soil that receives aerification (Murphy et al., 1993).

A further benefit of HTCA is the reduction and or control of thatch. Aerification works in two ways to reduce thatch. Primarily, aerification reduces thatch by physically removing pieces of thatch. Secondly, aerification opens up the thatch layer providing a better environment for microorganisms to decompose organic matter (Brauen et al., 1998).

Aerification tines are available in varying diameters and aerification units can make holes to varying depths. Aerification, when used in combination with topdressing, should be completed with tines of 1.27 cm or larger in diameter. A 1.27 cm tine diameter is the smallest hole that can be consistently filled with topdressing sand (O'Brien and Hartwiger, 2001).

In addition to selecting the correct tine, the proper seasonal timing of aerification is an important consideration. In the cool-season region, fairway aerification is performed in the spring or fall. This is the least stressful time for grass to undergo disruption to the crown and root zone. In regions that undergo the winter freeze thaw the optimum timing of aerification is unknown. In 1951, Tom Mascaro suggested fall aerification is most beneficial because it enhances the natural soil loosening of the freeze-thaw cycles. Despite this claim being made over fifty years ago, no research has been conducted to address this question.

As discussed, freeze-thaw cycles have beneficial effects on soil. There are several factors that affect the extent to which freeze-thaw cycles alter physical soil properties. Krumbach and White (1964) reported freeze depth is affected by crop cover. Currently, no research exists examining how the freeze-thaw process affects soil under a maintained fairway height turf cover.

Two soil properties that affect the freeze-thaw cycle are soil texture and moisture (Lehrsch et al., 1991; Bullock et al., 1988; Mostaghimi et al., 1988). Aerification and topdressing have the potential to alter these two soil properties, which may influence the extent to which the freeze-thaw cycles alter soil properties.

The objectives of this study were (i) determine the optimum rate and time to implement topdressing and aerification on creeping bentgrass fairways and (ii) understand the effects of timing and frequency of topdressing and aerification on the natural soil loosening of the winter freeze-thaw cycles.

Thesis Organization

This thesis is divided into three chapters. The first chapter describes the literature that was reviewed and why this research was needed. Chapter two is a manuscript to be submitted to *Crop Science* that describes work completed at Iowa State University and North Dakota State University. Chapter three is a summary of the results and overall conclusions drawn from this research.

References

Beard, J.B. 1973. Turfgrass science and culture. Prentice-Hall Inc., Englewood Cliffs, N.J.

Brauen, S.E., W.J. Johnston, and R.L. Goss. 1998. Long-term aerification: A bentgrass fairway study compares hollow- and solid-tine core aerification. USGA Green Sect. Rec. 36:13-15.

Bullock, M.S., W.D. Kemper, and S.D. Nelson. 1988. Soil cohesion as affected by freezing, water content, time and tillage. Soil Sci. Soc. Am. J. 52:770-776.

Callahan, L.M., W.L. Sanders, J.M. Parham, C.A. Harper, L.D. Lester, and E.R. McDonald. 1998. Cultural and chemical controls of thatch and their influence on root zone nutrients in a bentgrass green. Crop Sci. 38:181-187.

Clarke, B.B. (ed.) 1996. Rutgers Turf. Proc. Dec. 10-12. Atlantic City, N.J. Utilizing proper cultural practices to reduce turfgrass diseases.

Carrow, R.N. 1979. Topdressing: An essential management tool. Golf Course Mgt. 47:26-28, 30-32.

Christians, N.E. 2007. Fundamentals of turfgrass management 3rd ed. John Wiley & Sons Inc., Hoboken, N.J.

Christians, N.E. 2000. Fairway grasses for Midwest golf courses. Golf Course Mgt. 68:49-56.

Christians, N.E., K.L. Diesburg, and J.L. Nus. 1985. Effects of nitrogen fertilizer and fall topdressing on the spring recovery of *Agrostis palustris* Huds. (Penncross creeping bentgrass) greens. Proc. of the Fifth Int. Turf. Res. Conf. 5:459-468.

Cooper, R.J. and C.R. Skogley. 1981. An evaluation of several topdressing programs for *Agrostis palustris* Huds. and *Agrostis canina* L. putting green turf. P.129-136. *In* R.W. Sheard (ed.) Proc. Fourth Int. Turf. Res. Conf. Guelph, ON. 19-23 July 1981. Univ. of Guelph and ITS, Guelph, ON.

Fermanian, T.W., J.E. Haley, and R.E. Burns. 1985. The effects of sand topdressing on a heavily thatched creeping bentgrass turf. Proc. of the Fifth Int. Turf. Res. Conf. 5:439-448.

Fitts, O.B., 1925. The vital importance of topdressing in the maintenance of satisfactory creeping bent greens. USGA Greens Sect. Rec. 5:242-245.

Hurto, K.A., A.J. Turgeon, and L.A. Spomer. 1980. Physical characteristics of thatch as a turfgrass growing medium. Agron. J. 72:165-167.

Krumbach, A.J. and D.P. White. 1964. Moisture, pore space, and bulk density changes in frozen soil. Soil Sci. Soc. Am. Proc. 28:422-425.

Lehrsch, G.A., R.E. Sojka, D.L. Carter, and P.M. Jolley. 1991. Freezing effects on aggregate stability affected by texture, mineralogy, and organic matter. Soil Sci. Soc. Am. J. 55:1401-1406.

