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Integrated Nutrient Management Using Fertilizer Regimes and Plant Growth-Promoting Rhizobacteria Enhances Growth and Turf Quality of *Cynodon dactylon* ‘Fine Dacca’

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ABSTRACT

Optimizing fertilizer inputs through the integration of plant growth-promoting rhizobacteria (PGPR) offers a viable approach to enhance bermudagrass growth, quality and resource use efficiency. This study was aimed to evaluate the effects of various fertilizer regimes on growth and quality attributes of *Cynodon dactylon* (L.) Pers. ‘Fine Dacca’ under agro-ecological conditions of Faisalabad, Pakistan. Six fertilizer treatments, viz. no fertilization (control), N, NPK, NPK + Fe, NPK + Fe + PGPR (MN-54, *Bacillus* spp.) and polymer coated DAP were applied. Experiment was laid out in a randomized complete block design (RCBD) with three replications. Among tested fertilizer regimes, NPK + Fe + PGPR produced superior results for various growth and quality attributes were recorded, as highest tiller length (11.5 cm), number of tillers (27.8), leaves per tiller (13.8), leaf area (0.67 cm²), and leaf blade length (18.8 cm), along with higher fresh and dry weight of tillers (4.1 g and 1.7 g, respectively), chlorophyll contents (0.26 mg g⁻¹) and stolon diameter (0.94 mm). In contrast, grass fertilized with polymer coated DAP resulted in the highest moisture percentage (60.8%). Turf quality attributes including uniformity, density, texture, smoothness and color were also significantly improved under NPK + Fe + PGPR application. Leaf nitrogen content was highest (3.9%) with NPK + Fe + PGPR and NPK + Fe applications, whereas phosphorus (0.9%) and potassium (1.8%) were recorded highest under polymer-coated DAP and NPK treatments, respectively. It was concluded that integrating macronutrients with Fe and PGPR enhanced bermudagrass growth and aesthetic quality, indicating its potential as an effective alternative to conventional fertilization practices.

KEYWORDS: Beneficial microbes, Controlled release fertilizers, Micronutrients, Polymer-coated DAP, Turfgrass management, Eco-friendly enzymes, Sustainable production

INTRODUCTION

Turfgrass culture is the main natural asset and a pivotal component in horticulture, which characterizes a key unit in the global landscape ecological systems (Walker and Branham, 2020). Bermudagrasses, a widely distributed warm-season turf grass species worldwide, are mainly used in sports fields, golf courses, parks, lawns and prairies due to their high recuperative ability and exceptional tolerance to high temperatures (Fan *et al.*, 2024) and have variability in surface, shading, thickness, and ecological modification (Cui *et al.*, 2021).

Managing soil and plant nutrition is becoming a serious concern to achieve sustainable and quality production. Plant growth is mainly affected by availability of water, temperature, nutrition and light duration (Rehman *et al.*, 2020). Essential nutrients, particularly nitrogen (N), phosphorus (P) and potassium (K) are fundamental to plant growth and productivity due to their involvement in numerous physiological processes (Hussain *et al.*, 2026). Among the primary macronutrients, nitrogen (N) is considered the most vital macronutrient for turfgrass growth and development (Saud *et al.*, 2020). It is a key component of proteins, amino compounds, rubisco, and

chlorophyll and plays a vital role in regulating enzymes associated with stress tolerance (Tantray *et al.*, 2020). Sufficient nitrogen (N) dose is required to facilitate proper tiller growth during grass establishment. Moreover, being a vegetative cover, more nitrogenous fertilizer is required to keep turfgrasses lush green. Adequate nitrogen fertilization enhances photosynthetic activity, biomass accumulation, and plant tolerance to stress (Toor *et al.*, 2021). Furthermore, nitrogen fertilization has been shown to enhance nitrogen use efficiency (NUE) in turfgrass, particularly during periods of active growth. Phosphorous is also an essential macronutrient involved in energy transfer, cellular division, and tissues development in plants including turfgrasses (Fahad *et al.*, 2016; Ihtisham *et al.*, 2018). Application of phosphorous enhanced cold tolerance in *Poa paratensis* and drought resistance in *Cynodon dactylon* (Heydari and Balestra, 2008). Recent studies have shown that exogenous application of nutrients such as phosphorous (P) and potassium (K) can effectively alleviate the adverse effects of heat stress in plants (Hasanuzzaman *et al.*, 2013). Phosphorus deficiency in soil imposes considerable stress on plants and is often associated with elevated ethylene production

(Nagarajan and Smith, 2012; Song and Liu, 2015). Ethylene is a key phytohormone involved in regulating the senescence of plant tissues (Lim *et al.*, 2007). Although plants growing under phosphorus-deficient conditions can develop several adaptive responses (Parra-Almuna *et al.*, 2018; Richardson *et al.*, 2009), these mechanisms are often inadequate to sustain optimum crop productivity (Hocking, 2001; Vance *et al.*, 2003; Balemi and Negisho, 2012). Consequently, the application of inorganic phosphorus fertilizers remains a common practice for improving forage and crop production in phosphorus-deficit soils (Menezes-Blackburn *et al.*, 2017). In bermudagrasses, potassium has vital role in regulating plant water status and affects water potential of leaves and drought damage avoidance. It is essential for maintaining cellular homeostasis, activating enzymes, and regulating osmotic balance in plants (Johnson *et al.*, 2022; Zaman *et al.*, 2022). Potassium (K) fertilization plays a key role in turfgrass quality, root growth, disease, stress resistance, cold and heat hardiness (Ihtisham *et al.*, 2018).

Fertilization doses enriched with micronutrients are beneficial for minimizing cold stress and color development. Iron (Fe), a vital micronutrient, assists in color retrieval and photosynthesis (Taylor *et al.*, 2025). Application of iron assists bermudagrass cold-sensitive and cold-tolerant cultivars to sustain their aesthetic quality and CER (carbon dioxide exchange ratio) recovery. Foliar application of iron enhanced turf quality in winter and fall seasons but had no evidence of turf response in subsequent year (Radkowski *et al.*, 2023).

