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Biophysical Effects and Ground Force of the Baldree Traffic Simulator

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Abstract

Traffic simulators are often utilized when researching turfgrass wear tolerance and recovery. However, the availability of a durable traffic simulator capable of producing dynamic force is limited. Therefore, the objectives of this research were to: 1) evaluate a novel traffic simulator with improved durability and capable of producing dynamic force and 2) evaluate the bio-physical effects of the traffic simulator on a native soil turfgrass system. The Baldree Traffic Simulator is a modified Ryan GA 30 riding aerification unit, equipped with fabricated, spring loaded steel plate feet studded with screw in cleats. The effects of this unit on a 'Tifway' bermudagrass (*Cynodon dactylon* [L.] Pers. × *C. transvaalensis* Burtt-Davy) system established on a Tifton loamy sand (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults) were evaluated at the Coastal Plains Experiment Station, Tifton, GA. Factors included location (1 and 2) and traffic rate (0, 12 and 24 passes applied over a 6 week period). Field data included soil bulk density, turf density, and percent green turf cover. An in-ground force plate at the McPhail Equine Performance Center, East Lansing, MI was used to quantify vertical and net shear ground reaction force produced by the Baldree traffic simulator when operated in the forward and backward direction. The Baldree traffic simulator produced more cleat marks per pass than the Brinkman and Cady traffic simulators, as well as vertical force values comparable to that of a trotting horse. At the low traffic rate the Baldree traffic simulator increased soil bulk density, while turf density, percent green turf cover and vegetative indices decreased, therefore, the tool can be used to simulate heavy traffic conditions with a minimum number of passes.

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Athletic field traffic stress is the result of wear injury and soil compaction (Beard 1973; Shearman et al., 2001; Shearman 1988). Wear injury is the immediate physiological effect of crushing, shearing and tearing of the turfgrass (Bonos et al., 2001; Sherman et al., 1974). Soil compaction, an increase in soil bulk density, is the result of repeated exposure to an external force and has been shown to produce a variety of long-term detrimental effects, such as decreased shoot density (Carrow, 1980; Kowalewski et al., 2011), root growth and development (Matthieu et al., 2011), and soil water infiltration (Henderson et al., 2005a).

As early as the 1940s scientists began simulating traffic with vehicles to evaluate the effects of wear injury on turfgrass (Morrish and Harrison, 1948). Beginning in the 1950s machines were developed to simulate traffic stress, combining shearing and compactive forces (Perry, 1958). Prior to 2005, traffic simulators utilized rubber-wheels, rollers and studded drums (Canaway, 1976; Cockerham and Brinkman, 1989; Sherman et al., 2001; Vanini et al., 2007). These traffic simulators are durable, and generate significant turfgrass injury; however, they produce roller type compaction, and therefore, fail to simulate forces of varying magnitude and direction (dynamic force) that typically occur on an athletic field (Henderson et al., 2005b), producing minimal soil compaction (Vanini et al., 2007).

In 2005, researchers developed the Cady traffic simulator (CTS), which is capable of producing dynamic force (Henderson et al., 2005b), as well as significant soil compaction and turfgrass wear(Vanini et al., 2007). The CTS is a modified walk behind core cultivation unit which is capable of simulating a three-directional dynamic force of varying magnitude. In research comparing the CTS to the Brinkman traffic simulator (BTS), a draw-type wear machine with differentially connected studded drums, the CTS provided significantly greater compaction of a loam soil, increasing the bulk density from 1.53 to 1.68 g cm^{-3}, when 60 treatments were applied over a 6 week period. This research also determined that the CTS significantly decreased turfgrass density, shear resistance and divot resistance in comparison to the results produced by the BTS and the control. Although the CTS is capable of producing significant turfgrass injury and soil compaction because of the force it creates, the cleated feet, which are constructed using a lopped section of a 8-ply, load range D truck tire, lack the durability of the BTS. Therefore, there is a need for a more durable traffic simulator capable of creating dynamic force.

The objectives of this research were to: 1) evaluate a novel traffic simulator with improved durability and capable of producing dynamic force and 2) evaluate the bio-physical effects of the traffic simulator on a native soil turfgrass system.

