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RESEARCH

Divot Resistance of Thick Cut Sod as Influenced by Preharvest Nitrogen and Sand Topdressing

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ABSTRACT

Professional sports facilities in the United States install thick-cut sod during the playing season. Field performance immediately after installation is primarily determined by maintenance practices at the sod farm. This research investigated the influence of six N programs (98–245 kg N ha^{-1} yr^{-1} applied in spring or fall) and two sand-topdressing rates (0 and 8.5 kg m^{-2} yr^{-1}) on Kentucky bluegrass (KBG, *Poa pratensis* L.). In 2013 and 2014, KBG was established from seed in September and grown for 7 mo at a commercial sod farm (Hammonton, NJ) and then transported as sod and grown for another 7 mo under six by two treatment combinations at University Park, PA. Sod was harvested 14 mo after seeding and evaluated for divot resistance, shear, and sod strength. In 2013, all N treatments were similar in divot resistance except the 245-kg total N rate, which exhibited the lowest divot resistance. In 2014, the most divot resistance was observed with 49 kg N ha^{-1} applied three times in the spring (147 kg total N) or using the same N program with another 49 kg ha^{-1} applied in September (196 kg total N). Nitrogen treatments resulted in few meaningful differences in shear resistance. Sand topdressing affected divot and shear resistance differently. Topdressing reduced divot resistance by only 6% in 2014 and had no effect in 2013. Topdressing reduced shear resistance by averages of 21.6 and 28.4% in 2013 and 2014, respectively. Growers may improve the divot resistance of KBG sod by moderating N inputs.

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Abbreviations: KBG, Kentucky bluegrass; NFL, National Football League; TE, trinexapac-ethyl; TTF, Tuckahoe Turf Farms.

Most sports require stable footing to maximize athlete's performance and minimize injury risk. Turfgrass established over an internally drained, high-sand growing media (rootzone) is common in many modern sporting facilities. High-sand rootzones are chosen for their ability to maintain balanced air-filled and capillary porosity, despite compactive forces from athletes and maintenance equipment (Miller and Henderson, 2011).

Sand is a granular material with little inherent cohesion; thus, sand-based athletic fields depend on vegetative stabilization by the turfgrass plants to resist shearing forces imposed by athletes (Baker, 2006). Professional athletes possess exceptional size and speed, and their studded footwear can shear portions of turf away from the rootzone as they run, slide, and change directions. Portions of turf sheared from the rootzones have been termed divots. Resistance to divoting is a concern for most athletic field managers and a primary concern of high-level American football field managers, due to the size and speed of the players (Serensits et al., 2011).

As the playing season progresses, extensive divoting may reduce turfgrass cover to the point that the surface is destabilized and player performance is compromised. Also, venues host numerous sporting and nonsporting events that can damage the surface or that require a very quick conversion of the painted patterns on the surface. The entire field or sections of the surface may be replaced with a new layer of turfgrass sod having a profile thickness of up to 5 cm. Sod pieces are generally about 1.2 m wide and 9 to 12 m in length and weigh ~1000 kg. Sod sections are

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harvested, rolled, transported, and installed onto the existing stadium rootzone. Competition often resumes within days of installation, with little or no rooting of the sod into the underlying rootzone. This can be accomplished due to the substantial size and weight of the sod sections. Resurfacing of playing fields in the National Football League (NFL) is commonplace (Price, 2014). A number of stadia are now stripping the entire surface of sod in the spring, hosting concerts and other nonsporting events throughout the summer, and then replacing the sod shortly before the fall sporting season begins (T.L. Leonard, personal communication, 2016). Most stadia install new sod at least annually, with some replacing their turf up to five times during the playing season based on field usage and growing conditions (Belson, 2016). A number of NFL stadia replace at least some portion of the surface almost weekly throughout the playing season (L.T. Osterlind, personal communication, 2017). In-season field resodding occurs in non-NFL venues, but it is much less routine.

Assuming competition resumes shortly after the new sod is installed, the athletic field manager has little opportunity to alter the surface characteristics via maintenance practices. Thus, playing surface quality is chiefly a function of the turfgrass maintenance performed by the sod growers prior to harvest and installation. Fertilization and thatch control are two important cultural practices in this sod production setting.

