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EVALUATING TURFGRASS SHADE TOLERANCE FOR SUSTAINABLE URBAN LANDSCAPES

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ABSTRACT

The present study evaluated the comparative morphological responses and shade adaptability of four turfgrass species, namely *Cynodon dactylon* 'Local', *Cynodon dactylon* 'Selection 1', *Zoysia tenuifolia* (Korean velvet grass), and *Stenotaphrum secundatum* (St. Augustine grass), under three shade regimes (0%, 35%, and 50%) across rainy and spring seasons using a split-plot design. Growth performance was significantly superior under full sunlight (0% shade), characterized by earlier establishment (48.3 days), reduced leaf length (6.38 cm), shorter internodal length (43.35 mm), and increased internodal diameter (1.26 mm), along with higher shoot density (216.8 shoots per 100 cm²) and maximum fresh shoot biomass (11.6 g per 100 cm^2). Root development was also optimized under non-shaded conditions, with the highest root density (179.8 per 100 cm²) and root diameter (0.66 mm). Increasing shade intensity from 35% to 50% resulted in a marked decline in turf density, as indicated by the minimum number of shoots under 50% shade. Species-specific responses revealed that *Cynodon dactylon* 'Selection 1' and 'Local' (doob grass) exhibited superior performance under full sunlight but showed limited adaptability under shaded conditions. In contrast, *Stenotaphrum secundatum* maintained consistent turf quality across all shade levels (0%, 35%, and 50%), as reflected by relatively uniform shoot density, indicating higher shade tolerance. *Zoysia tenuifolia* demonstrated better growth performance under 0% and 35% shade but declined under higher shade intensity. Overall, *Stenotaphrum secundatum* emerged as the most suitable species for shaded environments, whereas *Cynodon dactylon* genotypes were better adapted to open, high-light conditions.

Keywords **:** Growth, landscape, light, shade, warm season, turfgrasses

Introduction

Light availability is a critical environmental factor governing the growth, development and persistence of turfgrasses (Gardner *et al.,* 2013). In urban landscapes, structural elements such as buildings, walls, and tree canopies significantly reduce both light intensity and quality, particularly the red to far-red (R:FR) ratio, creating shaded conditions that adversely affect turf performance and aesthetic value (Gao *et al.,* 2023). It has been reported that nearly 20–25% of managed turf areas experience some degree of shade, posing challenges for maintaining turf quality as many species are poorly adapted to low-light environments (Almodares & Beard, 1978; Winstead & Ward, 1974).

Shade stress induces several morphological and physiological changes, including increased leaf elongation, reduced shoot density, limited tillering and alterations in root-to-shoot balance due to reduced photosynthetic efficiency (Wherley *et al.,* 2005). Under prolonged shading, light availability may approach or fall below the light compensation point, where photosynthetic carbon gains equal respiratory loss, leading to depletion of carbohydrate reserves and decline in turf vigour (Danneberger, 1994). In response, some turfgrass species exhibit adaptive mechanisms such as increased chlorophyll content, improved light-harvesting efficiency and reduced respiration rates to sustain growth under low light conditions. However, turfgrasses exhibit varying degrees of morphological plasticity and adaptive

responses, which differ significantly among species (Olsrud & Michelsen, 2009; Huang *et al.,* 2011).

Warm-season turfgrasses, widely used in tropical and subtropical regions, are inherently adapted to high light and temperature conditions but often show reduced performance under shaded environments (Turgeon, 2012). Although several studies have reported declines in turf quality under moderate to heavy shade (Jiang *et al.,* 2004; Tegg & Lane, 2004), limited information is available on the comparative shade response of species such as *Cynodon dactylon* 'Local', *Cynodon dactylon* 'Selection 1', *Stenotaphrum secundatum* and *Zoysia tenuifolia*.

Therefore, the present study was undertaken to systematically evaluate the morphological responses and adaptive potential of selected warm-season turfgrass species under varying shade intensities, with the objective of identifying suitable species for sustained growth and turf quality in shaded environments.

Materials and Methods

The present investigation was carried out during 2022–2023 at the experimental area of the Department of Floriculture and Landscaping, Punjab Agricultural University, Ludhiana, India (30°54′ N latitude and 75°48′ E longitude). The experiment was conducted under a split-plot design with three shade levels as main plots and turfgrass species as subplots, replicated appropriately. Four warm-season turfgrass species, namely *Cynodon dactylon* 'Local', *Cynodon dactylon* 'Selection 1', *Zoysia tenuifolia* (Korean velvet grass), and *Stenotaphrum secundatum* (St. Augustine grass), were used as experimental material.

Turfgrasses were established during July 2022 using sprigs/dibbles obtained from a local grower. Planting was carried out in 1 m² plots at a spacing of 10 cm × 10 cm during the second fortnight of July. Three shade treatments were imposed, viz., 0% shade (open field), 35% shade, and 50% shade. The required shade levels were maintained using shade nets of appropriate mesh size (4–6 mm for 35% shade and 3–4 mm for 50% shade), while the control plots were maintained under natural open conditions. Standard agronomic and cultural practices were followed uniformly throughout the experimental period. Soil properties and meteorological parameters, including temperature and relative humidity, were recorded .

Assessment of various establishment and growth parameters

This study involved the measurement of various turfgrass establishment and growth parameter. In each replication, five random locations from each treatment were selected to record biometric observations before each mowing and averages were calculated of each growth attribute. Days to establishment were recorded in each plot, starting from the day of planting until when the grasses uniformly covered the 90% area of the entire plot. Leaf length was measured with a scale before each mowing as the distance between the apex and the base of the leaf. The leaf width, internodal diameter, internodal length and root diameter were measured using a digital vernier calliper (Baker Ed 10, with an accuracy of ±0.01 mm). The number of mowings were estimated at the end of each season ensuring that the grasses were not allowed to exceed 7 cm height from the ground level. Shoot count and root count was determined by counting the number of shoots and roots in a 100 cm^2 area using a 10x10 cm metal quadrat. The quadrat was placed on the turf plots, to extract shoots and roots within its confines by cutting to ground level. Above ground biomass was cut and segregated in to separate shoots and below ground biomass was extracted with weeding hoe and segregated separately ensuring minimal disturbance to the roots, thereafter were manually counted and mean values were computed. Further, the fresh weight of turfgrass shoots and roots were weighed, averaged and expressed in grams using an electronic weighing balance (Wensar Precision Balance (200g / 0.001g)).

