

RESEARCH ARTICLE

Effect of different nutrient management techniques on growth and physiological attributes of Kodo millet (*Paspalum scrobiculatum* L.) under western agroclimatic zone of Tamil Nadu

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ABSTRACT

The field experiment was conducted during summer 2022 at Eastern block, Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore. The field experiment was laid out in Randomized Complete Block Design (RCBD) which consists of eight treatments which are replicated thrice to assess the growth and physiological attributes of kodo millet. Growth, physiological, and yield attributes of kodo millet were significantly influenced by nutrient management practices. The treatment combining RDF + 33 kg K ha⁻¹ with foliar application of ZnSO₄ (0.5%) and FeSO₄ (1%) at active tillering and flowering initiation stages (T₆) recorded the highest plant height, tiller count, leaf number, dry matter production, and root volume. Physiological attributes such as LAI, CGR, RGR, NAR, and chlorophyll content peaked under T₆, contributing to superior biomass accumulation and yield performance. T₆ achieved the highest grain yield (2028 kg ha⁻¹), straw yield (6822 kg ha⁻¹), and harvest index (0.30). Correlation analysis revealed strong positive associations between plant height, tiller number, dry matter, LAI, CGR, NAR and yield, highlighting the integrated role of growth and physiological parameters in yield determination. These findings underscore the synergistic effect of potassium and foliar micronutrients in enhancing kodo millet growth and productivity under integrated nutrient management.

Keywords: Potassium, Zinc, Iron, Climate resilient crop, Meristematic activity, Nutrient use efficiency (NUE)

1. INTRODUCTION

As global food systems face increasing pressure from climate change, population growth, and unsustainable agricultural practices, there is an urgent need to promote climate-resilient and nutrient-rich crops. Kodo millet (*Paspalum scrobiculatum* L.) is a hardy, drought-tolerant cereal that thrives in marginal soils with low water requirements, making it a sustainable alternative to water-intensive crops such as rice and wheat (Surya et al., 2022;

Kumar et al., 2024). Recognizing the importance of millets in sustainable food systems, the United Nations declared 2023 the International Year of Millets. Kodo millet possesses superior nutritional qualities, containing 8-11% protein, 9% dietary fiber, and appreciable amounts of iron (5.6 mg/100 g), calcium (27 mg/100 g), and zinc (3.7 mg/100 g) (Shikha et al., 2024). Its low glycemic index, gluten-free nature, antioxidant compounds, and prebiotic

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fiber make it beneficial for preventing diabetes, obesity, cardiovascular diseases, and promoting gut health (Singh et al., 2023; Maurya et al., 2023). Consequently, interest in millet cultivation and consumption is increasing worldwide, particularly in India, where efforts are underway to restore millet production following its decline during the Green Revolution (Dixit, 2024).

Despite these advantages, Kodo millet productivity remains low because of limited high-yielding cultivars and suboptimal crop management (Vetriventhan and Upadhyaya, 2019). Although improved cultivars such as CKMV 1 have enhanced yield potential, their performance depends on efficient nutrient management (Nirmalakumari et al., 2022). Recent advances including genomic-assisted breeding, the System of Millet Intensification (SMI), intercropping with legumes, Integrated Nutrient Management (INM), agronomic biofortification, and conservation agriculture have demonstrated considerable potential for improving productivity, soil health, nutrient-use efficiency, and climate resilience (Sharma et al., 2020; Kaduwal et al., 2023).

Among plant nutrients, potassium regulates enzyme activation, photosynthesis, assimilate translocation, osmotic adjustment, and stress tolerance, whereas micronutrients such as zinc and boron are essential for enzymatic activity, reproductive development, and grain formation. Although their individual roles are well established in cereals, information on their combined effects and potential synergistic interactions in Kodo millet remains limited. Millets, owing to their C4 photosynthetic pathway, exhibit superior water-use efficiency and adaptability to harsh environments, making them suitable for climate-smart agriculture (Saxena et al., 2018; Kumar et al., 2024). However, wider adoption is constrained by limitations in processing, consumer acceptance, and market accessibility. While previous studies have emphasized varietal improvement, integrated nutrient management, and agronomic practices, limited attention has been given to the interactive effects of potassium and micronutrients on the growth and physiology of Kodo millet (Dixit, 2024). Understanding these interactions is essential for improving nutrient-use efficiency, sustaining productivity, and developing balanced fertilization strategies.

Therefore, the novelty of the present study lies in evaluating the interactive effects of potassium

and micronutrient management on the growth and physiological attributes of Kodo millet while integrating a scientometric assessment of global millet research to identify knowledge gaps and future research priorities. Based on these gaps, the objectives of the study were to: (i) assess global research trends in millet cultivation through scientometric analysis and identify major research gaps; (ii) evaluate the effects of potassium- and micronutrient-based nutrient management strategies on the growth of Kodo millet; and (iii) assess their influence on the physiological attributes of Kodo millet.

2. MATERIALS AND METHODS

2.1. Study location and weather condition

A field experiment was carried out during the summer season of 2022 (January-May) at the Eastern Block Farm (Field No. 37F) of the Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore. The study site is situated in the Western Agro-climatic Zone of Tamil Nadu, geographically positioned at 11°08'13" N latitude and 76°97'43" E longitude, with an elevation of 426 meters above mean sea level and the experimental field location was mentioned in Figure 1.

2.2. Treatment details and soil analysis

A total of eight nutrient management treatments, including combinations of recommended dose of fertilizers (RDF), potassium levels, micronutrient mixtures, and foliar applications of ZnSO_4 and FeSO_4 at active tillering (AT) and flower initiation (FI) stages, were evaluated against a control treatment. The details of the treatments follows: T_1 : RDF + MN Mixture @ 12.5 kg ha⁻¹, T_2 : RDF + foliar spray of ZnSO_4 @ 0.5% and FeSO_4 @ 1% at AT & FI, T_3 : RDF + 22 kg K ha⁻¹ + MN Mixture @ 12.5 kg ha⁻¹, T_4 : RDF + 22 kg K ha⁻¹ + foliar spray of ZnSO_4 @ 0.5% and FeSO_4 @ 1% at AT & FI, T_5 : RDF + 33 kg K ha⁻¹ + MN Mixture @ 12.5 kg ha⁻¹, T_6 : RDF + 33 kg K ha⁻¹ + foliar spray of ZnSO_4 @ 0.5% and FeSO_4 @ 1% at AT & FI, T_7 : RDF (44:22:0 kg NPK ha⁻¹), T_8 : Absolute Control. Prior to the initiation of the field experiment, composite soil samples were collected randomly from the experimental field at a depth of 15 cm to determine the baseline physico-chemical properties of the soil. The samples were air-dried, ground finely, and sieved through a 2 mm mesh before laboratory analysis. The soil analysis revealed that the experimental site was low in available nitrogen (213.0 kg ha⁻¹), medium in

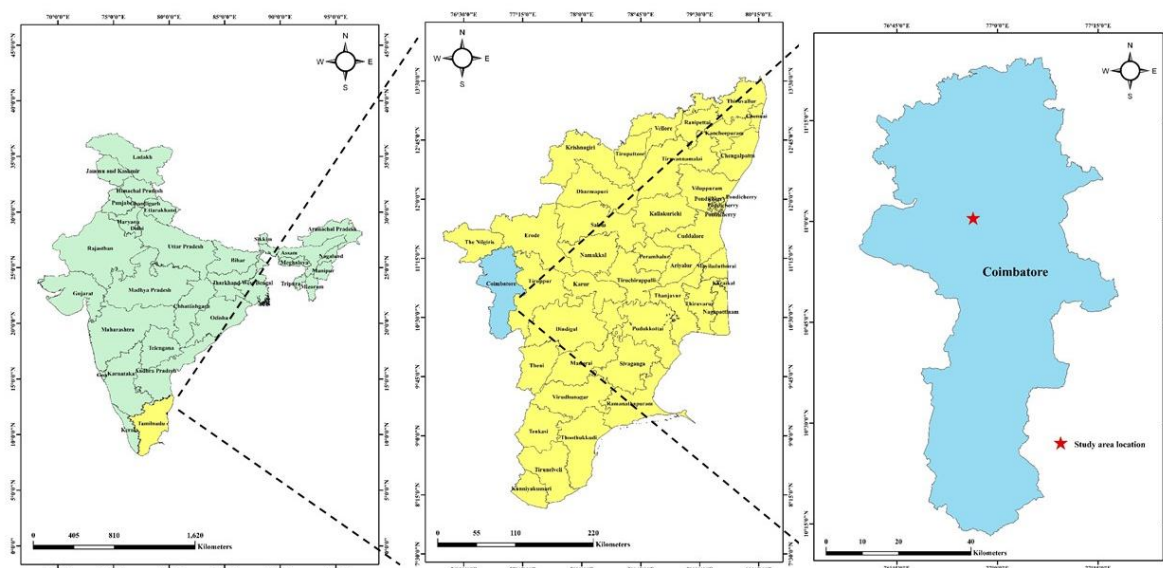


Figure 1. Research field location. The experimental location lies in the Western Agro-climatic Zone of Tamil Nadu, situated at 11°08'13" N latitude and 76°97'43" E longitude, with an elevation of 426 meters above mean sea level. The experimental site experiences a tropical climate with an average annual rainfall of approximately 694 mm (30 years average)

