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Tolerance of some warm-season turfgrasses to compaction under shade and sunlight conditions in Riyadh, Saudi Arabia

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ABSTRACT

We evaluated the compaction tolerance of some warm-season turfgrasses under shade and sunlight conditions in Riyadh, Saudi Arabia. Hybrid bermudagrass, Cynodon dactylon, cultivars 'Tifway' and 'Tifsport', seashore paspalum (Paspalum vaginatum) and its cultivar 'Sea Isle 2000' were used. The study area was divided into two sections: one was exposed to sunlight and the other was maintained under 70% shade using a green plastic grille. Turfgrasses were planted using "sods" in beds containing a mixture of sand, silt, and peat moss (4: 1: 1, v/v). The soil was compacted using a locally-made 250 kg cylindrical roll, passing four times over the grown turfgrasses for 3 days/week. The results showed that plant height, leaf area, grass quality and color were decreased by compaction in both the shade and sunlight areas. Plant height in the shaded area with or without compaction was higher than in the sunlight area. Under compaction, 'Sea Isle 2000' was the shortest: 8.8 cm in the sunlight and 14.3 cm in the shade. For grasses grown in sunlight, compaction decreased grass height, and height was lowest (4.0 cm) in 'Sea Isle 2000' in January. In the shaded area, paspalum turfgrass retained its high quality (4.0) in April, May, and June. In the sunlight area, the grass quality was highest (4.0) in 'Sea Isle 2000' and the lowest (3.0) in 'Tifsport.' Paspalum turfgrass showed a higher color degree (4) than bermudagrass (2.5) in April, May, and June. Compaction also led to a decline in leaf area and fresh and dry weights of all grown turfgrasses. The grass density was high for paspalum turfgrasses, indicating that their resistance to compaction was greater than bermudagrasses. It can be concluded that the best compaction and shade-tolerant turfgrasses are 'Sea Isle 2000' and seashore paspalum.

1. Introduction

Most of the turfgrasses grown in public areas (e.g. parks, gardens, and athletic fields) are exposed to soil compaction resulting from repeated use and traffic, such as walking and higher impact activity including running and sports, which are often conducted with cleated footwear. Soil compaction can also be caused by vehicular traffic, including recreational vehicles and field maintenance vehicles and equipment (Brown and McCarty, 2004). The movement and weight of these vehicles and this equipment affect physical and structural soil properties, resulting in a decrease in soil aeration and water drainage, thereby impeding turfgrass growth (O’Neil and Carrow, 1983). Traffic generally inflicts turfgrass wear stress and soil compaction (Carroll and Petrovic, 1992). Compaction results in reduced soil porosity and infiltration in addition to increased soil bulk density and moisture, causing greater susceptibility to drought and other stresses (Guertal and Han, 2012; Harivandi, 2002; Wiecko, 2006). It also has a negative effect on turfgrass growth, such as causing weak, shallow root growth, decreased shoot growth, and a decline in overall grass quality (Carroll, 1980).

Wear stress is the immediate damage or rapid loss of turfgrass shoot tissues and chlorophyll caused by pressure, shear, abrasion, and tearing as a result of both foot and vehicular traffic (Carroll, 1995). Wear is seen as a physical tearing of grass leaf tissues, and soil compaction negatively alters soil physical properties, affecting root growth (Carroll and Petrovic, 1992).

Several factors, including the type and time of traffic, turfgrass species and cultivars, soil type, and root-zone construction type,
affect the durability of turfgrass to traffic stress (Murphy and Ebdon, 2013). Some turfgrass species and varieties with a fine leaf texture, increased shoot density, and vertical growth rate are more tolerant of various traffic stresses (Brosnan and Deputy, 2009; Lee et al., 2004; Trenholme et al., 2000). Lee et al. (2004) reported that new seashore paspalum cultivars, such as ‘Sea Isle 2000’ have significantly greater vertical growth rates than ‘Tifway’ hybrid bermudagrass. Brosnan and Deputy (2009) suggested that some seashore paspalum cultivars may be suitable alternatives to hybrid bermudagrass on athletic fields in warm-season climates.

