



RESEARCH ARTICLE

# Effect of compaction intensity and abscisic acid on growth, turf quality and root development in turfgrass on clay-based surface

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## Abstract

Soil compaction is a key factor influencing turfgrass performance, especially in cricket pitches where a firm, consistent surface is essential for optimal playability. This study investigated the effect of varying soil compaction level (1.2 g/cc to 1.6 g/cc) on the growth and performance of two Bermuda grass varieties, namely Selection-1 and Tif-419 and evaluated the role of abscisic acid (ABA) in mitigating compaction stress. Among the two, Selection-1 consistently outperformed Tif-419 in terms of turf quality, Normalised difference vegetation index (NDVI) and root growth. Higher compaction (B<sub>3</sub>: 1.6 g/cc) significantly suppressed shoot and root biomass along with root morphological traits, while lower compaction levels (B<sub>1</sub>: 1.2 g/cc and B<sub>2</sub>: 1.3 g/cc) promoted healthier growth. ABA application showed a limited impact on shoot and root development. However, the highest concentration (10 µM) led to a slight decrease in NDVI. Strong positive correlations (> 0.9) were observed between root traits, NDVI and turf quality, underscoring the critical role of root health in turfgrass performance. The findings highlight that excessive compaction adversely affects turf growth and ABA offers minimal benefit under such stress. These findings pave the way for integrated soil management practices to alleviate compaction and enhance the sustainability of turfgrass systems.

**Keywords:** ABA; compaction; cricket pitch; NDVI; turfgrass

## Introduction

Cricket pitches are uniquely designed playing surfaces that require attentive preparation to ensure optimal performance. The pitch, which is the central strip of the cricket field, is critical to the game, as it directly influences ball behaviour, player performance and match outcomes. A well-prepared cricket pitch provides a consistent bounce and pace, creating favourable conditions for both batting and bowling. To achieve this, the pitch is deliberately compacted using smooth-wheeled rollers, resulting in a hard, consolidated surface that reduces energy absorption from the ball upon impact, thus enhancing ball rebound (1). This compacted nature is essential for creating a surface that supports fast bowling with enhanced swing and spin for spinners, making the game competitive and fair. However, while compaction benefits the game, it poses significant challenges for the growth of turfgrass, which is used to stabilise the pitch surface and maintain its integrity.

Soil compaction is the major concern in turfgrass management, particularly in high-traffic areas such as athletic fields,

home lawns, golf courses and cricket pitches (2). Compaction occurs due to numerous factors, such as heavy machinery use during land clearing, construction activities and the redistribution of topsoil during turf establishment (3). In cricket grounds, the primary reason for compaction is the need to create a firm, clay-based playing surface. The highly compacted clay pitch minimises soil disruption during play, ensuring a predictable bounce and consistent ball movement (1). Grass on these pitches serves an essential role in holding the clay together, preventing surface cracking and acting as a natural moisture remover from deeper soil layers. This moisture regulation is crucial in maintaining the pitch's hardness, which affects ball behaviour and subsequently, the game's dynamics (4).

While soil compaction is necessary for pitch performance, it poses significant challenges for turfgrass growth. Compacted soils are characterised by increased soil strength, which creates mechanical impedance, restricting root penetration and elongation (5). As a result, turfgrasses grown on such surfaces exhibit decreased root biomass, reduced root growth and difficulty in absorbing essential water and nutrients (6, 7). Moreover, compacted soils limit

oxygen availability, further hindering root respiration and overall plant vigour (8). These adverse conditions not only weaken the grass cover but also reduce its ability to recover from wear and tear, leading to poor pitch sustainability. Research has shown that plants growing in compacted soils often experience stunted shoot growth, reduced leaf area and diminished physiological functions, as observed in maize plants subjected to similar conditions (9). Given these challenges, finding strategies to improve turfgrass root growth in compacted soils is vital for maintaining high-quality cricket pitches.

In compacted soils, root growth limitations arise from both physical and physiological constraints. Mechanically, high soil strength prevents roots from penetrating deeper into the soil profile. Physiologically, compaction-induced stress conditions limit overall root and shoot growth by restricting water and nutrient uptake. To mitigate these effects and promote healthier root development, ground keepers employ various strategies including aeration, soil amendments and hormone applications. One potential approach to enhance root growth in compacted soils is the application of abscisic acid (ABA). Given ABA's role in enhancing root elongation and stress tolerance, we hypothesised that its application could improve turfgrass root growth in compacted cricket pitch soils. This study was undertaken to evaluate the effects of varying soil compaction levels on the growth of two turfgrass species commonly used on cricket pitches. Specifically, we aimed to assess how different ABA concentrations influence root growth under compacted conditions.

