Article

Evaluation of Humic Fertilizers on Kentucky Bluegrass Subjected to Simulated Traffic

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Abstract: Sports field traffic tolerance is critical for offering athletes a safe playing surface and adequate turfgrass performance. Humic substances act as bio-stimulants that could enhance turfgrass traffic tolerance by increasing turfgrass efficiency, which could be due to increased root growth, antioxidant activity, and/or physiological health. A two-year field experiment was conducted on a Kentucky bluegrass (*Poa pratensis* L.) sports field to investigate if incorporating humic substances with fertilizers could improve turfgrass traffic tolerance and performance, and enhance turfgrass recovery after traffic. Treatments included humic-coated urea, poly-coated humic-coated urea, synthetic fertilizer with black gypsum (two application timings), black gypsum, stabilized nitrogen, poly-coated sulfur-coated urea, urea, and a nontreated control. The addition of humic substances to fertilizer treatments did not result in improve traffic tolerance and performance. Fertilizer treatments did not lead to an effect on soil moisture, surface hardness, and shear strength. Turfgrass recovery varied between years. In 2020, the second year of the experiment, four applications of fertilizers increased turfgrass recovery by 136% relative to the nontreated. Furthermore, incorporating humic substances did not result in enhanced turfgrass recovery compared to fertilizers alone. Overall, applications of fertilizers with humic substances could improve turfgrass recovery from traffic compared to fertilizers alone, but results were variable between years.

Keywords: turfgrass; *Poa pratensis*; traffic tolerance; turfgrass recovery; humic substances

1. Introduction

Sports turf is the turfgrass and soil environment managed for aggressive sporting events and must offer a safe playing surface and adequate performance or playability for athletes [1,2]. Kentucky bluegrass (*Poa pratensis* L.) is one of the most common turfgrass species used for sports fields in cool-season turfgrass climates due its high traffic tolerance and recovery from rhizomes [3,4]. Traffic is composed of wear stress, which affects the shoot system of the turfgrass, and soil compaction, which alters the physical properties of the soil [5,6]. Simulated traffic replicates the horizontal and vertical forces that affect both the soil and turfgrass in a reproducible manner, which results in soil compaction and shearing of the turfgrass [1,7,8]. Traffic tolerant turfgrass genotypes have been associated with a more vertical leaf angle, wider leaf blades, greater leaf cell wall constituents, increased number of vascular bundles, high root length density, larger intercellular void spaces, and increased leaf antioxidant activity [9–13]. Sports turf managers have relied on effective fertilization programs to help ensure field safety and performance; however, in recent years, sustainable management practices and the utilization of bio-stimulants, such as humic substances, have garnered interest within the turfgrass industry [2].

Sports field safety and performance are often tracked by the turfgrass characteristics of wear, hardness, and traction [1,2]. Wear or traffic tolerance is often focused on maintaining adequate playability throughout the sporting season and is often measured by the percent of ground cover remaining after sporting events determined by digital image analysis

(DIA) [1,14]. Surface hardness affects athlete's ability to perform at maximum speed and to cut sharply and can increase injury from contact with the surface [2]. Surface hardness can be measured by a Clegg impact tester, which have been correlated to athletes perceptions of surface hardness [15]. Traction is critical to changes in direction and controlling speed [2]. Traction is often measured by shear strength, which is determined by the rotational force applied by a cleated plate to completely shear the turfgrass [1,16]. Low shear strength can cause athletes to slip and lead to lower body injuries and too high shear strength can result in athletes footing not being able to break away, which could cause injuries [17,18]. Different management strategies are utilized to ensure adequate field safety and performance.

Applications of fertilizer four times yr^{-1} (171–244 kg N ha^{-1} yr^{-1}) is common practice for cool-season sports fields grown on clay or silt-based soils to promote aggressive turf growth, enhance wear tolerance, and improve recuperation potential [2,19]. Fertilizer applications increased turfgrass cover, color, quality and recovery during maximum simulated wear [20–23]. Fertilizer applications have varied results on surface hardness depending on soil moisture. In periods of increased soil moisture, fertilizer increased surface hardness compared to no fertilizer; however, in drier periods fertilizers decreased surface hardness relative to no fertilizer [20]. Furthermore, traction increased with fertilizer application relative to no fertilizer [20,22].