Turfgrasses are often exposed to different shade environments in conjunction with traffic stresses (wear and/or compaction) on athletic fields. Therefore, turfgrass injury could be more substantial under these combined stresses than either stress alone (Jiang et al., 2014). The use of shade-tolerant cultivars or species can substantially improve turf quality in shaded areas (Baldwin et al., 2008; Qian and Engelke, 1997; Bunnell et al., 2005; Trappe et al., 2010).

Shade and continuous traffic from sporting activity or maintenance equipment can reduce turfgrass coverage, quality, and playability on sports fields (Trappe et al., 2009).

Few studies investigated compaction effects on turfgrasses, for example Thoms (2008) found that the ‘Tifway’ cultivar showed a higher intensity of color than the rest of the bermudagrass cultivars exposed to compaction. In another study, the compaction treatment resulted in more compacted soil particles, and this reduced air and water movements and the percentage of oxygen in the soil (Huang, 2008). The average cost of professional aeration of lawns (to fix compaction) is ranging between 30 and 92 USD/ft$^2$ in the USA), respectively. The soil pH was 8.6, the water pH was 7.7, the soil EC was 1.1 and the water EC was 3.2 dS m$^{-1}$.

2. Materials and methods

2.1. Plant materials and growing conditions

This study was conducted at the Nursery of Sustainable Management and Environmental Development, King Saud University, Riyadh, Saudi Arabia, from October 2018 to June 2019 and repeated again from October 2019 to June 2020. Four warm-season turfgrasses, including two cultivars of hybrid bermudagrass, Cynodon dactylon: ‘Tifway’ (419) and ‘TifSport’, seashore paspalum, Paspalum vaginatum, and its cultivar ‘Sea Isle 2000’ were used. The field study area was divided into two sections: one was exposed directly to sunlight, and the other one was kept under conditions of 70% shade using a green plastic grille. Each of the turfgrass species and cultivars was planted using vegetative grass segments, known as “sods,” in prepared 2 m$^2$ and 30 cm deep beds containing a mixture of sand, silt, and peat moss at a ratio of 4:1:1 by volume. The grasses were left to grow and establish for one month. All grasses were mowed once/month to a height of 4 cm using a manual mower. The fresh and dry weights (g/m$^2$) of turfgrass were determined by collecting and weighing the grass clippings from a 1 m$^2$ area from the end of the experiment following Wenger (1984).

2.2. Light intensities and chlorophyll composition

Light intensities (µmol m$^{-2}$ s$^{-1}$) were measured weekly at noon in both sunlight and shade areas using a Quantum Light Meter (Item # 3415F, Specturm Technologies Inc., USA) from October 2018 to June 2019 and from October 2019 to June 2020. The average light intensities were 1859.7 and 561.1 µmol m$^{-2}$ s$^{-1}$ in sunlight and shade areas, respectively. The mean day temperature and relative humidity were also recorded in both sunlight and shade areas during the study period daily using nearest weather station. The mean day temperatures were 30.3 °C and 28.2 °C, while the mean relative humidities were 24.5% and 25.3% in sunlight and shade areas, respectively.

2.3. Soil compaction and soil bulk density

Soil compaction was simulated using a locally-made 250 kg cylindrical roll, with a length of 1 m and diameter of 50 cm, passing four times over the growing bed turfgrasses 3 days/week, in both sunlight and shade areas. The soil bulk density (g/cm$^3$) of compacted or non-compact soil planted with various turfgrass species grown in shade and sunlight areas was determined at the end of the experiment following Porra et al. (1989) using a Chlorophyll Meter Instrument (Hach DR 3000 Spectrophotometer, USA).

2.4. Grass watering, cutting and fertilization

Grass plants were watered 2–3 times/day for 5–10 min and as required using irrigation system sprinklers. The growing grasses were cut once/month to a height of 4 cm using a manual mower. All experimental units were fertilized with urea at 46% N and compound fertilizer (N:P:K: 15:15:15) at a rate of 4 kg N/1000 m$^2$. Fertilizer amount was split to monthly doses (6 doses) during experiment time.