Statistical analysis

The experiment was conducted in a split-plot design comprising 12 treatment combinations (three shade levels × four turfgrass species) with three replications. Data recorded during the rainy (2022) and spring (2023) seasons were pooled after testing for homogeneity of variance.

Statistical analysis was performed using OPSTAT software (http://opstat.pythonanywhere.com/). The data were subjected to analysis of variance (ANOVA) appropriate for a split-plot design to evaluate the effects of shade levels, turfgrass species and their interactions. Treatment means were compared using the critical difference (CD) at the 5% level of significance ($P \leq 0.05$), and non-significant differences were denoted as "NS".

Results and Discussion

As presented in Table 3, turfgrass establishment was significantly influenced by shade intensity. The earliest establishment was recorded under 0% shade (48.3 days), whereas delayed establishment was observed under 50% shade (59.1 days). Interaction effects (Fig. 2a) indicated that *Cynodon dactylon* 'Selection 1' established fastest (36.3 days) under full

sunlight, while *Zoysia tenuifolia* exhibited the slowest establishment (73.3 days) under 50% shade. These results corroborate earlier findings that reduced light availability limits photosynthetic activity, thereby restricting stolon development and lateral spread in turfgrasses (Jiang *et al.,* 2004; Schnyder & Nelson, 1989). Interestingly, *Zoysia tenuifolia* and *Stenotaphrum secundatum* showed relatively improved establishment under moderate shade (35%) compared to full sunlight, which is consistent with observations in 'Meyer' zoysia grass where moderate shading enhanced turf cover (McBee & Holt, 1966).

Internodal traits were significantly influenced by shade intensity (Table 3). Internodal length increased progressively with shade, attaining a maximum under 50% shade (71.32 mm) and a minimum under full sunlight (43.35 mm). Interaction effects (Fig. 2b) indicated that *Stenotaphrum secundatum* exhibited the greatest internodal elongation (99.05 mm) under 50% shade, whereas *Zoysia tenuifolia* recorded the shortest internodes (13.16 mm) under 0% shade. The observed elongation under reduced light conditions can be attributed to shade-induced morphogenic responses, particularly the elevated far-red to red light ratio, which promotes stem elongation to enhance light capture efficiency (Casal, 2013). These findings are consistent with earlier reports documenting increased internodal elongation in turfgrasses under low-light environments (Kephart *et al.,* 1992; Winstead & Ward, 1974).

In contrast, internodal diameter decreased with increasing shade levels, with the highest value recorded under 0% shade (1.26 mm), followed by 35% shade (1.09 mm), and the lowest under 50% shade (0.86 mm) (Table 3). Interaction analysis (Fig. 2b) revealed that *Stenotaphrum secundatum* attained the maximum internodal diameter (1.73 mm) under full sunlight, while *Cynodon dactylon* 'Selection 1' recorded the minimum (0.57 mm) under 50% shade. The reduction in internodal thickness under shaded conditions may be associated with decreased photosynthetic assimilation and limited carbohydrate availability, resulting in reduced structural development (Winstead & Ward, 1974). Comparable trends have been reported in various turfgrass species under reduced light intensity, highlighting species-specific variability in response to shading (Van Huylenbroeck & Van Bockstaele, 2001; McBee & Holt, 1996; Gardner & Goss, 2013).

Leaf morphology was significantly influenced by shade intensity, with leaf length increasing and leaf width decreasing under shaded conditions (Table 3). Maximum leaf length (10.34 cm) was recorded under 50% shade, whereas the minimum (6.38 cm) occurred under full sunlight (0% shade). Interaction effects (Fig. 2c) showed that *Cynodon dactylon* 'Local' attained the greatest leaf length (12.55 cm) under 50% shade, while *Zoysia tenuifolia* exhibited the shortest leaves (3.62 cm) under 0% shade. The increase in leaf length under shade reflects a typical shade-avoidance response, wherein plants enhance leaf elongation to improve light interception under low irradiance (Tegg & Lane, 2004). This response is associated with altered biomass allocation and reduced root investment under shaded environments (Semchenko *et al.,* 2012) and is consistent with earlier reports across turfgrass species (Allard *et al.,* 1991; Woledge, 1971; Dudeck & Peacock, 1992; Kephart *et al.,* 1992; Wherley *et al.,* 2013; Peterson *et al.,* 2014; Jiang *et al.,* 2004).

Conversely, leaf width decreased with increasing shade levels, with the highest value observed under 0% shade (3.82 mm), followed by 35% shade (3.56 mm), and the lowest under 50% shade (3.34 mm) (Table 3). Interaction analysis (Fig. 2c) indicated that *Stenotaphrum secundatum* exhibited the widest leaves (6.94 mm) under full sunlight, whereas *Zoysia tenuifolia* recorded the narrowest leaves (1.31 mm) under 50% shade. The reduction in leaf width under shaded conditions is a common adaptive response associated with leaf elongation and structural adjustment to optimize light capture (Smith & Whitelam, 1997). Similar reductions in leaf width under shade have been reported across turfgrass species, including Bermuda grass and St. Augustine grass, highlighting a consistent morphological response to reduced light availability (Schnyder & Nelson, 1989; Winstead & Ward, 1974; Cai *et al.,* 2011; Trenholm & Nagata, 2005).

