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Influence of traffic stress on warm season turfgrass species under simulated traffic

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ABSTRACT

Traffic stress causes wear injury and soil compaction. Various anatomical and morphological plant characteristics have been suggested to correspond with turfgrass wear tolerance are well documented in cool season turfgrass but not much with warm season turfgrass. So in order to evaluate warm season turfgrass like cowgrass, Manilagrass and seashore paspalum grass were considered with two levels of traffic; No traffic (T_0) and High traffic (T_1). Results have shown that high traffic significantly reduced the performance of turfgrasses compared to no traffic. Manilagrass under high traffic recorded the lowest reduction in turf quality, turf cover (19.3% at 90 days after treatment), root length (2.5 cm), root fresh (0.61 g) and dry weight (0.31 g), total chlorophyll (0.02 mg/g) and total non-structural carbohydrates content (2.7%) with reduced cellulose (29.27%), hemicelluloses (63.49%) and lignin (5.58%) content. Manilagrass exhibited considerably better performance among evaluated turfgrasses and scored first position in wear tolerance even with increased bulk density.

Key words: Bulk density, Infiltration rate, Soil compaction, Turf quality, Warm season turfgrasses, Wear injury

Turfgrasses are getting exposed to various abiotic and biotic stresses while accounts for major damage by excessive vehicular and foot traffic. Regular traffic that occurs on sports fields, golf courses, recreational and residential areas can be detrimental to its growth and development. The effects being two fold; wear injury and soil compaction. Various anatomical and morphological plant characteristics have been suggested to correspond with turfgrass wear tolerance. Genotypes with superior wear tolerance have been associated with plant characteristics including total cell wall content, sclerenchyma fibre quantity, leaf width, leaf angle, shoot density and root density (Shearman and Beard 1975a). Several workers (Shearman and Beard 1975a, b; Trenholm *et al.* 2000) have verified the associations of these characteristics with turfgrass wear tolerance. Plants having higher percentage of cellulose, hemicellulose and lignin will be more tolerant to wear stress (Taiz and Zeiger 1972). In bermuda grass lignin and lignocelluloses helps to increase wear tolerance (Trenholm *et al*. 2000). In contrast, sclerenchyma tissue, consisting of sclereids and fibre cells provide flexibility and also enable plants to withstand pressure from outside sources (weight, bending, crushing) without damaging thinner walled plant cells (Taiz and Zeiger 1972).

Soil compaction is a problem in recreational turf areas (Sills and Carrow 1983) and can produce chronic stresses (Beard *et al*. 1974). The overall effect of injury is inhibition of turf growth, loss of shoot density, and premature senescence of shoot or root tissue (Trenholm *et al*. 2000). Soil compaction also reduces water, heat, and gas exchange (Linn and Doran 1984, Warkentin 1971), reduces root penetration (Taylor *et al.* 1966), and as a result crop production reduces (Hakansson *et al*. 1988). Compacted soil restricts air and water movement to roots (Bruneau *et al*. 2004), decreases soil infiltration (Akram and Kemper 1979), saturated hydraulic conductivity (Dawidowski and Koden 1987) and air entry values, while increasing saturated water content (Libardi *et al*. 1982) and increases bulk density (Soane *et al*. 1982).

It has been reported that warm season turfgrass species have more wear tolerance than comparative cool-season species (Shearman and Beard 1975 a, b). Studies to evaluate the traffic tolerance of various cool season turfgrass have been most aptly done by many researchers (Bonos *et al*. 2001, Minner and Valverde 2005, Minner *et al*. 2008) but not so in warm season turfgrass species. In

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this background the present experiment was conducted to study the tolerance level, morphological and physiological responses of three warm season turfgrasses under simulated traffic in comparison to effect of compaction on soil physical properties.