Kentucky bluegrass (KBG, *Poa pratensis* L.) is the predominant turfgrass species used for sod production in the northern United States (Rieke and Beard, 1969). Nitrogen is used in the production of KBG sod in greater quantities than any other mineral nutrient and has been demonstrated to drive turfgrass growth and uptake of other nutrients (Badra et al., 2005; Kussow et al., 2012). A minimum N supply is needed to maintain basic plant functions such as chlorophyll production and synthesis of proteins and plant hormones (Marschner, 2012). However, once the basal N demand is satisfied in C_3 turfgrasses, additional N promotes increases in shoot density, leaf growth, and leaf water status with consequent reductions in stored photosynthate and production of belowground plant parts such as adventitious roots and rhizomes (Adams et al., 1974; Nyahoza et al., 1974; Bowman, 2003). In general, high N availability also suppresses root branching (Marschner, 2012). Soil stabilization by turfgrasses has been shown to be greater when roots are shorter and highly branched, as opposed to longer and more herringbone-like (Ross et al., 1991). In addition to the current practices used by KBG sod producers to improve wear tolerance for athletic fields, producers should consider N fertilization practices that maximize divot resistance, especially for sod that will be exposed to athletic events shortly after installation.

Accumulation of excess surface biomass (thatch) can be a management challenge in sports turf settings. Thatch is the layer of intermingled living and dead plant tissues that accumulates between the green verdure and the mineral soil in a turfgrass system (Beard, 1973). Excessive thatch without sufficient topdressing sand integrated into it greatly increases the potential for divoting (Sherratt et al., 2005; Carrow, 2011). The extent of the damage resulting from the displacement of the thatch is unclear; however, per customer demand, some sod growers are attempting to produce sod with little to no thatch present (Schroder, 2017). Excess surface biomass may be removed by practices such as verticutting or core aerification (Murray and Juska, 1977; Carrow et al., 1987); however, sod growers tend to avoid mechanical cultivation due to its temporary detriment to sod strength and divot resistance. An alternative solution may be to topdress the sod as it matures in the production field. Light, frequent sand topdressing has been shown to mitigate buildup of organic matter without the need for mechanical cultivation and is being used to produce custom sod for professional venues (Carrow et al., 1987; McCarty et al., 2007; Price, 2014).

Guillard et al. (2015) lists a number of researchers that have examined cultural practices related to the force required to shear a strip of sod that is between 1 and 2 cm thick. Guillard et al. (2015) measured sod strength in this manner and compared it to sod producers' subjective ratings of the acceptability of the sod for harvesting and handling. Minimally acceptable strength occurred most frequently when peak sod strength was between 55 and 85 kg m^{-1} width of sod, whereas preferred sod strength occurred most frequently when peak sod strength was between 70 and 140 kg m^{-1} width of sod. Once peak force exceeded 58 and 86 kg m^{-1}, there was a >50% probability that sod strength would be judged at least adequate and at preferred strength, respectively, up to a peak force of 140 kg m^{-1}.

Although research on harvested sod strength exists for standard-thickness sod, there is minimal research with regard to preharvest culture of thick-cut sod and its divot resistance immediately after installation. The goals of this research were (i) to optimize divot resistance of thick-cut KBG sod through manipulation of preharvest cultural practices, (ii) to determine if these preharvest practices had a significantly negative effect on the sod strength required for harvest and handling activities, and (iii) to compare the method used to measure divot resistance with a method used to measure shear strength of turf surfaces.

MATERIALS AND METHODS

Experimental Site and Plot Establishment

The experiment was duplicated over two 14-mo periods (September 2012 to November 2013, September 2013 to November 2014). A four-way blend of KBG (30% 'P-105'. 30% 'Everest', 30% 'Boutique', and 10% 'Bewitched') was seeded at a rate of 100 kg ha^{-1} during the third week in August of each year at Tuckahoe Turf Farms (TTF) in Hammonton, NJ. The particle size distribution of the top 4.4 cm of soil was tested and had the following particle size distribution: >2.0 mm, 0.8%; 2.0 to 1.0 mm, 5.4%; 1.0 to 0.5 mm, 23.2%; 0.5 to 0.25 mm, 35.2%; 0.25 to 0.15 mm, 14.8%; 0.15 to 0.05 mm, 6.7%; 0.5 to 0.002 mm, 12.3%; <0.002 mm, 1.6%; organic matter content 9 g kg^{-1}. The entire experimental area was fertilized twice in the fall with ammonium sulfate (21–0–0, N–P_2O_5–K_2O). Each fall treatment supplied 49 kg N ha^{-1}. Two additional treatments, each supplying 49 kg N ha^{-1} from ammonium sulfate, were applied in late winter and early spring of the following year (196 total kg N ha^{-1} between September of Year 1 and March of Year 2). The immature turf was transported to the Joseph Valentine Turfgrass Research Center (University Park, PA) as big-roll thick-cut (4.4 cm) sod during the first week of May in each year and installed over an 80% sand/20% sphagnum peat (m^3 m^{-3}) rootzone constructed to United States Golf Association specifications (USGA Green Section Staff, 2004).