Polymer coated fertilizers enhance shelf life and efficiency of nutrients. Polymer coating have been found to be more beneficial than other fertilizers encapsulating technologies (Zywocinski *et al.*, 2011). Amount of commercial DAP fertilizer in wheat was lowered to half by using polymer coated DAP, which also enhanced plants growth and yield (Ali *et al.*, 2017).

PGPR contribute to plant growth by increasing nutrient availability particularly nitrogen, synthesizing phytohormones such as indole-3-acetic acid (IAA), and modulating stress related hormones like ethylene via ACC deaminase activity (Oleńska *et al.*, 2020; Gouda *et al.*, 2018). Species of *Bacillus* and *Pseudomonas*, widely applied in agriculture systems, are primarily valued for their antagonistic activity against plant pathogens and their capacity to improve nutrient uptake (He *et al.*, 2019). Plant growth-promoting rhizobacteria (PGPR) contribute significantly to improving both abiotic and biotic stress tolerance in cool and warm season grasses (Coy *et al.*, 2014). Similarly, the combined application of PGPR and nitrogen fertilizer in hybrid bermudagrass and tall fescue resulted in greater root biomass and improved resistance to white grub infestation (Coy *et al.*, 2019). Perennial ryegrass (*Lolium perenne*), treated with combined inoculation with *Bacillus* sp. EhS₅ and EhS₇

significantly increased biomass production and copper uptake (Ke *et al.*, 2021). Application of bio-fertilizers (*Bacillus megaterium* (M3) and *Bacillus subtilis* (OSU-142) along with nitrogenous fertilizers significantly improved clippings yield and turf color in perennial ryegrass (Acikgoz *et al.*, 2016). PGPRs application and soil microorganism inoculants have potential to improve soil microbial activity and supplements uptake by plants (Velez, 2013).

Among all turfgrasses, bermudagrass is widely grown throughout the world due to its fast growth, smoothness, fine look and greenish color. But its quality and development are influenced by salinity, poor fertilization and drought (Huang *et al.*, 2019). Bermudagrass is one of the most widely cultivated turfgrass species worldwide because of its rapid establishment, fine texture, smoothness and attractive green color. However, its growth and turf quality are often adversely affected by salinity, inadequate nutrient supply and drought stress (Huang *et al.*, 2019).

Despite the increasing interest in sustainable nutrient management, information on the integrated use of conventional fertilizers, iron and PGPR for bermudagrass production remains limited. Therefore, this study was conducted to improve growth and quality of *Cynodon dactylon* (L.) Pers. 'Fine Dacca' using nitrogen only, compound fertilizer containing NPK applied alone or along with iron, polymer coated DAP (a smart fertilizer) and a PGPR (*Bacillus* spp. MN-54). It was hypothesized that use of efficient modern fertilizer approach would improve turf growth and quality as well as will produce ecofriendly and more sustainable turf. The findings are expected to provide a sustainable nutrient management strategy for turfgrass managers and sod producers by improving turf performance.

MATERIALS AND METHODS

Field experiment was conducted during 2023-2024 at Floriculture Research Area, Institute of Horticultural Sciences, University of Agriculture, Faisalabad, Pakistan (Latitude = 31° - 26' N, Longitude = 73° - 06' E, Altitude = 184.4m). Grass plugs were collected from a local sod production farm at Alipur Chattha, Gujranwala, Punjab, Pakistan. Plugs were harvested during morning hours in early spring (March) and transported to experimental site within 24 h of harvest. On arrival, pieces of sod were placed under shade till transplanting next day. Next morning, soil was prepared thoroughly to a good tilth and levelled. Then, transplanting was done followed by light rolling, basal NPK (20:20:20) application @ 40 kg ha⁻¹ and surface irrigation. All cultural practices, viz. mowing, irrigation, weeding, IPM, etc. were same for all treatments (Nawaz *et al.*, 2025). Treatments included; control (no fertilizer except basal dose), N (450 g), NPK (20:20:20) (2.29 kg), NPK + Fe (2.29 kg NPK + 84.4 g Fe), NPK + Fe + PGPR (2.29 kg NPK + 84.4 g Fe + 666.7 mL PGPR) and polymer coated DAP (a smart fertilizer) (112.5 g P) per 1000 ft². Urea

fertilizer was used as nitrogen source, NPK (20:20:20), Iron sulphate for iron, *Bacillus* spp. MN-54 as PGPR and polymer coated DAP as smart fertilizer for the study. Iron sulphate and PGPR were sprayed, while urea, NPK and polymer coated DAP were applied in granular form followed by irrigation. Polymer coated DAP was prepared according to Ali *et al.* (2017).

Experiment was set in a Randomized Complete Block Design (RCBD) with three replications and each experimental unit had 272 ft² area. The grass was allowed to properly establish for two months with weekly surface irrigation and manual weeds removal. Once, more than 90% green cover was achieved, the turf mowed, and treatments were applied 48 h after mowing. Fertilizer treatments were applied monthly during July, August and September, and data were recorded seven days following treatments application. The same experimental procedure was repeated during the subsequent growing season in 2024 to ensure

consistency and reliability of results. Meteorological data, including minimum and maximum temperature, relative humidity, and precipitation were recorded throughout the experimental period to account for the influence of prevailing weather conditions on bermudagrass (Table 1). Measuring rod was used to measure tillers height. Number of tillers were measured quantitatively by counting tillers under a ring (Beard, 1973). For measuring length of leaf blades, length of top three leaf blades on a tiller was measured, and diameter of 3rd, 4th and 5th internode from top was measured using digital caliper for recording stolon diameter. Leaf area was calculated according to Carleton and Foote (1965), while fresh weight of tillers was recorded using electric weighing balance, followed by oven drying at 65°C for 72 h to record dry weight of tillers. Moisture percentage of grass was calculated using formula:

$$\text{Moisture percentage (\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Fresh weight}} \times 100$$

Canopy total chlorophyll content was measured by chopping fresh grass leaves into small pieces, taking 1 gram chopped leaves, which were extracted in 10 mL of 80% acetone at room temperature overnight.