MATERIALS AND METHODS

The study was conducted in a turf research plot at the Hort Park, National Parks Board, Singapore, which is geographically situated at an altitude of 10 metre above mean sea level (MSL) and between 1°22" North latitude and 103°48" East longitude, located in the northern hemisphere with tropical climate and is hot and humid throughout the year without any seasonal variation. The mean annual rainfall was 228.4 mm. Diurnal mean maximum and minimum temperatures were 31.6°C and 24.4°C respectively. The mean relative humidity recorded was 80-90% (NEA, Singapore 2013). The experimental plots (1 × 0.7 m^2) each on which the grasses were grown was with Approved Soil Mixture (ASM) comprising loamy soil, compost and sand in the ratio of 3:2:1 (CUGE Standards).

The common and extensively used three types of warm season turfgrasses namely; G_1 - Cowgrass (*Axonopus compressus*), G_2 - Manilagrass (*Zoysia matrella*) and G_3 - Seashore paspalum grass (*Paspalum vaginatum*) were used. The turfgrasses were planted by means of sodding. The sod rolls were cut in to 1 × 0.7 m^2 dimensions and planted randomly as per treatments. The major nutrients namely N, P and K were applied in the ratio of 24:3:10 at fortnightly intervals through fertilizer spreader at the rate of 2 kg/1000 m^2 (CUGE standards). Mowing was done at fortnightly intervals using a rotary mower with a bagging attachment and the clippings were collected individually. Individual experimental plots were edged using hand hoe all along the beds to avoid excess growth of stolons and rhizomes, thus ensuring maintenance of each of the experimental plot as a separate unit without the influence of other plots.

A Kesmac KTR 30 walk-behind turf roller (240 kg with 63'' long and 34'' wide) was used as a traffic simulator to impose traffic stress. Two levels of traffic were evaluated in this study; No traffic (T_0) and High traffic (T_1). High traffic (T_1) involved twelve traffic passes per week in alternate days. The traffic treatments were initiated after two months of establishment of turf. The experiment was arranged in a Factorial randomized block design in four replications. The experiment was repeated twice in 2012 and 2013 and the data were pooled. An analysis of variance (ANOVA) was run on the data, and the differences between the treatments mean were further determined with the IBM SPSS v21 statistical package.

The growth parameters like turfgrass visual quality score (1 to 9 as per National Turfgrass Evaluation Programme (NTEP) of United States), traffic tolerance was assessed visually by estimating the percentage of turfgrass cover (% by using 'digital image analysis technique'), DGCI-Dark green colour index (digital images were analyzed with Sigma Scan Pro v.5.0, SPSS, Inc., Chicago, IL 60611 and colour was determined by using the formula (1), and shoot length (cm) at fortnightly interval prior to every clipping, clipping yield (g/m^2) at monthly interval. Root parameters such as root length (cm), root volume (cm^3), root fresh weight (g) and root dry weight (g) at the end of the experiment. Physiological parameters, viz. total non-structural carbohydrates (TNC) (%) (Da Silveira *et al*. 1978), total cell wall content (%) as given by Sadasivam and Manickam (1996), total chlorophyll content (mg/g) (Yoshida *et al*. 1971) and relative water content (RWC) (%) (Barr and Weatherly 1950) at the end of the experiment and soil parameters namely, bulk density (mg/m^3) (Blake 1965) and infiltration rate (mm/s) at the end of experiment were determined.

$$\text{DGCI} = [(\text{Hue}-60)/60 + (1-\text{Saturation}) + (1-\text{Brightness})]/3 \quad (1)$$

RESULTS AND DISCUSSION

Traffic treatment showed significant difference among all turfgrass species for all the parameters. It had shown that traffic treatment significantly reduced the growth of turfgrasses compared to non-traffic treatment. Turf quality of all turfgrasses was affected significantly by traffic treatment except at 15 and 90 days after treatment (DAT) because 15 DAT and 90 DAT were the initiation and termination of traffic treatment. The lowest reduction in turf quality was observed with Manilagrass while highest reduction with seashore paspalum. This study confirmed the decline in turf quality with increase in traffic stress and is in trend as observed by several earlier investigators (Valoras *et al*. 1966, Van Wijk *et al*. 1977). According to Carrow *et al*. (2001) traffic stress includes primarily wear stress alone and the combination of wear plus soil compaction respectively. The reduced turf quality in turfgrasses under traffic can be ascribed to the facts that wear injury results in scuffing and tearing or stripping of the leaf tissue leading to a reduced shoot density, uniformity, colour and premature senescence of shoot tissue (O'Neil and Carrow 1983).