available phosphorus (15.4 kg ha⁻¹), and high in available potassium (640.0 kg ha⁻¹). This nutrient profile indicates a potential nitrogen deficiency, necessitating appropriate fertilization strategies for optimum crop growth.

2.3. Experimental design and varietal characters

The field experiment was laid out in a randomized complete block design (RCBD) with eight treatments replicated three times. The trial was conducted at Field No. 37F, Eastern Block Farm, Tamil Nadu Agricultural University (TNAU). The crop was sown on 6th January 2022 and harvested on 17th May 2022. The variety ATL 1 was spaced at 45 cm × 10 cm in plots measuring 4.0 m × 5.0 m (20 m²), with a net plot size of 3.8 m × 4.1 m (15.5 m²) for observations. The crop selected for the study was kodo millet (*Paspalum scrobiculatum* L.), an underutilized yet highly nutritious small millet recognized for its drought tolerance and suitability for cultivation in marginal environments. The variety used in the investigation was ATL 1, developed through pure line selection from the DPS 63 line. The seeds were procured from the Centre of Excellence for Millets, Athiyandal, Thiruvannamalai. ATL 1 is a medium-duration variety with a growth period of 110 days and is ideally cultivated during the Rabi season (September-October). It is characterized by its suitability for mechanical harvesting, high drought tolerance, uniform maturity, non-lodging

nature, and high milling outturn of 54%. Furthermore, both grain and straw are rich in nutrients, making it highly suitable for value addition. The varietal features of ATL 1 make it a promising candidate for enhancing the productivity and profitability of kodo millet under irrigated conditions.

2.4. Treatments implementation

The recommended dose of fertilizer application (44:22:0 kg ha⁻¹ NPK) was adopted. The NPK was applied in the form of Urea, SSP, Muriate of potash. The entire dose of phosphorus was applied as basal and potassium was applied based on treatments. Urea was applied through two equal splits. The first split application of N was given as basal at the time of sowing and second split dose at 30 DAS. The spray solution of ferrous sulphate (1%) and zinc sulphate (0.5%) were prepared by dissolving 10 g and 5 g respectively each in one litre of water separately. The spray fluid volume used was 500 litres ha⁻¹ and the spraying was applied at active tillering and flower initiation stages of crop growth.

2.5. Observations recorded

2.5.1. Growth parameters

Plant height was measured from the base to the tip of the last leaf on five tagged plants at 30, 60 DAS, and maturity, and expressed in cm. The number



of leaves per plant was counted on the same tagged plants at each stage and averaged. Tillers were counted on five randomly selected plants per plot at the same intervals and expressed as tillers per plant. Root length was measured using a scale, and root volume was determined by water displacement using a graduated cylinder, both at 30, 60 DAS, and maturity. For dry matter production, five plants were sampled from border rows at each stage, shade-dried, then oven-dried at 80 °C to a constant weight, and expressed in kg ha⁻¹.

2.5.2. Physiological parameters

For leaf area estimation, LICOR 3000 Leaf area meter was used, and it is a direct method of leaf area measurement. The leaves collected at early morning and leaf area was estimated in laboratory. In this method, the leaves are placed in conveyor, and it was moved towards scanning camera. The scanning camera reflected the image on mirror, and the reading was measured digitally. The obtained leaf area was multiplied with number of leaves plant⁻¹ and the value was divided by spacing followed for kodo millet (Chen *et al.* 1997)

CGR is a measure of how quickly a crop is increasing in biomass over time. It's essentially the rate at which a crop accumulates dry matter per unit area and per unit time. CGR was calculated by using the formula given by Watson (1958) and expressed in g m⁻² day⁻¹.

$$\text{CGR} = \frac{W_2 - W_1}{P(t_2 - t_1)}$$

Where,

W_1 - Whole plant dry weight at time t_1 (g)

W_2 - Whole plant dry weight at time t_2 (g)

P - Land occupied by the plant

t_1 and t_2 - Time interval in days

Relative growth rate (RGR) in plants measures how quickly a plant produces new biomass relative to its existing biomass. RGR was calculated by the formula given by Enyi (1962) and it was expressed as g g⁻¹ day⁻¹.

$$\text{RGR} = \frac{\text{Loge } W_2 - \text{Loge } W_1}{t_2 - t_1}$$

Where,

W_1 - Dry weight of the plant sample at t_1 (g)

W_2 - Dry weight of the plant sample at t_2 (g)

t_1 and t_2 - Time interval in days

Net assimilation rate (NAR) in plants refers to the

rate at which a plant gains dry weight per unit leaf area over a given period of time. NAR was worked out based on formula given by Williams (1946) and expressed as mg cm⁻² day⁻¹.

$$\text{NAR} = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\text{Loge } L_2 - \text{Loge } L_1}{L_2 - L_1}$$

Where,

W_1 and W_2 - Whole plant dry weight at time t_1 and t_2 (g)

L_1 and L_2 - Leaf area of plant at t_1 and t_2 (cm)

t_1 and t_2 - Time interval in days

2.5.3. Soluble protein and chlorophyll index (SPAD value)

The soluble protein content correlates with nitrogen availability and overall plant health, making it a useful diagnostic tool for nutrient management. The procedure to estimate the soluble protein was given by Lowery *et al.* (1951). For soluble protein estimation, 500 mg of leaf sample was taken and homogenized with 10 ml of phosphate buffer. Then the contents were centrifuged @ 3000 rpm for about 10 minutes. Supernatant was collected and volume made up to 25 ml. One ml of supernatant was pipette out in a test tube and 5 ml of alkaline copper tartarate reagent and 0.5 ml of folin ciocalteau reagent were added. Colour was developed within 30 minutes and measured the colour intensity at 660 nm using UV visible spectrophotometer. Bovine serum albumin was used as a standard solution for estimation of soluble protein content and it was expressed as mg g⁻¹ of fresh weight.

SPAD (Soil Plant Analysis Development) reading was taken from upper most leaves of five selected plants and it was recorded at different growth stages and then mean values were worked out. SPAD is a dimensionless index derived from the ratio of light transmittance through a leaf at two specific wavelengths: 650 nm (where chlorophyll strongly absorbs red light) and 940 nm (a reference wavelength minimally absorbed by leaf pigments), measured using a handheld chlorophyll meter to non-destructively estimate relative chlorophyll content

2.5.4. Yield attributes

Grain yield (kg ha⁻¹) was calculated from sun-dried, cleaned grains harvested from net plot areas. Straw yield (kg ha⁻¹) was quantified after threshing by drying residues to constant weight. Harvest index (%) was

computed as the ratio of grain yield (economic yield) to total biological yield (grain + straw) following Yoshida (1972).

$$\text{Harvest index (HI)} = \frac{\text{Economic yield (kg ha}^{-1}\text{)}}{\text{Biological yield (kg ha}^{-1}\text{)}}$$

2.6. Statistical analysis

The analysis of variance (ANOVA) for all measured traits was conducted using R software (version 4.2.1) through R Studio for Windows (R Core Team, 2020). Mean comparisons were made using Fisher's Least Significant Difference (LSD) test at a 5% significance level, and non-significant results were indicated as "NS" (Gomez and Gomez, 2010). To visualize the influence of various nutrient management practices the box plot on grain yield and straw yield were evaluated using R studio. Pearson correlation coefficients were calculated to examine the relationships among different traits.