Absorbance of extracted solutions was recorded using spectrophotometer at 645 and 663 nm and using following formula, total chlorophyll content was calculated:

$$\text{Total chlorophyll content (mg g}^{-1}\text{)} = [20.7 (\text{OD } 645) + 8.02 (\text{OD } 663)] \times V/1000 \times W$$

Turfgrass quality was measured according to Cooper and Spokas (1991) and leaf NPK contents were analyzed according to Chapman and Parker (1961) and Yoshida *et al.* (1971).

Statistical Analysis: The experiment was conducted using a Randomized Complete Block Design (RCBD) with three replications. Data were analyzed by

Analysis of Variance (ANOVA) using the General Linear Model (GLM) procedure in Statistix 8.1 (Analytical Software, Tallahassee, FL, USA). Treatment means were compared using Fisher's least significant difference (LSD) test at the 5% probability level ($P \leq 0.05$), and P-values were generated from the GLM analysis (Steel *et al.*, 1997).

Table 1. Monthly average of maximum, minimum, mean temperatures, average relative humidity and average precipitation during 2023-2024 from on-site weather station.

Monthly Mean Temperature, Relative Humidity and Precipitation												
	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
	Jan.	Jan.	Feb.	Feb.	Mar.	Mar.	Apr.	Apr.	May	May	June	June
Avg. Max. (°C)	17.2	13.3	26.0	24.6	28.8	28.1	34.9	35.8	37.6	43.6	40.3	43.2
Avg. Min. (°C)	5.2	5.3	10.5	7.5	15.5	11.4	18.5	15.8	23.2	23.0	27.0	27.1
Mean (°C)	11.3	9.3	18.3	16.0	22.2	19.8	26.7	25.8	30.4	33.3	34.2	35.2
Avg. RH (%)	85.0	82.3	72.0	58.1	82.4	55.5	68.9	49.5	55.7	36.5	59.2	41.0
Avg. Precip. (mm)	31.2	0.0	14.3	7.5	72.5	5.8	35.7	21.2	20.7	15.6	32.0	19.6
	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
	July	July	Aug.	Aug.	Sept.	Sept.	Oct.	Oct.	Nov.	Nov.	Dec.	Dec.
Avg. Max. (°C)	36.7	39.7	39.2	39.0	37.2	37.4	32.7	32.6	27.2	25.5	23.0	20.7
Avg. Min. (°C)	27.2	28.0	29.2	29.5	26.1	28.0	18.1	18.7	13.8	15.7	7.2	28.0
Mean (°C)	32.0	33.2	34.2	31.9	31.6	32.3	25.4	25.6	20.5	21.1	15.1	13.5
Avg. RH (%)	76.2	69.4	66.3	73.1	68.5	73.7	73.4	64.4	68.6	58.1	70.0	58.4
Avg. Precip. (mm)	66.4	201.9	12.3	116.2	95.0	191.6	30.7	0.0	3.8	0.0	0.0	0.0

(<https://web.uaf.edu.pk/Main/AgrometBuletin?iYear=2023>, <https://web.uaf.edu.pk/Main/AgrometBuletin?iYear=2024>)

RESULTS AND DISCUSSION

Results revealed significant differences of various fertilizer regimes compared to control for all growth

and quality attributes. Grass produced highest tiller length (11.5 cm), number of tillers (27.8), number of leaves per tiller (13.8) and length of leaf blade (18.8 mm) when fertilized with NPK + Fe + PGPR, but

results of leaf blade length and number of leaves were statistically at par with NPK + Fe and poly-coated DAP (Table 2). Similarly, application of NPK + Fe + PGPR resulted in the greatest leaf area (0.67 cm^2), internodal distance (12.8 mm) and stolon diameter (0.94 mm), with internodal distance and stolon diameter remained statistically similar to NPK + Fe. Canopy, total chlorophyll content was also found highest (0.26 mg g^{-1}) when fertilized with applications of NPK + Fe + PGPR (Table 3). It also produced greatest fresh and dry weights of tillers (4.1 g and 1.7 g, respectively). However, the moisture percentage of grass was recorded highest (60.8%) when grass was fertilized with smart fertilizer (polymer-coated DAP) which may be associated with its controlled nutrient release pattern.

Combined application of primary macro nutrients (NPK) along with essential micronutrient for chlorophyll, i.e. Fe, and a PGPR performed best compared to other fertilizer treatments and control (no fertilizer). Optimal doses of these fertilizers not only contributed towards better performance of grasses but also reduced the use of commercial fertilizers. Nitrogen has been recognized as a pivotal nutrient for the vegetative growth of plants because of its role in initiating meristematic activity, resulting in greater tiller height, leaf blade length, and the number of tillers and leaves. Previous studies have also reported that nitrogen enhances leaf cell division and enlargement, resulting in increased leaf production and improved turf performance (Li *et al.*, 2024). In addition, nitrogen deficiency is often associated with reduced growth and chlorosis (Hussain *et al.*, 2025), highlighting its importance in turfgrass management.