Li, D., M. Volterrani, N.E. Christians, D.D. Minner, and S. Magni. 2001. Freezing and thawing effects on sand-based media modified with soil amendments. Int. Turf. Soc. Res. J. 9:548-552.

Madison, J.H., J.L. Paul, and W.B. Davis. 1974. Alternative method of greens management. Proc. of the Sec. Int. Turf. Res. Conf. 2:431-437.

McCarty, L.B., M.F. Greg, and J.E. Toler. 2007. Thatch and mat management in an established creeping bentgrass golf green. Agron. J. 99:1530-1537.

Mascaro, T. 1951. Is the fall period a proper time for aerification?. 22nd National Turf Conference and Show. Jan. 29-Feb. 2, 1951. Chicago, IL.

Mostaghimi, S., R.A. Young, A.R. Wilts, and A.L. Kenimer. 1988. Effects of frost action on soil aggregate stability. Trans. ASAE 31:435-439.

Murphy, J.A., P.E. Rieke, and A.E. Erickson. 1993. Core cultivation of a putting green with hollow and solid tines. Agron. J. 85:1-9.

O'Brien, P. and C. Hartwiger. 2001. Aeration and topdressing for the 21st century: Two old concepts are linked together to offer up-to-date recommendations. USGA Greens Sect. Rec. 41:1-7.

Roberts, J.M. 1975. Some influences of cultivation on the soil and turfgrass. M.S. thesis. Dept. of Agron. Purdue Univ., West Lafayette.

Stier, J.C. and A.B. Hollman. 2003. Cultivation and topdressing requirements for thatch management in A and G bentgrasses and creeping bluegrass. HortScience 38:1227-1231.

Smith, G.S. 1979. Nitrogen and aerification influence on putting green thatch and soil. Agron. J. 71:680-684.

Unger, P.W. 1991. Overwinter changes in physical-properties of no-tillage soil. Soil Sci. Soc. Am. J. 55:778-782.

Waddington, D.V., T.L. Zimmerman, G.L. Shoop, L.T. Kardos, and J.M. Duich. 1974. P. 1-96. *In* Soil modification for turfgrass areas. Agric. Exp. Stn. Prog. Rep. 337: The Pennsylvania State Univ., University Park, P.A.

Zontek, S.J. 2005. Fairway topdressing in the Mid-Atlantic Region. USGA Greens Sect. Rec. 43:18-21.

Aerification and Topdressing to Enhance Fairway Soil Properties

A paper to be submitted to *Crop Science*

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Additional index words. freeze-thaw, winter, compaction, creeping bentgrass

ABSTRACT. The proper timing of topdressing and aerification for creeping bentgrass fairways and the effect that these two cultural practices have on soil physical properties have not been fully assessed. The first objective of this study was to determine the optimum timing of topdressing and aerification for golf course fairways. The second objective was to determine if varying schedules of topdressing and aerification influence the extent to which soil physical properties change following freeze-thaw cycles. The two year field study was conducted at Ames, IA, and Fargo, ND on established creeping bentgrass (*Agrostis stolonifera* L.) maintained at fairway mowing height. The study included three topdressing treatments: a control, with no topdressing; 3.2 mm topdressing in the fall; and 3.2 mm topdressing in the spring plus 3.2 mm in the fall. Six aerification treatments including a control, spring one pass, fall one pass, spring two passes, fall two passes, and spring one pass plus fall one pass were also evaluated. Soil bulk density decreased during both over winter periods at both locations from 4 to 6%, however, topdressing and aerification treatments did

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not consistently influence over-winter soil bulk density change. Topdressing and aerification increased turf quality at North Dakota but not Iowa. Soil in plots aerified in the fall had 4% lower soil strength than those aerified in the spring at both sites. Soil in aerified plots had a 48% increase in water infiltration as compared to the control at North Dakota but no increase was observed at Iowa.

INTRODUCTION

A problem commonly associated with golf course fairways is damage caused by soil compaction. Fairways are placed on natural soils, which often contain particle sizes are susceptible to compaction. Compaction directly affects turf quality by damaging roots (Murphy et al., 1993) and indirectly affects quality by increasing disease and weed incidence (Clarke, 1996; Beard, 1973). Traffic from mowers, sprayers, golfers, and golf carts compact fairway soils. Two cultural practices used to reduce compaction and improve fairway turf quality are topdressing and aerification.

Topdressing is the application of a layer of prepared soil mix to a turf surface (Carrow, 1979). Topdressing has been employed since the early days of greens keeping and originally was used to smooth the playing surface, control thatch, and supply nutrients to the turf (Fitts, 1925). Currently, topdressing is implemented in most greens programs and recently, it has seen increased use on golf course fairways due to increased turf quality expectations by golfers.

Several research projects have been completed on topdressing (Stier et al., 2003; Fermanian et al., 1985; Christians et al., 1985; Madison et al., 1974). These projects have shown topdressings beneficial effects are smoothing the playing surface, firming the turf, and enhancing thatch decomposition (Zontek, 2005; Callahan et al., 1998; Madison et al., 1974). The addition of sand to the thatch layer provides a better environment for the microorganisms to decompose organic matter (Zontek, 2005; Fermanian et al., 1985). Topdressing is effective at reducing winter damage (Christians et al., 1985), and topdressing used in conjunction with aerification, speeds the recovery of turf (Christians, 2007).