There was a significant reduction in turfgrass cover in all turfgrasses. Among all the three turfgrasses the lowest per cent turfgrass cover reduction was found with Manilagrass followed by seashore paspalum grass and highest reduction in cowgrass at all intervals except at 15 DAT. At 15, 45, 60 75 and 90 DAT, Manilagrass under traffic treatment recorded highest per cent of turfgrass cover (98.97, 97.29, 93.51, 92.51 and 80.43% respectively) and lowest per cent of turfgrass cover was observed with trafficated cowgrass (80.95, 69.35, 65.25, 64.41 and 57.47% respectively). The lowest per cent turf cover reduction was registered with Manilagrass (0.35, 2.6, 6.32, 7.39 and 19.34% respectively) while highest with cowgrass (4.88, 28.69, 33.63, 34.24 and 40.38%) at 15, 45, 60, 75 and 90 days after treatment. At 30 DAT lowest per cent turfgrass cover reduction was observed with seashore paspalum (0.01%) and highest with cowgrass (11.81%). This observation is supported by earlier reports of Christians (2003) which suggest that Manilagrass being a C_4 plant is much more efficient to mitigate stress conditions compared to other warm season turfgrasses. In the present study, the minimum turf cover reduction was found with Manilagrass and is in agreement with the findings of Lie *et al*. (2008). Further the poor performance of cowgrass can be ascribed to the fact that broad leaved turfgrass have lower shoot density, higher leaf surface and this may lead to higher wear injury.

Turfgrasses with non-traffic treatment showed increased DGCI and a decreased tendency was observed with turfgrasses under traffic treatment. A lower rate of reduction in DGCI was recorded with trafficated seashore paspalum grass followed by Manilagrass and a higher rate of reduction with cowgrass at all intervals. At 15 DAT, trafficated seashore paspalum grass recorded highest DGCI (0.45) and trafficated cowgrass (0.42) recorded the lowest. The highest DGCI was noticed with trafficated Manilagrass (0.45) and lowest with trafficated cowgrass (0.42) at 30 DAT. Digital Image Analysis (DIA) is an accurate, non-destructive method for assessment of turf colour. Previous research developed an index known as the dark green colour index (DGCI) *via* DIA as an indicator of turf colour and turf cover (Karcher and Richardson 2003). The observations made in the present study are also in agreement with that of Sherman *et al.* (2001).

Traffic treatment had reduced the shoot length in all three turfgrasses. Trafficated cowgrass recorded highest shoot length of 3.8, 5.58, 4.73, 4.28 and 3.8 cm respectively and the lowest shoot length of 1.10, 2.08, 1.75, 1.58 and 1.10 cm respectively in Manilagrass at 30, 45, 60, 75 and 90 days after treatment. Non-trafficated cowgrass recorded highest shoot length of 9.7, 10.4, 10.3, 9.85 and 9.7 cm respectively and the lowest shoot length of 2.93, 3.25, 2.95, 2.93 and 2.93 cm respectively in Manilagrass at 30, 45, 60, 75 and 90 days after treatment. This observation is in accordance with that of Rosenberg (1964). Soil compaction decreases extent of root distribution and the volume of soil explored by the roots for nutrient and water uptake were markedly reduced. Thus a plant growing on compacted soil will be more susceptible to abiotic stresses and less able to recuperate. With less shoot growth, the total photosynthates would decline and could be expressed as decreased lateral shoot growth.

