Indian Journal of Agricultural Sciences **95** (2): 219–224, February 2025/Article
https://doi.org/10.56093/ijas.v95i2.152417

Maximizing forage yield and quality of grasses through nutrient management in established coconut (*Cocos nucifera*) orchards

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Received: 05 June 2024; Accepted: 09 December 2024

ABSTRACT

The aim of crop intensification is to harvest the maximum biomass per unit area and improve the resources use efficiency in face of increasing food demand and decreasing land availability. The experiment was conducted from 2020–2022 at Zonal Agricultural Research Station, Vishveshwaraiah Canal Farm, Mandya, Karnataka to assess the performance of different forage grasses under varied nutrient levels in the established coconut (*Cocos nucifera* Linn.) orchard. Treatment consisted of three fodder grasses (Bajra Napier hybrid, Guinea and Signal grass) and three nutrient levels [(100% Recommended dose of nutrients (RDN), 125% RDN and 150% RDN). Experiment was laid out in factorial randomized block design (FRBD) and replicated three times. The results revealed that Bajra Napier hybrid grass produced significantly highest forage (832.14 q/ha), dry matter (181.48 q/ha) and crude protein yield (12.55 q/ha). Application of 150% RDN across grasses recorded maximum green forage (694.09 q/ha), dry matter (163.88 q/ha) and crude protein yield (12.73 q/ha). Similarly, bajra napier grass under 150% of RDN harvested the highest forage yield (492.23 q/ha) due to maximum light interception at the bottom (39.19%) and middle (29.18%) of the coconut canopy. Consequently, improved net returns and benefit cost ratio were noticed in this treatment combination. Therefore, productivity and profitability of established coconut orchards could be enhanced through inclusion of high yielding Bajra Napier hybrid grasses with intensive nutrient application. These results can be extrapolated to the coconut growing regions of the country to meet the green fodder demand and increase the land productivity.

Keywords: Coconut garden, Crude protein yield, Green forage yield, Light interception, Nutrient levels

Although India is the largest producer of milk globally, its per animal milk productivity is 20–60% lower than the world average (Roy *et al.* 2019). The primary reason for the low productivity is insufficient fodder and feed resources. The country faces a severe scarcity in feed and fodder, with an 11.24% shortage in green forage, 23.4% in dry forage and 28.9% of concentrates (Singh *et al.* 2022). Expanding fodder crop cultivation is impractical due to population pressure and competition with food crops (Rajak *et al.* 2022). The solution is to maximize fodder production per unit area and time by utilizing the inter-space in established plantation crops like coconut orchards.

Coconut (*Cocos nucifera* Linn.) is an important plantation crop of Karnataka and other coastal states which occupies an area of 4.4 lakh hectares with a production of 39130 lakh nuts and productivity of 8,924 nuts/ha (Kishore and Murthy 2016). Majority of the farmers are not utilizing the under-storey space available in coconut gardens for cultivation of food and fodder crops. The adult coconut palm, positioned 9.0 m × 9.0 m apart, efficiently utilizes just 22.3% of the land, while the canopy's average air space utilization is approximately 30% and its solar radiation interception is between 45 and 50% (Bavappa *et al.* 1986). For the efficient use of natural resources, coconut gardens provide great chances for the addition of complementary component crops. It is possible to utilize the available land resources for cultivation of fodder crops without hampering the yield of nuts, so that we can meet the deficit of fodder resources in the state without affecting food grain production. Grasses like hybrid napier, guinea grass and congo-signal grass are known for their strong persistence, palatability and suitability for intercropping under coconut-based cropping systems.

The productivity of grasses is largely governed by the availability of sufficient light, space and proper nutrient management (Sannagoudar *et al.* 2021). Among these factors, primary nutrients play a crucial role in enhancing

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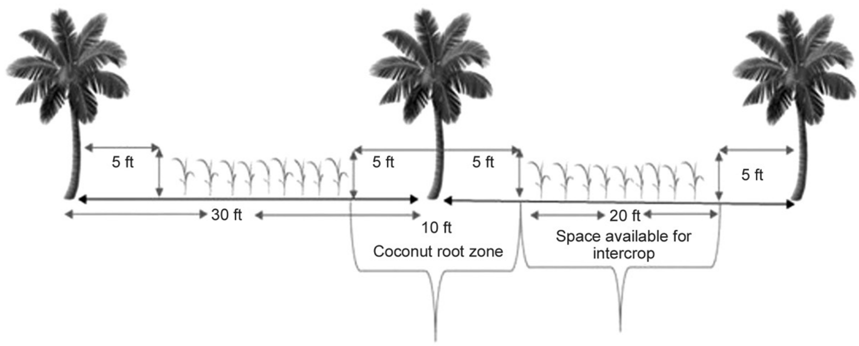

Fig. 1 Schematic representation of the coconut orchard and intercropping pattern.

both the quantity and quality of the crop. Nitrogen, in particular, promotes vegetative growth and improves quality by enhancing the protein content of fodder crops. As a key component of amino acids, a deficiency in nitrogen can lead to severe health issues in animals. Considering these aspects, the current study was conducted to examine the impact of nutrient levels on the green forage yield and quality of forage grasses grown in established coconut orchards.

