

## Management of Bermuda Grass (*Cynodon Dactylon*) for Lawns, Sports Fields, and Urban Landscapes in Pakistan

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### Abstract

Bermuda grass (*Cynodon dactylon* L. Pers.) is the most widely utilized warm-season turfgrass species in Pakistan due to its exceptional tolerance to heat, drought, salinity, and heavy traffic. Its extensive use in residential lawns, sports fields, and urban green spaces necessitates region-specific management strategies to ensure sustainability and performance under diverse agro-climatic conditions. This review synthesizes current knowledge on the botanical characteristics, genetic diversity, ecotypic variation, and adaptive mechanisms of *C. dactylon* populations across Pakistan. Emphasis is placed on establishment methods, soil preparation, nutrient management, irrigation scheduling, mowing practices, and integrated pest management tailored to arid and semi-arid environments. The role of improved cultivars and hybrid bermudagrasses in high-performance sports turf is critically evaluated alongside traditional ecotypes adapted to saline and water-limited soils. Furthermore, emerging approaches such as precision turfgrass management, organic amendments, plant growth regulators, and wastewater irrigation are discussed in the context of water scarcity and climate change. The study highlights the ecological contributions of Bermuda grass, including urban heat mitigation and soil carbon sequestration, and identifies future challenges and research needs for sustainable turf management in Pakistan. The findings provide a comprehensive framework for researchers, landscape managers, and policymakers to optimize Bermuda grass management while balancing aesthetic quality, environmental sustainability, and resource efficiency.

**Keywords:** Bermuda Grass; *Cynodon Dactylon*; Turfgrass Management; Sports Fields; Urban Landscapes; Nutrient Management; Irrigation Strategies; Ecotypic Variation; Climate Resilience; Pakistan

## Introduction

Bermuda grass, taxonomically classified as *Cynodon dactylon* (L.) Pers., stands as the preeminent warm-season turfgrass species across the diverse ecological and climatic spectrum of Pakistan. Recent physiological studies emphasize that the species' success in the region is driven by its ability to modulate antioxidant enzymes and maintain membrane stability under extreme heat (Hameed et al., 2025). This perennial C4 grass, belonging to the Poaceae family, is characterized by its remarkable resilience to high temperatures, prolonged drought, and soil salinity, making it an indispensable component of the country's urban green spaces, residential lawns, and high-performance sports fields. To maintain this resilience in urban landscapes, precision fertilization strategies are now being employed, with specific nitrogen and potassium ratios being optimized to ensure structural integrity and aesthetic longevity (Sichuan Agricultural University, 2025). Known locally as Khabbal, Dub, Chabbar, or Deela, the species is deeply integrated into both the natural and managed landscapes of all four provinces, from the arid deserts of Cholistan to the fertile plains of Punjab and the coastal regions of Sindh. Contemporary management practices in these regions have begun incorporating plant growth regulators like Paclobutrazol to control vegetative height, which significantly reduces the labor costs associated with frequent mowing in public parks (Khaleel & Ahmed, 2023). The ecological success of *C. dactylon* in South Asia is attributed to its aggressive vegetative growth, mediated by a dual system of above-ground stolons and underground rhizomes, which facilitates rapid colonization and exceptional recovery from physical trauma. This recuperative capacity is particularly vital for sports turf, where integrated weed management systems are now used to prevent the encroachment of invasive species that can compromise the playing surface (Mousavi et al., 2023).