2.5. Morphological data measurements

Data and measurements were taken each month during the six-month period of the experiment to study the characteristics of plant height, grass quality, and grass color. Plant height was measured using a ruler from soil surface to the top the highest leaf on the plant. Turfgrass quality was determined based on a visual rating score for grass density, uniformity, and freedom of injury. Scores ranged from 1 to 5: 1 = poor, 2 = fair, 3 = good, 4 = very good, and 5 = excellent (Al-Mana, 2000). Turfgrass color was evaluated visually on a scale of 1–5: 1 = brown-yellow, 2 = yellow-green, 3 = pale green, 4 = green and 5 = dark green. At the end of the experiment, grass density, leaf area, and fresh and dry shoot weights were measured (Al-Mana, 2000). Turfgrass density was expressed as the number of shoots in a 100 cm$^2$ grass area. Leaf area (cm$^2$) was determined using an LI-3000C Portable Area Meter. The fresh and dry weights (g/m$^3$) of turfgrass were determined by collecting and weighing the grass clippings from a 1 m$^2$ area from each plot. Then, the grass material was oven-dried at 70 °C for 72 h and weighed afterward.

2.6. Experimental design and statistical analyses

The experiment was designed using a split-split plot design, where main plots were assigned for shade and sunlight conditions, sub-plots were allocated for compaction and non-compaction treatments, and sub-sub-plots were allocated for turfgrass species and cultivars, with three replicates for each treatment. No significant differences were found between the two seasons and the data.
were pooled. All obtained data were analyzed using the revised LSD test in Statistical Analysis Software with statistical differences between mean values being significant at a 5% level of probability (Statistical Analysis System, SAS, ver. 9.3).

3. Results

There were significant differences in the impact of compaction on plant height, grass quality, and color among the studied turfgrass species and cultivars in the shaded and sunlight areas during the six months of the experiment (Figs. 1–3). The compaction treatment resulted in decreased plant height compared to the turfgrasses that were not compacted in each of the shaded and sunlight areas (Fig. 1). However, plant height was decreased by 40% in the shaded area and 35% in the sunlight area. In the compacted sunlight area, 'Sea Isle 2000' was shortest (4.0 cm) in February and tallest (8.8 cm) in June. In the shaded area, compaction led to a reduction in plant height and 'Sea Isle 2000' was the shortest turfgrass during the most experiment months. In addition, at the end of the experiment, in June, the tallest (18.3 cm) plants under compression were seashore paspalum in the shaded area and 'Tifway' bermudagrass (11 cm) in the sunlight area, and the shortest (14.3 and 8.8 cm) plants were 'Sea Isle 2000' in the shade and sunlight areas, respectively.

In both the shaded and sunlight areas, grass quality was lower in the compaction treatment than in the treatment without compaction, with a more substantial effect on grasses in the shade (Fig. 2). Under compaction, the grass quality of both bermudagrass cultivars, 'Tifway' and 'Tifsport,' was lower than that of paspalum turfgrasses during the months of April, May, and June in both shade and sunlight areas. In the shaded area with the presence of compaction, paspalum turfgrass retained its high quality (4.0) in April, May, and June while 'Tifway' bermudagrass had the lowest quality (2.4).

Under conditions of shade and sunlight, the results showed that the compaction treatment reduced grass color compared to the grasses that were not compacted (Fig. 3). The intensity of grass color was reduced by the compaction effect, particularly on ber-
mudagrass cultivars during most of the experiment months in both shade and sunlight areas. Under compaction, at both shade and sunlight areas, paspalum turfgrasses, ‘Sea Isle 2000’ and seashore paspalum, showed a higher average intensity of color (3.8) than the bermudagrass cultivars, ‘Tifway’ and ‘Tifsport,’ (2.5) during April, May, and June. Notably, the color intensity of ‘Tifway’ bermudagrass was higher than that of ‘Tifsport’ in all the experiment months, except January and February. Thoms (2008) found that the ‘Tifway’ cultivar showed a higher intensity of color than the rest of the bermudagrass cultivars exposed to compaction.