Traffic treatment significantly reduced the clipping yield of all turfgrasses. The clipping yield of trafficated grass species, viz. cowgrass (6.28, 3.03 and 3.87), Manilagrass (1.38, 0.70 and 0.70) and seashore paspalum (2.52, 0.70 and 0.70) were recorded against non-trafficated grasses like cowgrass (6.9, 9.24 and 12.76), Manilagrass (6.91, 3.99 and 5.04) and seashore paspalum (12.69, 11.96 and 13.15) (Table 1). The clipping yield indicates the biomass production under stress conditions. The level of biomass production reflects the tolerance behaviour of the grasses as well as their photosynthetic efficiency (Chaves *et al*. 2009). The shoot portion or stem portion which is the main translocation organ of the photo-assimilates has great influence on the production of total dry matter. It is possibly due to the decrease in total root growth and vertical shoot growth under compaction was suggested by Valoras *et al.* (1966). These results are in line with those of Thurman and Pokorny (1969) and Agnew and Carrow (1985) who found significant reduction in clipping weight of common Bermudagrass due to soil compaction. This might be related to various factors which influence the shoot growth rate under traffic stress, one of them being ethylene production which has been reported to influence the shoot growth in turfgrasses under stress conditions (Verslues *et al.* 1998).

Non-trafficated treatment for all three turfgrasses showed an increasing trend for RWC but a decreasing trend was observed with traffic treatment. The traffic treatment reduced the relative water content by 11.7% in cowgrass, 1.12% in Manilagrass and 6.59% in seashore paspalum compared to non-trafficated treatment. The lowest relative

Table 1 Effect of simulated traffic on clipping yield (g/m^2) of turfgrasses

Treatment	30 DAT			60 DAT			90 DAT		
	T0	T1	Mean	T0	T1	Mean	T0	T1	Mean
Cowgrass	47.75 (6.9)	39.55 (6.28)	6.59	85 (9.24)	8.75 (3.03)	6.14	162.47 (12.76)	14.5 (3.87)	8.31
Manilagrass	47.85 (6.91)	1.92 (1.38)	4.15	15.5 (3.99)	0 (0.7)	2.34	25 (5.04)	0 (0.7)	2.87
Seashore paspalum grass	161.1 (12.69)	6.37 (2.52)	7.60	142.75 (11.96)	0 (0.7)	6.33	172.5 (13.15)	0 (0.7)	6.93
Mean	8.83	3.39		8.40	1.48		10.32	1.76	
	G	T	G × T	G	T	G × T	G	T	G × T
F test									
SEm	0.161	0.146	0.057	0.167	0.136	0.059	0.126	0.103	0.044
CD (P=0.05)	0.11	0.09	0.16	0.13	0.10	0.18	0.10	0.08	0.14
CV	1.74			2.51			1.55		

water content was recorded with trafficated seashore paspalum (69.37%) followed by Manilagrass (65.98%) and highest relative water content was recorded with trafficated cowgrass (71.20%). The highest relative water content was recorded with non-trafficated cowgrass (82.90%) followed by seashore paspalum (72.57%) and Manilagrass (70.49%) (Table 2). The results are in concordance with reports of Kaiser (1987). Under traffic conditions, a decrease in plant photosynthetic capacity occurred due to membrane damage in chloroplasts (which can be witnessed as scorching symptoms on upper part of the leaves) this can be ascribed to drop in RWC. The RWC reduction under traffic stress may be attributed to leaf injury (Beard 2005) causing excessive oozing of the sap from the injured portions and also its subsequent evaporation (Canaway 1981). The maintenance of healthy turf, particularly during stressful periods is partially dependent on the water content which is more important for recovery from injury or stress (Watschke *et al.* 1992).

Traffic treatment significantly reduced the root length in all the studied turfgrass species, whereas lower reduction in root length was recorded with Manilagrass (2.58 cm) followed by cowgrass (6.12 cm) and seashore paspalum (8.1 cm). The results obtained are in accordance with the previous studies of Rosenberg (1964) who reported effects of compaction on plant growth. Further, Madison (1971) critiqued that soil compaction imparts an indirect effect on the root growth by altering the soil physical and aeration properties and termed the effect as 'hidden stress'. Compaction can limit root growth directly by physically restricting root penetration, which redistributes root growth and confines roots to the soil above the compacted layer.