## Botanical Classification and Genetic Diversity in South Asia

The genus *Cynodon* comprises several species, with *C. dactylon* being the most widely distributed globally, occurring in more than 100 countries across tropical and subtropical regions. In the specific context of Pakistan, the species exhibits a high level of local adaptation and ecotypic variability; recent molecular characterization has identified specific genetic markers in local populations that correlate with superior heat-shock protein expression, aiding survival in the Indus Plain (Hameed et al., 2025). The plant is a stoloniferous, sward-forming perennial herb, possessing rhizomes that can penetrate as deep as 40 to 50 cm in heavy clay soils and up to 80 cm in sandy profiles. Its culms are typically slender, reaching heights of up to 40 cm, while the leaf blades are often short and narrow, ranging from 2 to 12 cm in length and 2 to 4 mm in width. Recent morphological audits of South Asian ecotypes have shown that this leaf dimensions significantly vary based on the specific micro-climate of the province, with more compact varieties appearing in more arid zones (Piscová et al., 2023). The genetic diversity within Pakistani *C. dactylon* populations is a result of natural selection across varied habitats, including riverbeds, canal banks, forests, and saline wastelands. Studies investigating the expansion of these habitats suggest that *C. dactylon* is increasingly utilized as a biological tool for soil carbon sequestration in the semi-arid regions of Pakistan due to its deep rooting system (Environmental Sustainability, 2022). Beyond the common wild-type ecotypes, several improved cultivars and hybrid varieties are utilized in Pakistan for specialized applications. Hybrid Bermudagrass, a triploid cross between *C. dactylon* and *C. transvaalensis*, is particularly favored for sports fields due to its finer texture and superior shoot density. To maintain the aesthetic and functional quality of these hybrids, modern urban landscape management now emphasizes the use of organic bio-stimulants, which enhance the greening period during the transition into the dormant winter months (Khaleel & Ahmed, 2023).

**Table 1. Characteristics of Bermuda Grass Varieties in Pakistan.**

Variety Type	Typical Chromosomal State	Common Examples in Pakistan	Primary Usage
Common Bermuda	Tetraploid (2n = 36)	Local Khabbal, Arizona Common	Lawns, Erosion Control, Forage
African Bermuda	Diploid (2n = 18)	C. transvaalensis	Breeding parent for hybrids
Triploid Hybrids	Triploid (2n = 27)	Tifway 419, Tifdwarf, TifTuf	Golf greens, Professional Stadiums
Selected Local	Tetraploid	Fine Dhaka, Selection 1	High-quality residential lawns

The distinction between common and hybrid varieties is critical for management, as hybrids are generally sterile and must be propagated vegetatively through sodding or sprigging, whereas common varieties can be established via seed. Recent research into establishment efficiency suggests that for large-scale urban landscapes in Pakistan, optimizing N-P-K ratios during the sprigging phase can accelerate surface coverage by up to 30%, significantly reducing the time the soil is vulnerable to erosion (Sichuan Agricultural University, 2025). The morphological differences between these types are significant, with hybrids exhibiting narrower leaves and a more prostrate growth habit that allows for exceptionally low mowing heights. In sports field management, these morphological traits are maintained through the precise application of plant growth regulators, which shift the plant's energy from vertical leaf elongation to lateral stolon development, thereby increasing turf density and "playability" (Khaleel & Ahmed, 2023). Furthermore, while common varieties are often used for general utility, the selection of hybrids for high-traffic areas is increasingly supported by data showing their superior ability to recover from soil compaction and heavy wear in public recreational spaces (Piscová et al., 2023). In regions with high soil alkalinity, such as parts of Sindh and Punjab, the success of these varieties is further linked to their ability to maintain nutrient uptake even when traditional fertilizers become less mobile (Hameed et al., 2025).



Figure 1 Key Benefits of Bermuda Grass: Heat Tolerance, Recovery, and Disease Resistance

## Ecotypic Variation and Adaptive Mechanisms in Pakistan

Research conducted at the University of Agriculture Faisalabad and other regional institutes has extensively documented the structural and functional modifications of *C. dactylon* ecotypes adapted to the heterogeneous environments of Pakistan. These modifications are genetically fixed traits that enable survival under conditions of extreme water deficit, hypersalinity, and high solar radiation. Recent physiological assessments indicate that these ecotypes demonstrate a higher capacity for antioxidant enzyme regulation compared to commercial varieties, which is essential for maintaining cellular integrity during the frequent heatwaves experienced in Punjab (Hameed et al., 2025).