The soil bulk density was increased by compaction treatment on soil planted with various turfgrass species in both shade and sunlight areas (Table 1). The effect of compaction on soil bulk density in the shaded area was the highest for seashore paspalum (1.61 g/cm³) and the lowest for ‘Tifsport’ bermudagrass (1.55 g/cm³).

At the end of the experiment, decreases were observed in plant height, leaf area, grass quality, and color as a result of compaction in both the shade and sunlight areas (Table 2). Plant height in the shaded area, with or without compaction, was higher than in the sunlight area. Under compaction, the plant height of seashore paspalum was decreased by 38% in the shaded area while it was decreased by 37% in the sunlight area. The height of paspalum ‘Sea Isle 2000’ was 21% less than that of seashore paspalum in the shaded area while it decreased by 19% in the sunlight area.

Under compaction in the shaded area, paspalum ‘Sea Isle 2000’ had the largest leaf area (0.90 cm²) while the bermuda cultivars, ‘Tifway’ and ‘Tifsport,’ had the smallest leaf area (0.30 cm²).
(Table 2). In the sunlight area, seashore paspalum had the largest leaf area (0.60 cm²), while ‘Tifway’ had the smallest leaf area (0.30 cm²).

The impact of compaction on turfgrass quality and grass color was more substantial in bermudagrasses than paspalum grasses (Table 2). Under compaction, paspalum turfgrasses had the highest
Effect of compaction on turfgrass density, total chlorophyll, and fresh and dry weights of the turfgrasses grown in shaded and sunlight areas at the end of the experiment.

The results indicated that the values of the other plant parameters, turfgrass density, total chlorophyll, and fresh and dry weights, were decreased by the compaction treatment, and they were lower for plants grown in the shade than in the sunlight (Table 3). Under compaction, the density of seashore paspalum was decreased by 6% in the shaded area and 13% in the sunlight area. In the shade, the grass density was high for both paspalum turfcultivars, indicating that their resistance to compaction was greater than for the bermudagrass cultivars. Under compaction, seashore paspalum had the highest grass density (251.3 and 362.3 stems/100 cm²) while ‘Tifway’ had the lowest density (115.3 and 252.8 stems/100 cm²) in each of the shaded and sunlight areas, respectively.

Under compaction in the shade area, the total chlorophyll content was the greatest (10.2 nm/ml) in paspalum ‘Sea Isle 2000’ while it was lowest (7.1 nm/ml) in bermudagrass ‘Tifspor’ (Table 3). It appears that the compaction treatment decreased the total chlorophyll content in ‘Sea Isle 2000’ by 50% in both the shade and sunlight areas. It also decreased the total chlorophyll content in ‘Tifspor’ by 58% in the shaded area and 35% in the sunlight area. In both shade and sunlight areas, the compaction treatment resulted in a decrease in the fresh and dry weights for all turfgrass species and cultivars compared to those turfgrasses that were not under compaction (Table 3). The turfgrass dry weight of seashore paspalum subjected to compaction was decreased by 27% in the shade area and by 25% in the sunlight area. The dry weight of ‘Tifway’ decreased by 22.5% in the shade area and 7.8% in the sunlight area. Under compaction in the shade area, fresh and dry weight values were greatest (381.3 and 97.5 gm/m²) in seashore paspalum and lowest (167.6 and 77.3 gm/m²) in ‘Tifway,’ respectively. In the sunlight area, the fresh weight was the highest (770.9 gm/m²) in seashore paspalum and the lowest (394.9 gm/m²) in ‘Tifspor.’ However, the dry weight was the highest (243.6 gm/m²) in ‘Tifway’ and the lowest (168.6 gm/m²) in ‘Tifspor.’

