



RESEARCH ARTICLE

Optimisation of NPK fertilisation for enhanced growth, yield, quality and economic returns of climate-resilient dwarf red banana (*Musa acuminata* AAA)

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Abstract

The present study was undertaken to develop an optimised fertiliser recommendation for a climate-resilient dwarf mutant of red banana (dwarf red banana) and to compare its performance with the locally cultivated tall red banana. Field experiments were conducted during 2021–2022 and 2022–2023 at the Coconut Research Station, Balaramapuram, using a randomised block design (RBD) with 4 NPK (nitrogen, phosphorus and potassium) levels: N₁ (200:200:400 g per plant), N₂ (150:150:300 g per plant), N₃ (250:250:500 g per plant) and N₄ (300:300:600 g per plant), replicated 5 times. Across both years, the N₄ treatment consistently produced superior vegetative growth, as indicated by a higher number of functional leaves, increased pseudostem girth and maximum dry matter accumulation. Yield attributes including number of hands per bunch, fingers per hand and finger length and girth were also significantly higher in N₄. This treatment further recorded significantly greater N, P and K uptake, resulting in significantly higher bunch weight. Economic analysis revealed that N₄ achieved the highest gross return, net return and benefit cost ratio. Quality assessment revealed that, at the NPK level of 200:200:400 g per plant, dwarf red banana fruits exhibited significantly higher total soluble solids, reducing sugar and ascorbic acid content compared with those of the tall ordinary red banana. Overall, an NPK dose of 300:300:600 g per plant was identified as optimal for maximising the productivity and profitability of dwarf red banana. The cultivar's naturally reduced stature, sturdy pseudostem and enhanced tolerance to wind damage highlight its potential as a climate-smart alternative for banana growing regions vulnerable to climate variability.

Keywords: benefit cost ratio; bunch weight; dwarf red banana; gross return; net return; tall red banana

Introduction

Bananas (*Musa* spp.) rank among the most widely consumed fruits globally and maintain a strong presence in international markets (1). The crop plays a vital role in economic development, food security and human nutrition (2, 3). Nutritionally, bananas serve as an important source of potassium, magnesium, copper, manganese and vitamin C (4). Their high levels of fibre, protein, minerals and antioxidant compounds also make banana a valuable dietary supplement.

India is the world's leading banana producer, with a total production of 35.03 million tonnes from 0.956 million hectares (5). In Kerala alone, banana occupies 49020 ha with a production of 461244 tonnes (6). Located in southern India, Kerala possesses diverse agro-climatic zones and rich banana genetic resources, enabling the crop to thrive in both wild and cultivated forms (7).

Among the cultivated types, the red banana locally referred to as Chenkadali or Kappapazham is highly valued for its characteristic reddish peel, superior flavour, cultural significance and enhanced nutritional profile. Red bananas are particularly rich in polyphenols, vitamins, minerals and other bioactive compounds (8). The fleshy endocarp contains higher flavonoid levels than those found in the common yellow banana (9). Classified under the triploid genomic group AAA, red banana occupies an important place in local markets, homestead gardens and small-scale farming systems across Kerala.

During a field survey in the Maranalloor panchayat of Thiruvananthapuram district, a naturally occurring dwarf mutant of red banana was identified in a farmer's field. Plant stature is a crucial agronomic trait that affects crop stability, especially in regions prone to strong winds, heavy rainfall and seasonal storms. Tall banana cultivars, despite their popularity, frequently suffer lodging and

pseudostem breakage under adverse weather conditions, causing substantial yield losses and economic strain for growers.

Recognising its potential, the dwarf type was subjected to detailed evaluation to determine its horticultural value, distinctiveness and suitability for wider adoption. The mutant referred to as the dwarf red banana was assessed over 3 consecutive years at the Coconut Research Station, Balaramapuram and its performance was compared with that of the locally cultivated tall red banana from the same genomic group (AAA). Morphological and molecular analyses confirmed its distinctiveness. Yield evaluations showed that the dwarf red banana produced bunches comparable in weight to those of the tall type, demonstrating that reduced plant height did not compromise productivity. Additionally, the dwarf red banana reached maturity in approximately 12 months, compared with 15–16 months for the tall red banana, making it more suitable for commercial cultivation and high-density planting systems. The reduced stature, greater wind resistance and shorter crop duration collectively position the dwarf red banana as a climate-resilient alternative with reduced risk of environmental losses.