Soil testing of the top 15 cm of sod plus original rootzone revealed a pH of 6.5 and adequate levels of P, K, Ca, and Mg. Potassium sulfate (0–0–50) was applied at 49 kg K ha^{-1} to the entire experimental area on 13 May, 9 June, and 12 September of each year to ensure K sufficiency across all N rates. As part of plot maintenance, trinexapac-ethyl (TE) was applied on 28-d intervals to the entire experimental area from May to November at 0.20 kg a.i ha^{-1}; TE was included in the maintenance schedule because it has been shown to improve divot resistance (Serensits et al., 2011) and is used widely on professional athletic fields and some sod farms. Plots were cut at 3.2 cm twice per week with clippings returned. Irrigation was applied when wilting was evident.

Treatments

Treatments included sand topdressing and differing N application amounts and timing. On 13 May of each year, treatments were initiated at University Park. The topdressing factor included an untreated control and a treatment of three sand applications totaling 8.5 kg sand m^{-2}. Sand was weighed and applied in two directions with a 0.6-m walk-behind, variable-rate, drop-spreader (Gandy Company). The sand conformed to United States Golf Association rootzone specifications. The N fertilization factor had six regime treatments; three supplied 98, 146, or 195 kg N ha^{-1} during the spring months, and the remaining three supplied the same spring rates but with an additional 49 kg N ha^{-1} during September (Table 1). The N source was granular ammonium sulfate (21–0–0), applied by hand using a shaker jar and irrigated into the soil after application. Nitrogen applications were applied on identical dates in 2013 and 2014 (15 March, 1 April, 13 May, 9 June, and 12 September). Topdressing was applied at the same time as the N applications for the May, June, and September dates only. Individual plots measured 1.2 m × 2.4 m.

Data Collection

Sod was cut using a Ryan HD walk-behind sod cutter (Schiller Grounds Care) at a profile thickness of 4.4 cm, and data were collected 1 to 3 d after cutting on 9 to 12 Nov. 2013 and on 2 to 5 Nov. 2014. The sod was left in situ atop the sand rootzone, simulating a newly resodded playing field where no time was allowed for the sod to root. One half of each plot was used to evaluate divot resistance and shear resistance; the other half was used to evaluate sod strength. Divot resistance was assessed using a weighted pendulum device bearing the head of a golf club pitching wedge ("Pennswing"). The 70-kg pendulum was released from a horizontal position, and the club head produced a divot on contact with the surface. McNitt and Landschoot (2001) provide a more thorough description of this device. Three divots were created in each subplot. The device was centrally aligned over the longitudinal axis of the sod piece and divots were created perpendicular to this axis. Divot length, width, and depth were recorded for each of the three divots to the nearest millimeter using a ruler. The average of the three divot measurements was used to represent the divot size for each dimension. Smaller divots indicated a higher divot resistance.

Shear resistance was measured using the Turf-Tec Shear Strength Tester (Turf-Tec International). The device uses 12 vertically oriented fins (2.0-cm length) welded at right angles to a cutting head (7.0-cm diam.). The fins were inserted into the turf and rotated until the turf sheared. A torque wrench recorded the maximum rotational force in newton meters. This device is described by Rogers and Waddington (1989). Three shear measurements were taken per plot, and the average of these three measurements was used to represent the shear resistance of that experimental unit. Shear resistance has been correlated to divot resistance and may provide a more portable and rapid measurement of surface stability (Serensits, 2008).

Sod strength was measured using a device modeled after that described by Rieke et al. (1968). The device features two clamps, with one stationary and the other affixed to a sliding platform. An electronic winch applied a tensile force until the sod failed. A force gauge (AMETEK Test & Calibration Instruments) recorded the maximum axial tension. On 10 May 2013 at TTF, immature sod that varied in time since seeding was tested as 4.4-cm-thick cut sod using the sod strength device. This was done to estimate the acceptable lower sod strength

Table 1. Labels for the six N treatment regimes.