The influence of topdressing programs on the effects of winter freeze-thaw is not fully understood. Winter freeze-thaw cycles alone may reduce soil compaction (Beard, 1973). Soils in the northern region of the United States undergo a freeze to a depth of 0.91 m (DeJong-Hughes, personal communication). The top 5.1 to 12.7 cm of soil undergo more than one freeze-thaw cycle (DeJong-Hughes, personal communication). Freeze-thaw cycles have a major impact on soil formation and soil properties. Freeze-thaw cycles have been shown to reduce bulk density, a measure of compaction (Li et al., 2001; Unger, 1991). One possibility is that the application of topdressing may act as an insulating material and reduce the beneficial effects of the winter freeze-thaw cycles. Soil texture is a property that affects the extent to which the freeze-thaw alters soil properties (Lehrsch et al., 1991). The addition of sand topdressing to a turf stand will change the texture of the underlying soil. This could also influence the extent to which the freeze-thaw cycles alter physical soil properties.

Aerification, like topdressing, is a cultural practice used on fairway height turf. Aerification is a method of turf cultivation in which holes are created in the ground to a defined depth. It is one of a few ways to cultivate soil under a perennial turf cover without destroying the playing surface or killing the turf. Aerification is primarily used to reduce soil compaction and to improve drainage (Christians, 2007). Two types of aerification are used in the turf industry: solid tine and hollow tine core aerification (HTCA).

Solid tine aerification entails driving a spike into the ground and pulling it out. This method has two benefits over HTCA: reduction of clean-up time following the treatment and less disruption to turf (Murphy et al., 1993). On the other hand, the two main drawbacks of solid tine aerification are the creation of a compacted zone at the bottom and side of the tine and no physical removal of thatch (Brauen et al., 1998).

The second method, HTCA, is accomplished by driving a hollow tine into the soil and pulling it out. Soil will eject from the top or side of the tine and leave an open cylinder in the turf and a soil plug resting on the top of the grass surface. HTCA research has shown mixed results when tested for its influence on soil and plant properties. Some studies have shown HTCA increases water infiltration, while others have reported it decreases infiltration (McCarty et al., 2007; Waddington et al., 1974; Roberts, 1975). Other research has demonstrated that HTCA reduces soil bulk density (Murphy et al., 1993). In contrast, research has also shown HTCA increases bulk density below the zone of aerification (Brauen et al., 1998). HTCA research studies have shown improvement in plant rooting, while others studies have reported it either does not change root mass or even decreases root mass (Murphy et al., 1993; Smith, 1979). Experimental results have demonstrated HTCA decreases penetration resistance in the zone of soil that receives aerification (Murphy et al., 1993).

A further benefit of HTCA is the reduction and or control of thatch. Aerification works in two ways to reduce thatch. Primarily, aerification reduces thatch by physically removing pieces of thatch. Secondly, aerification opens up the thatch layer providing a better environment for microorganisms to decompose organic matter (Brauen et al., 1998).

Aerification tines are available in varying diameters and aerification units can make holes to varying depths. Aerification, when used in combination with topdressing, should be completed with tines 1.27 cm or larger in diameter. A 1.27 cm tine diameter is the smallest hole that can be consistently filled with topdressing sand (O'Brien and Hartwiger, 2001).

In addition to selecting the correct tine, the proper seasonal timing of aerification is an important consideration. In the cool-season region, fairway aerification is performed in the spring or fall. This is the least stressful time for grass to undergo this type of disruption to the crown and root zone. The optimum timing of aerification to harness the beneficial effects of the winter freeze-thaw cycles is unknown. In 1951, Tom Mascaro suggested fall aerification is beneficial due to enhancing the natural soil loosening of the freeze-thaw cycles. Despite the claim being made over fifty years ago, no research has been conducted to address this question. This study is designed to determine the optimum timing of aerification to increase the beneficial effects of winter.

There are several factors that affect the extent to which freeze-thaw cycles alter physical soil properties. Krumbach and White (1964) reported that freeze depth is affected by crop cover. Currently, no known research exists examining how the freeze-thaw process affects soil under a maintained fairway height turf cover.

Two of the soil properties that affect the freeze-thaw cycle are soil texture and moisture (Lehrsch et al., 1991; Bullock et al., 1988; Mostaghimi et al., 1988). Aerification and topdressing have the potential to alter these two soil properties, which may influence the extent to which the freeze-thaw cycles alter soil properties.

The objectives of this study were (i) determine the optimum rate and time to implement topdressing and aerification on creeping bentgrass fairways and (ii) understand the effects of timing and frequency of topdressing and aerification on the natural soil loosening of the winter freeze-thaw cycles.

MATERIALS AND METHODS

Trial overview

The study was initiated in fall 2006 on mature stands of creeping bentgrass maintained as golf course fairway height turf in both Ames, IA, and Fargo, ND. The bentgrass at the site in Iowa was a mixed stand of ‘1019’, ‘1020’, and ‘Penncross’, and the bentgrass at the site in North Dakota was ‘Penncross’. Soil at the site in Iowa was a 1:1:1 mix of sand:peat:soil with a particle size of 13.7% sand, 56.9% silt, and 29.5% clay. Soil pH was 7.6, with soil P and K contents of 17, and 58 mg kg^{-1}, respectively. The soil part of the mixture was Nicollet clay-loam (fine-loamy, mixed, mesic, Typic Hapludoll). Soil at the site in Fargo was a Fargo-Ryan silty clay [(fine, montmorillonitic, frigid Vertic Haplaquall)-(fine, montmorillonitic, Typic Natraquoll)], with a soil particle size composition of 2% sand, 46% silt, and 52% clay. Soil pH was 7.8, with soil P and K contents of 64, and 400 mg kg^{-1}, respectively.