Adequate nutrient supply is critical for optimising growth, yield and fruit quality in bananas. Although soil contribute part of the nutrient requirement, supplemental fertilisation is essential (10). Nitrogen strongly influences vegetative growth, flowering and productivity (11). Phosphorus, though required in smaller amounts, promotes robust rhizome and root development, improves plant vigour, reduces lodging and supports proper flower formation. Potassium widely regarded as a “quality nutrient” is particularly important during the flowering stage (12). Adequate potassium enhances growth, improves physiological efficiency, strengthens tolerance to biotic and abiotic stresses (13), promotes early shooting, increases fruit size and number, enhances sweetness and overall fruit quality and improves shelf life (14). As a result, banana fertiliser schedules typically prioritise higher levels of nitrogen and potassium (15).

Considering these aspects, the present study was undertaken to standardise NPK requirements for the dwarf red banana and to compare its fruit quality with that of the tall red banana, with the goal of developing a fertiliser recommendation schedule for this climate-resilient natural mutant.

Materials and Methods

Field experiments were conducted at the Coconut Research Station, Balaramapuram, during 2021–2022 and 2022–2023 with the objective of standardising the fertiliser recommendation for dwarf red banana (*Musa acuminata* AAA cv. dwarf red banana). The experimental site is located at 8°22'52" N latitude, 77°01'47" E longitude, at an altitude of 9 m above mean sea level and experiences a warm, humid climate. The rainfall received during 2021–2022 was 2753.2 mm and during 2022–2023 was 1721.8 mm. The mean maximum and minimum temperatures during 2021–2022 were 32 °C and 23.8 °C, respectively and during 2022–2023 were 31.4 °C and 21.9 °C, respectively.

The experiment was laid out in a randomised block design with 5 replications and 4 treatments. The treatments included NPK levels of N₁: 200:200:400 g per plant (package of practices recommendation for other banana varieties), N₂: 150:150:300 g per plant, N₃: 250:250:500 g per plant and N₄: 300:300:600 g per plant.

During 2021–2022, suckers of dwarf red banana were planted on 20 January 2021; during 2022–2023, planting was done on 20 February 2022. In each treatment plot, 4 plants were maintained. A bund of 30 cm height and 20 cm width was formed around each treatment plot to prevent leaching losses of nutrients. For comparison of fruit quality, suckers of tall red banana were planted on the same dates and were fertilised with NPK at 200:200:400 g per plant.

Nitrogen in the form of urea, phosphorus as rock phosphate and potassium as muriate of potash were applied according to the treatment schedule. Farmyard manure (10 kg per plant) and lime (250 g per plant) were uniformly incorporated into the soil prior to planting the suckers. All other cultural and management practices were carried out as per the KAU package of practice for banana cultivation (16). Suckers of tall red banana received NPK at 200:200:400 g per plant.

The soil of the experimental site was acidic in reaction and normal in electrical conductivity (EC) during both years. The initial available nutrient status during 2021–2022 was 265.2 kg N ha⁻¹, 23.2 kg P ha⁻¹ and 295.6 kg K ha⁻¹, while during 2022–2023 the available N, P and K contents were 234.6, 19.4 and 229.7 kg ha⁻¹, respectively.

Observations on growth parameters, plant height, pseudostem girth and number of leaves per plant were recorded at complete emergence of the bunch. Dry matter accumulation in the leaves, pseudostem, peduncle, fruits and rhizome were recorded at harvest for both dwarf red banana and tall red banana to determine the total dry matter produced by the plant. Yield attributes, including fruit girth, fruit length, number of fruits on the D hand, number of hands per bunch and bunch weight, were also recorded at harvest.