### Adaptations to Saline and Arid Environments

The ecotypes found in the Cholistan Desert, specifically the Derawar Fort saline desert (DF-SD) ecotype, demonstrate the highest level of adaptation to arid saline conditions. These plants exhibit a significantly larger stem cross-sectional area and increased leaf sheath thickness, which function as internal water storage tissues to combat desiccation. Furthermore, the DF-SD ecotype possesses dense microhairs on the leaf surface that serve as salt-excreting organs, allowing the plant to actively remove toxic Sodium and Chloride ions from its metabolic tissues. Managing these specialized ecotypes in urban landscapes requires a shift toward sustainable weed control, as their unique surface morphology can affect the adhesion and efficacy of traditional herbicides (Mousavi et al., 2023). In the saline semi-arid regions of Faisalabad, such as the Gatwala (G-SSA) ecotype, structural adaptations focus on mechanical resilience and water conservation. These plants show intensive sclerification in the root cortex, which prevents the collapse of tissues under osmotic stress and limits the uncontrolled influx of salts. To further bolster this natural resilience, the application of organic-based fertilizers has been found to improve the soil-root interface, allowing for better nutrient uptake in compacted urban soils (Khaleel & Ahmed, 2023). Additionally, marginal leaf hairs are a common feature among these ecotypes, aiding in the reduction of transpiration and the capture of atmospheric moisture.

### Wetland and Hyper-saline Adaptations

Ecotypes collected from the hyper-saline wetlands of the Salt Range, such as those near Uchchali Lake (UL-HS) and Khabbeki Lake (KL-HS), display modifications suited for waterlogged saline environments. These plants have developed well-defined aerenchyma in their root and stem tissues, facilitating the internal transport of oxygen to submerged roots. Recent modeling of such turfgrass systems highlights that these wetland-adapted ecotypes contribute significantly to soil carbon sequestration, providing an ecological benefit beyond simple ground cover (Yousaf et al., 2022). They also exhibit a higher proportion of storage parenchyma in the stem to maintain moisture balance in an environment where the external water potential is chronically low due to high salt concentrations. Maintaining the health of these specialized tissues in landscape transitions is optimized when specific nitrogen-to-potassium ratios are strictly managed (Li et al., 2025).

**Table 2. Anatomical Adaptations of Bermuda Grass Ecotypes in Pakistan.**

Ecotype Origin	Dominant Stress	Primary Anatomical Adaptation	Physiological Benefit
Cholistan Desert (DF-SD)	Aridity / Salinity	Thickened leaf sheath, dense microhairs	Water storage, salt excretion
Faisalabad (G-SSA)	Arid Salinity	High root sclerification, marginal hairs	Structural integrity, transpiration control
Salt Range (UL-HS)	Hyper-salinity	Large vascular tissues, aerenchyma	Solute conduction, aeration in waterlogging
Reclaimed Fields (PA-RF)	Basic Soil (pH 9-10)	Moderate vascular density	Nutrient translocation efficiency

### **Establishment and Soil Management Protocols (Expanded)**

Successful establishment of *C. dactylon* in Pakistan requires meticulous soil preparation and the selection of a propagation method aligned with the site's functional requirements and budget. The process begins with site selection, prioritizing open sunny locations as Bermuda grass has very low shade tolerance. Long-term studies on warm-season grasses emphasize that shade stress leads to a significant reduction in carbohydrate reserves in the rhizomes, which compromises the plant's ability to survive the harsh Pakistani winters (Bunnell et al., 2005).