Plant growth regulators (PGR) and bio-stimulants have been used in turfgrass management as stress mitigators [2]. Puhalla et al. [2] define a bio-stimulant as any substance that improve stress tolerance, enhance nutrient-use efficiency, and/or change growth response. Furthermore, PGRs and bio-stimulants have the potential to enhance traffic stress resistance by improving turfgrass quality, relative water content, antioxidant enzymes activities, and cell membrane stability [24,25]. Applications of PGRs (trinexapac-ethyl +/− ethephon or flurprimidol) before traffic stress improved turfgrass color, quality, and cover [26]. Humic substances contain humic acid, fulvic acid, humin, and humic acid precursor and have been reported to act as bio-stimulants [27,28]. The mode of action of humic substances has been proposed as a hormone-like or auxin-like activity [29,30]. In general, humic products have been reported to effect root growth and architecture, respiration and photosynthesis, nutrient uptake, and abiotic stress tolerance [28–30].

Earlier research has explored the benefits of humic substances on turfgrass. Applications of humic products on creeping bentgrass (*Agrostis stolonifera* L.) increased root dehydrogenase activity, root growth and weight, physiological health, antioxidant concentrations, turf quality, germination rate, and percent cover [31–39]. Humic substances improved antioxidant concentrations, recovery or tolerance to heat injury, transplant quality, and root weight of tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort.; syn. *Festuca arundinacea* Scherb.] [33,40]. Kentucky bluegrass heat injury recovery or tolerance, root mass, root strength, root growth and turf quality was enhanced by application of humic substances [41–45]. Humic substances applied to perennial ryegrass (*Lolium perenne* L.) improved root length and surface area, root architecture, and visual quality [46,47]. The numerous benefits of humic substances on turfgrass suggest that improved stress tolerance could be possible.

The objectives of this field-based study were to (1) determine if incorporating humic substances with fertilizers will improve turfgrass traffic tolerance and performance, and (2) determine if the addition of humic substances to fertilizers will enhance turfgrass recovery after simulated traffic. The hypotheses of this study were that humic products will result in greater traffic tolerance, longer performance, and quicker turfgrass recovery compared to urea and the nontreated control.

2. Materials and Methods

2.1. Experiment Location and Plot Maintenance

A field experiment was conducted on a native soil Kentucky bluegrass sports field at the Iowa State University Horticulture Research Station (Ames, IA, USA) in 2019 and 2020. The Kentucky bluegrass was seeded and established with 'Rush' Kentucky bluegrass

in 2015. The native soil was classified as a Clarion loam soil (Fine-loamy, mixed, superactive, mesic Typic Hapludolls) and contained 5.2% organic matter. The experiment was maintained at a 51 mm height of cut using a rotary mower three times week^{-1} [48]. The clippings were returned to the experimental site and irrigation was applied as needed to prevent drought stress [13,48]. The average high and low temperatures for 2019 and 2020 while simulated traffic was being applied were 27.3 and 15.2 °C, and 27.1 and 13.4 °C, respectively [49]. The average high and low temperatures after simulated traffic concluded in 2019 was 14.3 and 2.9 °C, and 16.1 and 3.2 °C in 2020 [49].

2.2. Treatments

The treatment design was a randomized complete block with four replications. The fertilizer treatments were humic-coated urea (HCU; The Andersons, Inc., Maumee, OH, USA), poly-coated humic-coated urea (PCHCU; The Andersons, Inc., Maumee, OH, USA), synthetic fertilizer with black gypsum (SFBG; two application timings; The Andersons, Inc., Maumee, OH, USA), black gypsum (BG; The Andersons, Inc., Maumee, OH, USA), stabilized nitrogen (Allied Nutrients, Brunswick, OH, USA), poly-coated sulfur-coated urea (PCSCU; Allied Nutrients, Brunswick, OH, USA), urea (The Andersons, Inc., Maumee, OH, USA), and a nontreated control (Table 1). Urea, HCU, PCHCU, SFBG, BG, stabilized nitrogen, and PCSCU were applied in April, May, September, and October each year and SFBG (2 apps.) was applied in April and September in 2019 and 2020. Fertilizer treatments were applied using a wooden box with offsetting wire mesh to equally distribute the fertilizer across the experimental units (EU). The EU size was 1 by 1 m. The experiment was replicated using different EU.

Table 1. Fertilizer treatments, nutrient analysis, and application rates.