N treatment label	Mar.†	Apr.†	May	June	July	Aug.	Sept.	Total
								kg N ha^{-1} yr^{-2}
2-0	x‡	x						98
2-1	x	x					x	146
3-0	x	x	x					146
3-1	x	x	x				x	195
4-0	x	x	x	x				195
4-1	x	x	x	x			x	244

† The March and April N was applied at Tuckahoe Turf Farm prior to transport.

‡ x indicates application of 49 kg N ha^{-1} via ammonium sulfate (21–0–0).

limit required to harvest and handle sod. The experienced sod producers indicated that sod yielding a strength value of 39 kg was only slightly below the harvestable threshold (J.T. Betts, personal communication, 2013). A factor of safety was considered, and a value of 100 kg was chosen as the minimum acceptable sod strength required to ensure successful harvest, transport, and installation of commercially sized big rolls. This is considerably higher than the 55- to 85-kg threshold suggested by Guillard et al. (2015) for thinner sod thickness of between 1 and 2 cm. In the current study, three sod strength measurements were taken per subplot, with the average used to represent the sod strength of the experimental unit.

Turfgrass color was rated on a 1-to-9 visual scale per the protocol used in National Turfgrass Evaluation Program trials (Morris and Shearman, 2008).

Immediately after divot resistance testing, two cylindrical cores measuring 5.1 cm in diameter and 4.4 cm deep were removed from random locations within each plot. The cores were refrigerated at 5°C for subsequent analysis. Parameters measured from the cores included shoot density, belowground biomass, and thatch thickness. The average between the values obtained from the two cores was used as a representative value for each plot. Thatch thickness was measured while the cores were compressed using a 450-g weight. Thickness was measured to the nearest millimeter using a ruler. Individual shoots were counted. Belowground biomass samples were washed free of soil, oven dried, and placed in a furnace at 440°C for 16 h. The weight difference before and after loss on ignition was used to represent the total belowground biomass (ASTM, 2014).

Experimental Design and Statistical Analysis

The topdressing and N treatments comprised a six by two factorial arrangement organized in a randomized complete block design. There were three replications for a total of 72 experimental units over the two study years. Data were subjected to ANOVA using the MIXED procedure in SAS (SAS Institute, 2015). After satisfying model assumptions of homogeneity of variance, normality of errors, and independence of errors, the 2013 and 2014 data were pooled for analysis; however, significant year × treatment interactions were noted, and it was deemed more appropriate to analyze the 2 yr separately. Thus, data were not pooled for this study. When an F-test returned a significant p-value (<0.05), means were separated using Fisher's LSD. Spearman correlation coefficients were calculated to determine whether measured parameters were linearly related to one another. The measured parameters included divot length, width, and depth, sod tensile strength, shear resistance, thatch thickness, shoot density, and belowground biomass. Additionally, because half of the treatments in the study had zero or near zero thatch thickness, correlation of shear resistance and thatch thickness was also examined using only the plots that did not receive topdressing.

RESULTS AND DISCUSSION

Divot Size

There were no significant two-way interactions for any divot size in either year of this experiment. The N treatment main effect was significant for divot length in both study years and for divot depth in 2013 (Table 2). Divot length is considered the best indicator of divot resistance, as width and depth are largely governed by the swing path of the device used (McNitt, 2000). Although differences occurred for both length and depth dimensions, trends were similar and only length values are discussed below.

In 2013, the highest N treatment regime (4-1, 196 kg N ha^{-1} from March to June plus 49 kg N ha^{-1} in September) was the only N treatment regime to significantly differ from all other treatments (Table 2). Divot lengths under this N regime were 30% longer than the mean of other treatments and 54% longer than treatment 2-0, which supplied just 98 kg N ha^{-1}. The 4-1 N treatment regime was most similar to the 2013 fertilization program used for production of thick-cut KBG sod at TTF (J.R. Betts, personal communication, 2013). The shortest divots in 2014 were produced by the intermediate N treatment regimes (3-0, 3-1), with longer divots occurring under the low (2-0) or high (4-1) N treatment regimes. In 2014, divots were larger than those measured in 2013 for all treatments except N treatment regime 4-1.