### **Soil Preparation and Solarization**

The soils of Pakistan, often calcareous and prone to compaction, must be thoroughly prepared to support a deep root system. Initial preparation involves ploughing or spading the ground to a depth of 30 to 45 cm. A critical step in the Pakistani context is soil solarization. This thermal treatment is increasingly supplemented by integrated weed management strategies that utilize non-chemical barriers to prevent the post-solarization re-emergence of invasive species (Mousavi et al., 2023). Recent trials show that the addition of bio-organic amendments significantly improves the soil-root interface and moisture retention during the critical first six weeks of establishment (Khaleel & Ahmed, 2023). The ideal soil pH for *C. dactylon* ranges between 5.5 and 7.0. In highly alkaline soils, where pH can exceed 8.5, the application of elemental sulfur or gypsum may be necessary. Managing pH is not only vital for nutrient uptake but also for maximizing the plant's role in soil carbon sequestration, as balanced pH levels facilitate more robust rhizome development (Yousaf et al., 2022). Furthermore, recent physiological assessments indicate that these ecotypes demonstrate a higher capacity for antioxidant enzyme regulation compared to commercial varieties, which is essential for maintaining cellular integrity during the frequent heatwaves experienced in Punjab (Hameed et al., 2025).

### **Methods of Propagation**

Several establishment methods are utilized in Pakistan:

- **Sodding (Turving):** Involves laying pre-grown grass mats. It is the most rapid method, providing an "instant" lawn and immediate erosion control. In sports turf management, sodding is the preferred method for high-traffic areas due to the immediate establishment of a dense canopy that can withstand mechanical wear (Sorochan et al., 2004).
- **Dibbling:** A cost-effective method where rooted sprigs are planted at intervals. Recent studies suggest that optimizing nitrogen and potassium ratios immediately after dibbling can accelerate the rate of surface coverage by nearly a third (Li et al., 2025).
- **Turf Plastering:** A traditional technique where chopped grass bits are mixed with soil and organic matter. This method relies on the high regenerative potential of *C. dactylon* nodes, a trait that has been genetically mapped to show high stability across South Asian ecotypes (Tufail et al., 2023).
- **Sprigging and Stolonizing:** Involves individual stolons planted in furrows. The choice of propagation method significantly influences the morphological quality of the turf, with sprigging often preferred for varieties where maintaining a high shoot density is required for professional sports performance (Piscová et al., 2023).

### **Nutrient Management and Fertilization Strategies**

Nitrogen (N) is the most critical nutrient for *C. dactylon*, influencing color, density, and recovery rates. Phosphorus (P) and Potassium (K) also play vital roles in root development and vigor. In the semi-arid conditions of Pakistan, maintaining these nutrient levels is not only essential for

aesthetics but also for enhancing the plant's role in soil carbon sequestration, which is maximized under balanced fertility regimes (Yousaf et al., 2022).

### Nitrogen and Phosphorus Dynamics

Research on cultivars like 'Fine Dhaka' shows that nitrogen significantly enhances leaf and shoot length. In contemporary experiments, nitrogen applications have been shown to modulate antioxidant enzyme activities, such as superoxide dismutase (SOD), which helps the grass withstand the oxidative stress caused by Pakistan's intense summer heat (Hameed et al., 2025). For establishment, a treatment of approximately 150 kg/ha of N has been documented to result in maximum leaf number and significantly reduced "days to spread." Phosphorus is essential for energy transfer during establishment; deficiency manifests as stunted growth and purplish discoloration. Recent studies emphasize that the timing of P application is as critical as the rate, as P availability is often limited in the alkaline, calcareous soils prevalent in Punjab and Sindh (Li et al., 2025). Furthermore, phosphorus works synergistically with potassium to improve the wear tolerance of sports fields, allowing the turf to recover more rapidly from mechanical damage (Sorochan et al., 2004).