3. Results

3.1. Growth parameters

The growth parameters of kodo millet were significantly influenced by varying nutrient management practices and the results on growth attributes were mentioned in Table 1 and Table 2. Plant height exhibited no significant differences at 30 days after sowing (DAS). However, at 60 DAS and maturity, the treatment (T_6) combining recommended dose of fertilizers (RDF) + 33 kg K ha⁻¹ + foliar application of ZnSO₄ (0.5%) and FeSO₄ (1%) at active tillering (AT) and flower initiation (FI) stages resulted in the maximum plant height (55.2 cm and 84.1 cm, respectively), and it is on par with (T_4) RDF + 22 kg K ha⁻¹ + foliar ZnSO₄ and FeSO₄. Tiller production was also highest under the RDF + 33 kg K ha⁻¹ + micronutrient foliar spray, reaching 19.2 tillers per plant at maturity, with a progressive increase from 30 DAS onward. Similarly, leaf count per plant was greatest in the same treatment, recording 55.6 and 70.3 leaves at 60 DAS and maturity, respectively. Dry matter accumulation (DMP) increased progressively with crop development, peaking at 43.8 g plant⁻¹ at maturity under RDF + 33 kg K ha⁻¹ + ZnSO₄ and FeSO₄ foliar application, closely followed by other potassium and micronutrient-supplemented treatments. Root length did not vary significantly at 30 DAS. However, the absolute control (T_8) exhibited the longest roots at 60 DAS (18.8 cm) and maturity (19.7 cm), though RDF (44:22:0 kg NPK ha⁻¹) alone (T_7) also demonstrated comparable performance. In contrast, root volume

showed significant treatment effects at later growth stages. The RDF + 22 kg K ha⁻¹ + foliar ZnSO₄ and FeSO₄ treatment produced the highest root volume (2.22 cc at 60 DAS), followed by treatments with elevated potassium and micronutrient combinations.

3.2. Physiological attributes

The physiological attributes of kodo millet were significantly influenced by different nutrient management practices and the results were mentioned in Table 3 and Table 4. Leaf area index (LAI) exhibited a progressive increase from seedling to maturity, correlating with dry matter accumulation. Nutrient management practices exerted a significant influence on LAI at 30, 60 DAS, and maturity. At 30 DAS, the highest LAI (0.20) was recorded under (T_7) recommended dose of fertilizers (RDF: 44:22:0 kg NPK ha⁻¹), which was statistically on par with (T_3) RDF + 22 kg K ha⁻¹ + micronutrient (MN) mixture (12.5 kg ha⁻¹) (0.19) and (T_2) RDF + foliar ZnSO₄ (0.5%) and FeSO₄ (1%) at active tillering (AT) and flowering initiation (FI) stages (0.18). In contrast, (T_5) RDF + 33 kg K ha⁻¹ + MN mixture recorded the lowest LAI (0.09) at this stage. By 60 DAS, LAI markedly improved, with the highest values observed under (T_6) RDF + 33 kg K ha⁻¹ + foliar ZnSO₄ and FeSO₄ (2.55), followed closely by (T_3) RDF + 22 kg K ha⁻¹ + foliar micronutrients (2.18). This trend persisted at maturity, where the same treatment maintained superiority (2.70), while the absolute control (T_8) exhibited the lowest LAI (1.32 at 60 DAS, 1.53 at maturity).

Crop growth rate (CGR) was significantly enhanced under combined soil and foliar nutrient applications. The highest CGR during 30-60 DAS (6.84 g m⁻² day⁻¹) was recorded in (T_6), followed by T_5 (6.24 g m⁻² day⁻¹) and T_4 (6.08 g m⁻² day⁻¹). A similar trend was observed during 60 DAS to maturity, with the highest CGR (10.88 g m⁻² day⁻¹) under T_5 , followed by T_4 (10.44 g m⁻² day⁻¹) and T_2 (10.40 g m⁻² day⁻¹). The control (T_8) consistently recorded the lowest CGR (4.69 and 7.99 g m⁻² day⁻¹, respectively). Relative growth rate (RGR), which declined toward maturity, followed a treatment-dependent pattern. The highest RGR at 30-60 DAS (137.5 mg m⁻² day⁻¹) and 60 DAS-maturity (24.15 mg g m⁻² day⁻¹) was observed under T_6 , closely followed by T_4 (22.75 mg m⁻² day⁻¹). T_8 exhibited the lowest RGR (106.5 and 19.93 mg m⁻² day⁻¹, respectively). Net assimilation rate (NAR), an indicator of photosynthetic efficiency, was significantly

Table 1. Growth parameters (plant height, number of tillers and dry matter production) influenced by different nutrient management practices at various stages of kodo millet

Treatments	Plant height (cm)			Number of tillers plant ⁻¹			Drymatter production (g plant ⁻¹)		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T ₁ : RDF + MN Mixture @ 12.5 kg ha ⁻¹	21.5	42.3	68.1	4.5	12.8	15.2	0.28	7.45	35.1
T ₂ : RDF + foliar spray of ZnSO ₄ @ 0.5% and FeSO ₄ @ 1% at AT & FI	22.1	46.0	77.3	4.8	14.3	17.1	0.26	7.48	40.3
T ₃ : RDF + 22 kg K ha ⁻¹ + MN Mixture @ 12.5 kg ha ⁻¹	21.0	45.3	78.6	4.9	12.5	16.0	0.25	7.81	37.0
T ₄ : RDF + 22 kg K ha ⁻¹ + foliar spray of ZnSO ₄ @ 0.5% and FeSO ₄ @ 1% at AT & FI	20.3	51.2	82.3	4.7	15.2	18.1	0.21	8.43	41.3
T ₅ : RDF + 33 kg K ha ⁻¹ + MN Mixture @ 12.5 kg ha ⁻¹	20.1	48.2	73.9	4.1	14.5	17.0	0.25	8.68	38.3
T ₆ : RDF + 33 kg K ha ⁻¹ + foliar spray of ZnSO ₄ @ 0.5% and FeSO ₄ @ 1% at AT & FI	20.2	55.2	84.1	4.4	15.9	19.2	0.26	9.49	43.8
T ₇ : RDF (44:22:0 kg NPK ha ⁻¹)	20.6	43.1	73.8	4.3	12.8	14.5	0.25	6.85	33.7
T ₈ : Absolute Control	22.1	40.8	71.6	4.8	11.3	13.7	0.22	6.56	31.7
S. Ed	1.08	2.53	4.44	0.425	0.92	0.86	0.047	0.47	1.89
CD at 5 %	NS	5.44	9.52	NS	1.99	1.86	NS	1.01	4.06

Table 2. Growth parameters (number of leaves plant⁻¹, root length and root volume) influenced by different nutrient management practices at various stages of kodo millet

Treatments	Number of leaves Plant ⁻¹			Root length (cm)			Root volume (cc)		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T ₁ : RDF + MN Mixture @ 12.5 kg ha ⁻¹	18.2	45.8	59.6	11.2	15.0	16.1	0.35	1.78	4.75
T ₂ : RDF + foliar spray of ZnSO ₄ @ 0.5% and FeSO ₄ @ 1% at AT & FI	18.4	52.3	65.2	9.92	16.1	17.6	0.36	1.90	4.91
T ₃ : RDF + 22 kg K ha ⁻¹ + MN Mixture @ 12.5 kg ha ⁻¹	19.2	48.4	62.7	11.6	16.5	17.8	0.41	2.00	4.77
T ₄ : RDF + 22 kg K ha ⁻¹ + foliar spray of ZnSO ₄ @ 0.5% and FeSO ₄ @ 1% at AT & FI	16.7	53.7	67.0	9.6	15.1	16.5	0.30	2.22	5.12
T ₅ : RDF + 33 kg K ha ⁻¹ + MN Mixture @ 12.5 kg ha ⁻¹	14.9	50.8	63.8	8.24	13.7	15.1	0.28	2.17	5.00
T ₆ : RDF + 33 kg K ha ⁻¹ + foliar spray of ZnSO ₄ @ 0.5% and FeSO ₄ @ 1% at AT & FI	17.3	55.6	70.3	8.05	15.1	16.4	0.33	2.02	5.20
T ₇ : RDF (44:22:0 kg NPK ha ⁻¹)	16.9	43.1	57.4	7.50	16.8	17.9	0.30	1.69	4.65
T ₈ : Absolute Control	17.4	41.7	53.7	10.5	18.8	19.7	0.34	1.53	4.38
S. Ed	1.71	2.41	3.13	1.36	0.84	0.86	0.048	0.147	0.046
CD at 5 %	NS	5.18	6.73	NS	1.81	1.85	NS	0.317	0.099