Nutrient uptake (N, P and K) by dwarf red banana and tall red banana was determined at harvest by summing the N, P and K uptake of the leaves, pseudostem, peduncle, fruits and rhizome. Uptake in each plant part was calculated by multiplying its respective N, P and K content with the corresponding dry matter production. The NPK content of different plant parts was determined following standard procedures. Post-harvest soil available N, P and K were also assessed using standard analytical methods.

Economic parameters, gross return, net return and benefit cost ratio were computed based on input costs and the market price of dwarf red banana fruits (₹60 kg⁻¹). Fruit quality attributes namely titratable acidity, total soluble solids, total sugars, reducing sugar and ascorbic acid contents of both tall and dwarf red banana fruits fertilised with 200:200:400 g per plant were evaluated using standard protocols.

Experimental data were analysed using analysis of variance (ANOVA) for a randomised block design (RBD) following the standard procedures (17). Significance was tested using the F-test (18) and least significant difference (LSD) was calculated at $p < 0.05$. Statistical analyses were performed using Grapes Agri I, an open-source R package for agricultural research data analysis (19).

Results and Discussion

Effect of NPK levels on growth attributes of dwarf red banana

The results on the growth attributes of dwarf red banana at the bunch emergence stage during 2021–2022 and 2022–2023 indicated that NPK levels had a significant influence on plant height, pseudostem girth and number of functional leaves per plant in both

years (Table 1). Among the fertiliser treatments, the highest NPK level (N₄: 300:300:600 g per plant) produced the tallest plants in 2022–2023 and was statistically comparable with N₃ (250:250:500 g per plant) and N₂ (200:200:400 g per plant). Pseudostem girth was also significantly greater in N₄ followed by N₃. A similar trend was observed for leaf production: N₄ resulted in the highest number of leaves during both years, being on par with N₃ and N₂ in 2021–2022 and significantly superior to all other treatments in 2022–2023. These findings are consistent with observations in Njalipoovan, where higher NPK application rates enhanced plant growth under Onattukkara sandy plain conditions (20). The superior growth observed in N₄ (300:300:600 g NPK per plant) in the present study may be attributed to increased nutrient availability and uptake. Enhanced nutrient uptake likely supported a greater number of functional leaves, which improved photosynthetic efficiency and assimilate translocation, ultimately contributing to better overall plant growth.

Ordinary tall banana fertilised with NPK at 200:200:400 g per plant produced taller plants and a greater number of leaves per plant than dwarf banana fertilised with the same NPK level. However, pseudostem girth was found to be higher in the dwarf red banana.

Effect of NPK levels on dry matter production of dwarf red banana

Dry matter production per plant of dwarf red banana at harvest was significantly influenced by nutrient levels (Fig. 1). Among the nutrient levels, N₄ (NPK applied at 300:300:600 g per plant) resulted in significantly higher dry matter production per plant during both the years. The treatment N₄ was followed by N₃ and the lowest in N₂. The higher dry-matter production recorded in N₄ appears to result from its greater number of functional leaves per plant, larger pseudostem girth and increased plant height, along with enhanced nutrient uptake and higher bunch weight. Similar observations were also observed in banana cv. Robusta (21).

The dry matter production by tall ordinary banana fertilised with NPK at 200:200:400 g per plant was comparatively higher than that of dwarf red banana fertilised with the same NPK level.

Effect of NPK levels on yield attributes of dwarf red banana

The yield attributes of dwarf red banana were significantly influenced by nutrient levels during 2021–2022 and 2022–2023 (Table 2). In both years, the treatment N₄, dwarf red banana fertilised with NPK at 300:300:600 g per plant resulted in better expression of yield attributes. During 2021–2022, N₄ produced fruits with greater girth and significantly higher fruit length, as well as a higher number of fruits on the D hand. However, the number of hands per bunch was not significantly affected. During 2022–2023, N₄ again produced significantly higher fruit girth. Although fruit length, number of fruits on the D hand and number of hands per bunch were also higher in N₄, these values were on par with those of N₃. The treatment N₂ recorded lower values for fruit girth, fruit length, number of fruits on the D hand and number of hands per bunch. The superior expression of yield attributes in N₄ and N₃ was due to the higher dry matter production observed in these treatments, resulting from increased nutrient uptake and better translocation of assimilates from source to sink. Similar findings were observed in cultivar Robusta (22) and in Grand Naine (2, 23, 24).