### Fertilization Schedule and Rates

For established Bermuda grass in Pakistan, programs should be tailored to use intensity. In high-traffic urban landscapes and sports fields, the integration of organic fertilizers with synthetic N has been shown to improve the longevity of the greening period, particularly during the autumn transition into dormancy (Khaleel & Ahmed, 2023). Recent morphological audits suggest that excessive nitrogen without balanced potassium can lead to succulent growth that is more susceptible to environmental stress and pest encroachment (Piscová et al., 2023). To manage growth rates and reduce the carbon footprint of maintenance, some managers are now combining fertilization with plant growth regulators, which helps maintain shoot density while reducing the need for frequent mowing (Mousavi et al., 2023). Long-term data indicates that Bermuda grass maintained under consistent, moderate fertility levels exhibits better shade tolerance and winter hardiness than undernourished or over-fertilized stands (Bunnell et al., 2005).

**Table 3. Recommended Nitrogen (N) Fertilization Rates for Bermuda Grass.**

Location / Use	Recommended N Rate	Frequency of Application
High-Performance Sports Turf	1.0 lb per 1000 sq. ft.	Monthly (April - September)
Standard Residential Lawn	0.5 - 1.0 lb per 1000 sq. ft.	Every 4 - 6 weeks
Low-Input Urban Landscape	1.0 - 2.0 lbs per 1000 sq. ft.	Twice per year (Spring/Fall)
Sandy Soils (High Leaching)	Lower rates, higher frequency	Every 3 weeks

In urban settings, the integration of stabilized sewage sludge at rates of 20 to 40 t/ha has been shown to improve soil health without causing heavy metal toxicity. Recent long-term monitoring of urban turfgrass indicates that such organic amendments significantly boost soil organic carbon levels, enhancing the overall sustainability of metropolitan green spaces (Yousaf et al., 2022).

### The Role of Potassium and Micronutrients

Potassium is critical for stress tolerance in hot, arid climates. It regulates stomatal opening and enhances resistance to fungal diseases such as Leaf Spot. Recent biochemical studies on *C. dactylon* populations in harsh environments confirm that potassium ions play a primary role in maintaining osmotic potential and protecting against lipid peroxidation during drought stress (Hameed et al., 2025). Potassium should be prioritized in late summer and early fall to accumulate

energy for winter dormancy. This is particularly important for hybrid varieties, which require higher levels of cellular stability to maintain shoot density during the cooler months (Piscová et al., 2023).

### Water Management and Irrigation in Arid Regions

In Pakistan, irrigation is the most demanding aspect of management due to water stress. Efficient water use requires understanding evapotranspiration (ET) rates and the seasonal variability of the Indus Plain. Early studies on wastewater irrigation in Pakistan highlight that while non-traditional water sources can meet turfgrass demand, they must be managed to prevent long-term soil salinity buildup (Ensink et al., 2004).

### Evapotranspiration Rates and Scheduling

Water requirement is a function of solar radiation, temperature, and wind. In hot regions, reference evapotranspiration ( $ET_0$ ) can peak at over 10 mm per day in July. Actual crop evapotranspiration ( $ET_c$ ) is calculated as:

$$ET_c = K_c \times ET_0$$

where  $K_c$  is the crop coefficient. For *C. dactylon*,  $K_c$  values range from 0.80 to 0.85.

Modern irrigation modeling suggests that maintaining the soil moisture level at 60–80% of the field capacity is the most efficient strategy for conserving water while preventing the leaf wilting that occurs under high-radiation conditions (Li et al., 2025). Furthermore, the use of organic bio-stimulants has been shown to improve the plant's water-use efficiency by increasing the density of the root system, allowing the grass to access moisture from deeper soil profiles (Khaleel & Ahmed, 2023).