## Materials and Methods

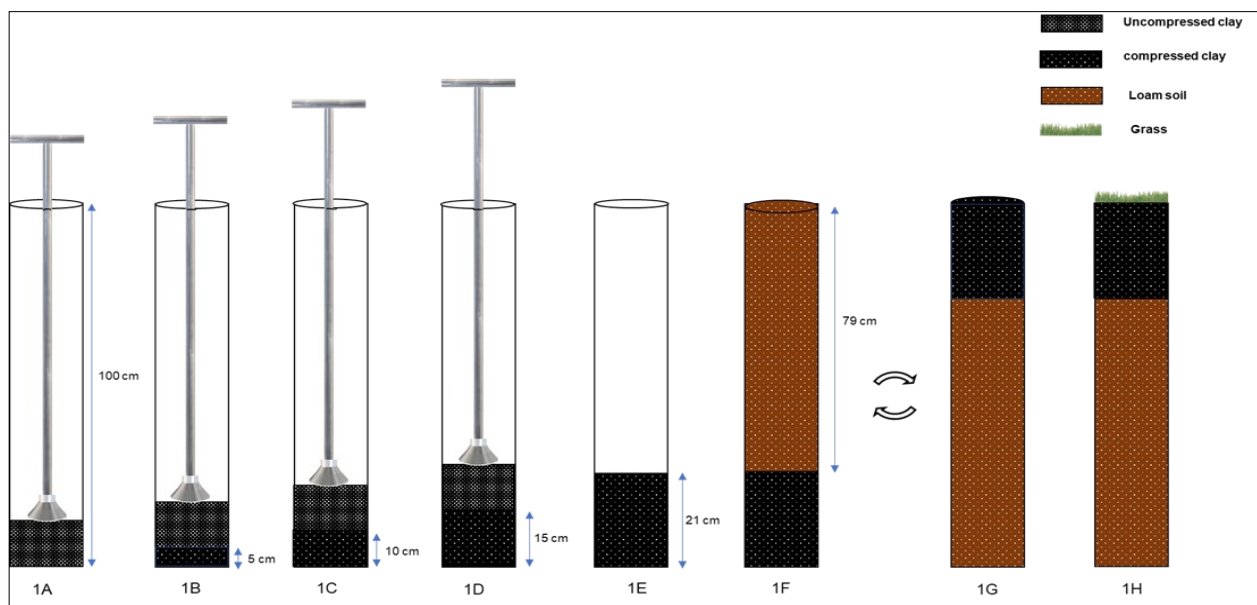
### Growing conditions and planting materials

The present investigation was carried out at the Experimental Farm of the Division of Floriculture and Landscaping, ICAR-Indian Agricultural Research Institute, New Delhi (28°63' N, 77°15' E,

228.6 m altitude). The experiment was laid out in a double split plot design with two Bermuda grass cultivars, Tif-419 (*Cynodon dactylon* × *C. transvaalensis*) and Selection-1 (*C. dactylon*), as main plot treatments; five soil compaction levels (1.2, 1.3, 1.4, 1.5 and 1.6 g/cm<sup>3</sup>) as subplots; and four ABA concentrations (0, 1, 5 and 10 μM) as sub-subplots. PVC pipes (1 m length, 15 cm diameter) were used as containers, with the upper 21 cm filled with compacted clay soil and the remaining 79 cm with loam soil. The clay soil was dried, sieved (2 mm) and compacted to specified densities by dividing the total clay into four parts: three equal layers of 5 cm each and a final 6 cm layer, compacted using a customised hammer (Fig. 1). Clay soil had a bulk density of 1.11 g/cm<sup>3</sup>, with a texture of 19 % silt, 34 % sand and 47 % clay; pH 7.21; EC 2.7 dS/m; organic carbon 0.35 %; and available N, P and K contents of 213.24, 9.86 and 511.84 kg/ha, respectively. After filling the columns, they were inverted so the clay layer was at the top and a polyethylene sheet with drainage holes was fixed at the bottom. Twenty-two-nodal cuttings were planted per column and ABA treatments were applied as foliar sprays at 30 and 60 days after planting.