The study was arranged as a split-plot design with three sand topdressing treatments (mainplot) and six HTCA treatments (split-plot) with three replications at each location.

Topdressing treatments included no topdressing, spring topdressing of 3.2 mm, or spring topdressing of 3.2 mm plus fall topdressing of 3.2 mm. The sand topdressing used at the site in North Dakota had a composition of 3.8% very coarse, 20.8% coarse, 42.0% medium, 29.4% fine, 3.7% very fine, and 0.3% silt and clay. The sand topdressing used at the site in Iowa had a composition of 8.2% very coarse, 35.3% coarse, 44.3% medium, 11.9% fine, 0.1% very fine, and 0.2% silt and clay. Sand was brushed in after application. Split-plot treatments included an untreated control, with no HTCA; one pass HTCA in spring; two passes HTCA in spring; one pass HTCA in fall; two passes HTCA in fall; one pass HTCA in both spring and fall. Aerification was accomplished using a Toro Greens Aerator, Model 09120 (Toro Co., Bloomington, MN), at both locations. Outside diameter of the tines was 1.3 cm and tines were allowed to penetrate the ground to a depth of 5.1 cm. Soil from the aerification cores was reincorporated into the turf and the thatch debris was removed. Treatment dates for the site in North Dakota were 15 Sept. 2006, 21 May and 11 Sept. 2007, and 12 June 2008. Treatment dates for the site in Iowa were 10 Nov. 2006, 7 June and 12 Oct. 2007, and 15 June 2008.

Both sites were mown two to three times per week at a height of 12.7 mm. Plots were irrigated as needed to prevent drought stress. The site in Iowa was treated with both liquid and granular fertilizer amounting to a total of 20 to 22 g m^{-2} N, 0 g m^{-2} P, and 0 to 7.3 g m^{-2} K in each 2006, 2007, and 2008. The site in North Dakota was treated with granular fertilizer amounting to 17 g m^{-2} N, 0 g m^{-2} P, and 27.5 g m^{-2} K in each 2006, 2007, and 2008.

Data collection

Measurements for quality, soil strength, water content, soil bulk density, and infiltration were used to assess the optimum number of aerification passes, amount of topdressing material, and timing of topdressing and aerification for creeping bentgrass fairways. One measurement of soil bulk density was taken from each split-plot using a bulk density core sampler each spring and fall. Samples were taken from 2.9 to 8.9 cm below the turf surface, to avoid sampling the thatch layer. Values of soil bulk density from fall were subtracted from values of bulk density from spring to determine the reduction of soil bulk density over winter. Penetration resistance of the top 15.2 cm of soil at the site in Iowa was measured with a Bush depth recording penetrometer (Andersons et al., 1980). Penetration resistance of the top 15.2 cm of soil at the site in North Dakota was measured with an American Corps of Engineering cone penetrometer (Lewis Center, OH). Both penetrometers had cone diameters of 12.83 mm and a 30 degree cone angle. Water infiltration rate of soil at the site in Iowa was measured using the falling-head, double-ring method with a 20 cm diameter inner ring and 30 cm diameter outer ring. Water infiltration rate at the site in North Dakota was measured using the constant-head method with a 10 cm diameter single ring with 1.5 cm water head. Volumetric water content was measured at both sites using the time-domain reflectometer (TDR) method by collecting five measurements per sub-plot. Turf quality was assessed for each split-plot using the National Turfgrass Evaluation Program (NTEP, Beltsville, MD http://www.ntep.org/) guidelines. A scale of 9-1 was used, with a rating of 9 representing the highest turf quality, a rating of 1 representing the lowest turf quality, and a rating of 6 representing a minimally acceptable quality rating.

Statistical analysis

Data were analyzed using the Proc Mixed function in Statistical Analysis Software version 9.1.3 (SAS Institute Inc., Cary, NC). Data from both sites were analyzed together with the exception of infiltration. Data were analyzed as a split-plot in time using narrow sense inference. The *F* test from the analysis of variance was used to identify main effects and interaction effects. Orthogonal contrasts and LSD means separation were used to compare responses to aerification and topdressing treatments.

RESULTS AND DISCUSSION

There were no differences between the North Dakota and Iowa sites for bulk density over-winter change, soil strength in aerification treatments, and soil moisture, so these data were combined for further analysis (Table 1). Differences between the two sites were observed for quality ratings, total bulk density, and soil strength for topdressing treatments so the two locations were analyzed separately for these ratings (Table 1). Data were not combined for infiltration because different methods were used to obtain the results at the two locations.

Bulk Density

When data were averaged over all treated and control plots, the soil at the site in Iowa had a 4% reduction of bulk density during both the 2006-2007 and 2007-2008 winters (Table 2). Soil at the site in North Dakota had a 6% bulk density reduction during the 2006-2007 winter, and a 5% reduction of bulk density during the 2007-2008 winter (Table 2). This is consistent with Unger (1991) who also observed a reduction of soil bulk density over winter.

At the site in North Dakota, soil collected from plots receiving aerification had a 2% lower bulk density than soil collected from plots receiving no aerification (Table 3). This is consistent with Murphy et al. (1993) who also found aerification to reduce bulk density. No soil bulk density differences were observed between plots receiving one or two passes of aerification, or between plots receiving spring or fall aerification (Table 3). At the site in North Dakota, no bulk density differences were observed between soil in plots that received topdressing and soil in plots that received no topdressing (data not shown).