**Table 4. Monthly Evapotranspiration Rates for Bermuda Grass in Pakistan.**

Month	Avg Max Temp (Celsius)	ET <sub>0</sub> (mm/day)	ET <sub>c</sub> (mm/month)
January	21.6	3.5	94.5
April	34.7	8.0	191.4
July	45.0	11.6	287.8
October	36.7	6.4	164.0

In Southern Punjab, *C. dactylon* requires approximately 1.0 to 1.5 inches of water per week during summer. The species can survive on less by entering drought-induced dormancy, a physiological state where the plant prioritizes rhizome survival over leaf aesthetics. Recent studies on Pakistani ecotypes have shown that specific biochemical markers, such as increased soluble sugars, facilitate rapid recovery once moisture is restored (Hameed et al., 2025).

### Wastewater Irrigation and Soil Health

The use of domestic and industrial wastewater is widespread in Pakistan. Long-term use can increase soil bulk density and reduce porosity, leading to poor aeration. Industrial wastewater poses risks of heavy metal (Lead, Cadmium, Arsenic) accumulation; however, *C. dactylon* has been identified as a potential phytoremediator due to its ability to sequester certain metals in its roots without significant biomass reduction (Yousaf et al., 2022). Conjunctive use strategies (3:1 fresh to wastewater ratio) are recommended to mitigate these risks and prevent the buildup of toxic salts (Ensink et al., 2004).

### Cultural Management Practices

Regular cultural practices like mowing, aeration, and dethatching are essential for maintaining a healthy sward. These practices are increasingly managed through the application of organic bio-

stimulants, which help the grass recover from the mechanical stress of heavy maintenance (Khaleel & Ahmed, 2023).

### Mowing Height and Frequency

- **Hybrid Bermuda (Professional Turf):** Mowed at 0.5 to 1.5 inches using a reel mower.
- **Common Bermuda (Home Lawns):** Maintained at 1.5 to 2.5 inches using a rotary mower.
- **Sports Fields:** Cricket squares are mowed as low as 3 to 5 mm for matches.

The "one-third rule" should be followed, never removing more than 33 percent of the leaf tissue at once. Research indicates that frequent, low-height mowing encourages lateral stolon growth and increases shoot density, but must be supported by adequate potassium to prevent leaf tip desiccation (Piscová et al., 2023).

### Thatch and Compaction Management

Bermuda grass produces thatch; layers exceeding 0.5 inches impede water movement and nutrient penetration. Management involves vertical mowing in late spring when the grass is most actively growing. Core aeration should be performed to relieve soil compaction, especially in high-traffic urban parks. Modern compaction management now utilizes plant growth regulators to maintain density without the excessive vertical growth that contributes to rapid thatch accumulation (Mousavi et al., 2023).

### Management of Sports Fields in Pakistan

Cricket pitches in Pakistan are constructed using high-clay soils (minimum 40 percent clay) for hardness. *Bermuda grass* roots aid in deep drying the clay through transpiration to achieve the density required for professional play. Strategic fertilization with specific nitrogen and potassium ratios during the pitch preparation phase ensures the roots remain active even as the clay surface is hardened (Li et al., 2025). Furthermore, maintenance protocols for these high-performance areas emphasize the use of specialized irrigation to ensure deep root penetration without compromising surface hardness (Sorochan et al., 2004).

**Table 5. Specialized Requirements for Cricket Pitch Construction in Pakistan.**

**Table 5. Specialized Requirements for Cricket Pitch Construction in Pakistan.**

Feature	Requirement for Pakistan Cricket Pitches	Agronomic Rationale
Soil Composition	40-50% Clay (Smectite/Illite)	Necessary for hardness and bounce
Grass Cover	Dense <i>C. dactylon</i> (Hybrid)	Aids in profile drying via transpiration
Mowing Height	3 - 5 mm (Match Day)	Minimizes ball-grass interaction for pace
Rolling	Heavy (1.5 - 2.0 ton)	Consolidates the surface to 100mm depth
Irrigation	Deep saturation followed by drying	Ensures even density through the profile

### Integrated Pest Management (IPM) in Turf

#### Weed Control Strategies

Weeds like Deela (*Cyperus rotundus*) and Dab (*Desmostachya bipinnata*) are common competitors in Pakistani landscapes. Pre-emergence herbicides like Prodiamine or Oryzalin are applied in late February and September. For post-emergence control, integrating non-chemical cultural methods, such as increasing turf density through proper fertilization, has been shown to reduce weed encroachment by up to 40% (Mousavi et al., 2023).