In 2013, the topdressing treatment main effect did not affect any divot dimension. In 2014, the topdressing treatment resulted in a significant but small increase in divot length (6% compared with the control, data not shown). Kowalewski et al. (2010) reported that KBG cut at 7.6 cm and topdressed with either zero sand or a sand depth of 1.3 cm resulted in greater shear strength, measured using a Clegg Shear Tester, than treatments receiving a greater depth of topdressing. Although not strongly indicated for the topdressing regime used in this study, it is postulated that the addition of excess sand may produce a reduction in divot resistance. For this reason, it is suggested that topdressing be applied judiciously, with care taken to mirror the growth rate of the turf.

Shear Resistance

A significant N regime by topdressing treatment interaction for shear resistance occurred in both study years (Table 3). The range of shear resistance differences due to N treatments was small and of little practical importance. When topdressing was absent, shear resistance varied slightly with N, but when topdressing was applied, no separation among N treatments was detected in 2013 and differences were minimal in 2014. The topdressing treatment main effect reduced shear resistance by 15% in 2013 and 23% in 2014 when averaged across all N rates. The fins on the shear strength tester measure 20 mm. The sod profile was 44 mm thick, so the fins did not penetrate past the depth of sod harvest. For plots receiving topdressing, the combined thickness of sand and plant tissues comprising the mat layer ranged from 13 to 17 mm (data not shown). For plots not receiving topdressing, mean thatch thickness across N regimes was 10.5 mm in 2013 and 9.3 mm in

Table 2. Divot dimensions for the N treatment main effect by year.

Year	N treatment†	Length	Width	Depth
		——— cm ———		
2013	2-0	20.4b‡	5.2a	1.3b
	2-1	22.2b	5.6a	1.6ab
	3-0	22.7b	5.0a	1.3b
	3-1	23.9b	5.9a	1.6ab
	4-0	20.5b	4.8a	1.5ab
	4-1	31.4a	5.5a	1.9a
2014	2-0	29.9a	7.6a	3.8a
	2-1	28.5ab	7.0a	3.7a
	3-0	26.7b	6.9a	3.9a
	3-1	26.6b	7.4a	3.8a
	4-0	30.0a	7.1a	3.8a
	4-1	29.5a	7.5a	4.4a

† Indicates number of N applications (each at 49 kg N ha^{-1}) made in the spring and fall, respectively.

‡ Within a given column, values sharing a letter are not significantly different.

Table 3. Mean shear resistance values for the N treatment regime by topdressing interaction.

Sand	N treatment†	2013	2014
kg m^{-2}		——— N m ———	
0.0	2-0	31.7bc‡	26.7a
	2-1	33.6a	25.0bc
	3-0	30.8c	26.9a
	3-1	31.7bc	25.2bc
	4-0	32.3abc	23.6c
	4-1	32.7ab	23.8c
8.5	2-0	26.7d	20.7d
	2-1	26.8d	20.1de
	3-0	27.9d	17.8f
	3-1	27.4d	20.4de
	4-0	27.9d	18.9ef
	4-1	26.4d	18.8ef

† Indicates number of N applications (each at 49 kg N ha^{-1}) made in the spring and fall, respectively

‡ Within a given column, values sharing a letter are not significantly different.

2014 (Table 4). No discernable mat layer was present in the nontopdressed plots. Thus, the shear resistance values for plots receiving topdressing mostly reflected the properties of the mat layer, which comprised ~75% of the penetration depth of the fins. For plots not receiving topdressing, the fins interacted with shoots, rhizomes, and fibrous roots present in the thatch layer (~50%) and the top 10 mm of the sod soil below the thatch.

All values measured in this study exceeded the lower limit of 10 N m suggested by Stier et al. (1999). The researchers stated that shear values below 10 N m were associated with turf that was easily torn from the soil but cautioned that other researchers had reported that it was difficult to define a practical value.

Sod Strength

Few meaningful differences occurred regarding sod strength. Sod strength was greatest under the moderate to high N treatment regimes (3-0, 3-1, 4-0, and 4-1; 146–244 kg N ha^{-1}) in 2013 and low to moderate N treatment regimes (2-0, 2-1, 3-0, and 4-0; 98–196 kg N ha^{-1}) in 2014 (Table 5). Despite differences among treatments, all sod strength values were considered well above the acceptable threshold (>100 kg) that the authors established in conjunction with testing done at TTF. Under the conditions of this study and considering the variables tested, the data presented in Table 5 indicate that none of the implemented treatments in this study compromised the sod strength required to harvest and handle.