At the site in Iowa, no soil bulk density differences were observed between plots that received aerification treatments and those that received no aerification treatments (data not shown). At the site in Iowa, soil bulk density means for topdressing plots, averaged over aerification treatments and four rating dates were 1.42, 1.36, and 1.35 g cm^{-3} for the control, fall topdressing, and spring plus fall topdressing, respectively. Soil in plots that received topdressing had a 5% lower bulk density than soil in the plots that received no topdressing at the site in Iowa. The plots receiving the highest rate of topdressing (fall plus spring) received a total of 1.3 cm of sand during the study. Soil cores were collected from 2.9 cm below the turf surface, so the reduction of bulk density can be attributed to sand mixing into the aerification holes.

Bulk Density Over-Winter Change

Bulk density change (ΔBD) from fall to spring was used to determine if topdressing or aerification treatments influenced the extent of over winter soil changes. While no ΔBD differences were observed between the sites, differences were observed between the two years and data for the two years separated for analysis (Table 1 and 3). During the 2006-

2007 winter, soil in plots with aerification had an average reduction of bulk density of 42% more than soil in the control plots (Table 3). However, in the 2007-2008 winter, soil in control plots had an average reduction of bulk density of 46% more than soil in the plots receiving aerification (Table 3). Topdressing did not influence ΔBD (Table 1). In the fall of 2006, all plots had similar bulk densities therefore all plots had the same capacity to change over winter. Going into the 2007-2008 winter, soil in the control plots had higher soil bulk densities than soil in the plots receiving aerification. It is likely that the control plots had a larger decrease in soil bulk density over the 2007-2008 winter because of the higher fall values.

Quality Ratings

Plots in Iowa had initially high quality ratings so neither topdressing nor aerification affected quality (data not shown). At the site in North Dakota, plots receiving topdressing had increased quality from 4 to 11% after the first rating (Table 4). McCarty et al. (2007) also reported that increased quality was observed with topdressing. At the site in North Dakota, no quality differences were observed between the two topdressing treatments (Table 4). Similarly, Fermanian et al. (1985) reported seeing no differences in quality between plots receiving varying topdressing treatments. At the site in North Dakota, plots receiving fall aerification had the highest quality during the last two rating dates (Table 5).

Water Content & Soil Strength

No differences were observed in water content among the plots receiving topdressing and aerification treatments (Table 1). Therefore, the differences observed in soil strength are presumably not caused by differing water contents. No soil strength differences were observed between the sites or rating dates for aerification treatments and data were combined for analysis (Table 1 and 3). The average soil strength of plots receiving aerification was 4% lower than the control (Table 3). Previous experiments have also demonstrated that HTCA decreases penetration resistance in the zone of soil that receives aerification (Murphy et al., 1993). No differences in soil strength were observed between plots receiving one pass and two passes of aerification (Table 3). Soil in plots receiving aerification in the fall had 4% lower soil strength than soil in plots receiving aerification in the spring (Table 3).

Differences in soil strength were observed between the sites for plots receiving topdressing treatments (Table 1). No differences in soil strength were observed between the topdressing treatments at North Dakota (data not shown). At the site in Iowa, on 7 Oct. 2007, plots receiving fall topdressing and spring plus fall topdressing had 10 and 9% lower soil strength than the control, respectively (Table 4). At the site in Iowa, on 8 June 2008, plots receiving fall topdressing and spring plus fall topdressing had 17 and 31% lower soil strengths than the control, respectively (Table 4). Furthermore, on 8 June 2008, plots with spring plus fall topdressing had an 11% lower soil strength than plots with fall only topdressing (Table 4).

Water Infiltration

At the site in North Dakota, plots receiving aerification treatments had water infiltration that was 48% greater than plots that received no aerification (Table 2 and 6). McCarty et al. (2007) also reported increased water infiltration with aerification. At the site in North Dakota, no water infiltration differences were observed among plots receiving one or two passes of aerification, or between plots receiving spring or fall aerification (Table 2). There were no differences in water infiltration rate among the plots in Iowa (Table 5). If improved drainage is one of the objectives of aerification, such as the site in North Dakota, then aerification in the spring or fall, with one or two passes, may improve water infiltration compared to no aerification. If water infiltration is initially adequate, such as the site Iowa, aerification may not increase infiltration rate.

CONCLUSIONS

Bulk density was reduced 4 to 6% at the sites in both Iowa and North Dakota during both winters. At the site in North Dakota, the freeze thaw cycles impacted soil bulk density more than aerification treatments, which only lowered soil bulk density by 2% during this study. The initial hypothesis for this study was that plots receiving aerification and topdressing in the fall would be affected more by freeze-thaw cycles, thereby further reducing bulk density compared to plots not treated in the fall. No topdressing or aerification treatment influenced over winter change of soil bulk density consistently. This study did not reveal a topdressing or aerification schedule that increases the beneficial effects of over winter change of soil bulk density. A longer study could be beneficial in finding the optimum topdressing and aerification schedule to maximize over winter reduction of soil bulk density. At the site in North Dakota, turf quality was increased by aerification and topdressing but no effects on quality were observed at the site in Iowa, which is likely due to initially high quality ratings. At both sites, fall aerification provided lower soil strength than spring aerification which indicated a potential advantage of fall aerification.