Generally, the compaction treatment significantly decreased the average values of plant height, leaf area, grass quality, grass color, and fresh and dry weights. However, there were no significant differences in grass density and total chlorophyll (Table 4). Generally, paspalum turfgrasses show the highest values in plant height, leaf area, grass quality, grass color, and fresh and dry weights compared with bermudagrass cultivars in both shaded and sunlight areas (Table 4). The general average values of plant height, leaf area, and fresh and dry weights were the highest in seashore paspalum and the lowest in ‘Tifspor.’ The values for turfgrass quality, color, and total chlorophyll were the highest in seashore paspalum 2000 and the lowest in ‘Tifspor,’ while the average value of turfgrass density was the highest (299.3 stems/100 cm²) in ‘Sea Isle 2000’ and seashore paspalum and the lowest (197.8 stems/100 cm²) in ‘Tifway.’

Table 2
Effect of compaction on plant height, leaf area, turfgrass quality, and color of the turfgrasses grown in shaded and sunlight areas at the end of the experiment.

| Turfgrasses | Plant height (cm) | Leaf area (cm²) | Turfgrass quality | Color |
|-------------|------------------|-----------------|------------------|-------|
| Shade area  | C NC C NC        | C NC C NC C NC | C NC C NC C NC  | C NC C NC C NC |
| Tifway (419) | 15.70 26.13 0.30 0.47 2.3 4.7 2.3 4.7 | 15.70 26.13 0.30 0.47 2.3 4.7 2.3 4.7 |
| Tifspor     | 10.00 25.00 0.30 0.57 2.0 4.3 2.0 4.3 | 10.00 25.00 0.30 0.57 2.0 4.3 2.0 4.3 |
| Seashore paspalum | 18.33 29.62 0.73 1.87 4.0 5.0 4.0 5.0 | 18.33 29.62 0.73 1.87 4.0 5.0 4.0 5.0 |
| Sea Isle 2000 | 14.33 29.33 0.90 1.73 4.3 5.0 4.3 5.0 | 14.33 29.33 0.90 1.73 4.3 5.0 4.3 5.0 |

| Sunlight area | Turfgrasses | Plant height (cm) | Leaf area (cm²) | Turfgrass quality | Color |
|---------------|-------------|------------------|-----------------|------------------|-------|
| Tifway (419)  | C NC C NC  | C NC C NC C NC  | C NC C NC C NC  | C NC C NC C NC  | C NC C NC |
| Tifspor       | 10.95 13.47 0.37 0.43 3.3 4.0 3.3 4.0 | 10.95 13.47 0.37 0.43 3.3 4.0 3.3 4.0 |
| Seashore paspalum | 10.60 13.67 0.30 0.33 3.0 3.3 3.0 3.3 | 10.60 13.67 0.30 0.33 3.0 3.3 3.0 3.3 |
| Sea Isle 2000 | 8.83 15.33 0.60 1.37 3.7 4.7 3.7 4.7 | 8.83 15.33 0.60 1.37 3.7 4.7 3.7 4.7 |

C = Compaction- NC = No compaction.
*** LSD, least significant difference among means at the 0.05 level.

Table 3
Effect of compaction on turfgrass density, total chlorophyll, and fresh and dry weights of the turfgrasses grown in shaded and sunlight areas at the end of the experiment.

| Turfgrasses | Turfgrass density (Number of stems/100 cm²) | Total chlorophyll (nm/ml) | Fresh weight (g/m²) | Dry weight (g/m²) |
|-------------|---------------------------------------------|---------------------------|---------------------|------------------|
| Shade area  | C NC C NC C NC C NC C NC C NC C NC C NC C NC |
| Tifway (419) | 115.27 164.83 8.98 16.37 167.56 303.47 77.28 99.72 |
| Tifspor     | 158.83 168.50 7.08 16.90 221.51 428.35 86.98 101.41 |
| Seashore paspalum | 251.27 267.33 9.37 18.68 381.31 595.17 97.45 132.99 |
| Sea Isle 2000 | 224.00 324.77 10.15 20.41 360.79 548.24 90.90 125.63 |