MATERIALS AND METHODS

The Baldree traffic simulator is a modified Ryan GA 30 (Jacobsen, A Textron Company, Charlotte, NC), riding aerification unit equipped with fabricated, spring loaded steel plate feet studded with screw in cleats (Figures 1, 2 and 3). For the following research, the traffic simulator was maintained at a forward or backward speed of 0.35 m s^{-1} using a fabricated speed pedal control governor, while the tine spacing lever was maintained at 25 mm (Figure 4). These settings (ground speed and tine spacing) equate to 1,129 cleat marks m^{-2} per pass, approximately the number of cleat marks produced in 2 football games within the zone of traffic concentration on a typical football field (Cockerham, 1989). Previous research conducted using the BTS and CTS, both cleat type traffic simulators, determined that these units produce 300 and 333 cleat marks per m^{-2} per pass (Cockerham and Brinkman, 1989; Henderson et al., 2005). While the 0.35 m s^{-1} ground speed and 25 mm tine spacing lever settings were maintained for the following research, the number of cleat marks per m^{-2} can easily be changed by adjusting the distance between the speed control petal pivot point and the governor, as well as the tine spacing lever setting. To evaluate the durability of this unit, 636 traffic treatments by a 3 m length were

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applied 636 times from 23 March to 16 November 2012 in Tifton, GA and East Lansing, MI without a mechanical failure.

Field Research

Field research was conducted from March 23 to June 1, 2012 at the University of Georgia Coastal Plains Experiment Station, Tifton, GA on 'Tifway' bermudagrass (*Cynodon dactylon* [L.] Pers. × *C. transvaalensis* Burtt-Davy) established vegetatively from sprigs in May 2009 on a loamy sand (Tifton-Urban land complex; pH 5.3). For this experiment the Baldree traffic simulator was operated at the 0.35 m s^{-1} ground speed. Experimental design was a 2 X 3 (location x traffic rate) randomized complete block design, with three replications. Location had two levels; 1 and 2, and traffic rate had three levels; 1) low (12 passes), 2) high (24 passes) and 3) an untreated control.

Traffic was applied once per week at location 1 from 23 March to 27 April 2012 and location 2 from 27 April to 1 June 2012. Simulated traffic was applied at a low rate, 1 pass forward and 1 pass backward per week totaling 12 passes over a 6 week period, and a high rate, 2 passes forward and 2 passes backward per week totaling 24 passes over a 6 week period. A control treatment, which did not receive traffic, was also included.

Turfgrass was maintained at a mowing height of 1.3 cm (clippings removed) and received monthly applications of 16N-1.8P-8.6K (Super Rainbow Plant Food; Agrium U.S. Inc, Denver, CO) ranging from 24 to 48 kg ha^{-1} N from April to October, totaling 366 kg ha^{-1} N annually. Plots also received daily irrigation (0.38 cm day^{-1}) during the growing season.

Response variables included soil bulk density, turf density and percent green turf cover collected at the conclusion of the two 6 week traffic periods. Soil bulk density samples were collected using a 110 mm diameter by 76 mm deep core, equating to a 722.3 cm^3 samples. Samples were dried for 72 hours at 37.8° C and then weighed using a Sartorius TE4101 (Sartorius Corporation; Edgewood, NY) with 0.1 g readability. The resulting weights were then used to calculate the soil bulk density (g cm^{-3}). Turf density was determined visually using a 1-9 scale, with 1 equaling a complete lack of turf and 9 equaling complete or maximum density (Morris, 2011). To determine percent green cover, digital images were collected using a Canon Powershot G5 (Canon, Tokyo) mounted on a 0.31 m^2 enclosed photo box with four 40-W spring lamps (TCP; Lighthouse supply, Bristol, VA). Digital images were then analyzed using SigmaScan Pro (v. 5.0, SPSS, Inc., Chicago, IL 60611) to determine percent green cover (0-100%) according to procedures developed by Richardson et al. (2001).

Data were analyzed as a randomized complete block design with three replications, using SAS (ver. 9.1.3, SAS Institute Inc., Cary, N.C.). Factors included location (1 and 2) and traffic rate [control, low (12 passes) and high (24 passes)]. Mean separations were obtained using Fisher's least significant difference (LSD) at a 0.05 level of probability (Ott and Longnecker, 2001).

Ground Force Research

Research was conducted to determine the peak ground reaction force produced by the Baldree traffic simulator using two adjacent 60 by 90 cm in-ground force plates (FP6090 Force Plate; Bertec Corp, Columbus, OH) at the McPhail Equine Performance Center, Michigan State University, East Lansing, MI on 3 August 2012. The two force plates had a 1.3 cm thick rubber mat adhered to the plate surface with a magnet. The traffic simulator was driven the length of the 90 cm force plate with the wheels straddling the plate. This orientation ensured that the simulator feet only struck the force plate, preventing the weight of the unit from skewing the ground force data. Because the force plate utilized in the research was 60 cm wide, two of the four simulator feet were removed at the time of testing. Because the remaining two foot plates alternately strike the ground, the force (N) produced by an individual simulator foot (124.5 cm^2) was measured.