REFERENCES

Anderson, G., J.D. Pidgeon, H.B. Spencer, and R. Parks. 1980. A new hand-held recording penetrometer for soil studies. J. Soil Sci. 31:279-296.

Beard, J.B. 1973. Turfgrass science and culture. Prentice-Hall Inc., Englewood Cliffs, N.J.

Brauen, S.E., W.J. Johnston, and R.L. Goss. 1998. Long-term aerification: A bentgrass fairway study compares hollow- and solid-tine core aerification. USGA Greens Sect. Rec. 36:13-15.

Bullock, M.S., W.D. Kemper, and S.D. Nelson. 1988. Soil cohesion as affected by freezing, water content, time, and tillage. Soil Sci. Soc. Am. J. 52:770-776.

Callahan, L.M., W.L. Sanders, J.M. Parham, C.A. Harper, L.D. Lester, and E.R. McDonald. 1998. Cultural and chemical controls of thatch and their influence on root zone nutrients in a bentgrass green. Crop Sci. 38:181-187.

Clarke, B.B. (ed.) 1996. Rutgers Turf. Proc. Dec. 10-12. Atlantic City, N.J. Utilizing proper cultural practices to reduce turfgrass diseases.

Carrow, R.N. 1979. Topdressing: An essential management tool. Golf Course Mgt. 47:26-28, 30-32.

Christians, N.E. 2007. Fundamentals of turfgrass management 3rd ed. John Wiley & Sons Inc., Hoboken, N.J.

Christians, N.E., K.L. Diesburg, and J.L. Nus. 1985. Effects of nitrogen fertilizer and fall topdressing on the spring recovery of *Agrostis palustris* Huds. (Penncross creeping bentgrass) greens. Proc. of the Fifth Int. Turf. Res. Conf. 5:459-468.

Cooper, R.J. and C.R. Skogley. 1981. An evaluation of several topdressing programs for *Agrostis palustris* Huds. and *Agrostis canina* L. putting green turf. P.129-136. *In* R.W. Sheard (ed.) Proc. Fourth Int. Turf. Res. Conf. Guelph, ON. 19-23 July 1981. Univ. of Guelph and ITS, Guelph, ON.

Fermanian, T.W., J.E. Haley, and R.E. Burns. 1985. The effects of sand topdressing on a heavily thatched creeping bentgrass turf. Proc. of the Fifth Int. Turf. Res. Conf. 5:439-448.

Fitts, O.B., 1925. The vital importance of topdressing in the maintenance of satisfactory creeping bent greens. USGA Greens Sect. Rec. 5:242-245.

Krumbach, A.J. and D.P. White. 1964. Moisture, pore space, and bulk density changes in frozen soil. Soil Sci. Soc. Am. Proc. 28:422-425.

Lehrsch, G.A., R.E. Sojka, D.L. Carter, and P.M. Jolley. 1991. Freezing effects on aggregate stability affected by texture, mineralogy, and organic matter. Soil Sci. Soc. Am. J. 55:1401-1406.

Li, D., M. Volterrani, N.E. Christians, D.D. Minner, and S. Magni. 2001. Freezing and thawing effects on sand-based media modified with soil amendments. Int. Turf. Soc. Res. J. 9:548-552.

Madison, J.H., J.L. Paul, and W.B. Davis. 1974. Alternative method of greens management. Proc. of the Sec. Int. Turf. Res. Conf. 2:431-437.

McCarty, L.B., M.F. Greg, and J.E. Toler. 2007. Thatch and mat management in an established creeping bentgrass golf green. Agron. J. 99:1530-1537.

Mascaro, T. 1951. Is the fall period a proper time for aerification., 22nd National Turf Conference and Show. Jan. 29-Feb. 2, 1951. Chicago, IL.

Mostaghimi, S., R.A. Young, A.R. Wilts, and A.L. Kenimer. 1988. Effects of frost action on soil aggregate stability. Trans. ASAE 31:435-439.

Murphy, J.A., P.E. Rieke, and A.E. Erickson. 1993. Core cultivation of a putting green with hollow and solid tines. Agron. J. 85:1-9.

O'Brien, P. and C. Hartwiger. 2001. Aeration and topdressing for the 21st century: Two old concepts are linked together to offer up-to-date recommendations. USGA Greens Sect. Rec. 41:1-7.

Roberts, J.M. 1975. Some influences of cultivation on the soil and turfgrass. M.S. thesis. Dept. of Agron. Purdue Univ., West Lafayette.

Stier, J.C. and A.B. Hollman. 2003. Cultivation and topdressing requirements for thatch management in A and G bentgrasses and creeping bluegrass. HortScience 38:1227-1231.

Smith, G.S. 1979. Nitrogen and aerification influence on putting green thatch and soil. Agron. J. 71:680-684.

Unger, P.W. 1991. Overwinter changes in physical-properties of no-tillage soil. Soil Sci. Soc. Am. J. 55:778-782.

Waddington, D.V., T.L. Zimmerman, G.L. Shoop, L.T. Kardos, and J.M. Duich. 1974. P. 1-96. *In* Soil modification for turfgrass areas. Agric. Exp. Stn. Prog. Rep. 337: The Pennsylvania State Univ., University Park, P.A.

Zontek, S.J. 2005. Fairway topdressing in the Mid-Atlantic Region. USGA Greens Sect. Rec. 43:18-21.