### Measurements and data collection

Turf quality was visually rated on a 1-9 scale based on colour, density, uniformity and texture as per NTEP guidelines (10). Shoot dry weight was determined by harvesting clippings from a 10 × 10 cm area and drying at 70 °C for 48 hours. NDVI was measured using a Trimble GreenSeeker™, held 2 feet above the canopy. For root analysis, the top 21 cm compacted clay section was extracted, soaked and washed to recover roots, followed by scanning with WinRHIZO to record root length, volume and surface area. Roots from the bottom loam layer were also extracted similarly and dry weights of both layers were recorded separately and summed for total root dry weight.



**Fig. 1.** The process of filling of the PVC columns with clay and loam soil. The process of filling the PVC columns with clay is outlined as follows: **A.** Filling clay layer: A PVC cylindrical column was secured upright on a wooden platform. The first portion of clay was added and the soil was gently compacted using a specially designed hammer to ensure it was packed into a 5 cm layer at the bottom of the column; **B.** The second portion of clay was added on top of the first layer and compacted similarly, reaching a total height of 10 cm; **C.** The third portions of clay were added and compacted in the same manner, contributing an additional 5 cm, bringing the column height to 15 cm; **D.-E.** The fourth portion of clay was then added and compressed into a 6 cm layer, completing the 21 cm clay column at the desired bulk density; **F.** Remaining Column: The remaining 79 cm of the column was filled with pre-weighed loam soil; **G.** Column Inversion and Final Preparations: The column was inverted so that the clay layer was on top; **H.** The bottom of the cylinder was covered with a polyethylene sheet, equipped with holes to ensure proper drainage and Planting: 20 two-nodal grass cuttings were planted on a clay layer in each column.

## Statistical analysis

Data were analysed using ANOVA, with means compared at 5 % significance using SAS 9.1 software. Pearson's correlation coefficients were calculated to assess the relationships between root traits (root length, volume, surface area, dry weight) and turf performance parameters (turf quality, shoot dry weight and NDVI).

## Results

### Turf quality

Significant differences were observed in turf quality between the two Bermuda grass cultivars (Table 1). Selection-1 consistently achieved higher visual quality ratings compared to Tif-419. Soil compaction in the top 21 cm clay layer significantly influenced turf quality, with increased compaction leading to a decline in ratings. The highest compaction level ( $B_5$ : 1.6 g/cm<sup>3</sup>) recorded the lowest visual quality, followed by  $B_4$  (1.5 g/cm<sup>3</sup>), while the control ( $B_1$ : 1.2 g/cm<sup>3</sup>) maintained the best turf appearance. ABA treatments did not significantly affect turf quality.

### Shoot dry weight

Shoot biomass decreased with increasing compaction levels (Table 1). The highest shoot dry weight was recorded in  $B_1$  (9.59 g), while the lowest was observed in  $B_5$  (7.55 g). Among the two cultivars, Selection-1 produced significantly more shoot biomass (10.72 g) than Tif-419. However, interactions among turfgrass cultivars, soil compaction and ABA concentrations were not statistically significant with respect to shoot weight.

## Normalised difference vegetation index (NDVI)

Selection-1 registered significantly higher NDVI values compared to Tif-419 (Table 2). Soil compaction exerted a strong negative effect on NDVI readings. The most compacted treatments,  $B_5$  and  $B_4$ , showed the lowest NDVI values, whereas the control ( $B_1$ ) recorded the highest. ABA treatments did not cause any significant changes in NDVI values.

### Root biomass in the top 21 cm clay layer

Varietal differences were also apparent in root biomass within the compacted clay layer, with Selection-1 outperforming Tif-419 (Table 2). Increasing soil compaction significantly reduced root biomass, with  $B_5$  exhibiting the lowest values, followed by  $B_4$  and  $B_3$ . Treatments  $B_2$  and  $B_1$  were statistically comparable, with  $B_1$  showing the highest root biomass. ABA had no significant effect, but a significant interaction was observed between variety and compaction level, wherein both cultivars showed a marked reduction in root biomass under  $B_5$  and  $B_4$  and a peak under  $B_1$ .

### Root length, surface area and volume

Root morphological parameters were significantly higher in Selection-1 than in Tif-419 (Table 2). The highest compaction level ( $B_5$ ) significantly reduced root length, surface area and volume, followed by  $B_4$ . In contrast,  $B_1$  recorded the highest values, while  $B_2$  and  $B_3$  remained comparable to the control. ABA applications did not have a significant effect on these root parameters. However, significant interaction was found between grass cultivars and compaction levels, where higher compaction drastically reduced root development in both grasses, while the control provided optimal conditions for root growth.