Table 3. Physiological parameters (leaf area index, crop growth rate, relative growth rate and net assimilation rate) influenced by different nutrient management practices at various stages of kodo millet

Treatments	Leaf area index			Crop growth rate (g m ⁻² day ⁻¹)		Relative growth rate (mg g ⁻¹ day ⁻¹)		Net assimilation rate (mg cm ⁻² day ⁻¹)	
	30 DAS	60 DAS	Harvest	30-60 DAS	60-harvest	30-60 DAS	60-harvest	30-60 DAS	60-harvest
T ₁ : RDF + MN Mixture @ 12.5 kg ha ⁻¹	0.15	1.69	1.95	5.31	8.77	111.0	21.81	0.86	0.47
T ₂ : RDF + foliar spray of ZnSO ₄ @ 0.5% and FeSO ₄ @ 1% at AT & FI	0.18	2.05	2.14	5.34	10.40	114.9	22.75	0.90	0.50
T ₃ : RDF + 22 kg K ha ⁻¹ + MN Mixture @ 12.5 kg ha ⁻¹	0.19	1.84	2.04	5.60	9.27	121.3	22.25	0.85	0.51
T ₄ : RDF + 22 kg K ha ⁻¹ + foliar spray of ZnSO ₄ @ 0.5% and FeSO ₄ @ 1% at AT & FI	0.13	2.18	2.39	6.08	10.43	123.6	22.26	0.93	0.57
T ₅ : RDF + 33 kg K ha ⁻¹ + MN Mixture @ 12.5 kg ha ⁻¹	0.09	1.96	2.18	6.24	9.40	121.9	20.54	0.89	0.52
T ₆ : RDF + 33 kg K ha ⁻¹ + foliar spray of ZnSO ₄ @ 0.5% and FeSO ₄ @ 1% at AT & FI	0.12	2.55	2.70	6.84	10.88	137.5	24.15	1.03	0.69
T ₇ : RDF (44:22:0 kg NPK ha ⁻¹)	0.20	1.70	1.90	4.88	8.53	109.0	20.89	0.80	0.45
T ₈ : Absolute Control	0.15	1.32	1.53	4.69	7.99	106.5	19.93	0.72	0.41
S. Ed	0.024	0.20	0.19	0.36	0.60	6.31	0.74	0.073	0.06
CD at 5 %	0.052	0.43	0.41	0.78	1.29	13.54	1.60	0.15	0.12

Table 4. Physiological parameters (SPAD values and soluble protein) and yield (grain yield, straw yield and harvest index) influenced by different nutrient management practices at various stages of kodo millet

Treatments	SPAD values			Soluble protein ¹			Grain yield (kg/ha)	Straw yield (kg/ha)	Harvest index
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest			
T ₁ : RDF + MN Mixture @ 12.5 kg ha ⁻¹	22.8	34.8	27.2	46.98	46.21	30.15	1521	5666	0.27
T ₂ : RDF + foliar spray of ZnSO ₄ @ 0.5% and FeSO ₄ @ 1% at AT & FI	24.1	35.4	31.0	47.31	47.88	30.10	1772	6518	0.27
T ₃ : RDF + 22 kg K ha ⁻¹ + MN Mixture @ 12.5 kg ha ⁻¹	21.3	34.5	27.7	50.14	47.42	31.80	1679	6000	0.28
T ₄ : RDF + 22 kg K ha ⁻¹ + foliar spray of ZnSO ₄ @ 0.5% and FeSO ₄ @ 1% at AT & FI	25.6	36.7	32.5	50.71	47.87	31.74	1930	6533	0.30
T ₅ : RDF + 33 kg K ha ⁻¹ + MN Mixture @ 12.5 kg ha ⁻¹	23.0	34.1	28.3	45.23	49.87	29.06	1856	6229	0.30
T ₆ : RDF + 33 kg K ha ⁻¹ + foliar spray of ZnSO ₄ @ 0.5% and FeSO ₄ @ 1% at AT & FI	27.7	37.7	33.0	50.62	51.44	32.13	2028	6822	0.30
T ₇ : RDF (44:22:0 kg NPK ha ⁻¹)	21.5	32.2	25.9	45.59	43.18	28.20	1483	5540	0.27
T ₈ : Absolute Control	19.4	29.3	23.0	43.45	41.85	28.86	1379	5311	0.26
S. Ed	0.58	1.78	1.48	3.08	3.41	2.55	85.05	385.2	0.023
CD at 5 %	1.25	3.82	3.18	NS	NS	NS	182.4	826.4	NS

influenced by treatments and highest NAR at 30-60 DAS (1.03 mg cm⁻² day⁻¹) and 60 DAS-maturity (0.69 mg cm⁻² day⁻¹) was recorded under T₆ followed by T₄ (0.93 and 0.57 mg cm⁻² day⁻¹, respectively). The control (T₈) had the lowest NAR (0.72 and 0.41 mg cm⁻² day⁻¹).

Chlorophyll content (SPAD values) peaked at 60 DAS before declining. The highest values were recorded under T₆ (27.7 at 30 DAS, 37.7 at 60 DAS, 33.0 at maturity), statistically comparable to most treatments except the control and RDF alone at 60 DAS. The absolute control (T₈) exhibited the lowest chlorophyll content (19.4, 29.3, and 23.0, respectively). While soluble protein content did not vary significantly among treatments, T₆ recorded the highest protein levels at 60 DAS (51.44 mg g⁻¹) and maturity (32.13 mg g⁻¹). At 30 DAS, T₄ showed marginally higher protein content (50.71 mg g⁻¹), whereas the control (T₈) and RDF alone (T₇) had the lowest values (41.85 mg g⁻¹ at 60 DAS and 28.20 mg g⁻¹).

3.3. Yield

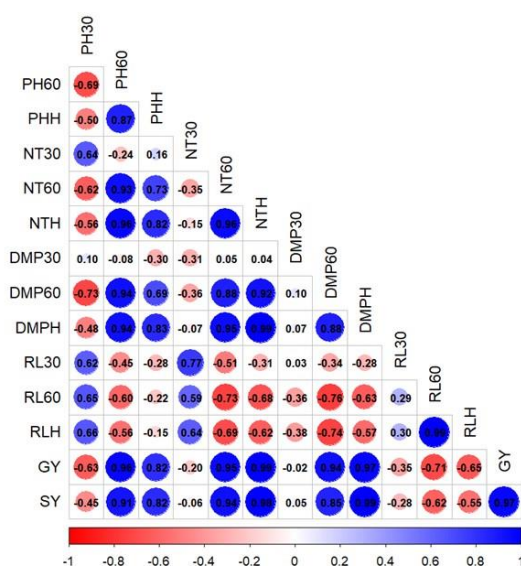
The nutrient management practices exerted a significant influence on the grain and straw yield, as well as the harvest index of kodo millet. Among the

treatments, the application of RDF + 33 kg K ha⁻¹ along with foliar spray of ZnSO₄ @ 0.5% and FeSO₄ @ 1% at active tillering and flower initiation stages (T₆) recorded the highest grain yield (2028 kg ha⁻¹) and straw yield (6822 kg ha⁻¹), coupled with an improved harvest index (0.30). This treatment was statistically on par with (T₄) RDF + 22 kg K ha⁻¹+ foliar spray of ZnSO₄ and FeSO₄ (1930 kg ha⁻¹ grain, 6533 kg ha⁻¹ straw, HI: 0.30) and (T₅) RDF + 33 kg K ha⁻¹+ micronutrient mixture @ 12.5 kg ha⁻¹ (1856 kg ha⁻¹ grain, 6229 kg ha⁻¹ straw, HI: 0.30). These results emphasize the synergistic role of potassium and foliar micronutrients in enhancing biomass partitioning and productivity. On the other hand, the absolute control recorded the lowest values for grain yield (1379 kg ha⁻¹), straw yield (5311 kg ha⁻¹), and harvest index (0.26), followed by the application of (T₇) RDF alone, indicating the importance of supplementary nutrient inputs beyond the recommended basal dose.