Table 1. Analysis of variance (ANOVA) results for bulk density (BD), bulk density over-winter reduction (ΔBD), quality, soil strength, and volumetric water content.

Source[†]	BD	ΔBD [‡]	Quality	Soil Strength	Water Content
Topdressing (Top)	0.0049	0.9621	0.0090	0.2457	0.3999
Top*time	0.1623	0.1041	0.0747	0.2937	0.1455
Top*site	0.0190	0.3624	0.0445	0.2504	0.7267
Top*site*time	0.2068	0.5875	0.0690	0.0244	0.2028
Aerification (Aer)	0.4977	0.8242	0.2110	0.0048	0.6950
Aer*time	0.2185	0.0095	0.6023	0.1748	0.0885
Aer*site	0.0137	0.1644	<0.0001	0.5293	0.5020
Aer*site*time	0.2592	0.4401	<0.0001	0.4685	0.7596
Aer*top	0.1312	0.9123	0.1980	0.7904	0.3171
Aer*top*time	0.9865	0.5991	0.9978	0.9920	0.8834
Aer*top*site	0.4185	0.8134	0.3809	0.5084	0.7545
Aer*top*site*time	0.9511	0.3918	0.0167	0.9074	0.6033

[†]ANOVA using type III sums of squares of the SAS version 9.1.3 proc mixed procedure.

[‡]Over-winter change of bulk density was determined by subtracting the fall values from spring values.

Table 2. Soil bulk density in Iowa and North Dakota. Soil bulk density is the average of 54 plots.

Rating	Iowa (g cm^{-3})†	North Dakota (g cm^{-3})
Fall 2006	1.40a†	1.57a
Spring 2007	1.35b	1.45c
Fall 2007	1.40a	1.52b
Spring 2008	1.36b	1.45c

†Means in columns followed by the same letter are not different at $P \leq 0.05$.

Table 3. Physical properties of soil in response to spring or fall aerification with one or two passes. Soil Bulk density (BD) is the average of 12 replicates from Fargo, ND. Change in soil bulk density (ΔBD) of 2006-2007 and 2007-2008 winters are the means of 18 replicates, 9 from each of two sites (Ames, IA and Fargo, ND). Soil strength (Strength) is a mean of 90 replicates measured over five rating dates (Fall 2006, Spring 2007, Fall 2007, Spring 2008, and June 2008) in two sites (Ames, IA and Fargo, ND). Infiltration measurement at North Dakota averaged over four rating periods (Fall 2006, Spring 2007, Fall 2007, and Spring 2008). Iowa infiltration was not shown because no differences were observed. All means were combined over three topdressing treatments because they were not different.

	BD ($g\ cm^{-3}$)	ΔBD ($g\ cm^{-3}$)†		Strength	Infiltration (cm/hr)
Treatment	North Dakota	06-07	07-08	(MPa)	North Dakota
Control	1.53	-0.04	-0.09	1.01	15.1
Spring 1	1.51	-0.07	-0.04	1.01	20.7
Fall 1	1.52	-0.08	-0.05	0.97	31.3
Spring 2	1.49	-0.07	-0.07	0.99	28.3
Fall 2	1.50	-0.09	-0.04	0.94	29.8
Spring 1 + fall 1	1.51	-0.07	-0.05	0.96	34.4
Orthogonal contrasts					
Control vs. all	**‡	*	**	*	**
Spring vs. fall	NS	NS	NS	**	NS
2 passes vs. 1 pass	NS	NS	NS	NS	NS

†ΔBD change of bulk density was determined by subtracting fall BD from spring BD.

‡NS,*,** nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

Table 4. North Dakota quality ratings in response to topdressing from Fall of 2006 to the Spring of 2008. Iowa quality ratings are not shown because no differences were observed. Iowa soil strength (MPa) ratings in response to topdressing treatments from the Fall of 2006 to June of 2008. North Dakota soil strength ratings not shown as differences were not observed.

	Quality†				Soil Strength (MPa)‡				
	2006	2007		2008	2006	2007		2008	
Treatment	8 Aug.	5 May	29 Aug.	28 May	6 Nov.	7 May	7 Oct.	8 May	8 June
Control	5.9a§	5.4a	6.8a	6.4a	1.58a	1.00a	1.58a	0.89a	1.01a
Fall	5.9a	6.1b	7.2b	6.7b	1.50a	1.08a	1.43b	0.91a	0.86b
Fall + spring	5.9a	6.2b	7.2b	6.7b	1.54a	1.02a	1.45b	0.90a	0.77c

†Quality was assessed using the National Turf Evaluation Program (NTEP) guidelines (9-1 scale) where 9 = highest quality turf, 6 = minimal acceptable turf, 1 = dead turf.

‡Soil strength was assessed using a Bush Depth Recording soil penetrometer (Andersons et al., 1980).

§Means in columns followed by the same letter are not different at $P \leq 0.05$.

Table 5. Quality[†] response to aerification at North Dakota from Fall 2006 to Spring 2008.

	2006	2007		2008
Treatment	8 Aug.	5 May	29 Aug.	28 May
Control	6.0a[‡]	6.0ab	6.7a	6.4ab
Spring 1	5.8a	6.2b	6.8a	6.3a
Fall 1	5.9a	5.7a	7.2bc	6.7bc
Spring 2	6.0a	5.8a	6.9ab	6.4ab
Fall 2	5.9a	5.9ab	7.6e	6.9c
Spring1 + Fall 1	5.9a	6.0ab	7.3ce	6.9c

[†]Quality was assessed using the National Turf Evaluation Program (NTEP) guidelines (9-1 scale) where 9 = highest quality turf, 6 = minimal acceptable turf, 1 = dead turf.
[‡]Means in columns followed by the same letter are not different at $P \leq 0.05$.