**Table 1.** Effect of varied levels of soil compaction (21 cm top clay layer) and ABA levels on visual quality and total shoot biomass of Tif-419 and Selection-1

	Visual colour ratings	Total shoot biomass (g)
<b>Grasses</b>		
G <sub>1</sub>	6.33	6.50
G <sub>2</sub>	6.98	10.72
SEM	0.018	0.040
CD ( $p = 0.05$ )	0.318	0.726
<b>Bulk density Levels</b>		
B <sub>1</sub> - control	6.97	9.59
B <sub>2</sub>	6.88	9.55
B <sub>3</sub>	6.66	8.79
B <sub>4</sub>	6.38	7.57
B <sub>5</sub>	6.38	7.55
SEM	0.080	0.176
CD ( $p = 0.05$ )	0.260	0.574
<b>ABA Levels</b>		
C <sub>1</sub> - control	6.65	8.66
C <sub>2</sub>	6.63	8.62
C <sub>3</sub>	6.65	8.55
C <sub>4</sub>	6.68	8.62
SEM	0.065	0.102
CD ( $p = 0.05$ )	NS	NS
<b>Interaction</b>		
<b>G × B</b>		
SEM	0.11	0.25
CD ( $p = 0.05$ )	NS	NS
<b>G × C</b>		
SEM	0.09	0.14
CD ( $p = 0.05$ )	NS	NS
<b>B × C</b>		
SEM	0.15	0.23
CD ( $p = 0.05$ )	NS	NS
<b>G × B × C</b>		
SEM	0.21	0.32
CD ( $p = 0.05$ )	NS	NS

**G** (Grasses): G<sub>1</sub> - Tif-419 and G<sub>2</sub> - Selection-1. **B** (Compaction levels (g/cc) (top 21cm clay layer)): B<sub>1</sub> - 1.2, B<sub>2</sub> - 1.3, B<sub>3</sub> - 1.4, B<sub>4</sub> - 1.5 and B<sub>5</sub> - 1.6. **C** (ABA concentration (μM)): C<sub>1</sub> - 0, C<sub>2</sub> - 1, C<sub>3</sub> - 5 and C<sub>4</sub> - 10. \* **NS** - Non-significant.

**Table 2.** Effect of varied levels of soil compaction (21 cm top clay layer) and ABA levels on NDVI and root characters of Tif-419 and Selection-1

	NDVI	Root biomass on a dry weight basis (g) Top layer (clay)	Total root length (cm)	Root surface area (cm <sup>2</sup> )	Root volume (cm <sup>3</sup> )
<b>Grasses</b>					
G <sub>1</sub>	0.60	0.90	2985.35	545.06	6.11
G <sub>2</sub>	0.76	1.56	5443.06	888.06	11.00
<b>SEM</b>	0.001	0.003	18.043	5.140	0.031
<b>CD (p = 0.05)</b>	0.019	0.046	324.224	92.360	0.564
<b>Bulk density Levels</b>					
B <sub>1</sub> - control	0.73	1.35	4665.41	754.34	8.98
B <sub>2</sub>	0.69	1.31	4576.65	738.93	8.81
B <sub>3</sub>	0.68	1.22	4524.38	730.90	8.77
B <sub>4</sub>	0.67	1.15	3716.70	692.98	8.26
B <sub>5</sub>	0.64	1.12	3587.89	665.63	7.97
<b>SEM</b>	0.005	0.011	79.959	10.649	0.076
<b>CD (p = 0.05)</b>	0.018	0.036	260.758	34.729	0.247
<b>ABA Levels</b>					
C <sub>1</sub> - control	0.68	1.23	4148.26	712.77	8.33
C <sub>2</sub>	0.68	1.23	4287.71	721.85	8.72
C <sub>3</sub>	0.68	1.23	4289.71	721.51	8.71
C <sub>4</sub>	0.68	1.23	4131.15	710.09	8.47
<b>SEM</b>	0.005	0.016	51.783	5.621	0.149
<b>CD (p = 0.05)</b>	NS	NS	NS	NS	NS
<b>Interaction</b>					
<b>G × B</b>					
G <sub>1</sub> × B <sub>1</sub>	0.68	1.05	3282.46	596.84	6.52
G <sub>1</sub> × B <sub>2</sub>	0.60	0.99	3143.32	568.96	6.35
G <sub>1</sub> × B <sub>3</sub>	0.59	0.84	3081.07	557.62	6.41
G <sub>1</sub> × B <sub>4</sub>	0.57	0.81	2734.28	516.04	5.62
G <sub>1</sub> × B <sub>5</sub>	0.56	0.80	2685.64	485.80	5.65
G <sub>2</sub> × B <sub>1</sub>	0.78	1.66	6048.36	911.84	11.43
G <sub>2</sub> × B <sub>2</sub>	0.78	1.62	6009.98	908.88	11.27
G <sub>2</sub> × B <sub>3</sub>	0.77	1.59	5967.68	904.18	11.12
G <sub>2</sub> × B <sub>4</sub>	0.76	1.48	4699.13	869.91	10.91
G <sub>2</sub> × B <sub>5</sub>	0.73	1.44	4490.14	845.45	10.30
<b>SEM</b>	0.01	0.02	113.08	15.06	0.11
<b>CD (p = 0.05)</b>	0.02	0.05	368.77	NS	NS
<b>G × C</b>					
<b>SEM</b>	0.01	0.02	73.23	7.95	0.21
<b>CD (p = 0.05)</b>	NS	NS	NS	NS	NS
<b>B × C</b>					
<b>SEM</b>	0.01	0.04	115.79	12.57	0.33
<b>CD (p = 0.05)</b>	NS	NS	NS	NS	NS
<b>G × B × C</b>					
<b>SEM</b>	0.01	0.05	163.75	17.77	0.47
<b>CD (p = 0.05)</b>	NS	NS	NS	NS	NS