The ordinary tall banana recorded higher values for fruit girth, fruit length, number of hands per bunch and number of fruits on the D hand compared to the dwarf red banana when fertilised with NPK at 200:200:400 g per plant

Effect of NPK levels on bunch weight of dwarf red banana

During both years, the bunch weight of dwarf red banana was significantly influenced by NPK levels (Fig. 2). Among the treatments, N₄ resulted in significantly higher bunch weight (24.4 and 25.0 kg per plant, respectively). The higher bunch weight recorded in this treatment was due to the greater number of hands per bunch, as well as higher finger girth and length. Increased availability of

Table 1. Effect of nutrient levels on the growth attributes for dwarf red banana at bunch emergence stage

Treatments	Plant height (cm)		Pseudostem girth (cm)		Number of functional leaves per plant	
	2021–2022	2022–2023	2021–2022	2022–2023	2021–2022	2022–2023
N ₁ : NPK at 200:200:400 g per plant (POP)	185.5	190.1	66.1	65.7	11.7	11.5
N ₂ : NPK at 150:150:300 g per plant	185.0	176.7	64.0	63.3	9.8	9.8
N ₃ : NPK at 250: 250: 500 g per plant	185.9	193.8	74.3	76.1	12.4	12.0
N ₄ : NPK at 300: 300: 600 g per plant	195.1	203.7	78.8	79.2	12.5	13.1
SEm ±	3.8	3.5	0.70	0.96	0.40	0.35
CD ($p = 0.05$)	NS	11.07	2.16	2.95	1.24	1.09
Ordinary tall red banana (NPK at 200:200:400)	315.5	319.6	65.6	64.3	13.5	12.9

NS: not-significant; POP: package of practice.