Table 4. Mean compressed thatch thickness values for the N treatment regime by topdressing interaction.

Sand	N treatment†	2013	2014
kg m^{-2}		——— mm ———	
0.0	2-0	9.0‡	10.6
	2-1	9.3	9.5
	3-0	9.3	6.4
	3-1	10.7	6.9
	4-0	13.0	10.6
	4-1	11.8	11.7
8.5	2-0	2.0	0.0
	2-1	3.0	0.0
	3-0	1.3	0.0
	3-1	3.7	0.0
	4-0	4.2	0.0
	4-1	3.3	0.0

† Indicates the number of N applications (each at 49 kg N ha^{-1}) made in the spring and fall, respectively.

‡ Interaction data were nonsignificant for both years. The topdressing main effect data for thatch thickness was significant in both years, with the nontopdressed plots having a greater thatch thickness than the topdressed plots.

Turfgrass Characteristics

Turfgrass color and shoot density ratings were generally increased by higher N rates but were confounded by the presence or absence of a September N application (Table 6). November color and shoot density ratings were chiefly influenced by the presence or absence of a September N application, regardless of the N rate during the preceding spring months. These results generally concur with the typical plant response to increasing N (Bell, 2011). Belowground biomass was significantly affected by N in 2013, with the higher N treatments 3-1, 4-0, and 4-1 producing fewer roots and rhizomes than the lower N treatments 2-0 and 2-1. In 2014, no significant difference was observed in belowground biomass due to N treatments, although the trend was similar to 2013 (Table 6).

The N regime by topdressing treatment interaction for thatch thickness was not significant in either year of the study (Table 4). Topdressing treatment main effect for thatch thickness was significant for each of the study, with plots receiving topdressing having less thatch thickness than plots not receiving topdressing.

Belowground biomass and all three measures of sod performance (divot resistance, shear resistance, and sod strength) were superior in 2013 compared with 2014. The

Table 5. Sod strength values for the N treatment regime main effect by year.

N treatment†	2013	2014
2-0	202.0c‡	150.3a
2-1	205.5bc	150.8a
3-0	220.9a	145.1ab
3-1	211.8abc	139.9b
4-0	215.2ab	149.1a
4-1	214.9ab	139.0b

† Indicates the number of N applications (each at 49 kg N ha^{-1}) made in the spring and fall, respectively.

‡ Within a given column, values sharing a letter are not significantly different.

Table 6. Mean values for turfgrass color, shoot density, and belowground biomass for the N treatment regime main effect by year.

	Color		Shoot density		Belowground biomass	
N treatment†	2013	2014	2013	2014	2013	2014
	— 1-to-9 rating —		— no. dm^{-2} —		— g core^{-1} —	
2-0	4.5b‡	5.0e	209c	306a	2.38a	1.32a
2-1	7.2a	7.0a	257ab	323a	2.35a	1.15a
3-0	4.8b	5.8cd	233bc	335a	2.10ab	1.17a
3-1	7.2a	6.3bc	266a	353a	2.00b	0.87a
4-0	5.2b	5.7d	229c	331a	1.87b	0.93a
4-1	7.2a	6.8ab	270a	336a	2.10ab	0.83a

† Indicates the number of N applications (each at 49 kg N ha^{-1}) made in the spring and fall, respectively.

‡ Within a given column, values sharing a letter are not significantly different.

reason for these differences is not known. Inspection of weather data from 1 May through 9 November of each year indicated slightly higher precipitation in 2014 than in 2013 (740 and 598 mm respectively; NOAA, 2014). However, these plots were irrigated when water stress was observed, and it is unlikely that the difference in precipitation alone was the cause of the variation between years. Temperature over the same period averaged 17.6 and 17.5°C for 2013 and 2014, respectively. Additional research is needed on the effect of water management on divot resistance of KBG sod.

Correlations

There was a significant interaction with years, and thus the correlations between parameters were examined within years. Few consistent trends among parameters were present (Table 7). Divot width and divot depth correlated in both years of the study, as did shear strength and thatch thickness. Shear strength was greatly affected by the topdressing treatment, as discussed above (Table 3). The topdressing treatment resulted in half the plots having thatch thicknesses at or near zero. This created a cluster of data points that skewed the thatch thickness versus shear strength correlation. When only the nontopdressed plot data were analyzed, thatch thickness and shear strength did not correlate in either year ($r^2 = -0.059$ and -0.263).