Treatment [1]	Nutrient Analysis	Application Rate
Humic-coated urea (HCU)	44N-0P-0K, 2% humic acid (HA)	48.8 kg N ha^{-1}
Poly-coated humic-coated urea (PCHCU)	45N-0P-0.2K, 2% HA	48.8 kg N ha^{-1}
Synthetic fertilizer with black gypsum (SFBG) [2]	22N-0P-3.3K, 30% gypsum, 4.7% HA	48.8 kg N ha^{-1}
SFBG (2 apps.)	22N-0P-3.3K, 30% gypsum, 4.7% HA	48.8 kg N ha^{-1}
Black gypsum (BG)	48% gypsum, 21% HA	146.5 kg BG ha^{-1}
Stabilized nitrogen	46N-0P-0K	48.8 kg N ha^{-1}
Poly-coated sulfur-coated urea (PCSCU)	43N-0P-0K, 4% sulfur	48.8 kg N ha^{-1}
Urea	46N-0P-0K	48.8 kg N ha^{-1}
Nontreated	-	-

[1] Fertilizer treatments HCU, PCHCU, SFBG, BG, stabilized nitrogen, PCSCU, and urea were applied in April, May, September, and October in 2019 and 2020, and SFBG (2 apps.) was applied in April and September in 2019 and 2020 in Ames, IA, USA. [2] Black gypsum is homogenous mixture of gypsum and humic substances.

2.3. Simulated Traffic

Simulated traffic events were applied using a modified Baldree traffic simulator following methods by Dalsgaard et al. [48] and Dickson et al. [50]. The Baldree traffic simulator has been used to simulate athletic field traffic in many previous studies [8,48,50]. Traffic was initiated on 29 July in 2019 and 2020 to coincide with the start of the Iowa High School Football Season [48]. Three traffic events week^{-1} were applied to EU until 25 traffic events were completed.

2.4. Data Collection

Digital images were collected before simulated traffic began, and then weekly during the application of traffic and for six weeks after traffic concluded using techniques described by Thoms et al. [51]. Digital images were subjected to DIA to determine percent green cover (PGC) [52]. The threshold settings for the DIA were hue 71 to 176, saturation 10 to 100, and brightness 0 to 100. Soil moisture was measured using a time domain reflectance (TDR)

sensor (Field Scout 350, Spectrum Technologies Inc., Aurora, IL, USA) on three random locations EU^{-1}. Surface hardness was measured on three random locations EU^{-1} using a 2.25 kg Clegg impact tester (Turf-Tec International, Tallahassee, FL, USA). Shear strength was using a shear strength tester (shear vane; Turf-Tec International, Tallahassee, FL, USA) following techniques described by Dalsgaard et al. [48]. Soil and surface parameters were measured before simulated traffic began and then after every three traffic events until traffic concluded. Soil and surface parameters were not measured after traffic concluded because the sports field would not be in use during the recovery period.