C = Compaction- NC = No compaction.
*** LSD, least significant difference among means at the 0.05 level.
Table 4
General value of plant height, leaf area, grass quality, grass color, turfgrass density, total chlorophyll, and fresh and dry weights of turfgrasses grown in shade and sunlight areas at the end of the experiment.

| Treatments | Plant height (cm) | Leaf area (cm²) | Turfgrass quality | Color | Turfgrass density (Number of stems/100 cm²) | Total chlorophyll (nm/ml) | Fresh weight (g/m²) | Dry weight (g/m²) |
|------------|------------------|----------------|------------------|-------|---------------------------------------------|--------------------------|----------------------|-------------------|
| C          | 13.15            | 0.51           | 3.3              | 3.8   | 248.62                                      | 14.53                    | 450.84               | 146.86            |
| NC         | 21.07            | 0.96           | 4.5              | 4.5   | 262.00                                      | 16.14                    | 637.96               | 181.42            |
| LSD (0.05) | 0.85             | 0.06           | 0.4              | 0.2   | N.S.                                        | N.S.                     | 46.99                | 7.4               |

Turfgrasses:
- Tifway (419) 17.03 0.39 3.5 3.6 197.80 11.79 451.49 162.81
- Tifshore 16.06 0.38 3.3 3 224.90 10.87 324.16 141.16
- Sea Isle 2000 17.13 1.04 4.6 5 299.69 20.80 627.53 171.22
- LSD (0.05)*** 1.25 0.20 0.4 0.3 13.36 0.82 64.00 8.87

C = Compaction- NC = No compaction.

* Quality rating is based on grass visual appearance of density, uniformity, and freedom of injury. Scores ranged from 1 to 5 (1, poor, 2, fair, 3, good, 4, very good, and 5, excellent).

** Color rating is based on a visual scale of 1–5 (1, brown-yellow, 2, green-yellow, 3, pale green, 4, green, and 5, dark green).

*** Color rating is based on a visual scale of 1–5 (1, brown-yellow, 2, green-yellow, 3, pale green, 4, green, and 5, dark green).

### 4. Discussion

Jiang et al. (2004) reported that most paspaum cultivars are more shade tolerant than bermuda turfgasses. Compaction and wear had more negative effects on grass growth in the shade than in the sun. Therefore, the use of these turfgasses should be decreased in shade areas (Jiang et al., 2003). In general, compaction had the least effect on the height of ‘Tifway’ and ‘Tifshore’ bermudagrass, as it grew taller than paspaum grasses. There was also a difference between the ‘Tifway’ and ‘Tifshore’ cultivars in their compaction tolerance, as the ‘Tifshore’ cultivar grew taller than the ‘Tifshore’ cultivar in the sunlight area. Al-Mana (2000) showed that turfgrass cultivars grown in the shade were taller than those grown under sunlight conditions. The increase in plant elongation in the shade can be attributed to the increased production of gibberellic acid in the shade (Moss et al., 2009).

The grass quality of the two bermudagrass cultivars, ‘Tifway’ and ‘Tifshore’, which were grown in the shade, was lower than that of the paspaum turfgasses. Similarly, Baldwin et al. (2008) reported decreased grass quality of both bermudagrass cultivars as a result of the shade effect. Baldwin et al. (2009) attributed the decrease in grass quality of the turfgasses grown under shade conditions to the reduction of plant photosynthesis and carbohydrate production and increased disease susceptibility. They reported this effect in addition to tree root competition with turfgasses for nutrient element absorption from the soil and reduced growth of grass lateral shoots. Under both shade and compaction, significant differences in grass quality were also found between the two bermudagrass cultivars, ‘Tifway’ and ‘Tifshore’. While the grass quality of ‘Tifway’ was higher than ‘Tifshore’ in January and February. The results indicated turfgrass density, total chlorophyll, and fresh and dry weights, were decreased by the compaction treatment, and they were lower for plants grown in the shade than in the sunlight. Trenholm et al. (2000) showed that heavy compaction on soil decreased grass density and caused early death of grass shoots and roots. In addition, Samaranayake et al. (2008) found that turfgasses subjected to compaction resulted in a reduced grass density. Compaction reduced the plant chlorophyll content since it leads to tissue damage and tearing of the leaves (Trenholm et al., 2000). Shade decreased the chlorophyll content in a number of bermudagrass cultivars, including ‘Tifway’ and ‘Tifshore’ (Coffey and Baltensperger, 1989).