Simulated traffic reduced the root volume significantly in all three turfgrass species. The non-trafficated grasses recorded higher fresh weight values, whereas a significant reduction was observed in the root fresh weight of all the trafficated turfgrasses. Traffic treatment showed the reduction in the fresh weight of root by 0.61 g in Manilagrass, 1.71 g in cowgrass and 2.02 g in seashore paspalum. Non-trafficated turfgrasses recorded increased dry weight of root compared to trafficated turfgrasses. Trafficated treatment significantly reduced the dry weight of root in all turfgrasses. Traffic treatment reduced the dry weight of root by 0.31 g in Manilagrass, 0.43 g in cowgrass and 1.73 g in seashore paspalum when compared to their respective control. The highest dry weight of root was observed with Manilagrass (2.25 g), whereas lowest with cowgrass (1.6 g). This observation is in agreement with that of Letey *et al.* (1966) and Thurman and Pokorny (1969). The maximum root volume reduction was recorded with cowgrass. This may be attributed to the slower root growth rate due to lower oxygen and higher soil strength, which would cause higher percentage of the roots to accumulate in the upper root zone and fewer roots to grow deeper, resulting in reduced root density (Voorhees *et al.* 1975 and Van Wijk 1980).

Root biomass of turfgrasses had a deep influence on their response to abiotic stress such as traffic, water logging, drought and salinity. The total root biomass varied considerably among the turfgrasses with the following ranking: seashore paspalum>manilagrass>cowgrass. Of the three warm season turfgrass species studied, seashore paspalum and Manilagrass had vigorous root systems. The decrease in root biomass of cowgrass shows that its root system is sensitive to compaction. In addition to changes in root distribution within a soil profile, changes in root morphology can occur when roots are grown in compact soil. Root systems of most of the cool and warm season turfgrass species have been observed to encounter some difficulty in growing under traffic stress. Evidence supporting this trend comes from reports of Ishaq *et al*. (2001).

Traffic treatment significantly reduced the chlorophyll content in all turfgrasses. The highest reduction in chlorophyll

Table 2 Effect of simulated traffic on relative water content, total cell wall content, total non-structural carbohydrates of warm season turf grasses and their bulk density and infiltration rate

Turf grasses	Traffic level	Relative water content (RWC) (%)	Total cell wall content (%)				Total Non-structural carbohydrates (TNC) (%)	Bulk density (BD)	Infiltration rate (IR) (m/ms)
			Cellulose	Hemicellulose	Lignin	Pectin			
Cowgrass	Trafficated	71.20	39.39	48.51	9.76	2.34	3.32	1.74	0.98
	Non-trafficated	82.90	53.27	32.89	11.10	2.75	3.52	1.46	2.45
Manilagrass	Trafficated	69.37	29.27	63.49	5.58	1.67	2.67	1.80	0.85
	Non-trafficated	70.49	51.49	35.85	10.79	1.88	3.33	1.52	3.55
Seashore paspalum grass	Trafficated	65.98	45.94	41.36	9.32	3.38	3.07	1.87	2.18
	Non-trafficated	72.57	57.93	26.36	11.26	4.46	3.41	1.41	3.10
F test			NS	NS			NS		
SEm		5.35	3.20	3.49	0.76	0.17	0.13	0.03	0.17
CD (P=0.05)		16.14	9.66	10.53	2.30	0.50	0.40	0.11	0.53

- a content was recorded with trafficated Manilagrass (1.1 mg/g) and lowest reduction was recorded with trafficated seashore paspalum (0.16 mg/g). The highest chlorophyll a content was observed with Manilagrass (1.3 mg/g) and the lowest was observed with seashore paspalum (0.53 mg/g) in non-trafficated treatment. Trafficated Manilagrass (0.35 mg/g) recorded highest reduction in chlorophyll - b content and lowest reduction was recorded with trafficated seashore paspalum (0.13 mg/g). Among non-traffic treatment highest chlorophyll - b content was recorded with Manilagrass (0.71 mg/g) and lowest with seashore paspalum (0.52 mg/g). The highest reduction in total chlorophyll content was observed with trafficated cowgrass (0.04 mg/g) and lowest reduction was recorded with trafficated Manilagrass (0.02 mg/g). In non-traffic treatment cowgrass recorded the highest (0.26 mg/g) total chlorophyll content and the lowest was recorded with seashore paspalum (0.22 mg/g). Traffic reduces the rate of photosynthesis and the ability of the turfgrasses to produce carbohydrates, which are necessary for growth and survival (Nolan 2009). In the present work, as evident from the data all the turf species under trafficated condition revealed reduced chlorophyll concentrations, which in turn might have led to reduced photosynthetic rates. Leaf tissues and chlorophyll molecules especially under high light conditions during traffic stress may experience oxidative stress from reactive oxygen species (ROS) expressed as reduction in the overall chlorophyll (a, b and total chlorophyll) contents of the leaf as reported earlier by Inze and Montagu (2002).