3.4. Correlation analysis

The Pearson's correlation analysis (Figure 2) revealed strong interrelationships among physiological, growth, and yield (grain yield and straw yield) parameters of kodo millet under different

Correlation matrix for growth parameters



Correlation matrix for physiological parameters

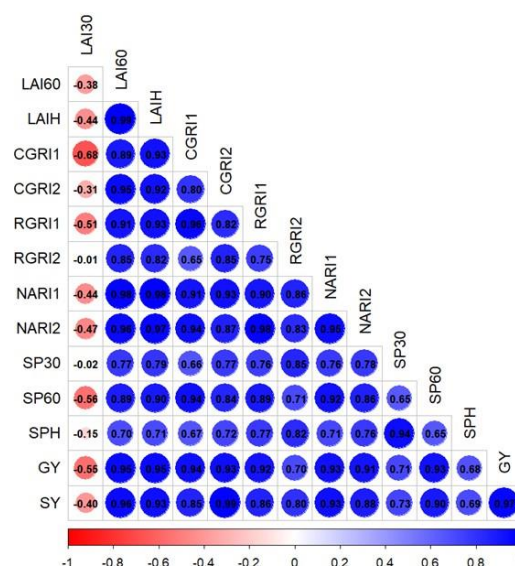


Figure 2. Pearson's correlation matrix depicting relationships among growth, physiological, and yield parameters of kodo millet under nutrient management. Parameters include: plant height (PH), number of tillers plant⁻¹ (NT), dry matter production (DMP), root length (RL), leaf area index (LAI), and soluble protein (SP), measured at 30 DAS, 60 DAS, and harvest. Growth indices include crop growth rate (CGR), relative growth rate (RGR), and net assimilation rate (NAR) for intervals 30–60 DAS and 60 DAS–harvest. Grain yield (GY) and straw yield (SY) are included as yield components.

nutrient management strategies. Strong and significant positive correlations were observed among key growth and yield attributes such as plant height at harvest (PHH), number of tillers per square metre at harvest (NTH), dry matter production (DMPH), grain yield (GY), and straw yield (SY). PHH was notably correlated with NTH ($r = 0.93$), DMP60 ($r = 0.92$), and DMPH ($r = 0.94$), suggesting that increased plant stature is associated with better canopy structure and enhanced biomass accumulation. Similarly, DMPH exhibited strong positive correlations with GY ($r = 0.89$) and SY ($r = 0.90$), highlighting the critical role of vegetative biomass in determining final yield performance. GY displayed robust associations with PHH ($r = 0.91$), NTH ($r = 0.91$), and DMPH ($r = 0.89$), indicating that taller plants with more tillers and greater biomass tend to produce higher grain output. Straw yield also reflected strong positive correlations with PHH ($r = 0.89$), NTH ($r = 0.88$), and DMPH ($r = 0.90$), reaffirming the contribution of vegetative vigor to overall productivity.

Physiological parameters such as Leaf Area Index (LAI), Crop Growth Rate (CGR), Relative Growth Rate (RGR), and Net Assimilation Rate (NAR) also demonstrated meaningful correlations, particularly at later stages. LAI at harvest (LAIH) showed strong positive relationships with CGR1-Crop growth rate for the interval 30-60 DAS ($r = 0.93$), CGR2- Crop growth rate for the interval 60-Harvest ($r = 0.89$), and Relative growth rate for interval 30-60 DAS-RGR1 ($r = 0.91$), underscoring its central role in sustaining growth efficiency. GY was positively correlated with CGR1 ($r = 0.91$), net assimilation rate for interval 30-60 DAS-NAR1 ($r = 0.91$), and RGR1 ($r = 0.90$), indicating that efficient growth and assimilation during early to mid-stages are crucial for yield realization. A particularly strong correlation was observed between GY and SY ($r = 0.97$), emphasizing the shared physiological determinants of both grain and straw yield.

3.5. Multivariate linear regression analysis

Multivariate linear regression models were developed to assess the predictive power of different physiological and morphological traits which are measured at 30, 60 DAS and at harvest on grain yield (GY) and mentioned in Figure 3.

Across all traits studied, plant height (PH), number of tillers (NT), dry matter production (DMP), root length (RL), leaf area index (LAI), and soluble protein content (SP) at mid-growth stage (60 DAS) frequently

emerged as the most statistically significant predictor. For instance, PH60 ($p = 0.0307$), SP60 ($p = 0.0209$), DMP60 ($p = 0.0363$), and DMPH ($p = 0.00812$) significantly contributed to yield prediction, indicating their strong influence on yield formation. Models based on NT and DMP exhibited exceptionally high coefficients of determination ($R^2 = 0.982$ and 0.985 , respectively), reflecting minimal unexplained variance and excellent overall model fits. However, these high R^2 values often co-occurred with a lack of significance in early or late-stage predictors (e.g., NT30, NT60), suggesting possible multicollinearity among time-stage variables. Negative regression coefficients for some early-stage traits (e.g., NT30, DMP30, LAI30) and harvest traits (e.g., SPH, LAIH) suggest diminishing returns or resource competition, possibly reflecting physiological inefficiencies when early vegetative growth is excessive or when late-stage resource remobilization is suboptimal. Despite high R^2 values in most models (ranging from 0.742 to 0.985), statistical significance was concentrated primarily in mid-season traits, reinforcing the notion that crop growth metrics at 60 DAS offer the highest predictive reliability for yield. These findings suggest that monitoring crop traits at this critical phenological stage may offer a statistically robust and operationally efficient strategy for yield forecasting.

3.6. Principal Component Analysis (PCA)

Principal Component Analysis (PCA) was conducted to examine the interrelationships among six key agronomic and physiological traits such as plant height (PH), number of tillers (NT), dry matter production (DMP), root length (RL), leaf area index (LAI), and soluble protein content (SP) which are measured at three critical crop growth stages: 30 days after sowing (DAS), 60 DAS, and at harvest and mentioned In Figure 4. The PCA variable plots revealed consistent trends across all traits, where observations recorded at 60 DAS and at harvest exhibited strong positive correlations, with their vectors closely aligned and primarily contributing to the first principal component (PC1). This indicates that mid-stage measurements (60 DAS) are highly predictive of final performance outcomes for these traits. In contrast, measurements taken at 30 DAS generally loaded more strongly on the second principal component (PC2), and their vectors were often oriented in directions distinct from their 60 DAS and harvest counterparts. For instance, early