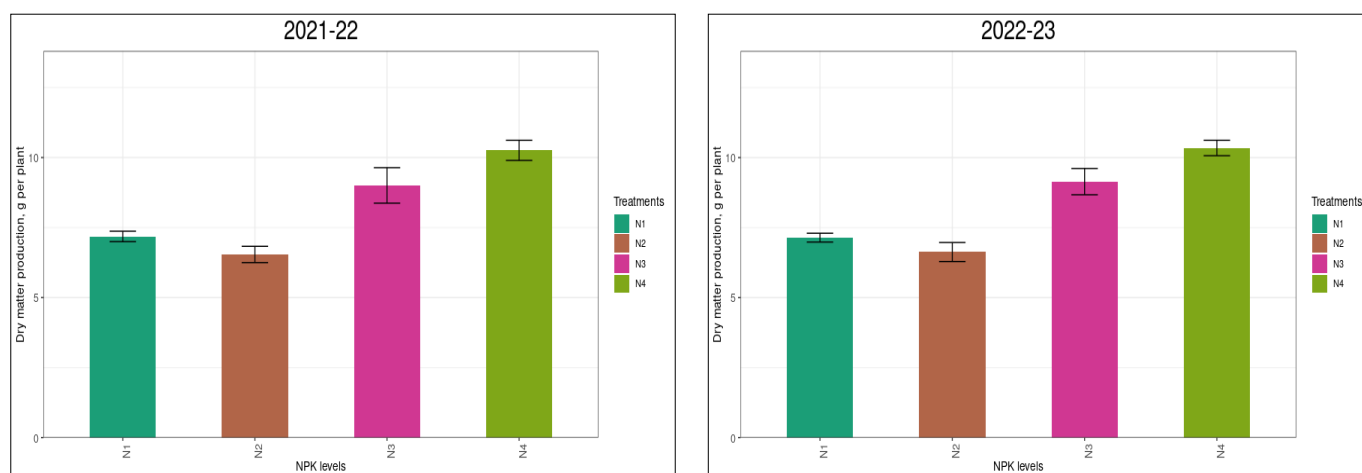
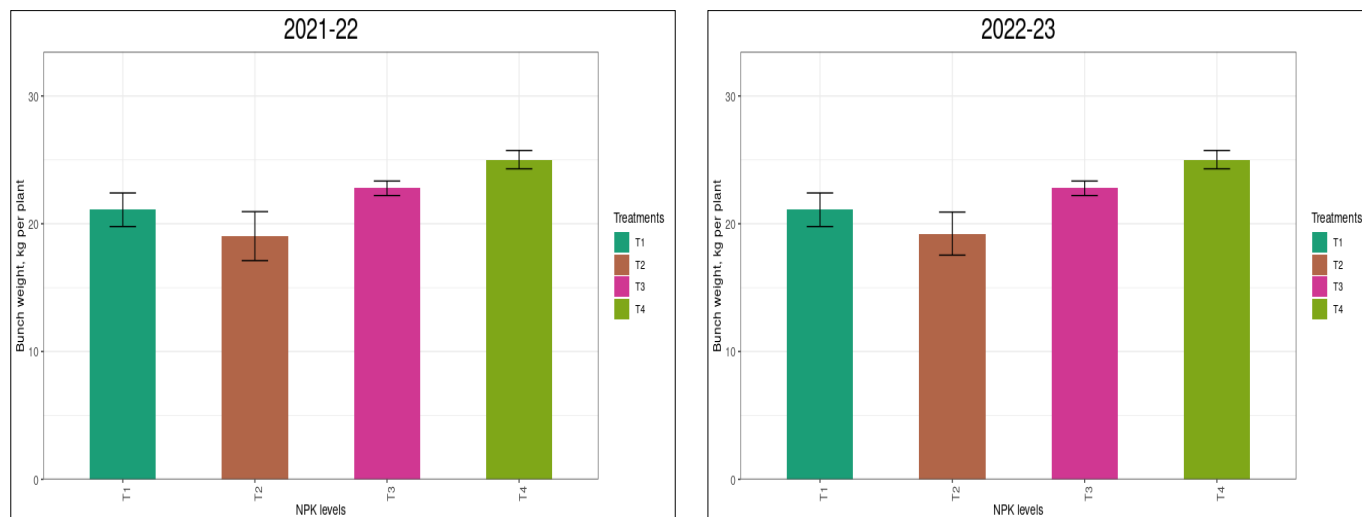


Fig. 1. Effect of NPK levels on dry matter production of dwarf red banana, gram per plant.

Table 2. Effect NPK levels on the yield attributes of dwarf red banana

Treatment	Fruit length (cm)		Fruit girth (cm)		Number of hands in the bunch		Number of fruits on D hand	
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
N ₁ : NPK at 200:200:400 g per plant (POP)	19.1	19.1	14.6	15.6	5.7	5.4	13.2	13.4
N ₂ : NPK at 150:150:300 g per plant	19.7	17.1	13.3	13.3	5.5	4.6	11.6	11.8
N ₃ : NPK at 250: 250: 500 g per plant	20.3	20.2	15.5	15.8	5.8	5.4	14.2	14.6
N ₄ : NPK at 300: 300: 600 g per plant	22.0	21.8	16.6	17.7	6.0	5.8	15.2	15.6
SEm ±	0.6	0.4	0.3	0.6	0.2	0.2	0.3	0.4
CD ($p = 0.05$)	1.74	1.33	1.05	1.85	NS	0.52	0.79	1.20
Ordinary tall red banana (NPK at 200:200:400)	20.9	21.7	15.8	16.2	6.0	6.0	15.4	15.0

NS: not-significant; POP: package of practice.