Highest tiller length (11.5 cm), number of tillers (27.8), number of leaves per tiller (13.8) and length of leaf blade (18.8 mm) were produced, when grass was fertilized with NPK + Fe + PGPR. The synthesis of phytohormones like auxins, cytokinins, and gibberellins, which directly promote root and shoot growth, is one of the significant approaches used by PGPRs to boost growth. (Ahmad *et al.*, 2023). Additionally, these microorganisms can assist in solubilizing phosphates and mobilizing other nutrients, making them readily available to plants. The production of phytohormones and the nutrient solubilization ability of the PGPR strains might be the possible reason for the observed increases in growth parameters. The synergistic effect of PGPR with NPK and micronutrients suggests that the bacteria may enhance the nutrient use efficiencies of NPK fertilizers and reduce their fixation in the soil and assist in improving the soil structure (Iqbal *et al.*, 2022). Using various mechanisms, plant growth-promoting rhizobacteria (PGPR) participate in geochemical nutrient cycles and influence their access to plants and the microbial community of the soil. Using these

bacteria as bio-inoculants also increases the availability of nutrient elements in soil, helps to minimize chemical fertilizer application, reduce environmental pollution, and promote sustainable agriculture (Etesami and Adl, 2020).

Application of NPK + Fe + PGPR resulted in the greatest leaf area (0.67 cm^2), internodal distance (12.8 mm) and stolon diameter (0.94 mm). Applications of NPK along with micronutrient and PGPR might have improved protein synthesis, photosynthesis and respiration rates (Garg *et al.*, 2026). The inclusion of PGPR further contributed to enhanced plant growth because they contain microorganisms, which improve nutrient cycling processes and their availability. PGPRs assist in boosting vegetative plant growth by variety of mechanisms as solubilization (P, K, and Zn-solubilizing bacteria), production of siderophores (low-molecular-weight proteins that chelates ferric ions from the environment), hormones like Indole acetic acid (IAA) (both in the presence and absence of Tryptophan), GA, etc. that help in the growth of the plant. These organisms can degrade chemical fertilizer residues like urea by producing urease enzyme. Apart from that many agriculturally significant enzymes like catalase, phosphatase, sulphate etc. These findings support the current study that NPK + Fe + PGPR-treated grass plants have greater chlorophyll contents and highest moisture percentage, which may be due to controlled nutrient release (Roy *et al.*, 2022).

Moreover, beneficial microorganisms such as *Bacillus* spp. are known to facilitate biological nitrogen fixation and enhance nutrient uptake, thereby reducing dependence on synthetic fertilizers (Farrar *et al.*, 2014). Similar findings in tiller height and density with PGPR inoculated with *Paenibacillus polymyxa* bacteria, have been reported in switchgrass and other turf species (Ker *et al.*, 2012). Similarly, nitrogen @ 30 g m^{-2} applied to turfgrass throughout the year enhanced number of tillers (Oral and Acikgoz, 2001). Moreover, N application in ryegrass enhanced growth by increasing dry matter production and leaves per stolon (Acero-Camelo *et al.*, 2020), which supports the present findings. Proper application of N and water to switchgrass enhanced the leaf blade area than the plants grown under water and N deficit conditions (Sanderson and Reed, 2000). Greater leaf area provides an expanded photosynthetic surface, enhancing assimilate production and overall turf health. N is a constituent of chlorophyll, promotes rapid growth and improves leaf quality. It was observed that an optimum dose of N improved cell numbers and sizes in leaves by enhancing leaf production and biomass yields along with more internodal distance among four to five upper internodes. PGPRs have significant influence on leaf elongation in turfgrass species. Increased leaf length in turfgrass is evidence of higher leaf area (Arredondo and Schnyder, 2003).

Table 2. Effect of various fertilization regimes on growth attributes of *Cynodon dactylon* (L.) Pers. 'Fine Dacca'. (n = 9)

Treatments	Height of tiller (cm)	Number of tillers	Number of leaves per tiller	Length of leaf blade (mm)	Stolon diameter (mm)	Internodal distance (mm)
Control	5.8 c ^z	12.0 d	9.3 c	9.6 c	0.62 d	8.5
N application	7.0 bc	17.7 c	10.9 bc	11.4 bc	0.71 cd	9.4
NPK application	7.8 bc	15.9 c	11.4 abc	12.8 bc	0.76 bcd	9.7
NPK + Fe application	9.0 b	21.9 b	11.9 ab	15.9 ab	0.91 ab	10.5
NPK + Fe + PGPR	11.5 a	27.8 a	13.8 a	18.8 a	0.94 a	12.8
Polymer coated DAP	9.0 b	22.4 b	11.8 ab	16.4 ab	0.88 abc	9.7
Significance ^y	0.0022	0.0000	0.0408	0.0226	0.0122	NS

^zMeans sharing different letters in the column are statistically different at P≤0.05.

^yP values were obtained using general linear models (GLM) of Statistix (version 8.1).

Table 3. Effect of various fertilization regimes on physiological attributes of *Cynodon dactylon* (L.) Pers. 'Fine Dacca'. (n = 9)

Treatments	Leaf area ^z (cm ²)	Canopy chlorophyll contents (mg g ⁻¹)	Fresh weight of tillers ^y (g)	Dry weight of tillers ^y (g)	Moisture percentage (%)
Control	0.28 d ^x	0.09 d	1.7 d	0.8 d	51.7 d
N application	0.35 cd	0.15 c	2.8 c	1.2 c	54.2 c
NPK application	0.42 c	0.15 c	2.8 c	1.2 c	55.8 bc
NPK + Fe application	0.54 b	0.19 b	3.4 b	1.5 b	55.6 bc
NPK + Fe + PGPR	0.67 a	0.26 a	4.1 a	1.7 a	57.5 b
Polymer coated DAP	0.55 b	0.15 c	3.3 b	1.3 bc	60.8 a
Significance ^w	0.0001	< 0.0001	< 0.0001	0.0001	0.0001

^zLeaf area was recorded for individual leaf for three (basal, central and upper) leaves per tiller and averaged.

^yFresh and dry weight of tillers were recorded for tillers from the ring used in the study for data collection.

^xMeans sharing different letters in the columns are statistically different at P≤0.05.

^wP values were obtained using general linear models (GLM) of Statistix (version 8.1).