**G** (Grasses): G<sub>1</sub> - Tif-419 and G<sub>2</sub> - Selection-1. **B** (Compaction levels (g/cc) (top 21cm clay layer)): B<sub>1</sub> - 1.2, B<sub>2</sub> - 1.3, B<sub>3</sub> - 1.4, B<sub>4</sub> - 1.5 and B<sub>5</sub> - 1.6. **C** (ABA concentration (μM)): C<sub>1</sub> - 0, C<sub>2</sub> - 1, C<sub>3</sub> - 5 and C<sub>4</sub> - 10. \* **NS** - Non-significant.

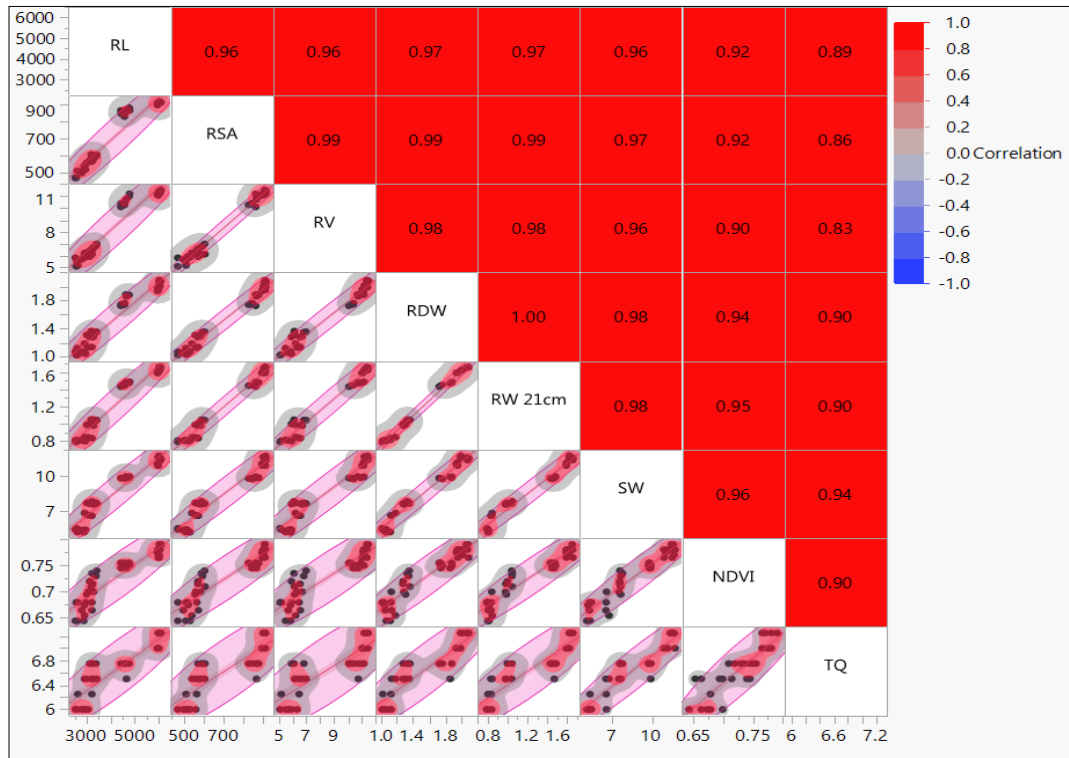
### Correlation analysis

Multivariate correlation analysis revealed strong positive associations between root traits and turf quality parameters across treatments. Total root dry weight, root biomass in the clay layer, root length, surface area and volume exhibited strong correlations with turf quality scores. NDVI showed a particularly strong positive correlation (> 0.9) with all root parameters, indicating its effectiveness as a non-destructive proxy for root health. Similarly, shoot weight was also strongly correlated (> 0.9) with root parameters, further emphasising the influence of below-ground traits on above-ground turf performance (Fig. 2).