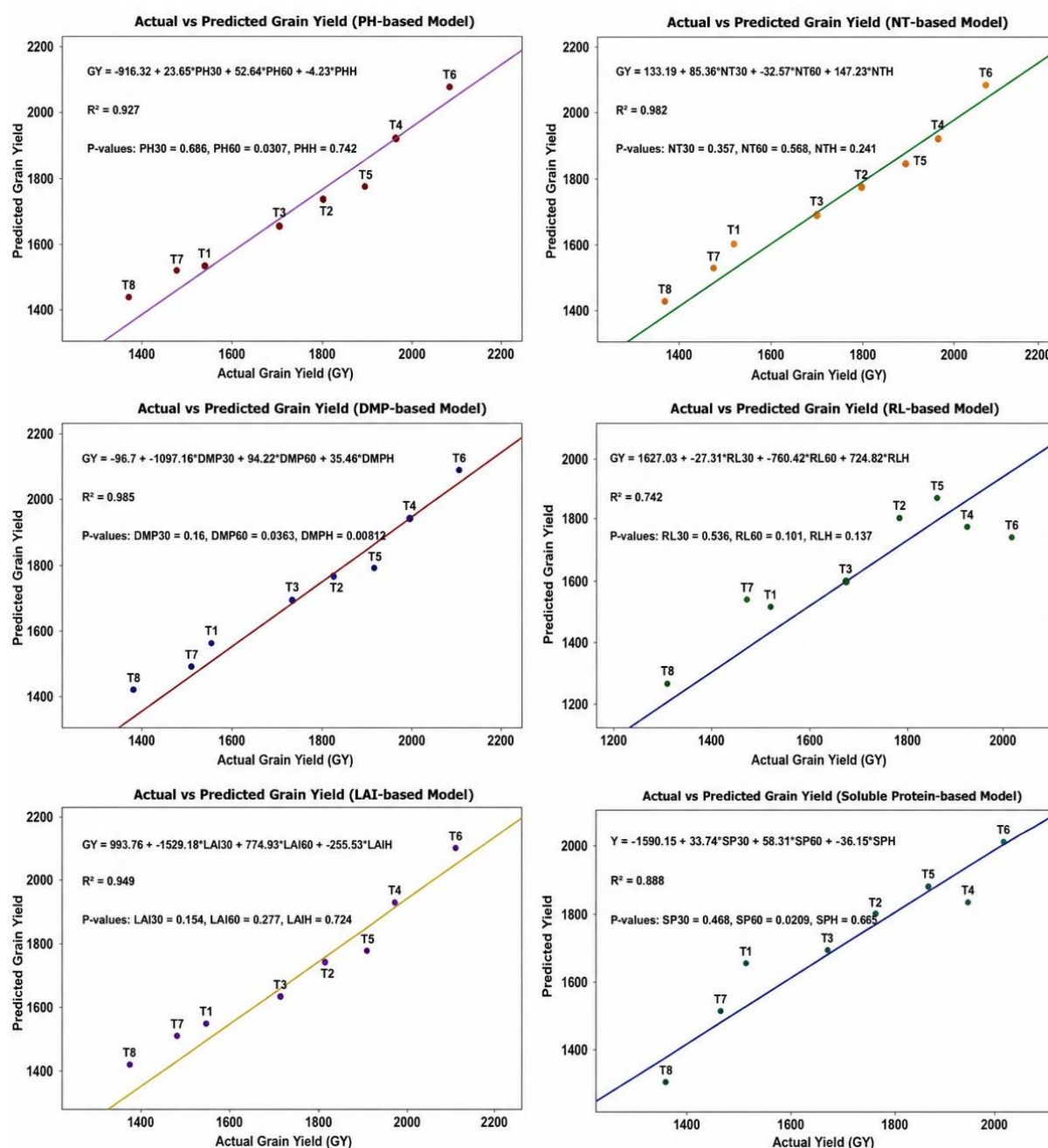


Figure 3. Multivariate linear regression models showing the predictive contributions of physiological and morphological traits measured at early (30 DAS), mid-growth (60 DAS), and harvest stages to grain yield (GY). Mid-growth traits, particularly plant height (PH60), soluble protein (SP60), and dry matter production (DMP60) are emerged as the most significant predictors (*p < 0.05), while models based on NT and DMP achieved the highest R² values (0.982 and 0.985). Negative coefficients for some early and harvest-stage traits suggest diminishing returns due to potential physiological inefficiencies. High R² values across models reinforce the critical role of mid-season traits in yield prediction, although multi-collinearity may influence model interpretability.

measurements such as NT30, RL30, DMP30, and LAI30 demonstrated unique variation patterns and were weakly correlated with later-stage measurements. These observations suggest that early-stage growth

is influenced by different developmental dynamics and may not directly reflect final trait expression. The magnitude and orientation

of vectors in the correlation circle further indicated that traits measured at 60 DAS and harvest not only contributed significantly to the total variance explained by PC1 but were also more tightly clustered, reflecting shared developmental pathways or environmental responses. On the other hand, the distinct positioning of 30 DAS traits implies that they represent unique biological processes occurring during early vegetative growth.

4. Discussion

The growth of kodo millet was significantly influenced by different nutrient management strategies. Among the treatments, the combined application of (T_6) RDF + 33 kg K ha⁻¹ + foliar spray of ZnSO₄ (0.5%) and FeSO₄ (1%) at active tillering and flower initiation (AT & FI) consistently recorded superior performance in most growth parameters including plant height, number of leaves plant⁻¹, number of tillers plant⁻¹, dry matter production, and root volume. The enhanced plant height observed was primarily attributed to potassium promoting meristematic activity and the synergistic effect of foliar-applied micronutrients (Zn and Fe) enhancing cell division and shoot elongation (Guggari and Kalaghatagi, 2005). The number of leaves and tillers were notably higher with this treatment due to potassium-induced cytokinin synthesis and improved nutrient uptake from foliar sprays, which promoted vegetative growth (Reddy et al., 2018; Surya and Krishnan, 2025). Increased tiller count directly contributed to higher productive potential, aligning with the findings of Yadav et al. (2012) and Arockia Infant Paul et al. (2025). Similarly, dry matter accumulation was greater in treatments that received adequate K and micronutrients, reflecting improved photosynthetic efficiency and nutrient assimilation. Root traits were also influenced by nutrient levels. Maximum root length was observed under (T_3) RDF + 22 kg K ha⁻¹ + MN mixture @ 12.5 kg ha⁻¹ at early stages, whereas absolute control showed longer roots at later stages, likely as an adaptive mechanism to explore nutrients under deficient conditions. However, root volume increased with higher nutrient supply, particularly with RDF + 33 kg K ha⁻¹ and foliar micronutrients, which supported better nutrient uptake and biomass production (Patel et al., 2018).

Physiological parameters such as leaf area index (LAI), crop growth rate (CGR), relative growth rate (RGR), net assimilation rate (NAR), chlorophyll content, and soluble protein content were significantly

influenced by different nutrient management strategies. Among all treatments, T_6 consistently recorded superior values across most physiological traits. Enhanced LAI under this treatment was attributed to improved nutrient uptake and increased photosynthetic surface area, aided by the role of potassium in water regulation and the contributions of zinc and iron to photosynthesis and enzyme function (Reddy et al., 2021). Higher CGR and RGR were also observed under this treatment, likely due to better canopy development and enhanced metabolic activity promoted by potassium and micronutrients, which are involved in cell division and elongation (Basha et al., 2019). The improved NAR indicated efficient assimilate production and utilization, which may be linked to the synergistic effect of potassium and foliar-applied zinc and iron in enhancing chlorophyll synthesis and enzymatic activities (Surya et al., 2025). Chlorophyll content (SPAD values) was highest in plots receiving micronutrient sprays, supporting the role of Fe and Zn in pigment formation and photosynthetic efficiency (Meena et al., 2018). Similarly, soluble protein content was significantly higher in nutrient-enriched treatments, especially at later stages, likely due to increased protein synthesis and carbohydrate metabolism facilitated by potassium and zinc (Wang and Wu, 2013; Lizabeni et al., 2025a).

Grain yield and straw yield were highly influenced with different nutrient management practices. Higher grain and straw yield were recorded with (T_6) RDF + 33 kg K ha⁻¹ + foliar spray of ZnSO₄ @ 0.5% and FeSO₄ @ 1% at active tillering and flower initiation stage. Higher yield was recorded with T_6 (18.8 %) followed by T_4 (15.2 %) over recommended dose of fertilizers (1379 kg ha⁻¹). Lower grain and straw yield were recorded in absolute control. Application of potassium and foliar nutrition of micro nutrients effectively promoted growth parameters at initial stages of crop growth. Lower nutrient supply reduced LAI, number of effective leaves and leads to less biomass production in kodo millet. The results are confirmed with findings of Dwivedi et al. (2016). From a practical perspective, the superior performance of T_6 suggests that supplementing the recommended fertilizer dose with potassium and two foliar sprays of ZnSO₄ and FeSO₄ at active tillering and flower initiation is a feasible nutrient management strategy under field conditions. Since foliar application requires relatively small