Shade significantly influenced shoots and roots densities, with both declining as shade increased. The highest shoot count (216.8/100 cm^2) was recorded under full sun, while the lowest (103.1/100 cm^2) occurred under 50% shade (Table 3). Korean velvet showed exceptional shoot density (566.7/100 cm^2) under full sun, highlighting its prolific growth, while local doob had the lowest density (23.7/100 cm^2) under 50% shade. St. Augustine maintained a relatively stable shoot density across shade levels, with 71.33/100 cm^2 under full sun and 45.67/100 cm^2 under 50% shade. Similarly, Korean velvet showed minimal variation between full sun (566.7/100 cm^2) and 35% shade (510.3/100 cm^2), demonstrating its adaptability in Fig. 2(d). This can be attributed as reduction in shoot density is a key morphological adaptation in plants undergoing shade avoidance. Huylenbroeck & Bockstaele (2001) reported similar findings in *Lolium*

perenne and *Poa pratensis*, while Wu *et al.,* (1985) observed this in *Cynodon dactylon* and *Zoysia japonica*. McBee & Holt (1966) noted that low light induced a more open, upright growth pattern in Bermuda grasses. Consistent with earlier studies by Beard (1965), Schmidt & Blaser (1967), and Wilkinson & Beard (1974), increasing shade levels consistently reduced shoot density across various turfgrasses.

The mean maximum root count (179.8 /100cm^2) was observed in turf exposed under 0% shade and minimum mean root count (84.7 /100cm^2) was recorded in turf raised under 50% shade (Table 3). Interaction effect showed that Korean velvet exhibited the highest root count (351.5/100cm^2) under 0% shade. Conversely, the lowest root count (86.7/100cm^2) was observed in local doob under the same conditions. This trend remained consistent when the shade levels were increased to 35% and 50%, with Korean Velvet maintaining the maximum root count and local doob showing the minimum (in Fig. 2 (d)). This can be attributed by lower light intensity, which limits the photosynthetic rate necessary to support optimal root growth (Christians, 2004). Newell *et al.,* (1999) reported a 30% reduction in root density under high shade, while Eriksen and Whitney (1981) noted faster declines in root and rhizome growth compared to shoots. Shade avoidance responses, including a 20–50% reduction in tillering, further diminish root density (Wherley *et al.,* 2005). Consistent with our findings, Burton *et al.,* (1959) and Schmidt & Baser (1969) observed a 40% decline in root and rhizome production in Bermuda grass with increasing shade.

Furthermore, considering shoot biomass production the highest shoot fresh weight (11.64 g/100 cm²) was observed under 0% shade, while the lowest (6.43g/100 cm²) occurred under 50% shade, comparable to 35% shade (7.23g/100 cm²). This underscores the sensitivity of shoot biomass to shading, with significant reductions at higher shade levels. Korean velvet exhibited the highest fresh weight (16.23g/100 cm²) under full sun, demonstrating its superior biomass production under optimal light, while local doob showed the lowest (2.15g/100 cm²) under 50% shade (In Fig.2(a)). The reduction in shoot fresh weight correlates with decreased shoot densities as shading decline the photosynthesis, leads to decreased biomass allocation to both shoots and roots, ultimately resulting in reduced shoot fresh weight. These results align with findings by Wilkinson & Beard (1974) and Wu *et al.,* (1985) in turfgrasses.

In terms of root parameters, the highest fresh weight of roots (0.98g /100cm^2) was found in turfgrass exposed to full sunlight (0% shade), while the lowest fresh weight of roots (0.62g /100cm^2) was recorded under 50% shade. Additionally, the highest root diameter (0.66 mm) was recorded in turf exposed under 0% shade followed by 35% shade (0.35 mm) and lowest (0.31mm) root diameter was measured in grass raised under 50% shade. Local doob displayed the maximum root diameter (0.94 mm) under 0% shade, while Korean Velvet exhibited the lowest root diameter (0.24 mm) under 50% shade (in Fig. 2 (a)). Shade significantly impacts root density, growth, and morphology in grasses by reducing light availability, which limits photosynthesis and decreases root density, as reported by Christians (2004) and Newell *et al.,* (1999), who observed a 30% reduction under heavy shade. Eriksen and Whitney (1981) noted that root and rhizome growth declines faster than shoot growth in shaded conditions, while shade avoidance responses, such as a 20–50% reduction in tillering, further contribute to reduced root production (Wherley *et al.,* 2005). Similarly, Burton *et al.,* (1959) and Schmidt & Baser (1969) observed a 40% reduction in Bermuda grass root and rhizome production with increasing shade. Morphological changes, such as auxin-induced root bending away from the shaded side and resource allocation toward stem elongation, further reduce root length and diameter under extreme shade (Givnish, 1998).

The highest number of mowings (5.3) was done in established turf exposed under 0% shade, suggesting that more frequent mowing is needed when the sunlight is not a limiting factor for the shoot biomass to carry out photosynthesis. On the other hand, the least number of mowings (4.24) were recorded in turf that was exposed to 50% shade. Statistical analysis indicated non-significance in the interaction between shade levels and grass genotypes concerning the number of mowing and fresh weight of roots. Grasses exposed to 50% shade prolonged the interval and mowing frequency throughout the study. Zoysia grass, especially, required an extended period under 35% and 50% shade, while Selection 1 reached mowing height earliest under 0% shade. Lower light conditions generally led to higher shoot growth rates due to increased internode elongation. However, it leads to slower initial growth and reduced shoot density. Prolonged exposure to reduced light caused delayed growth and, in some cases, excessive height, leading that may increase the energy consumption of the mower or may cause it to malfunction due to winding of grass over mower blades (author's personal observation). These findings align with studies of Mohanthy, (1991). Shaded environments indicate insufficient light for effective photosynthesis, reducing carbohydrate production and creating stressful

conditions for turfgrass, ultimately prolonging the time interval for mowing.