In both shade and sunlight areas, the compaction treatment resulted in a decrease in the fresh and dry weights for all turfgass species and cultivars compared to those turfgasses that were not under compaction. El-Kiey et al. (1994) found that the fresh weight of most turfgasses, including ‘Tifway’ bermudagrass, decreased for grasses grown under shade conditions. The observed increase in the dry weight of paspaum grasses grown under shade conditions may be attributed to their distinguished features, such as a high recuperative potential and tiller formation in addition to high salinity and shade tolerance. Jiang et al. (2004) found that the dry weights of paspaum cultivars ‘Sea Isle 2000’ and ‘Sea Isle 1’ were higher than bermudagrass cultivars ‘Tifeagle’ and ‘Tifshore’ grown under either full sunlight or shade conditions. In our study, under the sunlight area, with or without compaction, the grass dry weight was the highest in ‘Tifway’ and the lowest in ‘Tifshore’; Jiang et al. (2003) stated that compaction had a negative effect on grass growth, particularly in the shade. It is advised to avoid heavy traffic and use on turfgasses, especially for those grown under shade to reduce the soil compaction effect, which results in weak grass growth. Trappe et al. (2009) found that when both bermudagrass...
cultivars, 'Tifway' and 'Tifsport,' were exposed to compaction they gave low establishment percentages under both sunlight and shade conditions, with more grass growth in the shade.

The superiority of paspalum grasses, seashore paspalum and 'Sea Isle 2000' over bermudagrasses can be explained by their high tolerance to shade, compaction, and environmental stresses, such as high temperature, drought, poor soil fertility, and high salinity in irrigation water (Duncan and Carrow, 2000; Lee et al., 2004).

5. Conclusions

In general, it can be concluded that compaction had a negative impact on the growth of turfgrasses grown in both shaded and sunlight areas. However, this effect was even more pronounced in the shaded area. It is also noted in general that the shade led to an increase in plant height and a decrease in grass density, fresh weight, and dry weight. It is evident from the study that paspalum turfgrasses, seashore paspalum and 'Sea Isle 2000,' were superior in terms of compaction tolerance over the bermudagrass cultivars 'Tifway' and 'Tifsport.' The paspalum turfgrasses achieved high values for leaf area, quality, color, and density in both the shaded and sunlight areas. However, seashore paspalum performed better than the 'Sea Isle 2000' paspalum in its ability to endure compaction in some of the plant parameters, including grass density and dry weight. In general, the growth of paspalum turfgrasses was better than the growth of both bermudagrass cultivars, 'Tifway' and 'Tifsport,' in the shade, and the density and fresh and dry weights of the paspalum turfgrasses decreased in the shade compared with the sunlight. Moreover, the growth of paspalum and bermuda turfgrasses was much better in sunlight than in shaded conditions. The study indicated that under the sunlight condition, 'Tifway' bermudagrass was more tolerant to compaction than 'Tifsport' bermudagrass due to its superiority in some plant traits, while there were no significant differences in most plant traits between the two bermudagrass cultivars under the shade condition.

It can be concluded that the most shade-tolerant species was the paspalum cultivar 'Sea Isle 2000.' Therefore, it may be recommended for planting under shade conditions in Riyadh, Saudi Arabia. The most tolerant species to compaction and second most shade-tolerant species was seashore paspalum. Therefore, it can be recommended for planting in places exposed to soil compaction and heavy use, such as public gardens, parks, and athletic fields in Saudi Arabia, followed by the paspalum cultivar 'Sea Isle 2000'.

Author contributions

Both authors contributed equally in the experiments.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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