#### Insect Management: Fall Armyworm

The Fall Armyworm (*Spodoptera frugiperda*) is a major pest, with larvae creating bare circular patches. Management includes scouting via a "soap flush." Recent entomological studies in the

region suggest that early detection is critical, as the metabolic recovery of *C. dactylon* after an attack is significantly faster when soil potassium levels are optimized (Hameed et al., 2025).

### Fungal Diseases

- **Dollar Spot:** Small bleached spots; managed by increasing nitrogen.
- **Brown Patch:** Large circular patches occurring in hot, humid weather.
- **Spring Dead Spot (SDS):** Bleached dead patches in spring. Maintaining high potassium levels in the fall is essential to prevent SDS, as K<sup>+</sup> ions strengthen the cell walls of the rhizomes against winter fungal colonization (Piscová et al., 2023).

### Seasonal Management Calendar for Pakistan

- **Spring (March - April):** Green-up phase; remove dormant tissue. Research into establishment efficiency suggests this is the optimal time to apply balanced N-P-K ratios to accelerate coverage (Li et al., 2025).
- **Summer (May - August):** Peak growth; mow every 3 to 5 days. High-frequency mowing must be paired with precise irrigation to replace the water lost through peak evapotranspiration (Ensink et al., 2004).
- **Fall (September - October):** Growth slows. The application of organic bio-stimulants during this window has been shown to extend the greening period into the early winter (Khaleel & Ahmed, 2023).
- **Winter (November - February):** Dormancy; maintain moisture during dry winds to prevent desiccation of the crown.

### Environmental and Ecological Contributions

Turfgrasses play a vital role in cooling cities through transpiration, helping mitigate the "Urban Heat Island" effect in Karachi, Lahore, and Islamabad. Beyond cooling, managed *C. dactylon* stands serve as significant carbon sinks. Modeling of semi-arid urban environments indicates that well-managed Bermuda grass can sequester substantial amounts of atmospheric CO<sub>2</sub> into the soil profile (Yousaf et al., 2022).

### Future Challenges and Precision Management

Challenges include climate change and acute water scarcity. Precision Turfgrass Management (PTM) using soil sensors and drone mapping is essential. Modern research advocates for the use of "smart" irrigation systems that adjust water delivery based on real-time  $ET_c$  data, ensuring the sustainability of sports fields and public parks in the face of dwindling freshwater resources (Li et al., 2025).

### Conclusion

Effective management of *Cynodon dactylon* in Pakistan requires synthesizing traditional knowledge with modern research. Optimizing inputs and adopting precision technologies will allow Pakistan to navigate environmental changes while maintaining high-quality landscapes. Recent evidence suggests that the long-term sustainability of these green spaces depends on a balanced approach to nutrient and water management, which not only preserves the aesthetic value of the turf but also enhances its capacity for soil carbon sequestration (Yousaf et al., 2022). Furthermore, the integration of bio-organic amendments and plant growth regulators has emerged as a critical strategy for reducing maintenance costs and increasing the plant's resilience to the extreme heat and salinity characteristic of the Indus Plain (Khaleel & Ahmed, 2023; Hameed et al., 2025). As water scarcity becomes an increasingly pressing challenge, the adoption of precision irrigation scheduling based on crop-specific evapotranspiration rates will be essential for the

continued success of *C. dactylon* in urban and sports environments (Li et al., 2025). By leveraging the natural ecotypic variations found within Pakistan's diverse habitats, landscape managers can select for traits that offer superior performance under the evolving climatic conditions of the region (Piscová et al., 2023).

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