Conclusion

Optimal growth and establishment of turfgrasses were observed under full sunlight conditions (0% shade), where *Cynodon dactylon* 'Selection 1' exhibited the earliest establishment, along with superior growth metrics and turf quality. Under moderate shade (35%), *Zoysia tenuifolia* (Korean velvet) and *Stenotaphrum secundatum* (St. Augustine grass) demonstrated enhanced adaptability, characterized by higher shoot density, improved canopy coverage and favorable turfgrass attributes. Conversely, *Cynodon dactylon* 'Local' and 'Selection 1' showed reduced shade tolerance, with a marked decline in growth performance under these conditions. At higher shade intensity (50%), *Stenotaphrum secundatum* emerged as the most shade-tolerant species, maintaining relatively stable shoot density, uniform canopy structure, and overall superior performance. *Zoysia tenuifolia* exhibited moderate tolerance, sustaining acceptable growth and turf quality, although with some reduction compared to lower shade levels.

Table 1 : Description of the different warm season grasses used in the study

Common names of genotypes	Scientific name	Native	Growth habits	Establishment method
Bermuda grass	*Cynodon dactylon* 'Local'	Ludhiana(India)	Stoloniferous, Rhizomatous	Seed, Stolon, Sod, Sprig, Plug
Bermuda grass	*Cynodon dactylon* 'Selection 1'	East Africa	Stoloniferous, Rhizomatous	Seed, Stolon, Sod, Sprig, Plug
St. Augustine grass	*Stenotaphrum secundatum*	Coastal regions of Mexico and the Mediterranean	Stoloniferous	Sod, Sprig, Plug
Korean velvet or Mascarene grass	*Zoysia tenuifolia*	Mascarene Islands	Rhizomatous, Stoloniferous	Seed, Stolon, Sod, Sprig, Plug

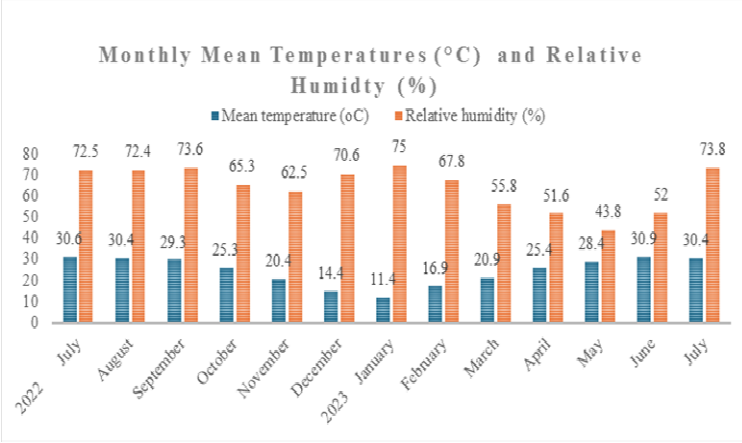

Fig. 1: Monthly mean temperatures (°C) and relative humidity for the experimental site (Floriculture and Landscaping Department, PAU, Ludhiana, India) during 2022-2023.The data was provided by the Department of Climate Change and Agro-meteorology Ludhiana, PAU and was recorded at the Ludhiana district of Punjab, India weather office.

Table 2: Soil properties of the experimental site (0-15cm depth) during 2022-2023

Parameter	Value	Permissible range	Remarks
pH	7.2	6.0 - 7.5	Normal
Electrical conductivity (dS m^{-1})	0.16 dSm^{-1}	0.8 - 2.0 dS m^{-1}	
Organic carbon (%)	0.15%	< 0.40 = Low; 0.40-0.75 =Medium; > 0.75 =High	Low
Available N (Kg ha^{-1})[1]	109.3 (Kg ha^{-1})	<271=Low; 271-543=Medium; >543=High	Low
Available P (Kg ha^{-1})	18.4(Kg ha^{-1})	5=Low; 5-9=Medium 9-20=High; >20=Very High	High
Available K(Kg ha^{-1})	89.2 (Kg ha^{-1})	<55 = Low; 55 – 135= Medium; >135= High	Medium

Table 3 : Effect of different shade levels on the mean shoot and root characteristics and mowing attributes of warm season turfgrass species.

		Shoot characteristics					Root characteristics				Mowing trait
Shade levels	**Days to establishment**	**Internodal length (mm)**	**Internodal diameter (mm)**	**Leaf length (cm)**	**Leaf width (mm)**	**Shoot count (no.per 100 cm^2)**	**Fresh weight of shoots (g/100 cm^2)**	**Root count (no.per 100 cm^2)**	**Fresh weight of roots (g per 100 cm^2)**	**Root diameter (mm)**	**Number of mowings**
S1 (0% shade)	48.3[a]	43.35[c]	1.26[a]	6.38[c]	3.82[a]	216.83[a]	11.64[a]	179.81[a]	0.98[a]	0.66[a]	5.3[a]
S2 (35% shade)	50.6[b]	57.76[b]	1.09[b]	8.75[b]	3.56[b]	167.67[b]	7.23[b]	139.54[b]	0.72[b]	0.35[b]	4.7[b]
S3 (50% shade)	59.1[c]	71.32[a]	0.86[c]	10.34[a]	3.34[c]	103.08[c]	6.43[b]	84.67[c]	0.62[b]	0.31[b]	4.2[c]
CD (p<0.05) level of significance	0.91	2.21	0.05	0.37	0.06	30.08	1.22	16.69	0.19	0.06	0.3

Values represent the mean of three replications. CD = Critical Difference at $p < 0.05$ as per ANOVA. Data were analysed using two-way ANOVA in OPSTAT software. Shade treatments: S1 = open field (0% shade), S2 = 35% shade using green shade net, S3 = 50% shade using green shade net. Means followed by the same letter in a column do not differ significantly according to CD at $p < 0.05$. All values are expressed in the units indicated in column headings.