Traffic treatment significantly affected the total cell wall constituents of all the turfgrasses. The highest cellulose content was recorded in non-trafficated seashore paspalum (57.93%) and highest reduction in cellulose content recorded in the Manilagrass in trafficated treatment (29.27%). The lowest cellulose content was observed in non-trafficated Manilagrass (51.49%) and lowest reduction in cellulose content was observed in trafficated treatment in the same grass (22.22%). Hemicellulose was significantly increased by traffic treatment in all turfgrasses. Among trafficated treatment, Manilagrass (63.49%) recorded highest in hemicellulose content and the lowest was recorded with seashore paspalum (41.36%). With respect to non-traffic treatment, Manilagrass (35.85%) recorded highest hemicellulose content and the lowest was recorded with seashore paspalum (26.36%). In trafficated treatment reduction in lignin was observed. The highest reduction in lignin was observed with trafficated Manilagrass (5.58%) and lowest reduction was recorded with trafficated cowgrass (9.76%). In non-trafficated treatment seashore paspalum recorded the highest (11.26%) lignin and the lowest was recorded in Manilagrass (10.79%). The highest pectin content was recorded in non-trafficated seashore paspalum (4.46%) and highest pectin content also recorded in the same turfgrass in trafficated treatment (3.38%). The lowest pectin content was observed in non-trafficated Manilagrass (1.88%) and lowest pectin content was observed trafficated treatment in same turfgrass (1.67%) (Table 2).

Total non-structural carbohydrates (TNC) were significantly reduced by traffic treatment in all turfgrasses (Table 2). Among trafficated treatment, Manilagrass (2.67%) recorded highest reduction in TNC content and the lowest was recorded with cowgrass (3.32%). With respect to non-traffic treatment, cowgrass (3.52%) recorded highest TNC content and the lowest was recorded with Manilagrass (3.33%). Manilagrass was found to be performing better even under increased bulk density. In trafficated treatment reduction in infiltration rate was observed. The highest reduction in infiltration rate was observed with trafficated Manilagrass (2.7 mm/s) and lowest reduction was recorded with trafficated seashore paspalum (0.92 mm/s) (Table 2).

The results for bulk density and effects of soil compaction are in accordance with findings of Carrow (1980). This might be owing to a thin layer of compacted soil at the surface and can greatly reduce the water infiltration. Compaction influences the air-water relationship by increasing moisture retention capacity (Carrow and Petrovic 1992) and is a good indication for less frequent watering provided the rate of infiltration are also good. Infiltration is highest through larger pores, soil cracks, root channels, and worm or insect channels. It depends on matrix and gravitational forces. Compacted soil can produce stresses of poor soil aeration (low oxygen), low infiltration rates and high mechanical impedance to root growth (Harivandi *et al.* 2009).

All the three turfgrasses exhibited a wide range of variation in their performance under simulated traffic. Simulated traffic reduced the turf quality, turf cover, shoot length, clipping yield, relative water content, root parameters and biochemical parameters in the studied warm season turfgrasses. Even though, the growth and performance of Manilagrass was the best under simulated traffic. Seashore paspalum grass exhibited moderate level of performance, whereas cowgrass exhibited the poorest performance. Considering the tropical climate of Singapore and sandy loam soils of the experimental area the tolerance level of turfgrasses for simulated traffic was in order of Manilagrass>seashore paspalum>cowgrass.

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