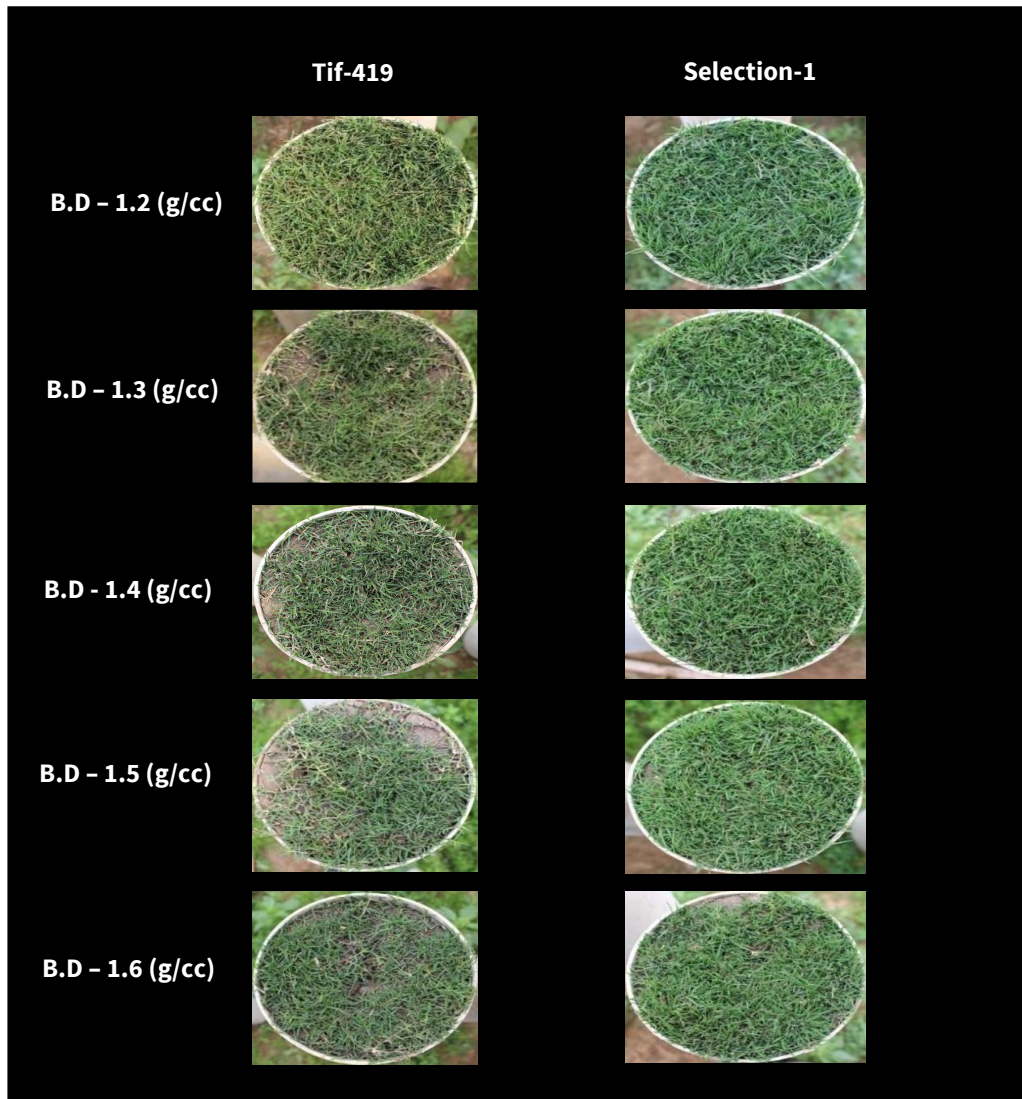
### Discussion

Higher soil compaction levels resulted in reduced shoot production (Fig. 3) due to the physical restriction of root penetration, ultimately lowering overall shoot biomass (11, 12). Despite this, both turfgrass varieties maintained acceptable turf quality ratings (≥ 6) throughout the study, with Selection-1 consistently performing better than Tif-419. Interestingly, the application of abscisic acid (ABA) did not negatively affect turf

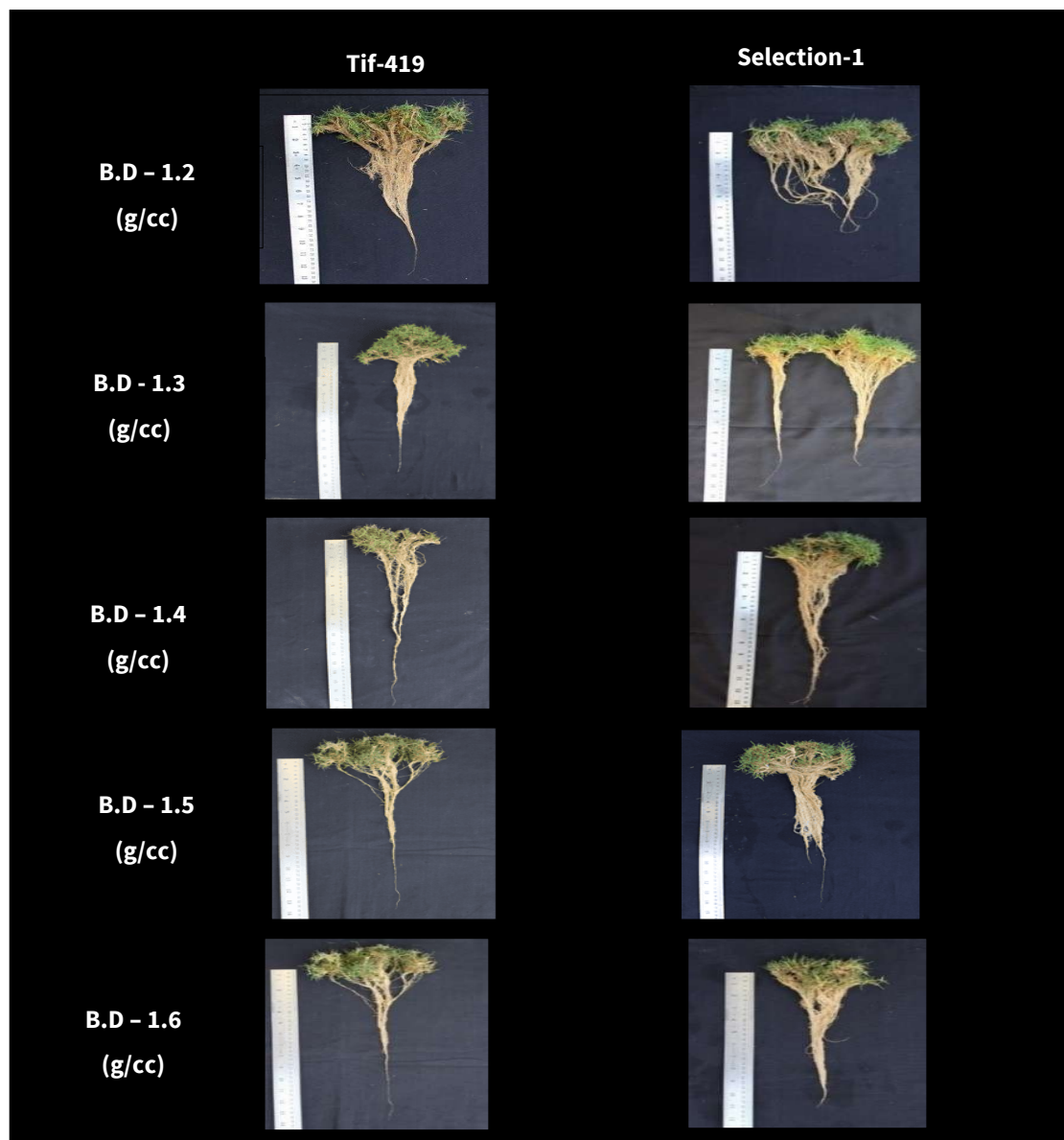
quality. Similar observations have been made in other plant species, where soil compaction significantly reduced shoot and root biomass in turfgrasses (11). Research indicates that a decline was noticed in root length density, slower root elongation and reductions in straw yields in wheat occur when compared to a non-compacted layer (1.33 g cm<sup>-3</sup>) compared to compacted subsurface bulk density (1.52 g cm<sup>-3</sup>). NDVI, a key indicator of plant health and biomass productivity, declined with increasing soil bulk density, indicating a direct relationship between compaction and reduced plant vigour (14). The decrease in shoot biomass under higher compaction levels (B<sub>5</sub>, B<sub>4</sub>, B<sub>3</sub>) may be attributed to increased ethylene production under stress, which is known to suppress shoot elongation (15). Regarding root characteristics, Selection-1 exhibited significantly higher root biomass than Tif-419, likely due to genotypic differences in root penetration ability (Fig. 4) (16). Compaction had a significant negative effect on root biomass in both varieties, with higher compaction levels reducing root development in Bermuda grass (17, 18). Root length also varied significantly between varieties, with Selection-1 displaying greater elongation. Root length declined under severe compaction (B<sub>5</sub> and B<sub>4</sub>), while B<sub>3</sub> and B<sub>2</sub> were comparable to the