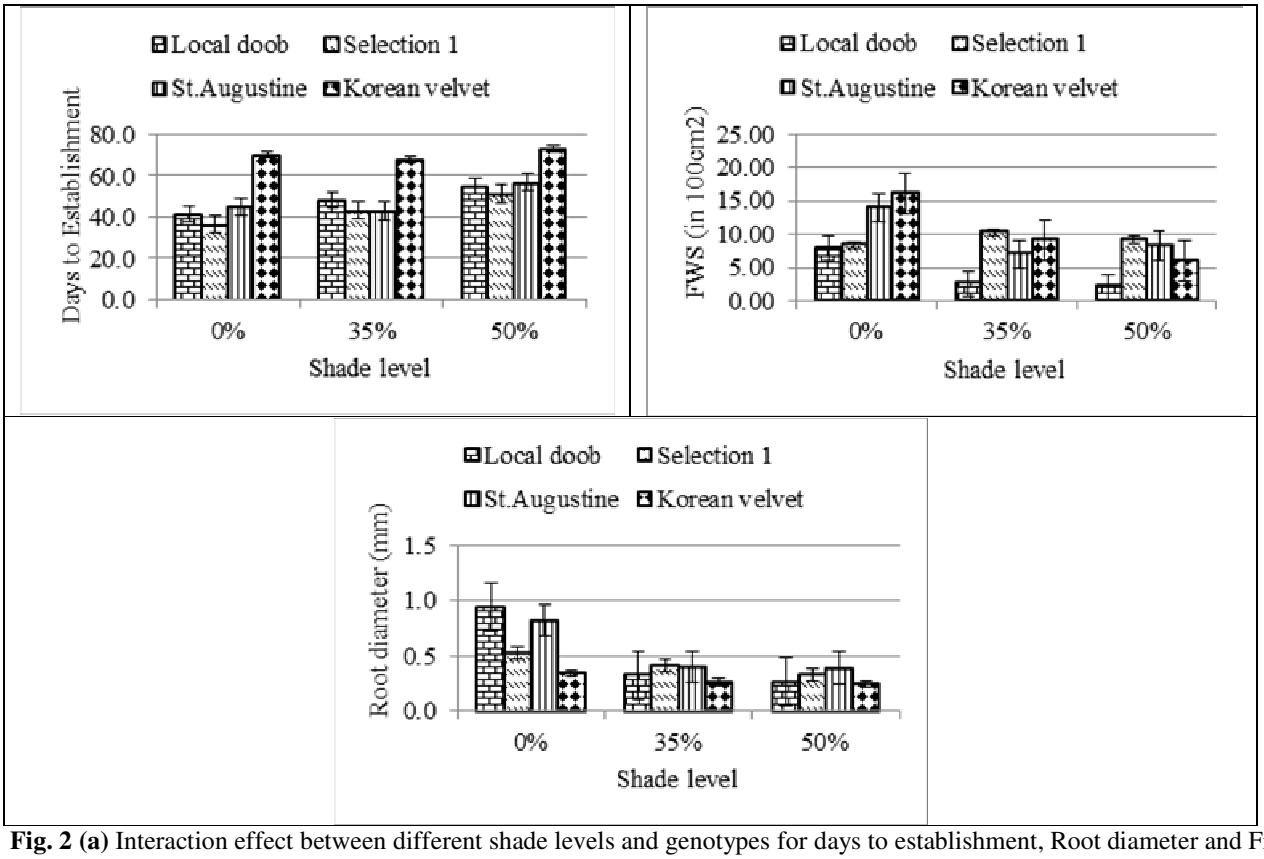

Fig. 2 (a) Interaction effect between different shade levels and genotypes for days to establishment, Root diameter and Fresh weight of shoots. Bars represent mean ± SE (n = 3).