Turf quality was also significantly enhanced under the integrated application of primary macronutrients and PGPR. Applications of NPK + Fe + PGPR resulted in more uniformity (7.5), high density (8.2), fine texture (8.1), smoothness (8.3) and dark green colored (7.8) grass as compared to applications of only primary macronutrients (Table 4). Improved turf color and appearance can be linked to enhanced chlorophyll content and nutrient status. In particular, iron plays a critical role in chlorophyll synthesis and chloroplast function, which directly influences turf color. Previous studies have reported that foliar iron application enhances and prolong turfgrass color and quality (Schmidt, 2003), while late-season nitrogen application contributes to sustained greenness and improved seasonal color retention (Schmidt and Chalmers, 1993). Similarly, application of late-season nitrogen improved fall color and spring green-up in 'Tifway' bermudagrass (Richardson, 2002) which also supports these results.

Nutrient analysis revealed that leaf nitrogen content was highest (3.9%) under both NPK + Fe + PGPR and NPK + Fe treatments, whereas total leaf phosphorous contents were recorded highest (0.9%) when smart fertilizer (polymer coated DAP) was applied (Table 5). Although, total leaf potassium contents were observed highest (1.8%) when grass was

fertilized with NPK applications but were statistically not different from NPK + Fe and NPK + Fe + PGPR. Increased nutrients rates maximized their concentrations in plants because of more accessibility of nutrients and well uptakes by plants. Zhang *et al.* (2012) also reported similar trends and demonstrated the impact of nitrogen, phosphorous and potassium application on their contents, distributions and accumulation characteristics in *Petunia hybrida*. Similarly, N, P and K applications in *Matthiola incana* enhanced nitrogen, phosphorous and potassium contents in the leaves of stock (Sarwar *et al.*, 2013). Moreover, increasing N, P and K levels in *Polianthes tuberosa* (tuberose) exhibited significant impacts on N, P and K in leaves (Khalaj *et al.*, 2012). NPK applied either as foliar spray or in combination with micronutrients or biostimulants enhanced nutrient uptake in cut flowers (Hussain *et al.*, 2026; Ahmad *et al.*, 2025). Overall, the combined application of macronutrients, iron, and PGPR proved to be the most effective strategy for improving growth and quality of bermudagrass. This integrated approach not only enhanced plant performance but also demonstrated potential for reducing reliance on conventional fertilizers through improved nutrient use efficiency, microbial activity environment friendly sustainable production.

Table 4. Effect of various fertilization regimes on quality attributes of *Cynodon dactylon* (L.) Pers. 'Fine Dacca'. (n = 9)

Treatments	Uniformity	Density	Texture	Smoothness	Color
Control	3.0 e ^z	2.9 d	3.2 f	2.9 e	3.3 e
N application	4.5 d	5.1 c	4.4 e	4.4 d	4.6 d
NPK application	5.3 c	4.8 c	5.5 d	5.9 c	5.5 c
NPK + Fe application	6.1 b	6.4 b	6.6 b	7.1 b	6.6 b
NPK + Fe + PGPR	7.5 a	8.2 a	8.1 a	8.3 a	7.8 a
Polymer coated DAP	6.2 b	6.4 b	6.0 c	6.4 c	6.2 b
Significance ^y	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

^zMeans sharing different letters in the columns are statistically different at P≤0.05.

^yP values were obtained using general linear models (GLM) of Statistix (version 8.1).

Table 5. Effect of various fertilization regimes on leaf nutrient contents of *Cynodon dactylon* (L.) Pers. 'Fine Dacca'. (n = 3)

Treatments	Total nitrogen contents (%)	Total phosphorous contents (%)	Total potassium contents (%)
Control	2.9 c ^z	0.3 c	0.8 c
N application	3.7 ab	0.4 c	1.0 bc
NPK application	3.6 ab	0.7 b	1.8 a
NPK + Fe application	3.9 a	0.6 b	1.7 a
NPK + Fe + PGPR	3.9 a	0.7 b	1.7 a
Polymer coated DAP	3.2 bc	0.9 a	1.1 b
Significance ^y	0.0271	< 0.0001	0.0001

^zMeans sharing different letters in the columns are statistically different at P≤0.05.

^yP values were obtained using general linear models (GLM) of Statistix (version 8.1).

CONCLUSION

Application of macronutrients, NPK along with Fe, and PGPR is an effective strategy for improving turf growth, quality, and nutrient status of bermudagrass. Integrated fertilizer approach enhanced key morphological and physiological attributes, including tillering, biomass production, chlorophyll contents, and overall turf appearance. Compared to conventional fertilization, the inclusion of PGPR and micronutrients improved nutrient uptake efficiency and contributed to superior plant performance. Although polymer-coated DAP improved moisture retention and phosphorus availability, it was less effective in enhancing overall growth and quality traits. Therefore, integrating macronutrients with iron (Fe) and PGPR can be considered a sustainable and effective nutrient management strategy for maintaining lush green healthy bermudagrass.

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AUTHORS' CONTRIBUTION

Muhammad Usman Tanveer: Conducted the experiment, data recording, data analysis and manuscript first draft write-up. **Iftikhar Ahmad:** Conceived the idea, provided resources and funding, technically reviewed and edited the manuscript. **Tazkia Hussain:** Assisted in data recording, manuscript formatting and editing.