2.5. Statistical Analysis

All data were subjected to analysis of variance (ANOVA) with repeated measures using SAS (version 9.4; SAS Institute Inc., Cary, NC, USA). The experiment was repeated in time. A significant year-by-rating date-by-treatment interaction was present for PGC while traffic was being applied (traffic). Significant year-by-treatment and rating date-by-treatment interactions were present for PGC after traffic concluded (recovery). Linear regression analysis was conducted on PGC over time for the traffic portion (2019, $R^2 = 0.81$; 2020, $R^2 = 0.93$) and recovery portion (2019, $R^2 = 0.01$; 2020, $R^2 = 0.46$) of the experiment to obtain estimates for slopes and intercepts for each treatment in 2019 and 2020. Linear fit was low in the recovery portion in 2019 because PGC had minimal changes over time (Figure 1). Orthogonal contrasts were performed to compare slopes and intercepts of each treatment at the $p \leq 0.05$ level. A non-significant interaction with treatment effect was present for soil moisture, surface hardness, and shear strength, data combined across years and rating dates. Fertilizer treatment mean comparisons were separated using Fisher's protected least significant difference (LSD) at the $p \leq 0.05$ level.
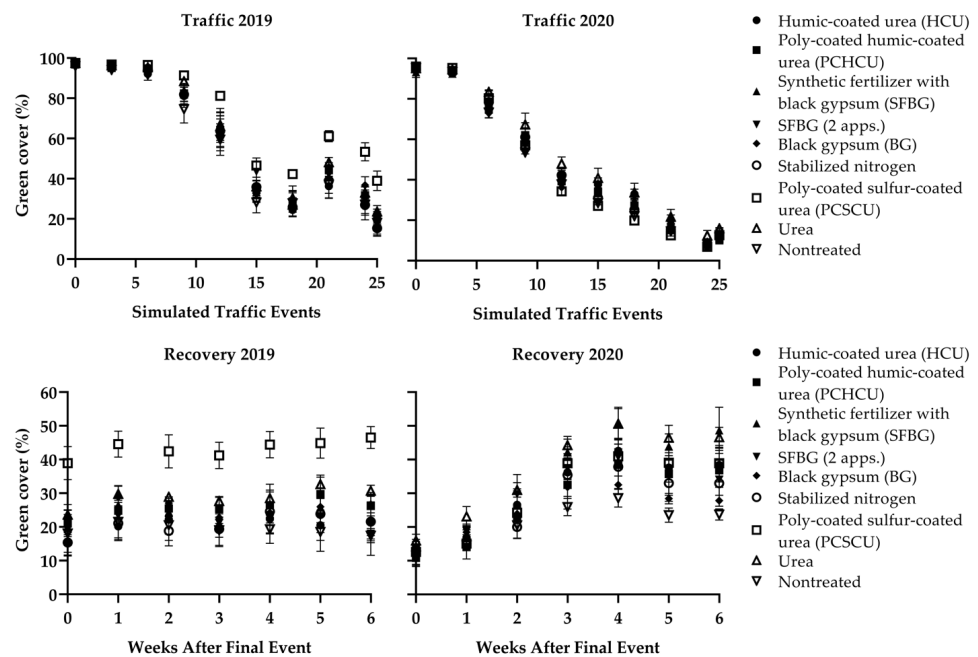
Figure 1. Effects of various fertilizers on percent green cover of a native soil Kentucky bluegrass (*Poa pratensis* L.) subjected to simulated traffic events using a modified Baldree traffic simulator with three traffic events week^{-1} in Ames, IA, USA in the fall of 2019 and 2020. Fertilizer treatments humic-coated urea (HCU), poly-coated humic-coated urea (PCHCU), synthetic fertilizer with black gypsum (SFBG), stabilized nitrogen, poly-coated sulfur-coated urea (PCSCU), and urea were applied at 48.8 kg N ha^{-1} in April, May, September, and October; black gypsum (BG) was applied at 146.5 kg BG ha^{-1} in April, May, September, and October; and SFBG (2 apps.) was applied at 48.8 kg N ha^{-1} in April and September. All treatments were applied in 2019 and 2020. Percent green cover was determined using digital image analysis. Means and standard error bars are shown (*n* = 4).

3. Results

3.1. Percent Green Cover

During the traffic portion of the experiment, PGC was reduced by simulated traffic events in both years (Figure 1). There were minimal differences in starting PGC (intercept) for any treatments in 2019 and 2020 (Table 2). However, in 2019, PCSCU (−2.5) was the only treatment that retained more PCG event^{-1} compared to the nontreated (−3.4). Furthermore, all treatments resulted in 36% greater PGC loss event^{-1} compared to PCSCU. In 2020, no treatment differences occurred in terms of PGC event^{-1}. Overall, minimal differences were observed during the traffic portion of the experiment.

Table 2. Effects of various fertilizers on percent green cover (PGC) of a Kentucky bluegrass (*Poa pratensis* L.) subjected to simulated traffic using a modified Baldree traffic simulator with three traffic events week^{-1} (25 traffic events total) in fall of 2019 and 2020 in Ames, IA, USA.

Treatment [1]	2019		2020	
	Slope PGC [2] Event^{-1}	**Intercept PGC**	**Slope PGC Event^{-1}**	**Intercept PGC**
Humic-coated urea (HCU)	−3.6	104.0	−3.6	95.5
Poly-coated humic-coated urea (PCHCU)	−3.3	102.8	−3.8	96.7
Synthetic fertilizer with black gypsum (SFBG)	−3.4	105.5	−3.6	94.9
SFBG (2 apps.)	−3.4	103.6	−3.7	95.3
Black gypsum (BG)	−3.2	102.4	−3.5	91.8
Stabilized nitrogen	−3.6	105.0	−3.7	95.9
Poly-coated sulfur-coated urea (PCSCU)	−2.5	103.7	−3.9	95.6
Urea	−3.3	104.6	−3.6	99.0
Nontreated	−3.4	100.6	−3.7	92.9
Orthogonal Contrast				
HCU vs. urea	NS [3]	NS	NS	NS
PCHCU vs. urea	NS	NS	NS	NS
SFBG vs. urea	NS	NS	NS	NS
HCU vs. nontreated	NS	NS	NS	NS
PCHCU vs. nontreated	NS	NS	NS	NS
SFBG vs. nontreated	NS	NS	NS	NS
PCSCU vs. nontreated	**	NS	NS	NS
Urea vs. nontreated	NS	NS	NS	NS