Shear resistance was not significantly correlated with shoot density, in contrast with other studies of turf shear resistance (Shildrick and Peel, 1984; Serensits, 2008). However, these other studies included a simulated wear treatment that thinned the turfgrass prior to shear resistance testing. In the present study, no wear was applied

Table 7. Spearman correlation coefficients (*n* = 32) among measured parameters in 2013 and 2014.

2013	Divot width	Divot depth	Shear strength	Sod strength	Shoot density	Thatch thickness	BGB†	Color
Divot length	0.545**	0.423**	−0.148	0.131	−0.051	−0.179	0.03	0.369*
Divot width	–	0.471**	−0.131	0.073	−0.097	−0.084	−0.023	0.214
Divot depth		–	0.123	−0.055	0.159	0.319	−0.296	0.388*
Shear strength			–	0.182	−0.018	0.738***	−0.748***	−0.155
Sod strength				–	0.127	0.133	−0.143	0.115
Shoot density					–	0.002	−0.053	0.338*
Thatch thickness						–	−0.842***	−0.032
BGB							–	0.12
Color								–

2014	Divot width	Divot depth	Shear strength	Sod strength	Shoot density	Thatch thickness	BGB	Color
Divot length	−0.007	−0.129	−0.247	0.283	−0.12	0.048	0.072	0.261
Divot width	–	0.472**	0.247	0.051	0.16	0.242	0.032	−0.142
Divot depth		–	0.208	−0.238	0.273	0.201	−0.081	0.101
Shear strength			–	−0.082	−0.083	0.416*	0.064	−0.06
Sod strength				–	0.061	0.025	−0.123	0.018
Shoot density					–	0.183	0.198	0.049
Thatch thickness						–	0.085	−0.028
BGB							–	0.085
Color								–

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at 0.001 probability level.

† Belowground biomass.

to accurately simulate the divot resistance at the time of a new sod installation.

SUMMARY AND CONCLUSIONS

The highest N treatment regime tested (244 kg N ha^{-1}) dramatically lowered the divot resistance of thick-cut KBG sod in 2013. In 2014, the intermediate N treatment rates of 146 or 195 kg N ha^{-1} resulted in greater divot resistance than treatments receiving higher or lower N rates. In both years, the standard rate of 244 kg N ha^{-1} resulted in sod that measured among the lowest in divot resistance compared with other N treatment regimes. In 2014, all three measures of sod performance (divot resistance, shear resistance, and sod strength) along with belowground biomass were lower than those measured in 2013. The reason for this difference was not apparent. The N demand of managed turfgrass is governed by species, temperature, light, and performance goals for the surface (Carrow et al., 2001; Schlossberg and Karnok, 2001; Kussow et al., 2012). In sod production for American football, where surface stability underfoot is a primary concern, moderating annual N rates to <244 kg N ha^{-1} may improve the surface stability of the sod at the time of installation.

Three applications of sand topdressing totaling 8.5 kg sand m^{-2} in the 7-mo period prior to harvest as sod limited the formation of a thatch layer in 2013 and resulted in no discernable thatch layer in 2014; however, thatch dilution had no effect on divot resistance in 2013 and reduced divot resistance by only 6% in 2014. The practice of topdressing sod during production warrants further study, including varying rates and timings, before definitive claims can be made about its influence on surface stability. Growers should monitor turf growth rate closely to optimize topdressing rates, as overapplication of sand may negatively affect surface stability.

The results of this study indicate that the two methods used to measure surface stability were not equally affected by treatments. Compared with the Pennswing device, the shear strength tester was less sensitive to N treatments and more sensitive to topdressing. Topdressing decreased shear resistance during both years of the experiment but resulted in a minor increase in divot size in 2014 only. More research is needed to develop and evaluate a method to compare divot resistance measured by a device to the actual divoting occurring during a sporting event.

This study did not demonstrate any consistent relationship between surface stability measured with either device and the turfgrass characteristics evaluated. Continued research should investigate the effects of water management, alternative thatch control methods such as fraise mowing, and plant uptake of N on the divot resistance of thick-cut sod. The results of this research may help sod growers optimize divot resistance while maintaining the strength required to harvest and handle thick-cut KBG sod.

Conflict of Interest

The authors declare that there is no conflict of interest.

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