CONFLICT OF INTEREST

All authors declare that there is no conflict of interest

REFERENCES

- Acero-Camelo, A., Pabón, M. L., Fischer, G., & Carulla-Fornaguera, J. E. (2020). Optimum harvest time for Kikuyu grass (*Cenchrus clandestinus*) according to the number of leaves per tiller and nitrogen fertilization. *Revista Facultad Nacional de Agronomía Medellín*, **73**(3), 9243–9253.
- Acikgoz, E., Bilgili, U., Sahin, F., & Guillard, K. (2016). Effect of plant growth-promoting *Bacillus* sp. on color and clipping yield of three turfgrass species. *Journal of Plant Nutrition*, **39**(10), 1404–1411.
<https://doi.org/10.1080/01904167.2016.1143501>
- Ahmad, I., Ashfaq, H., Dole, J. M., Hussain, T., Safdar, H., & Jabeen, A. (2025). Biostimulants improve growth, yield and quality of *Eustoma grandiflorum* L. and *Matthiola incana* L. *Ornamental Horticulture*, **31**, e312816.
- Ahmad, I., Hussain, S., Naveed, M., Mumtaz, M. Z., Shahid, M., & Zahir, Z. A. (2023). Mineral-solubilizing bacteria-mediated enzymatic regulation and nutrient acquisition benefit cotton (*Gossypium hirsutum* L.) vegetative and reproductive growth. *Microorganisms*, **11**, 861.
doi:10.3390/microorganisms11040861
- Ali, I., Mustafa, A., Yaseen, M., & Imran, M. (2017). Polymer coated DAP helps in enhancing growth, yield and phosphorus use efficiency of wheat (*Triticum aestivum* L.). *Journal of Plant Nutrition*, **40**(18), 2587–2594.
<https://doi.org/10.1080/01904167.2017.1381118>
- Arredondo, J. T., & Schnyder, H. (2003). Components of leaf elongation rate and their relationship to specific leaf area in contrasting grasses. *New Phytologist*, **158**(2), 305–314.
<https://doi.org/10.1046/j.14698137.2003.00745>

- Balemi, T., & Negisho, K. (2012). Management of soil phosphorus and plant adaptation mechanisms to phosphorus stress for sustainable crop production: a review. *Journal of Soil Science and Plant Nutrition*, **12**(3), 547–562. <https://doi.org/10.4067/S071895162012005000015>
- Beard, J. B. (1973). *Turfgrass: Science and culture*. Prentice-Hall.
- Carleton, A. E., & Foote, W. H. (1965). A comparison of methods for estimating total leaf area of barley plants. *Crop Science*, **5**(6), 602–603. <https://doi.org/10.2135/cropsci1965.0011183X0005000600041x>
- Chapman, H. D., & Parker, F. P. (1961). *Methods of analysis for soils, plants and waters*. Division of Agricultural Sciences, University of California. (pp. 150–179).
- Cooper, R. J., & Spokas, L. A. (1991). Growth, quality, and foliar iron concentration of Kentucky bluegrass treated with chelated iron sources. *Journal of the American Society for Horticultural Science*, **116**(5), 798–801.
- Coy, R. M., Held, D. W., & Kloepper, J. W. (2014). Rhizobacterial inoculants increase root and shoot growth in ‘Tifway’ hybrid bermudagrass. *Journal of Environmental Horticulture*, **32**(3), 149–154. <https://doi.org/10.24266/0738-2898.32.3.149>
- Cui, F., Taier, G., Li, M., Dai, X., Hang, N., et al. (2021). The genome of the warm-season turfgrass African bermudagrass (*Cynodon transvaalensis*). *Horticulture Research*, **8**, 93. <https://doi.org/10.1038/s41438-021-00519-w>
- Etesami, H., & Adl, S. M. (2020). Plant growth-promoting rhizobacteria (PGPR) and their action mechanisms in availability of nutrients to plants. In M. Kumar, V. Kumar, & R. Prasad (Eds.), *Phyto-microbiome in stress regulation* (Environmental and Microbial Biotechnology). Singapore: Springer. doi:10.1007/978-981-15-2576-6_9
- Fahad, S., Hussain, S., Saud, S., Hassan, S., Tanveer, M., Ihsan, M. Z., Shah, A. N., Ullah, A., Nasrullah, Khan, F., Ullah, S., Alharby, H., Nasim, W., Wu, C., & Huang, J. (2016). A combined application of biochar and phosphorus alleviates heat-induced adversities on physiological, agronomical and quality attributes of rice. *Plant Physiology and Biochemistry*, **103**, 191–198. <https://doi.org/10.1016/j.plaphy.2016.03.001>
- Fan, J., Xiang, Y., Zhang, B., Noor, M., Zhang, J., & Yan, X. (2024). Progress and prospects of bermudagrass research in the last decade. *Grass Research*, **4**(1).
- Farrar, K., Bryant, D., & Cope-Selby, N. (2014). Understanding and engineering beneficial plant–microbe interactions: Plant growth promotion in energy crops. *Plant Biotechnology Journal*, **12**(9), 1193–1206. <https://doi.org/10.1111/pbi.12279>
- Garg, N., Gupta, N., Vyas, P., Bhardwaj, R., Goyal, M., & Kaur, G. (2026). Biofortification of millets with zinc and iron by plant growth promoting rhizobacteria (PGPR). *Journal of Pure and Applied Microbiology*, **20**(1), 139.
- Gouda, S., Kerry, R. G., Das, G., Paramithiotis, S., Shin, H. S., & Patra, J. K. (2018). Revitalization of plant growth-promoting rhizobacteria for sustainable development in agriculture. *Microbiological Research*, **206**, 131–140. <https://doi.org/10.1016/j.micres.2017.08.016>
- Hasanuzzaman, M., Nahar, K., Alam, M. M., Roychowdhury, R., & Fujita, M. (2013). Physiological, biochemical, and molecular mechanisms of heat stress tolerance in plants. *International journal of molecular sciences*, **14**(5), 9643–9684.
- He, Y., Pantigoso, H. A., Wu, Z., & Vivanco, J. M. (2019). Co-inoculation of *Bacillus* sp. and *Pseudomonas putida* at different development stages acts as a biostimulant to promote growth, yield and nutrient uptake of tomato. *Journal of Applied Microbiology*, **127**(1), 196–207. <https://doi.org/10.1111/jam.14273>
- Hocking, P. J. (2001). Organic acids exuded from roots in phosphorus uptake and aluminum tolerance of plants in acid soils. In: *Advances in Agronomy*, pp. 63–97. [https://doi.org/10.1016/S0065-2113\(01\)74031-X](https://doi.org/10.1016/S0065-2113(01)74031-X)
- Huang, S., Jiang, S., Liang, J., Chen, M., & Shi, Y. (2019). Current knowledge of bermudagrass responses to abiotic stresses. *Breeding Science*, **69**(2), 215–226. <https://doi.org/10.1270/jsbbs.18164>
- Hussain, T., Ahmad, I., Dole, J. M., & Khalid, B. (2026). Optimal production protocols for cut China aster (*Callistephus chinensis* L.) and snapdragon (*Antirrhinum majus* L.). *Pakistan Journal of Botany*, **58**(1), 273–280. doi:10.30848/PJB2026-1(5)
- Hussain, T., Ahmad, I., Ziaf, K., Ahmad, N., Hussain, Z., & Sardar, S. (2025). Nitrogen fertilization enhances growth, quality and seed production of celosia (*Celosia cristata* L.), marigold (*Tagetes erecta* L.) and zinnia (*Zinnia elegans* L.). *Journal of Horticultural Science & Technology*, **8**(3), 76–81. <https://doi.org/10.46653/jhst25083076>
- Ihtisham, M., Fahad, S., Luo, T., Larkin, R. M., Yin, S., & Chen, L. (2018). Optimization of nitrogen, phosphorus, and potassium fertilization rates for overseeded perennial ryegrass turf on dormant bermudagrass in a transitional climate. *Frontiers in Plant Science*, **9**, 487. <https://doi.org/10.3389/fpls.2018.00487>
- Iqbal, Z., Mumtaz, M. Z., Naveed, M., Ali, A., Zahir, Z. A., & Shahid, M. (2022). Combined use of novel endophytic and rhizobacterial strains upregulates antioxidant enzyme systems and mineral accumulation in wheat. *Agronomy*, **12**, 551. doi:10.3390/agronomy12030551