**Fig. 2.** Multivariate analysis showing correlation between root Parameters vis-à-vis turf quality under different treatment combinations of grasses, ABA and bulk density. The upper triangle shows heat maps having a significant correlation coefficient ( $p = 0.05$ ), while the lower triangle displays the scatter plot matrix with line fit.



**Fig. 3.** Effect of varied levels of soil compaction (21 cm top clay layer) on shoot growth of Tif-419 and Selection-1.



**Fig. 4.** Effect of varied levels of soil compaction (21 cm top clay layer) on root characters of Tif-419 and Selection-1.

control ( $B_1$ ). Mechanical resistance in compacted soils limited root elongation and development (19). Root surface area and volume followed similar trends and the overall reduction in root traits at higher compaction levels was likely due to mechanical impedance and increased ethylene production (15, 20). While ABA is known to promote root elongation under water stress, its application did not significantly affect root biomass, surface area or volume in this study, suggesting its limited efficacy in overcoming physical constraints posed by soil compaction (21). A strong correlation was observed between root traits and turf quality across varieties, compaction levels and ABA concentrations. Root parameters such as total dry weight, root biomass in the top 21 cm clay layer, root length, surface area and volume were significantly correlated with turf quality. NDVI, a widely accepted indicator of vegetation health, showed a high correlation ( $> 0.9$ ) with all root traits, supporting its utility in evaluating plant performance (14). Moreover, shoot weight exhibited a similarly strong correlation ( $> 0.9$ ) with root parameters, indicating that root health plays a critical role in above-ground biomass production. These results align with previous findings suggesting that vigorous root systems enhance plant resilience and turfgrass performance (22).

### Conclusion

This study confirms that soil compaction negatively affects turfgrass growth by reducing shoot biomass, NDVI, root biomass and root morphological traits. Selection-1 performed better than Tif-419 in terms of turf quality and root growth. While the ABA application did not significantly influence root development in compacted soils, further research is needed to explore its potential interactions with mechanical and hormonal root growth mechanisms. Future studies could also examine alternative strategies, such as soil amendments and aeration, to mitigate the negative effects of compaction on turfgrass growth.

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## Authors' contributions

LM conceptualized the study, carried out the investigation, performed formal analysis, curated the data and prepared the original draft of the manuscript. PKV contributed to conceptualization and provided essential resources for the study. RVSD supervised the research and assisted in manuscript editing. N provided resources and guidance throughout the study. MKM contributed to supervision and critical reviewing of the manuscript. NPHP participated in manuscript editing and refinement. HMN carried out data analysis and assisted in editing. MP contributed to editing and final drafting of the manuscript. All authors read and approved the final version of the manuscript.

## Compliance with ethical standards

**Conflict of interest:** Authors do not have any conflict of interest to declare.

**Ethical issues:** None

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