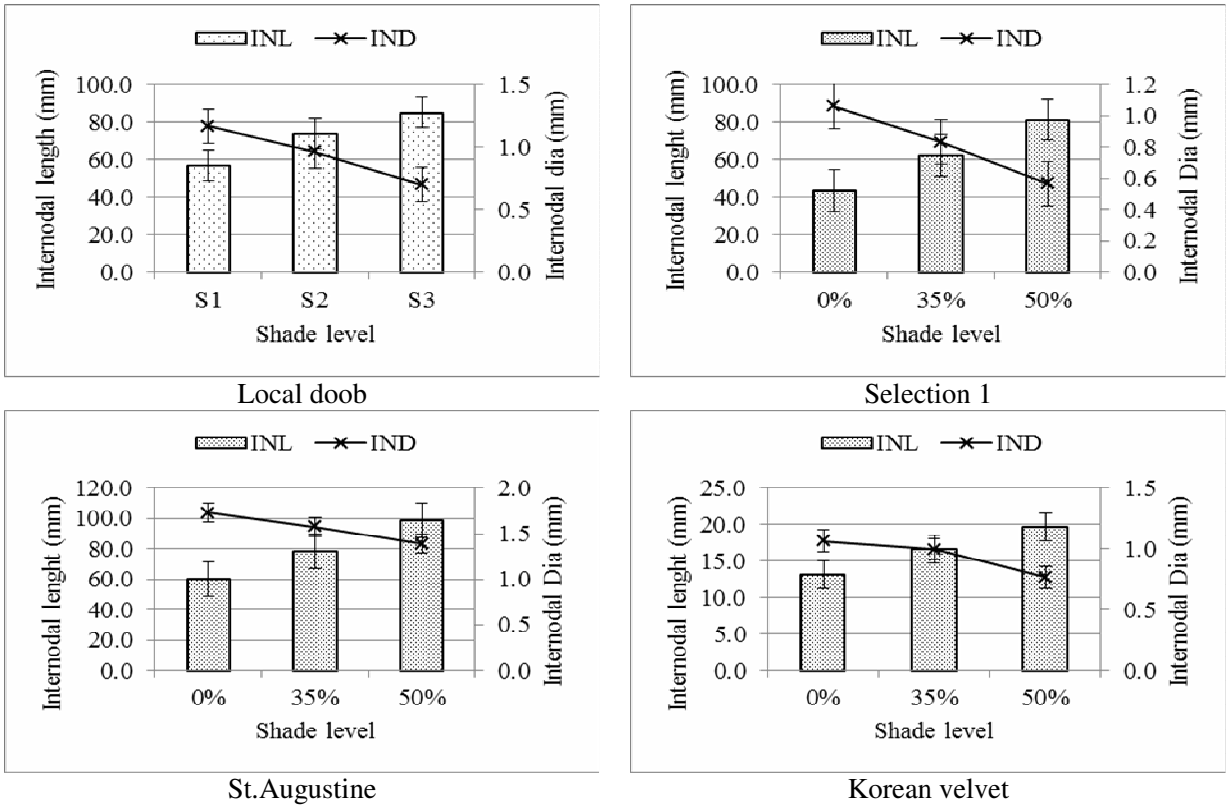

Fig. 2 (b) Interaction effect between different shade levels and genotypes for Internodal length and Internodal diameter. (a) Local doob, (b) Selection 1, (c) St. Augustine and(d) Korean velvet. Bars represent mean ± SE (n = 3). INL = Internodal Length; IND = Internodal Diameter.

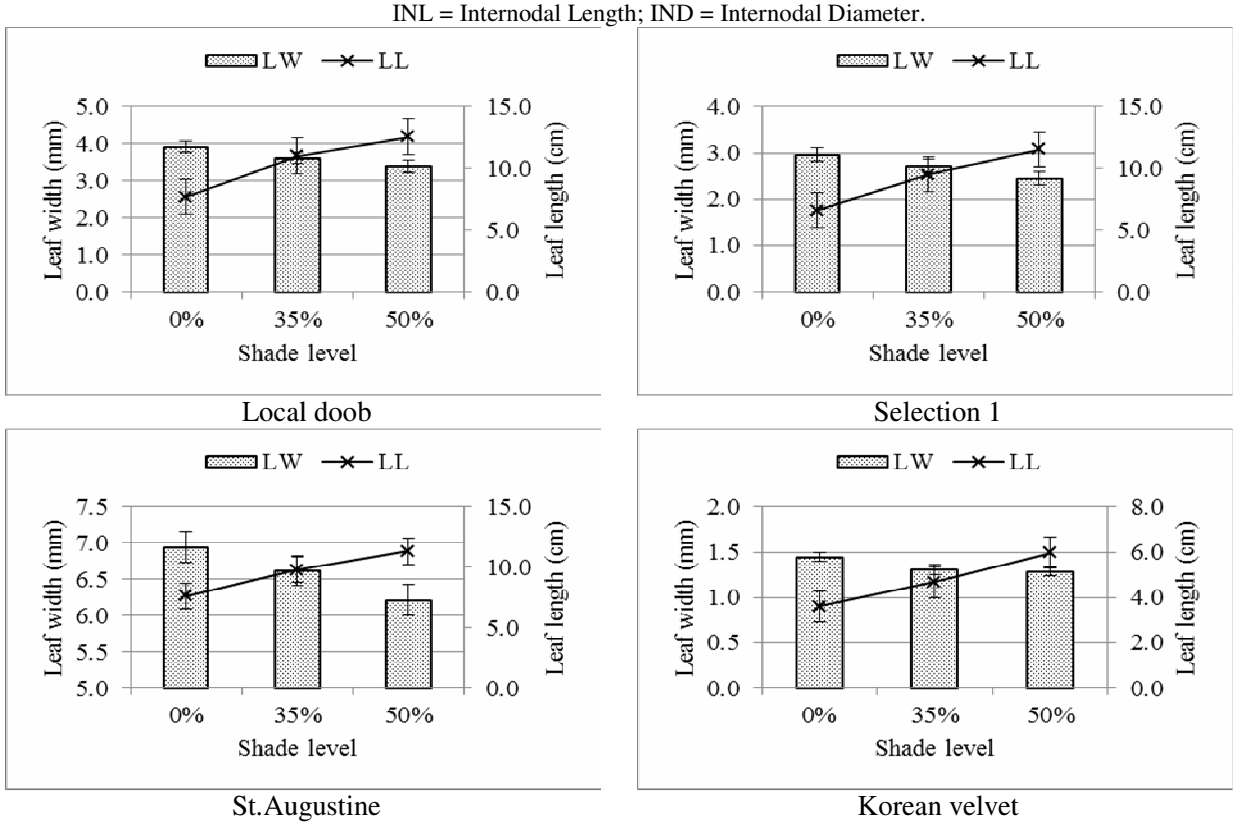

Fig.2 (c) Interaction effect between shade levels and genotypes on leaf width and leaf length in (a) Local doob, (b) Selection 1, (c) St. Augustine and(d) Korean velvet. Bars represent mean ± SE (n = 3). LW = Leaf width; LL = Leaf length