Ground force data included vertical, longitudinal (front-to-back) and transverse (side-to-side) force (N) collected at a rate of 960 Hz. Longitudinal and transverse forces were combined using the Pythagorean Theorem ($c^2 = a^2 + b^2$) and termed net shear. Vertical and net shear force per plate were averaged to calculate the mean peak ground force per treatment.

Data were analyzed as a completely randomized design with six replications using SAS (ver. 9.1.3, SAS Institute Inc., Cary, N.C.). Treatments included traffic direction, forward and backward, at a ground speed of 0.35 m s^{-1}. Mean separations were obtained using Fisher's least significant difference (LSD) at a 0.05 level of probability.

RESULTS AND DISCUSSION

Field Research

Soil Bulk Density

A significant traffic rate effect on soil bulk density was observed at the conclusion of the 6 week traffic period; location and the location by traffic were not significant (Table 1). The high traffic rate produced the greatest soil bulk density (1.52 g cm^{-3}), followed by the low traffic rate, while the control had the lowest bulk density (1.15 g cm^{-3}). Research conducted by Vanini et al. (2007) determined that 60 passes applied over 6 weeks with the CTS increased soil bulk density from 1.53 g cm^{-3} to 1.68 g cm^{-3}. This research also determined that the BTS, regardless of the number of passes, did not significantly affect soil bulk density. Matthieu et al. (2011) determined that a loamy sand compacted to a soil bulk density of 1.80 g cm^{-3} was required to inhibit root growth of zoysiagrass (*Zoysia japonica* Steud.), centipedegrass (*Eremochloa ophiuroides* [Munro] Hack.) and bermudagrass. This research also determined that a soil bulk density of 1.70 g cm^{-3} was sufficient to reduce root growth of creeping bentgrass (*Agrostis stolonifera* L.), Kentucky bluegrass (*Poa pratensis* L.), tall fescue (*Festuca arundinacea* Schreb.), perennial ryegrass (*Lolium perenne* L.) and St. Augustinegrass (*Stenotaphrum secundatum* [Walt.] Kuntze). Other detrimental effects associated with soil compaction include reduced visual quality, turf cover, shoot density and total nonstructural carbohydrates (Carrow et., 1980; Vanini et al., 2007).

Turf Density and Percent Green Turf Cover

Traffic rate produced significant turf density and percent green turf cover differences at the conclusion of the 6 week traffic period, while location did not affect these characteristics (Table 2). A significant location by traffic rate effect on turf density was observed; however, this interaction was a difference in magnitude between traffic at the low rate in each location and not a change in direction of response between traffic rate by location. Therefore turf density means over both locations were used in the analysis.

The high traffic rate resulted in the lowest turf density, followed by the low traffic rate and finally the control, which provided the greatest turf density. Both the high and low traffic rate, regardless of location, produced turf densities less than 6, which is considered unacceptable (Morris, 2011). Vanini et al. (2007) observed a significant difference between turf density (assessed using plants counts) when traffic was applied using the CTS at the high rate (60 passes). However, Vanini et al. (2007) did not observe differences in turf density between the control and traffic applied at the low rate (12 passes) using the CTS, or the low and high rates when utilizing the BTS.

The high traffic rate reduced the mean percent green turf cover to less than 50% while the control provided the greatest mean percent green turf cover value of 98% (Table 2). Other research observed fall Tifway vegetative cover rating of 83% after 16 passes and 59% after 48 passes with the CTS (Goddard et al., 2008). Trappe et al. (2011) observed fall Tifway percent green turf cover values ranging from 67 to 85.7% and summer values ranging from 92.5 to 93.8% after 40 passes with the CTS.