- Johnson, R., Vishwakarma, K., Hossen, M. S., Kumar, V., Shackira, A. M., Puthur, J. T., Abdi, G., Sarraf, M., & Hasanuzzaman, M. (2022). Potassium in plants: Growth regulation, signaling, and environmental stress tolerance. *Plant Physiology and Biochemistry*, **172**, 56–69. <https://doi.org/10.1016/j.plaphy.2022.01.001>
- Ke, T., Zhang, J., Tao, Y., Zhang, C., Zhang, Y., Xu, Y., & Chen, L. (2021). Individual and combined application of Cu-tolerant *Bacillus* spp. enhance the Cu phytoextraction efficiency of perennial ryegrass. *Chemosphere*, **263**, 127952. <https://doi.org/10.1016/j.chemosphere.2020.127952>
- Khalaj, M. A., Edrisi, B., & Amiri, M. (2012). Effect of nitrogen and plant spacing on nutrients uptake, yield and growth of tuberose (*Polianthes tuberosa*). *Journal of Ornamental and Horticultural Plants*, **2**(1), 45–54.
- Kumar, D., Singh, M., Kushwaha, M., Makarana, G., & Yadav, M. R. (2021). Integrated use of organic and inorganic nutrient sources influences the nutrient content, uptake and nutrient use efficiencies of fodder oats (*Avena sativa*). *Indian Journal of Agronomy*, **66**(4), 466–473.
- Li, D., Wang, J., Chen, R., Chen, J., Zong, J., Li, L., & Guo, H. (2024). Nitrogen acquisition, assimilation, and seasonal cycling in perennial grasses. *Plant Science*, **342**, 112054. <https://doi.org/10.1016/j.plantsci.2024.112054>
- Lim, P. O., Kim, H. J., & Gil Nam, H. (2007). Leaf senescence. *Annual Review of Plant Biology*, **58**, 115–136. <https://doi.org/10.1146/annurev.arplant.57.032905.105316>
- Menezes-Blackburn, D., Giles, C., Darch, T., George, T. S., Blackwell, M., Stutter, M., Shand, C., Lumsdon, D., Cooper, P., Wendler, R., Brown, L., Almeida, D. S., Wearing, C., Zhang, H., & Haygarth, P. M. (2017). Opportunities for mobilizing recalcitrant phosphorus from agricultural soils: a review. *Plant and Soil*, **427**, 5–16. <https://doi.org/10.1007/s11104-017-3362-2>
- Nagarajan, V. K., & Smith, A. P. (2012). Ethylene's role in phosphate starvation signaling: more than just a root growth regulator. *Plant and Cell Physiology*, **53**, 277–286. <https://doi.org/10.1093/pcp/pcr186>
- Nawaz, U., Ahmad, I., Hussain, T., Qamar, S., Munir, H. B., Shehryar, H. S., Nawaz, A., & Munir, T. Evaluation of various exotic gladiolus cultivars through staggered planting in subtropics. *Trends in Animal and Plant Sciences*, 2025, 6:147-157. <https://doi.org/10.62324/TAPS/2025.088>
- Oleńska, E., Małek, W., Wójcik, M., Świąćicka, I., Thijs, S., & Vangronsveld, J. (2020). Beneficial features of plant growth-promoting rhizobacteria for improving plant growth and health in challenging conditions: A methodical review. *Science of the Total Environment*, **743**, 140682. <https://doi.org/10.1016/j.scitotenv.2020.140682>
- Parra-Almuna, L., Diaz-Cortez, A., Ferrol, N., & Mora, M. L. (2018). Aluminium toxicity and phosphate deficiency activates antioxidant systems and up-regulates expression of phosphate transporters gene in ryegrass (*Lolium perenne* L.) plants. *Plant Physiology and Biochemistry*, **130**, 445–454. <https://doi.org/10.1016/j.plaphy.2018.07.031>
- Radkowski, A., Wolski, K., Radkowska, I., Burduk, R., Khachatryan, K., Bujak, H., & Jelen, L. (2023). Variance analysis of an experimental study of the effects of amino acids and Fe chelate on turfgrass. *Journal of Elementology*, **28**(4), 1155-1174.
- Rehman, F. U., Kalsoom, M., Adnan, M., Toor, M. D., & Zulfiqar, A. (2020). Plant growth promoting rhizobacteria and their mechanisms involved in agricultural crop production: A review. *SunText Review of Biotechnology*, **1**(2), 1–6.
- Richardson, M. D. (2002). Turf quality and freezing tolerance of 'Tifway' bermudagrass as affected by late-season nitrogen and trinexapac-ethyl. *Crop Science*, **42**(5), 1621–1626. <https://doi.org/10.2135/cropsci2002.1621>
- Richardson, A. E., Barea, J. M., McNeill, A. M. & Prigent-Combaret, C. (2009). Acquisition of phosphorus and nitrogen in the rhizosphere and plant growth promotion by micro-organisms. *Plant and Soil*, **321**, 305–339. <https://doi.org/10.1007/s11104-009-9895-2>
- Roy, S., Bhowmik, S., Chowdhury, A. D., Dhara, B., & Mitra, A. K. (2022). Plant growth-promoting rhizobacteria: An alternative for NPK fertilizers. In *Microbes and microbial biotechnology for green remediation* (pp. 149–167). Elsevier.
- Sanderson, M. A., & Reed, R. L. (2000). Switchgrass growth and development: Water, nitrogen, and plant density effects. *Journal of Range Management*, **53**(2), 221–227.
- Sarwar, M., Rehman, S. U., Ayyub, C. M., Ahmad, W., Shafi, J., & Shafique, K. (2013). Modeling growth of cut-flower stock (*Matthiola incana* R. Br.) in response to differing nutrient levels. *Universal Journal of Food and Nutrition Science*, **1**(1), 4–10.
- Saud, S., Fahad, S., Cui, G., Chen, Y., & Anwar, S. (2020). Determining nitrogen isotope discrimination under drought stress on enzymatic activities, nitrogen isotope abundance and water contents of Kentucky bluegrass. *Scientific Reports*, **10**, 6415. <https://doi.org/10.1038/s41598-020-63548-w>
- Schmidt, R. E. (2003). Late-season fertilization of bermudagrass. *Golf Course Management*, **71**, 125–127.
- Schmidt, R. E., & Chalmers, D. R. (1993). Late summer to early fall application of fertilizer and biostimulants on bermudagrass. *International Turfgrass Society Research Journal*, **7**, 715–721.
- Song, L., & Liu, D. (2015). Ethylene and plant responses to phosphate deficiency. *Frontiers of*