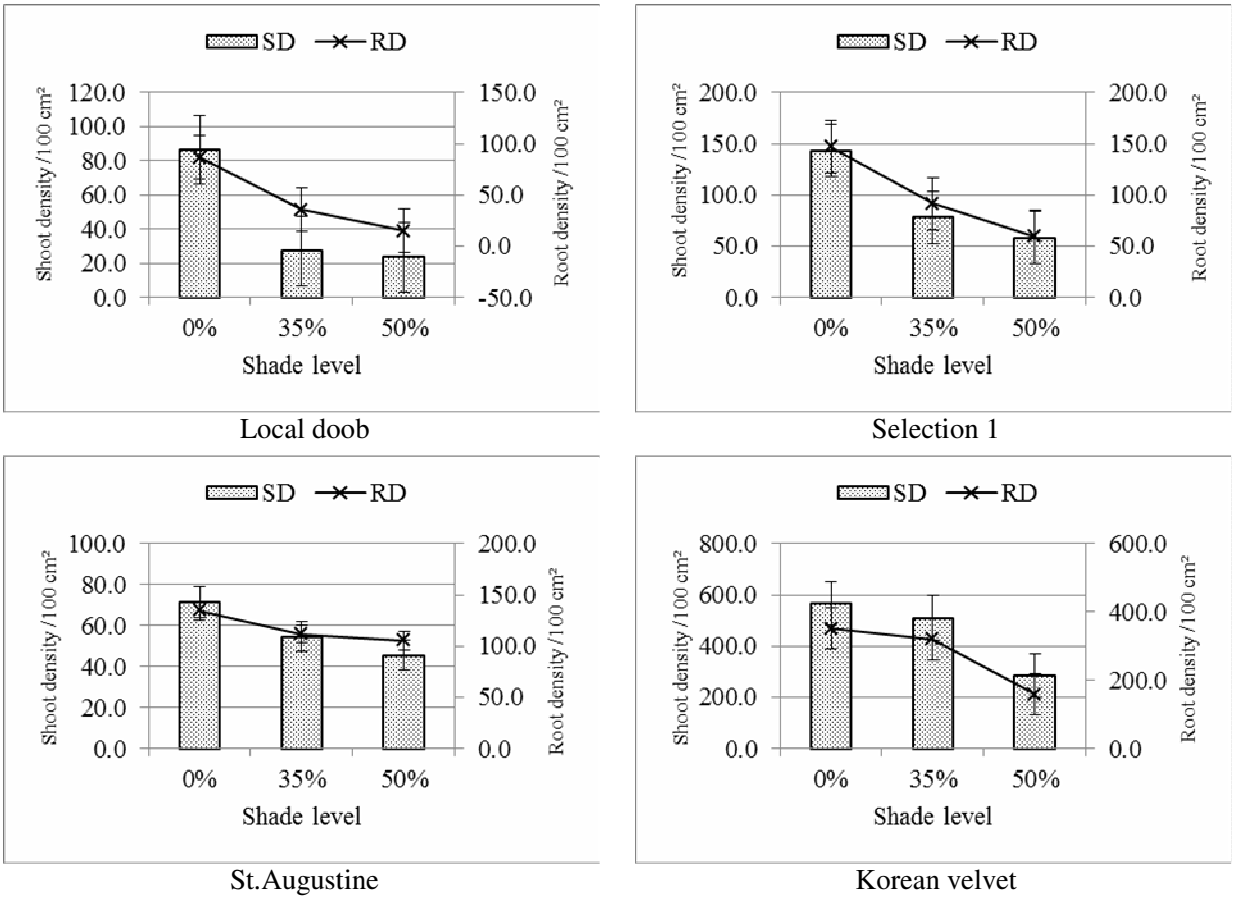

Fig.2. (d) Interaction effect between different shade levels and genotypes for Shoot density and Root density in (a) Local doob, (b) Selection 1, (c) St. Augustine and(d) Korean velvet. Bars represent mean ± SE (n = 3). SD = Shoot density; RD = Root density.

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Author Contributions

Conceptualization and Methodology: Rishu Sharma; Formal analysis and investigation: Manvir Singh Sidhu; Writing: original draft preparation: Manvir Singh Sidhu; Writing: review and editing: Simrat Singh; Resources and Supervision: KK Dhatt.

Conflict of Interest

The authors state no conflict of interest with respect to the research, authorship and publication of this manuscript.

References

Allard, G., Nelson, C. J., & Pallardy, S. G. (1991). Shade effects on growth of tall fescue: I. Leaf anatomy and dry matter partitioning. *Crop Science*, **31**(1), 163–167. https://doi.org/10.2135/cropsci1991.0011183X003100010037x

Almodares, A., & Beard, J. B. (1978). Turfgrass shade research update. *Texas Turfgrass Research*, **79**, 25–28.

Beard, J. B. (1965). Factors in the adaption of turfgrasses to shade. *Agronomy Journal*, **57**(5), 457–459. https://doi.org/10.2134/agronj1965.00021962005700050015x

Beard, J. B. (1973). *Turfgrass: Science and culture*. Prentice-Hall.

Burton, G. W., Jackson, J. E., & Knox, F. E. (1959). Influence of light reduction upon the production, persistence and chemical composition of coastal Bermuda grass (*Cynodon dactylon*). *Agronomy Journal*, **51**, 537–542. https://doi.org/10.2134/agronj1959.00021962005100090009x

Cai, X., Trenholm, L. E., Kruse, J., & Sartain, J. B. (2011). Response of 'Captiva' St. Augustinegrass to shade and potassium. *HortScience*, **46**(10), 1400–1403. https://doi.org/10.21273/HORTSCI.46.10.1400

Casal, J. J. (2013). Photoreceptor signaling networks in plant responses to shade. *Annual Review of Plant Biology*, **64**, 403–427. https://doi.org/10.1146/annurev-arplant-050312-120221

Christians, N. (2004). *Fundamentals of turfgrass management* (2nd ed.). John Wiley & Sons.

Danneberger, T. K. (1994). Integrating classroom instruction with turfgrass field experience through a golf course project. *Journal of Natural Resources and Life Sciences Education*, **23**(1), 56–58. https://doi.org/10.2134/jnrlse.1994.0056

Dudeck, A. E., & Peacock, C. H. (1992). Shade and turfgrass culture. In *Turfgrass* (**32**, pp. 269–284). https://doi.org/10.2134/agronmonogr32.c8

Eriksen, F. I., & Whitney, A. S. (1981). Effects of light intensity on growth of some tropical forage species: I. Interaction of light intensity and nitrogen fertilization on six forage grasses. *Agronomy Journal*, **73**(3), 427–433. https://doi.org/10.2134/agronj1981.00021962007300030011x

Gao, Y., Farrokhirad, E., & Pitts, A. (2023). The impact of orientation on living wall façade temperature: Manchester case study. *Sustainability*, **15**(14), 11109. https://doi.org/10.3390/su151411109

Gardner, D. S., Goss, R. M., Stier, J. C., Horgan, B. P., & Bonos, S. A. (2013). Management of turfgrass in shade. In *Turfgrass: Biology, use, and management* (**56**, pp. 219–247).