[1] Fertilizer treatments HCU, PCHCU, SFBG, stabilized nitrogen, PCSCU, and urea were applied at 48.8 kg N ha^{-1} in April, May, September, and October; BG was applied at 146.5 kg BG ha^{-1} in April, May, September, and October; and SFBG (2 apps.) was applied at 48.8 kg N ha^{-1} in April and September. All treatments were applied in 2019 and 2020. [2] PGC was determined using digital image analysis. Slope and intercept values were determined using linear regression analysis. [3] NS, nonsignificant at the 0.05 probability level. ** Significant at the 0.01 probability level.

During the recovery portion of the experiment, PGC gained weeks after final event (WAFE)$^{-1}$ differed between years (Figure 1). In 2019, there were no treatment differences in terms of PGC WAFE^{-1} (Table 3). Furthermore, no or minimal recovery occurred and ranged from −0.3 to 1.1 PGC WAFE^{-1}. In 2019, PCSCU started with the highest PGC (40.5), which was 85% greater than all other treatments. In 2020, there were no differences in starting PGC between treatments, which ranged from 12.7 to 19.9%. However, differences occurred in PGC WAFE^{-1}. Urea (5.6), PCSCU (5.1), SFBG (6.6), PCHCU (4.9), and HCU (4.8) resulted in 145%, on average, greater PGC gained WAFE^{-1} compared to the nontreated (2.2). No treatments were significantly greater than urea in terms of turfgrass recovery. Among the treatments that received four applications of nitrogen (N), SFBG resulted in 34% greater PGC gained WAFE^{-1} compared to the other treatments. Furthermore, four applications of N and SFBG resulted in 33% and 69% greater PGC WAFE^{-1} relative to SFBG (2 apps.). On average in 2020, incorporating humic substances with fertilizer applications enhanced turfgrass recovery by 9% relative to fertilizer alone. In general, four applications of N provided the best recovery in terms of PGC and incorporating BG with N applications resulted in the greatest turfgrass recovery.

Table 3. Effects of various fertilizers on percent green cover (PGC) of a native soil Kentucky bluegrass (*Poa pratensis* L.) after simulated traffic concluded in fall of 2019 and 2020 in Ames, IA, USA.

Treatment [1]	2019		2020	
	Slope PGC [2] WAFE^{-1}	Intercept PGC	Slope PGC WAFE^{-1}	Intercept PGC
Humic-coated urea (HCU)	0.7	18.3	4.8	15.8
Poly-coated humic-coated urea (PCHCU)	0.9	22.8	4.9	12.7
Synthetic fertilizer with black gypsum (SFBG)	0.8	22.4	6.6	14.8
SFBG (2 apps.)	−0.2	22.2	3.9	18.1
Black gypsum (BG)	−0.4	25.9	2.6	17.3
Stabilized nitrogen	1.1	17.5	4.2	14.2
Poly-coated sulfur-coated urea (PCSCU)	0.9	40.5	5.1	14.6
Urea	1.0	26.0	5.6	19.9
Nontreated	−0.3	20.2	2.2	14.5
	Orthogonal Contrast			
HCU vs. urea	NS [3]	*	NS	NS
PCHCU vs. urea	NS	NS	NS	NS
SFBG vs. urea	NS	NS	NS	NS
HCU vs. nontreated	NS	NS	*	NS
PCHCU vs. nontreated	NS	NS	*	NS
SFBG vs. nontreated	NS	NS	***	NS
PCSCU vs. nontreated	NS	***	*	NS
Urea vs. nontreated	NS	NS	**	NS

[1] Fertilizer treatments HCU, PCHCU, SFBG, stabilized nitrogen, PCSCU, and urea were applied at 48.8 kg N ha^{-1} in April, May, September, and October; BG was applied at 146.5 kg BG ha^{-1} in April, May, September, and October; and SFBG (2 apps.) was applied at 48.8 kg N ha^{-1} in April and September. All treatments were applied in 2019 and 2020. [2] PGC was determined using digital image analysis. WAFE, weeks after final event. Slope and intercept values were determined using linear regression analysis. [3] NS, nonsignificant at the 0.05 probability level. * Significant at the 0.05 probability level. ** Significant at the 0.01 probability level. *** Significant at the 0.001 probability level.