**Fig. 2.** Effect of NPK levels on the bunch weight of dwarf red banana, kg per plant.

nutrients led to increased nutrient uptake, which ultimately resulted in better expression of growth attributes, dry matter production and yield attributes, thereby contributing to the higher yield observed in N₄. Similar observations were also observed in Grand Naine (24) and in Njalipoovan (19). Earlier studies have also reported that a higher potassium application rate (600 g per plant) increased bunch weight in the cultivar Palayankodan (25).

Pseudostem height, pseudostem girth and leaf area are key contributors to dry matter production, which in turn resulted in higher bunch yield (26). Tall banana plants, because of their greater height and larger leaves, exhibited enhanced photosynthetic activity and assimilate accumulation, leading to higher yields than dwarf red banana under the same NPK application level (200:200:400 g per plant).

Effect of NPK levels on NPK uptake by dwarf red banana

During both years of the study, NPK uptake by dwarf red banana was significantly influenced by nutrient levels (Table 3). Among the treatments, the application of NPK at 300:300:600 g per plant

resulted in the highest uptake of N, P and K, followed by the application of 250:250:500 g per plant. The lowest uptake of all 3 nutrients was recorded in the treatment receiving 150:150:200 g per plant. The higher NPK uptake observed in the treatments N₃ and N₄ was attributed to the greater dry matter production recorded in these treatments (Fig. 1), as well as the higher N, P and K concentrations in the plant tissue. A positive correlation was found between dry matter production and nutrient uptake. Banana is a heavy feeder and absorbs large quantities of nutrients from the soil due to its rapid growth and high yield potential (24). It was also observed from a study in cultivar Njalipoovan that application of nutrients through fertilisers increased the availability of N, P and K in the soil which in turn enhanced nutrient uptake (20). In the present study as well, higher levels of NPK application increased nutrient uptake in dwarf red banana.

The results further revealed that tall red banana receiving 200:200:400 g NPK per plant exhibited higher NPK uptake than dwarf red banana supplied with the same nutrient level, which could be attributed to the greater dry matter production recorded

Table 3. Effect of NPK levels on NPK uptake by dwarf red banana during 2021–2022 and 2022–2023

Treatments	N uptake (g per plant)		P uptake (g per plant)		K uptake (g per plant)	
	2021-2022	2022-2023	2021-2022	2022-2023	2021-2022	2022-2023
N ₁ : NPK at 200:200:400 g per plant (POP)	888.8	903.4	47.8	54.5	1750.4	1762.6
N ₂ : NPK at 150:150:300 g per plant	791.4	801.9	41.8	45.5	1623.9	1613.2
N ₃ : NPK at 250: 250: 500 g per plant	1095.2	1098.5	58.0	62.3	1868.8	1884.0
N ₄ : NPK at 300: 300: 600 g per plant	1220.7	1238.2	69.5	74.2	1983.9	2003.7
SEm ±	22.1	18.5	1.22	1.7	56.0	81.7
CD ($p = 0.05$)	68.20	56.94	3.77	5.12	172.6	251.83
Ordinary tall red banana (NPK at 200:200:400)	1123.4	1298.4	75.9	82.9	1987.6	1978.6

POP: package of practice.

in the tall red banana.

Effect of NPK levels on available N, P and K status of soil

Results of the year study revealed that nutrient levels did not have any significant effect on the available NPK status of post experiment soil (Table 4). However, in general there was a reduction in the NPK content of the post experiment soil compared to the initial soil test data. The reduction in the nutrient status observed was due to the heavy feeding of nutrients by the dwarf red banana as observed from the data on NPK uptake by crop. Previous studies have similarly noted that banana plants are heavy nutrient feeders, extracting considerable quantities of nutrients from the soil (24, 26).