Ground Force Research

Traffic direction produced differences in peak ground reaction force, and both vertical and net shear (Table 3). When the Baldree traffic simulator was operated in the backward direction it produced significantly greater force, vertical and net shear, than when it operated in the forward direction. Contrary to these findings, Henderson et al. (2005b) determined that the CTS, which is also a modified aerification unit, produced greater compression (vertical) and net shear force when operated in the forward direction. The Baldree traffic simulator produced an average vertical force of 9,395 N and net shear force of 4,866 N. These findings are substantially greater than those observed by Henderson et al. (2005b) when evaluating the ground force produced by the CTS and BTS. Henderson and associates determined that the CTS is capable of producing a vertical force of 5,899 N and a net shear force of 1,613 N, while the BTS produces a vertical and net shear force of 2,831 and 1,711 N, respectively. Nigg et al. (1987) reported a vertical force of 1,860 to 2,260 N for running human subjects, while Browning et al. (2007) observed a walking vertical force ranging from 676 to 1,383 N.

CONCLUSIONS

The Baldree traffic simulator is a durable yet versatile tool capable of being operated at various ground speeds and directions to produce simulated athletic field use. This traffic simulator can significantly increase soil bulk density and decrease turf density and percent green turf cover with as little as 12 traffic treatments. As the number of traffic treatments applied with Baldree increased from 12 to 24, treatment differences in soil compaction also increased, while turf density and cover decreased, an effect not produced by other traffic simulators. When operated in the reverse direction the Baldree traffic simulator produces significantly greater vertical and net shear force compared to the forward direction. It also produces substantially greater ground force than the BTS and CTS when operated in the reverse direction. Because the Baldree traffic simulator produces substantially more cleat marks per pass and ground reaction force than the BTS and CTS, the tool is useful for scientists intending to simulate heavy athletic field use in a limited number of passes.

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Figure 1: Baldree Traffic Simulator foot construction. A: top foot plate pictured with nylon lock nuts, grade 8 washers, tap nuts and wheel studs. B: bottom foot plate pictured with clutch springs, pipe collars, grade 8 bolts and screw in steel cleats, cleat holes were drilled with a 4.15 cm (#19) bit, then tapped with a 5.0 mm tap. *Inner diameter.

Figure 2: Bottom view of a constructed Baldree Traffic Simulator foot, Tifton, GA, 2012. Visible parts from this vantage point include 7 screw in cleats, 4 grade 8 bolts, 2 steel plates, and 2 of the 4 clutch springs.

Figure 3: Baldree traffic simulator, a riding Ryan GA 30 with fabricated steel feet, Tifton, GA, 2012 (left), in comparison to the Cady traffic simulator, a walk behind Aero King 30 with rubber feet, East Lansing, MI, 2010 (right).

Figure 4: Speed pedal control governor installed on the Jacobsen Ryan GA 30 to maintain a ground speed of 0.35 m s-1 in the forward and backward direction (left) and the tine spacing lever set to a 25 mm spacing (right), which equates to 1,129 cleat marks m-2 per pass, Tifton, GA, 2012.

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Table 1: Effects of location and traffic rate on surface hardness and soil bulk density observed after 6 weeks of traffic applied using the Baldree Traffic Simulator in Tifton GA, 2012.

			Soil bulk density
Source of variation	Num DF	Den DF	*Pr* > F
Location (L)	1	6	ns
Traffic rate (T)	2	4	**
L X T	2	6	ns

Location: Traffic initiation date	Soil bulk density ($g\ cm^{-3}$)	
1: March 23, 2012	1.38	a
2: April 27, 2012	1.32	a
Traffic rate		
0 passes (control)	1.15	c
12 passes	1.38	b
24 passes	1.52	a

** Significant at a 0.01 level of probability.

NS = not significant at a 0.05 level of probability.

[z]Means followed by the same letter are not significantly different according to LSD (0.05).

Table 2: Effects of location and traffic rate on Tifway bermudagrass density and percent green turf cover observed after 6 weeks of traffic applied using the Baldree Traffic Simulator in Tifton GA, 2012.

			Turf density	Percent green turf cover
Source of variation	**Num DF**	**Den DF**	----------*Pr* > F---------	
location (L)	1	2	ns	ns
Traffic (T)	2	4	***	**
L X T	2	4	*	ns

Location: Traffic intiation date	Turf density (1-9)		Percent green turf cover (0-100%)	
1: March 23, 2012	3.4	a[z]	68.7	a
2: April 27, 2012	3.9	a	76.2	a
Traffic Rate				
0 passes (control)	6.0	a	97.7	a
12 passes	3.2	b	71.1	b
24 passes	1.8	c	48.6	c

* Significant at a 0.05 level of probability

** Significant at a 0.01 level of probability.

*** Significant at a 0.001 level of probability.

NS = not significant at a 0.05 level of probability.

[z]Means followed by the same letter are not significantly different according to LSD (0.05).