- Plant Science*, **6**, 1–14.
<https://doi.org/10.3389/fpls.2015.00796>.
- Steel, R. G. D., Torrie, J. H., & Dickey, D. A. (1997). *Principles and procedures of statistics: A biometrical approach* (3rd ed., pp. 328–345). McGraw-Hill.
- Tantray, A. Y., Bashir, S. S., & Ahmad, A. (2020). Low nitrogen stress regulates chlorophyll fluorescence in coordination with photosynthesis and Rubisco efficiency of rice. *Physiology and Molecular Biology of Plants*, **26**, 83–94.
<https://doi.org/10.1007/s12298-019-00721-0>
- Taylor, J. W., Liu, H., White, S. A., & Luo, H. (2025). Iron fertilization and shade impacts on two warm-season turfgrasses under greenhouse conditions. *International Turfgrass Society Research Journal*, **15**(1), 420–444. <https://doi.org/10.1002/its2.192>
- Toor, M. D., Adnan, M., Rehman, F. U., Tahir, R., Saeed, M. S., Khan, A. U., & Pareek, V. (2021). Nutrients and their importance in agricultural crop production: A review. *Indian Journal of Pure and Applied Biosciences*, **9**(1), 1–6.
<https://doi.org/10.18782/2582-2845.8527>
- Vance, C. P., Uhde-Stone, C., & Allan, D. L. (2003). Phosphorus acquisition and use: critical adaptations by plants for securing a nonrenewable resource. *New Phytologist*, **157**, 423–447.
<https://doi.org/10.1046/j.1469-8137.2003.00695.x>
- Velez, P. C. (2013). *Effect of microbial inoculation on nitrogen plant uptake and nitrogen losses from soil and plant soil systems* (Doctoral dissertation). Auburn University.
- Walker, W. J., & Branham, B. (2020). Environmental impacts of turfgrass fertilization. *Golf Course Management & Construction*, 105–219.
- Yoshida, S., Forno, D. A., Cock, J. H., & Gomez, K. A. (1971). *Laboratory manual for physiological studies of rice*. International Rice Research Institute.
- Zaman, F., Zhang, E., Khattak, W. A., Li, J., Ilyas, M., Deng, X., Ihtisham, M., Guo, F., Wang, P., Wang, M., Wang, Y., Ni, D., & Zhao, H. (2022). Natural variations and dynamics of macronutrients for 87 tea plant (*Camellia sinensis*) varieties throughout the growing seasons in Wuhan. *Scientia Horticulturae*, **306**, 111425.
<https://doi.org/10.1016/j.scienta.2022.111425>
- Zhang, W., Li, X., Chen, F., & Lu, J. (2012). Accumulation and distribution characteristics for nitrogen, phosphorus and potassium in different cultivars of *Petunia hybrida* Vilm. *Scientia Horticulturae*, **141**, 83–90.
<https://doi.org/10.1016/j.scienta.2012.04.010>
- Zywocinski, K., Gozdecka, G., & Korpai, W. (2011). Application of aqueous polymer dispersions for encapsulation of granular fertilizers. *Chemik*, **65**(4), 347–352.

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