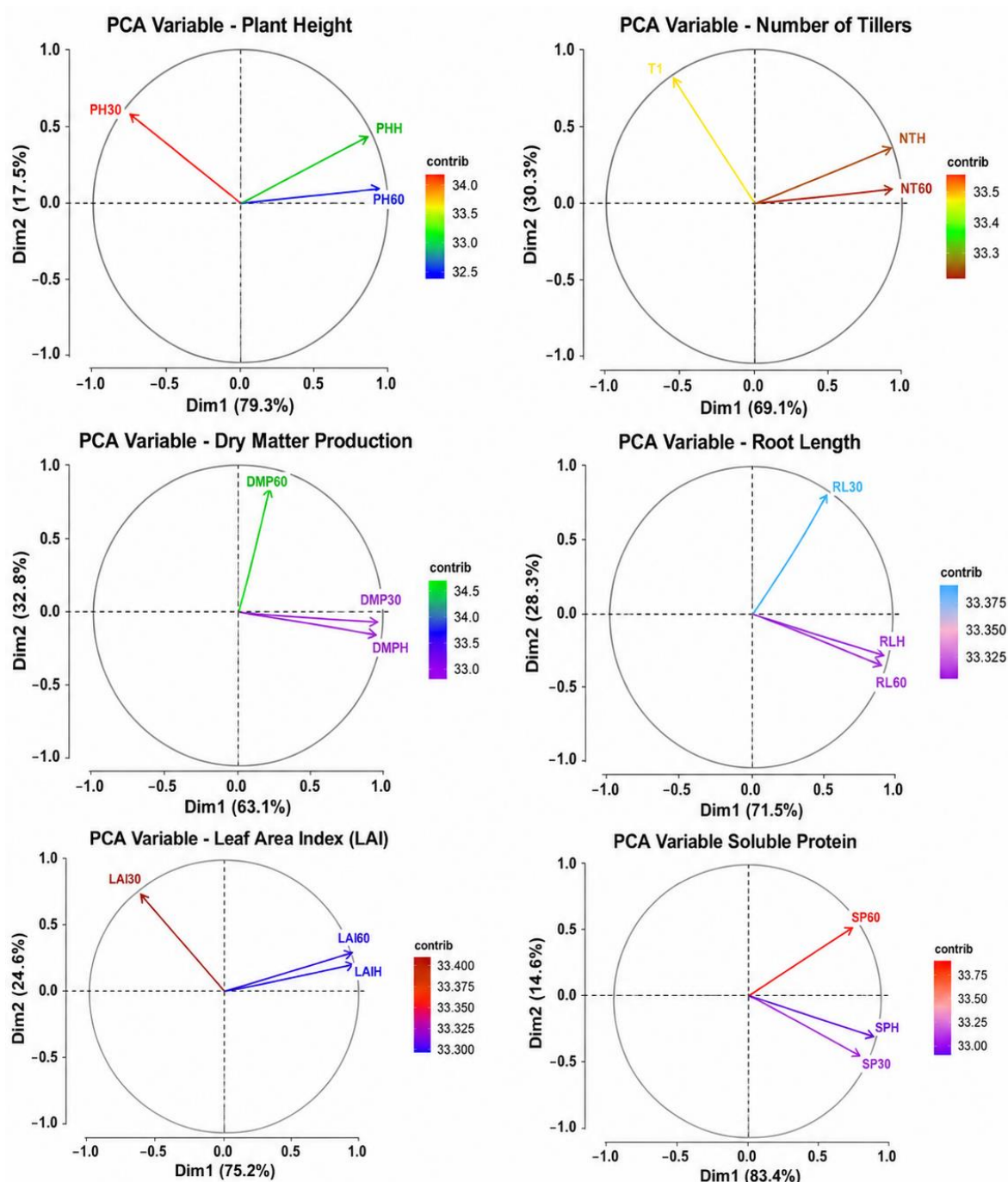


Figure. 4 Principal Component Analysis (PCA): Variable plots showing the relationships among six traits - plant height (PH), number of tillers (NT), dry matter production (DMP), root length (RL), leaf area index (LAI), and soluble protein content (SP) which are measured at 30, 60 days after sowing (DAS), and at harvest. Traits measured at 60 DAS and harvest are closely grouped and mainly contribute to the first principal component (PC1), showing strong positive relationships and indicating their importance in final crop performance.

quantities of micronutrients and can be synchronized with routine crop management operations, it offers a cost-effective approach for improving crop productivity and nutrient-use efficiency, thereby enhancing the economic returns to farmers

The correlation analysis clearly demonstrates that rice yield performance under different treatment combinations with nutrient management strategies, is strongly influenced by key physiological and growth

parameters. Traits such as plant height, number of tillers, and dry matter production are highly interrelated and exhibit strong positive correlations with both grain and straw yield. These results were strongly supported by Lizabeni et al., 2025b. The consistent improvement in physiological traits further demonstrates that foliar application of Zn and Fe, when integrated with balanced potassium nutrition, can be readily adopted by farmers as a practical intervention to enhance crop performance under field conditions without major modifications to existing cultivation practices. Moreover, mid to late-stage physiological processes reflected through parameters like CGR, RGR, NAR, and LAI at harvest played a critical role in supporting yield formation. The multivariate regression and PCA analysis revealed that physiological and morphological traits measured at the mid-growth stage (60 DAS) were the strongest predictors of grain yield. Multivariate regression models showed significant contributions from traits such as plant height (PH60), dry matter production (DMP60), and soluble protein content (SP60), with particularly high R^2 values observed in models involving number of tillers (NT) and DMP. Despite strong model fits, several early-stage (NT30, DMP30) and harvest-stage traits (SPH, LAIH) showed weak or negative associations, likely due to multicollinearity or biological inefficiencies such as unbalanced resource allocation. To explore trait interrelationships and assess redundancy, PCA was conducted. The results showed that traits at 60 DAS and harvest clustered together and loaded strongly on PC1, indicating shared developmental pathways and strong correlations with yield. Conversely, 30 DAS traits were more dispersed and loaded on PC2, reflecting different early-growth dynamics. These results underscore the predictive value of mid-season traits and highlight the utility of PCA in diagnosing multi-collinearity and guiding effective trait selection in regression modeling.

Conclusion

The present study demonstrated that the integrated application of RDF + 33 kg K ha⁻¹ + foliar sprays of ZnSO₄ (0.5%) and FeSO₄ (1%) at active tillering and flower initiation significantly improved the growth, physiological performance, and yield of kodo millet. Correlation analysis further confirmed the strong association between physiological traits and grain yield, emphasizing the importance of balanced nutrient management for enhancing crop productivity.

Agronomic recommendation:

Based on the experimental findings, the integrated application of RDF with 33 kg K ha⁻¹ and foliar sprays of ZnSO₄ (0.5%) and FeSO₄ (1%) at active tillering and flower initiation is recommended as an effective nutrient management strategy for improving the productivity and physiological performance of kodo millet under field conditions.

Future research:

Further studies should focus on validating this nutrient schedule across diverse agro-climatic regions and seasons, while exploring under investigated areas such as potassium–micronutrient interactions, phytate and polyphenol modulation, nutrient-use efficiency, and grain nutritional quality to strengthen sustainable millet production and biofortification strategies.

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Originality and Plagiarism

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Competing Interests

The authors declare that there are no competing interests, financial or non-financial, that could have influenced the research or its interpretation.

CRedit authorship contribution statement

K Surya: writing original draft, formal analysis, software R Krishnan: Conceptualization, methodology, supervision, investigation

REFERENCES:

- Arockia Infant Paul, R., Murali Arthanari, P., Panneerselvam, P., Kumar, V., Bagavathiannan, M. and K. Surya. 2025. Comparative analysis of UAV and electric backpack sprayers for herbicide efficacy and crop-weed nutrient dynamics in direct-seeded rice. J. Agric. Food Res., 23: 102307. <https://doi.org/10.1016/j.jafr.2025.102307>