Table 3: Peak ground reaction force produced by the Baldree Traffic Simulator operated in the forward and backward direction in East Lansing, MI, 2012.

			Vertical force	Net shear
Source of Variation	Num DF	Den DF	-------- *Pr* > F -------	
Traffic direction	1	5	***	***

Traffic direction	Vertical force (N)		Net shear (N)	
Forward	9155	b	4842	b
Backward	9634	a	4890	a

* Significant at a 0.05 level of probability

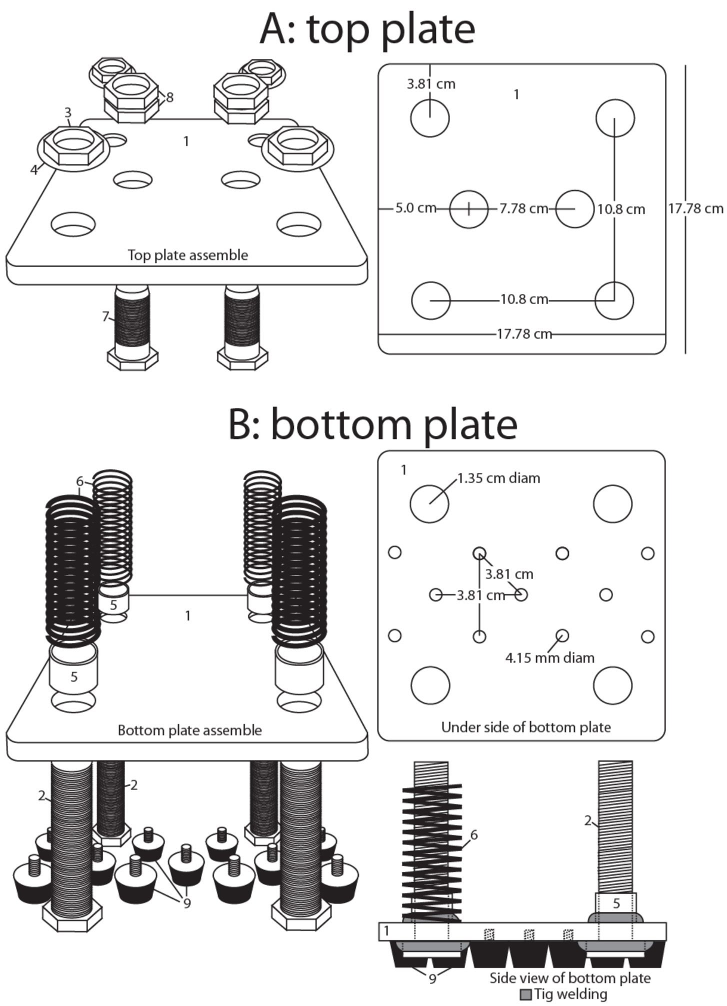
** Significant at a 0.01 level of probability.

NS = not significant at a 0.05 level of probability.

[x]Peak force per foot.

[y]Longitudinal and transverse forces were combined using Pythagorean Theorem ($c^2 = a^2+b^2$) and termed net shear.

[z]Means followed by the same letter are not significantly different according to LSD (0.05).



Part number	Item	Dimensions	Cost per item	Quantity	Total
1	Metal plate	17.8 cm x 17.8 x 0.64 cm	$2.56	2	$5.12
2	Grade 8 bolt	12.7 cm x 1.27 cm	$1.50	4	$6.00
3	Nylon lock nut	1.27 cm	$0.40	4	$1.60
4	Grade 8 washers	1.27 cm	$0.38	4	$1.52
5	Pipe collars	1.27 cm x 1.27 cm*	$0.05	8	$0.40
6	Clutch springs (R26637)	8.9 cm x 2.45 cm*	$3.00	4	$12.00
7	Wheel studs	1.27 cm	$2.50	2	$5.00
8	Tap nuts	1.27 cm	$0.20	4	$0.80
9	Steel cleats	1.27 cm	$0.42	7	$2.94
			Price per traffic simulator foot		**$35.38**

Figure 1: Baldree Traffic Simulator foot construction. A: top foot plate pictured with nylon lock nuts, grade 8 washers, tap nuts and wheel studs. B: bottom foot plate pictured with clutch springs, pipe collars, grade 8 bolts and screw in steel cleats, cleat holes were drilled with a 4.15 cm (#19) bit, then tapped with a 5.0 mm tap. *Inner diameter.

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