3.2. Soil Moisture, Surface Hardness, and Rotational Resistance

Fertilizer treatments did not lead to an effect on soil moisture, surface hardness, and shear strength. Soil moisture ranged 36.5 to 37.3% (*v/v*). Surface hardness varied from 86.4 to 91.5 G_{max}. Shear strength ranged from 16.8 to 17.5 Nm. Overall, no differences were seen in soil moisture, surface hardness, and shear strength throughout the duration of the experiment.

4. Discussion

Minimal fertilizer treatment differences were observed in terms of PGC while simulated traffic events occurred. In 2019, PCSCU resulted in 26% greater PGC event^{-1} compared to the nontreated. This is similar to other studies that found applications of N increased turfgrass cover during simulated traffic [20–22]. However, this result was not replicated in 2020. No treatment differences were seen in 2020. Humic substances have been classified as plant growth promoters or plant growth stimulators, which are forms of PGRs [28–30,53]. However, the addition of humic substances did not result in enhanced traffic tolerance compared to fertilizer alone. This is similar to Ervin and Koski [19], which reported that applications of N +/− PGRs did not result in improve turfgrass quality under traffic. In contrast, Brosnan et al. [26] found that, on average, applications of PGRs increased turfgrass cover by 45% compared to the nontreated at the conclusion of traffic events. Overall, humic substances incorporated with fertilizer treatments resulted in no improvements in terms of PGC loss event^{-1}.

Turfgrass recovery (PGC WAFE^{-1}) from traffic events varied between years. In 2019, minimal recovery occurred and no treatments were different from the nontreated. In 2020, HCU, PCHCU, SFBG, PCSCU, and urea resulted in greater turfgrass recovery compared to the nontreated. On average, in 2020, four applications of N yr^{-1} increased turfgrass recovery by 33% and 136% relative to two applications of N yr^{-1} and the nontreated, respectively. Similar results were found by Hoffman et al. [23], which reported that

increased N rates provided quicker turfgrass recovery to simulated wear. Differences in recovery between years could be due to differences in temperature during the recovery period. The average high and low temperatures during the recovery period in 2019 was 14.3 and 2.9 °C, and 16.1 and 3.2 °C in 2020 [49]. The optimal temperature range for shoot growth of cool-season grasses is 15 to 24 °C and on average temperatures reached this range in 2020, which could allow for greater turfgrass recovery [54]. Overall, turfgrass recovery from simulated traffic varied between years, but it appears that applications of fertilizers can improve turfgrass recovery.

Fertilizer treatments did not lead to an effect on soil moisture, surface hardness, and shear strength during simulated traffic events. In contrast, other studies found that applications of N increased shear strength [20,22]. Baker et al. [20] reported that the effect of N application on surface hardness depended on wet or dry conditions. Since this experiment received uniform irrigation throughout the growing season, the effects of N applications on surface hardness could have been minimized. The addition of humic substances to fertilizer treatments did not result in changes in soil and surface physical parameters. Overall, fertilizer treatments +/− humic substances resulted in no effect on soil moisture, surface harness, or shear strength.

In conclusion, the addition of humic substances to fertilizer treatments did not result in improved traffic tolerance. Only PCSCU, in 2019, resulted greater traffic tolerance than the nontreated and no differences were seen in 2020. Fertilizer treatments did not lead to an effect on soil moisture, surface hardness, and shear strength during traffic. Turfgrass recovery varied between years with greater recovery seen in warmer temperatures. In 2020, four applications of N increased turfgrass recovery compared to the nontreated. Turfgrass recovery was not improved by incorporating humic substances with fertilizers relative to fertilizer alone. Future research is needed to determine if climatic conditions change the turfgrass response to the addition of humic substances to fertilizers and to determine the best timing of fertilizer treatment applications. Additionally, future experiments could incorporate aeration and topdressing treatments in combination with incorporating humic substances to fertilizer applications.

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