Effect of NPK levels on economics of cultivation of dwarf red banana

Results on the economics of cultivation revealed that dwarf red banana fertilised with NPK at 300:300:600 g per plant recorded the highest gross return, net return and benefit-cost (B:C) ratio per plant (Table 5). The higher returns and B:C ratio were attributed to the increased yield obtained in this treatment compared with the others. When compared with tall red banana, dwarf red banana also generated higher profit at the same NPK level (200:200:400 g per plant), primarily due to its lower cost of cultivation. Dwarf red banana does not require propping, owing to its sturdy pseudostem and has a shorter crop duration of 12–13 months compared with 15–16 months in tall red banana, further reducing cultivation costs.

Quality attributes of dwarf and tall red banana

A comparative analysis of fruits from both cultivars fertilised with NPK at 200:200:400 g per plant showed that dwarf red banana had higher total soluble solids, total sugar, reducing sugar and ascorbic acid content (Table 6), indicating superior fruit quality

over tall red banana. The difference might be due to the genetic makeup of the plant.

Conclusion

It can be concluded that the naturally reduced stature, sturdy pseudostem and enhanced tolerance to wind damage of dwarf red banana highlight its potential as a climate-smart alternative to tall red banana. To maximise yield and economic returns in dwarf red banana, the application of 10 kg FYM per plant combined with NPK at 300:300:600 g per plant was found to be the most effective. The study also revealed that dwarf red banana generated higher returns than tall ordinary red banana at the same fertiliser level (200:200:400 g per plant), owing to its lower cost of cultivation and shorter crop duration. In addition, the fruit quality of dwarf red banana was superior to that of tall red banana. Therefore, the popularisation of dwarf red banana could serve as an effective climate-smart strategy to reduce crop losses caused by heavy winds.

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Authors' contributions

SKR designed the experiment, developed the experimental layout, and prepared the manuscript. JVG and NSK provided technical guidance in experimental layout and assisted in manuscript preparation and revision. AC, SAM, and NW assisted in recording biometric observations and performed the statistical analysis. JD,

Table 4. Effect of NPK levels on available N, P and K content of post experiment soil

Treatments	2021–22			2022–23		
	N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)	N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)
N ₁ : NPK at 200:200:400 g per plant	223.9	17.3	222.5	225.9	19.3	227.1
N ₂ : NPK at 150:150:300 g per plant	206.1	16.5	230.3	221.9	20.8	233.2
N ₃ : NPK at 250: 250: 500 g per plant	232.4	18.3	221.0	233.2	19.8	227.4
N ₄ : NPK at 300: 300: 600 g per plant	230.5	17.5	211.5	243.1	19.9	226.1
SEm ±	7.5	1.1	8.8	5.9	0.9	8.8
CD ($p = 0.05$)	NS	NS	NS	NS	NS	NS

NS: not-significant.

Table 5. Effect of NPK levels on economics of cultivation in dwarf red banana during 2021–2022 and 2022–2023

Treatments	Gross returns (₹ per plant)		Net returns (₹ per plant)		B:C ratio (₹ per plant)	
	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23
N ₁ : NPK at 200:200:400 g per plant	1319	1266	896	843	3.11	2.99
N ₂ : NPK at 150:150:300 g per plant	1289	1152	872	735	3.09	2.76
N ₃ : NPK at 250: 250: 500 g per plant	1374	1368	945	939	3.20	3.19
N ₄ : NPK at 300: 300: 600 g per plant	1464	1500	1030	1066	3.37	3.46
Ordinary tall red banana (NPK at 200:200:400)	1494	1518	854	878	2.33	2.37

Table 6. Comparison of quality attributes of dwarf red banana fruit and ordinary red banana fruit

Cultivar name	Titrateable acidity (%)	Total soluble solids (°Brix)	Total sugar (%)	Reducing sugar (%)	Ascorbic acid (mg per 100 g)
Dwarf red banana	0.34	16.9	20.0	11.3	8.8
Tall red banana	0.35	16.4	17.9	7.7	8.4

NVR, and KGV contributed to drafting, reviewing the manuscript, and correcting the references. All authors read and approved the final manuscript.

Compliance with ethical standards

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

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT to improve the language. After using this tool, the authors reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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