Table 6. Analysis of variance (ANOVA) results for water infiltration at Iowa and North Dakota.

Source†	Iowa	North Dakota
Topdressing (Top)	0.9258	0.4336
Top*time	0.3751	0.8922
Aerification (Aer)	0.1345	0.0473
Aer*time	0.9867	0.1439
Aer*top	0.1830	0.8988
Aer*top*time	0.9999	0.9476

†ANOVA using type III sums of squares of SAS version 9.1.3 proc mixed procedure.

GENERAL CONCLUSIONS

Bulk Density

Soil at the site in Iowa had a 4% reduction of bulk density during both the 2006-2007 and 2007-2008 winters. Soil at the site in North Dakota had a 6% bulk density reduction during the 2006-2007 winter, and a 5% reduction of bulk density during the 2007-2008 winter. This is consistent with Unger (1991) who also observed a reduction of soil bulk density over winter.

At the site in North Dakota, soil collected from plots receiving aerification had a 2% lower bulk density than soil collected from plots receiving no aerification. This is consistent with Murphy et al. (1993) who also found aerification to reduce bulk density. At the site in North Dakota, no bulk density differences were observed between soil in plots that received topdressing and soil in plots that received no topdressing.

At the site in Iowa, no soil bulk density differences were observed between plots that received aerification treatments and those that received no aerification treatments. At the site in Iowa, soil in plots that received topdressing had a 5% lower bulk density than soil in the plots that received no topdressing. The plots receiving the highest rate of topdressing (fall plus spring) received a total of 1.3 cm of sand during the study. Soil cores were collected from 2.86 cm below the turf surface, so the reduction of bulk density can be attributed to sand mixing into the aerification holes.

Bulk Density Over-Winter Change

Bulk density change from fall to spring was used to determine if topdressing or aerification treatments influenced the extent of over-winter soil changes. The initial hypothesis for this study was that plots receiving aerification and topdressing in the fall would be affected more by freeze-thaw cycles, thereby further reducing bulk density compared to plots not treated in the fall. No topdressing or aerification treatment influenced over winter change of soil bulk density consistently. From this information, it was determined that this study did not reveal a topdressing or aerification schedule that increases the beneficial effects of over winter change of soil bulk density. A longer study could be beneficial in finding the optimum topdressing and aerification schedule to maximize over winter reduction of soil bulk density.

Quality Ratings

The site in Iowa initially had high quality ratings in all plots and topdressing and aerification had no affect on quality. At the site in North Dakota, plots receiving topdressing had increased quality after the first rating. McCarty et al. (2007) also reported increased quality was seen with topdressing. At the site in North Dakota, no differences in quality were seen between the two topdressing treatments. Fermanian et al. (1985) also reported seeing no differences in quality between plots receiving varying topdressing treatments. Fall aerification produced the highest quality turf during last two rating dates at the site in North Dakota.

Soil Strength & Water Content

No differences were observed in water content among the plots receiving topdressing and aerification treatments. Therefore, the differences observed in soil strength are presumably not caused by differing water contents. The average soil strength of plots receiving aerification was 4% lower than the control. Murphy et al. (1993) also demonstrated that HTCA decreases penetration resistance in the zone of soil that receives aerification. No differences in soil strength were observed between plots receiving one pass and two passes of aerification. Soil in plots receiving aerification in the fall had 4% lower soil strength than soil in plots receiving aerification in the spring. Aerification in the spring or fall is recommended in order to avoid additional stress to the turf due to the extreme heat of the summer. At our sites, fall aerification provided lower soil strength than spring aerification which indicated a potential advantage of fall aerification. At the site in Iowa, on two of the five rating dates, plots that received topdressing had lower soil strength than plots that received no topdressing.

Water Infiltration

At the site in North Dakota, soil in plots receiving aerification treatments had water infiltration that was 47.8% greater than soil in plots that received no aerification. McCarty et al. (2007) also reported increased water infiltration with aerification. At the site in North Dakota, no water infiltration differences were observed between plots receiving one or two passes of aerification, or between plots receiving spring or fall aerification. There were no differences in water infiltration rate among the plots that received aerification treatments in Iowa. If improved drainage is one of the objectives of aerification, such as site in North

Dakota, then aerification in the spring or fall, with one or two passes, may improve water infiltration compared to no aerification. If water infiltration is initially adequate, such as the site in Iowa, aerification may not increase infiltration rate.

REFERENCES

Fermanian, T.W., J.E. Haley, and R.E. Burns. 1985. The effects of sand topdressing on a heavily thatched creeping bentgrass turf. Proc. of the Fifth Int. Turf. Res. Conf. 5:439-448.

McCarty, L.B., M.F. Greg, and J.E. Toler. 2007. Thatch and mat management in an established creeping bentgrass golf green. Agron. J. 99:1530-1537.

Murphy, J.A., P.E. Rieke, and A.E. Erickson. 1993. Core cultivation of a putting green with hollow and solid tines. Agron. J. 85:1-9.

Unger, P.W. 1991. Overwinter changes in physical-properties of no-tillage soil. Soil Sci. Soc. Am. J. 55:778-782.