- Basha, D. M. A., Hellal, F. and S. El-Sayed. 2019. Effects of potassium and humic acid on amelioration of soil salinity hazardous on pea plants. *Asian J. Plant Sci. Nutr.*, 5: 1–10. <https://doi.org/10.9734/AJSSPN/2019/V5I430073>
- Biswas, S. and R. Das. 2023. System of finger millet intensification. *Indian Farming*, 73: 35–38. <https://epubs.icar.org.in/index.php/IndFarm/article/view/131526>
- Chen, M., Paul, M. R., Stith, T. G., John, M. N. and S. P. Steven. 1997. Leaf area index of border forests: theory, techniques and measurements. *J. Geophys. Res.*, 102: 429–443. <https://doi.org/10.1029/97JD01107>
- Dixit, P. and R. Ravichandran. 2024. The potential of millet grains: a comprehensive review of nutritional value, processing technologies, and future prospects for food security and health promotion. *J. Food Technol. Nutr. Sci.*, 6: 2–8. [https://doi.org/10.47363/jfns/2024\(6\)170](https://doi.org/10.47363/jfns/2024(6)170)
- Dwivedi, B., Rawat, A., Dixit, B. and R. Thakur. 2016. Effect of inputs integration on yield, uptake and economics of kodo millet (*Paspalum scrobiculatum* L.). *Econ. Affairs*, 61: 519–523. <https://doi.org/10.5958/0976-4666.2016.00065.6>
- Enyi, B. 1962. The contribution of different organs to grain weight in upland and swamp rice. *Ann. Bot.*, 26: 529–531. <https://doi.org/10.1093/oxfordjournals.aob.a083812>
- Gomez, K. A. and A. A. Gomez. 1984. Statistical procedures for agricultural research. John Wiley and Sons, New York. <https://surl.li/bavpec>
- Guggari, A. and S. Kalaghatagi. 2005. Effect of fertilizer and biofertilizer on pearl millet (*Pennisetum glaucum*) and pigeonpea (*Cajanus cajan*) intercropping system under rainfed conditions. *Indian J. Agron.*, 50: 24–26. <https://doi.org/10.59797/ija.v50i1.5052>
- Kaduwal, S., Karki, T. B., Neupane, R., Battarai, R. K., Chaulagain, B., Ghimire, P., Gyawaly, P. et al. 2023. Residue management and nutrient dynamics in conservation agriculture: a review. *Agron. J. Nepal*, 7: 139–148. <https://doi.org/10.3126/ajn.v7i1.62169>
- Kumar, S., Kumar, A., Sen, H., Janeja, H. S., Maity, S., Banerjee, S., Singh, P. and A. M. Channapur. 2024. Small millets: a multifunctional crop for achieving sustainable food security under climate change. *Plant Sci. Today*. <https://doi.org/10.14719/pst.4113>
- Lizabeni, M. K., Somasundaram, E., Murali, A. P., Kannan, R., Janaki, P., Sunitha, R., & Surya, K. 2025b. Effect of non-chemical weed management on nutrient uptake, microbial population and grain nutritional parameters in transplanted rice (*Oryza sativa* L.). *Plant Science Today*, 12(sp4). <https://doi.org/10.14719/pst.9374>
- Lizabeni, M. K., Somasundaram, E., Murali, A. P., Kannan, R., Janaki, P., Sunitha, R. and K. Surya. 2025a. Non-chemical approaches for effective weed management and productivity of transplanted rice (*Oryza sativa* L.). *Plant Sci. Today*, 12. <https://doi.org/10.14719/pst.8582>
- Maurya, R., Boini, T., Misro, L., Radhakrishnan, T., Sreedharan, A. P. and D. Gaidhani. 2023. Comprehensive review on millets: nutritional values, effect of food processing and dietary aspects. *J. Drug Res. Ayurvedic Sci.*, 8: S82–S98. https://doi.org/10.4103/jdras.jdras_123_23
- Meena, B., Kumar, P., Kumar, A., Meena, R., Kaledhonkar, M. and P. Sharma. 2018. Zinc and iron nutrition to increase the productivity of pearl millet-mustard cropping system in salt affected soils. *Int. J. Curr. Microbiol. Appl. Sci.*, 7: 3201–3211. <https://doi.org/10.20546/ijcmas.2018.708.343>
- Nirmalakumari, A., Subramanian, A., Geethanjali, S., Kanchanarani, R., Rajesh, M., Sathiy, K., Manimozhi Selvi, V., Senthil, N., Ambethgar, V., Geetha, S., Subramanian, K. S., & Tonapi, V. A. (2022). CKMV 1: A short duration, high yielding, drought tolerant, non lodging kodo millet variety suitable for rainfed cultivation in India. *Electronic Journal of Plant Breeding*, 13(3), 1126–1131. <https://doi.org/10.37992/2022.1303.114>
- Patel, A., Vidyalaya, K. V., Parihar, P., Dhumketi, I. K., Patel, C. A. and K. Dhumketi. 2018. Nutritional evaluation of kodo millet and puffed kodo. *Int. J. Chem. Stud.*, 6: 1639–1642. <https://surl.li/vlkebb>
- Porwal, A., Bhagwat, G., Sawarkar, J., Kamble, P. and M. Rode. 2023. An overview of millets—the nutrients: its nutritional profile, potential health benefits and sustainable cultivation approach. *Int. J. Sci. Res. Arch.*, 10: 841–859. <https://doi.org/10.30574/ijrsra.2023.10.1.0828>
- Reddy, B., Bulbule, A., Gajbhiye, P. and D. Patil. 2018. Effect of foliar application of plant nutrients on growth and yield of finger millet. *Int. J. Curr.*

- Microbiol. Appl. Sci., 7: 2203–2209. <https://doi.org/10.20546/ijcmas.2018.703.260>
- Reddy, K. M., Umesha, C. and M. Meshram. 2021. Impact of potassium and sulphur levels on pearl millet (*Pennisetum glaucum* L.). Biol. Forum Int. J., 13: 92–97. <https://surl.li/szvcjt>
- Saxena, R., Vanga, S. K., Wang, J., Orsat, V. and V. Raghavan. 2018. Millets for food security in the context of climate change: a review. Sustainability, 10: 2228. <https://doi.org/10.3390/su10072228>
- Sharma, D., Ghimire, P., Bhattarai, S., Adhikari, U., Khanal, S. and P. B. Poudel. 2020. Biofortification of wheat: genetic and agronomic approaches and strategies to combat iron and zinc deficiency. Int. J. Environ. Agric. Biotechnol., 5. <https://doi.org/10.22161/ijeab.54.29>
- Shikha, D., Kumar, Y., Sharanagat, V. S. and D. C. Saxena. 2024. Kodo millet: technological impact and nutritional benefits for value-addition in food products. J. Food Process Eng., 47: e14655. <https://doi.org/10.1111/jfpe.14655>
- Singh, N., Kumari, P., Gulati, J., & Bassi, N. 2023. Nutrient rich kodo millet, importance and value addition: an overview. Pharma Innov. J., 12: 3713–3719. <https://surl.li/lorjtn>
- Surya, K. and R. Krishnan. 2025. Trends and patterns of publications in the Indian Journal of Agricultural Sciences through bibliometric analysis. Madras Agric. J., 112: 64–78. <https://doi.org/10.29321/MAJ.10.901221>
- Surya, K., Krishnan, R., Vaddi, S., Sanbagavalli, S., Senthil Kumar, G., Parameswari, E., Janaki, P., Gnanachitra, M., Gopalakrishnan, M., Ratchagar, A. I. P. and G. Selvakumar. 2025. Polyhalite as a next generation chloride free multi nutrient fertilizer for sustainable agriculture – review. J. Plant Nutr. <https://doi.org/10.1080/01904167.2025.2523539>
- Surya, K., Sanbagavalli, S., Somasundaram, E., Renukadevi, A. and S. Panneerselvam. 2022. Effect of potassium and foliar nutrition on yield and economics of kodo millet under irrigated condition. Biol. Forum Int. J., 14: 42–46. <https://surl.li/iilxow>
- Vetriventhan, M. and H. D. Upadhyaya. 2019. Variability for productivity and nutritional traits in germplasm of kodo millet, an underutilized nutrient-rich climate smart crop. Crop Sci., 59: 1095–1106. <https://doi.org/10.2135/cropsci2018.07.0450>
- Wang, Y. and W. H. Wu. 2013. Potassium transport and signaling in higher plants. Annu. Rev. Plant Biol., 64: 451–476. <https://doi.org/10.1146/annurev-arplant-050312-120153>
- Watson, D. 1958. The dependence of net assimilation rate on leaf-area index. Ann. Bot., 22: 37–54. <https://doi.org/10.1093/oxfordjournals.aob.a083596>
- Williams, R. 1946. The physiology of plant growth with special reference to the concept of net assimilation rate. Ann. Bot., 10: 41–72. <https://doi.org/10.1093/oxfordjournals.aob.a083119>
- Yadav, S., Tikko, A. and J. Singh. 2012. Effect of potassium on pearl millet-wheat cropping system in coarse textured soils of southern Haryana. J. Indian Soc. Soil Sci., 60: 145–149. <https://surl.li/doekyv>