Gardner, D. S., & Goss, R. M. (2013). Management of turfgrass in shade. In *Turfgrass: Biology, use, and management* (**56**, pp. 219–247). https://doi.org/10.2134/agronmonogr56.c6

Huang, D., Wu, L., Chen, J. R., & Dong, L. (2011). Morphological plasticity, photosynthesis and chlorophyll fluorescence of *Athyrium pachyphlebium* at different shade levels. *Photosynthetica*, **49**, 611–618. https://doi.org/10.1007/s11099-011-0076-1

Jiang, Y., Duncan, R. R., & Carrow, R. N. (2004). Assessment of low light tolerance of seashore paspalum and Bermuda grass. *Crop Science*, **44**(2), 587–594. https://doi.org/10.2135/cropsci2004.5870

Kephart, K. D., Buxton, D. R., & Taylor, S. E. (1992). Growth of C3 and C4 perennial grasses under reduced irradiance. *Crop Science*, **32**(4), 1033–1038. https://doi.org/10.2135/cropsci1992.0011183X003200040040x

McBee, G. G., & Holt, E. C. (1966). Shade tolerance studies on bermuda grass and other turfgrasses. *Agronomy Journal*, **58**(5), 523–525. https://doi.org/10.2134/agronj1966.00021962005800050021x

Mohanty, C. R. (1991). *Turf grass management under different intensities of light* (Doctoral dissertation, University of Agricultural Sciences, Bangalore).

Niklas, K. J. (1992). *Plant biomechanics: An engineering approach to plant form and function*. University of Chicago Press.

Olsrud, M., & Michelsen, A. (2009). Effects of shading on photosynthesis, plant organic nitrogen uptake and root fungal colonization in a subarctic mire ecosystem. *Botany*, **87**(5), 463–474. https://doi.org/10.1139/B09-021

Poorter, H., & Nagel, O. (2000). The role of biomass allocation in the growth response of plants to different levels of light, CO_2, nutrients and water: A quantitative review. *Australian Journal of Plant Physiology*, **27**(6), 595–607. https://doi.org/10.1071/PP99173_CO

Schmidt, R. E., & Blaser, R. E. (1967). Effect of temperature, light and nitrogen on growth and metabolism of 'Cohansey' bentgrass (*Agrostis palustris* Huds.). *Crop Science*, **7**(5), 447–451. https://doi.org/10.2135/cropsci1967.0011183X000700050012x

Schmidt, R. E., & Blaser, R. E. (1969). Effect of temperature, light and nitrogen on growth and metabolism of 'Tifgreen' Bermuda grass (*Cynodon* spp.). *Crop Science*, **9**(1), 5–9. https://doi.org/10.2135/cropsci1969.0011183X000900010002x

Schnyder, H., & Nelson, C. J. (1989). Growth rates and assimilate partitioning in the elongation zone of tall fescue leaf blades at high and low irradiance. *Plant Physiology*, **90**(3), 1201–1206. https://doi.org/10.1104/pp.90.3.1201

Smith, H., & Whitelam, G. C. (1997). The shade avoidance syndrome: Multiple responses mediated by multiple phytochromes. *Plant, Cell & Environment*, **20**(6), 840–844. https://doi.org/10.1046/j.1365-3040.1997.d01-104.x

Tilman, D. (1988). *Plant strategies and the dynamics and structure of plant communities*. Princeton University Press.

Trenholm, L. E., & Nagata, R. T. (2005). Shade tolerance of St. Augustinegrass cultivars. *HortTechnology*, **15**(2), 267–272. https://doi.org/10.21273/HORTTECH.15.2.0267

Turgeon, A. J. (2012). *Turfgrass management*. Prentice Hall.

Van Huylenbroeck, J. M., & Van Bockstaele, E. (2001). Effects of shading on photosynthetic capacity and growth of turfgrass species. *International Turfgrass Society Research Journal*, **9**, 353–359.

Wherley, B., Chandra, A., Genovesi, A., Keans, M., Pepper, T., & Thomas, J. (2013). Developmental response of St. Augustinegrass cultivars and experimental lines in moderate and heavy shade. *HortScience*, **48**(8), 1047–1051. https://doi.org/10.21273/HORTSCI.48.8.1047

Wherley, B. G., Gardner, D. S., & Metzger, J. D. (2005). Tall fescue photomorphogenesis as influenced by changes in the spectral composition and light intensity. *Crop Science*, **45**(2), 562–568. https://doi.org/10.2135/cropsci2005.0562

Wilkinson, J. F., & Beard, J. B. (1974). Morphological responses of *Poa pratensis* and *Festuca rubra* to reduced light intensity. In *Proceedings of the Second International Turfgrass Research Conference* (pp. 231–240). American Society of Agronomy.

Winstead, C. W., & Ward, C. Y. (1974). Persistence of southern turfgrasses in a shade environment. In *Proceedings of the Second International Turfgrass Research Conference* (pp. 221–230). American Society of Agronomy.

Woledge, J. (1971). The effect of light intensity during growth on the subsequent rate of photosynthesis of leaves of tall fescue (*Festuca arundinacea* Schreb.). *Annals of Botany*, **35**(2), 311–322. https://doi.org/10.1093/oxfordjournals.aob.a084480

Wu, L., Huff, D., & Davis, W. B. (1985). Tall fescue turf performance under a tree shade. *HortScience*, **20**(2), 281–282. https://doi.org/10.21273/HORTSCI.20.2.281