MATERIALS AND METHODS

Description of study location: The experiment was conducted from 2020–2022 at Zonal Agricultural Research Station, Vishveshwaraiah Canal Farm, Mandya (12°45'–13°57' N and 76°45'–78°24' E, at an altitude of 695 m asl), Karnataka. This region is part of Karnataka's southern dry zone and falls within India's semi-arid area.

Weather and soil characteristics: Maximum and minimum temperatures exhibit variations across the years and months. There's a typical seasonal pattern, with higher temperatures in summer (March–June) and lower temperatures in winter (December–February). The monthly rainfall pattern showed significant variability. May and August months experienced substantial rainfall, while January and February, have minimal rainfall. Each year demonstrates distinct patterns in rainfall (Supplementary Fig. 1). The experimental soil is characterized as red sandy-loam in texture, exhibiting a neutral *p*H of 7.10. It has a medium level of organic carbon (0.58%), as well as available nitrogen (278.5 kg/ha), phosphorus (26.2 kg/ha) and potassium (178.43 kg/ha).

Experimental setup and crop management: The experiment was laid out in a factorial randomized block design (F-RBD) with three replications and first factor includes three forage grasses such as [(Bajra Napier hybrid (*Pennisetum purpureum* × *Pennisetum typhoides*) (C_1), Guinea grass (*Megathyrsus maximus*) (C_2), and Signal grass (*Brachiaria decumbens*) (C_3)] and second factor consists three nutrient levels [(100% recommended dose of nutrients (RDN) (N_1), 125% RDN (N_2) and 150% RDN (N_3)]. The recommended dose of nitrogen was given in equal splits after each cut (6–7/annum) as per recommendation. Both the factors were laid out in the existing coconut orchards. The production packages were followed for different grasses as per local recommendations (Table 1). Irrigation was scheduled based on crop needs, with intervals of 12–15 days during the *kharif* and *rabi* seasons, depending on soil moisture and rainfall. During the summer season, it was applied consistently every 8–10 days interval.

Description about the coconut orchard: The 20-year-old coconut orchard was selected for cultivation of perennial grasses. The coconut palms were planted at a spacing of 30 ft between rows and 30 ft within rows and in between, forage grasses were planted leaving 5 ft area from the trunks region of palm to avoid competition of grasses for available soil moisture and nutrients (Fig. 1). The perennial grasses like BN hybrid was planted at a spacing of 90 cm × 60 cm and guinea grass was planted with a spacing of 60 cm × 45 cm. While signal grass was planted with a spacing of 45 cm × 45 cm.

Growth and yield attributes of grasses: The fodder grasses were planted in *kharif* 2020, and once they had fully established, growth observations were made. As soon as each plot was cut, the fresh fodder yield was measured and expressed in q/ha. Five plants were randomly selected from each plot to measure their fresh green weight. These plants were then dried at 80 ± 5°C for 24 h until a constant weight was achieved. The dry matter yield (q/ha) was calculated based on this value.

Crude protein analysis: The modified micro Kjeldhal method (Banerjee 1978) was used to measure the nitrogen content of the entire plant, and the results were represented as a percentage. By multiplying the per cent nitrogen by factor 6.25, one can get the crude protein (CP) content of fodder (Doubetz and Wells 1968). The dry matter yield was multiplied by the crude protein percenatge to determine the crude protein yield, which was then expressed in q/ha.

Table 1 Recommended production packages followed for different forage crops

Crop	Variety	Root slips for planting (No./ha)	Spacing's (cm)	Recommended nutrients NPK (kg/ha)	First cut after planting (days)	Subsequent cut (days)	No. of cuts/ annum
Bajra Napier hybrid	Co-3	20,000	90 × 60	180:120:80	60–70	35–45	7–8
Guinea grass	JHGG-08-1	75,000	60 × 45	200:50:25	70	30–35	7–8
Signal grass	DBRS-1	75,000	45 × 30	100:60:40	40–50	30–40	8–9

Light interception: The light interception by intercrops at the bottom and middle of the canopy was carried out with the help of Lux meter. The interception was measured in 10 locations randomly in each treatment and average values were computed separately for bottom and middle of the canopy. The light intensity was recorded between 12:30 and 1:00 pm. (Yoshida *et al.* 1972).

Economics: The successful adoption of any technology relies on its economic advantage over the existing options, especially through higher net returns and an improved benefit-cost (B:C) ratio. The B:C ratio was determined using a specific formula.

$$\text{B:C ratio} = \frac{\text{Gross returns (₹/ha)}}{\text{Cost of cultivation (₹/ha)}}$$

Statistical analysis: Analysis of variance was used to the data on several growth and yield attributes, as described in Gomez and Gomez (1984). Results for the three-year mean data have been interpreted (Table 2).

RESULTS AND DISCUSSION

Growing conditions for crops have a direct or indirect influence on a number of physiological processes in plants. Through the use of agronomic methods, the environment, especially the soil, can be somewhat controlled in order to maximize crop genetic yield potential and improve overall productivity and sustainability.

Growth attributes of grasses: The Bajra Napier hybrid consistently demonstrated superior plant height (107.28 cm) compared to guinea grass and signal grass. This superiority is attributable to the Bajra Napier hybrid's inherent genetic traits, which include a more vigorous growth habit and higher nutrient uptake efficiency. The higher leaf-to-stem ratio (0.66) (Table 2) observed in the Bajra Napier hybrid indicates a greater proportion of leaves, which are crucial for photosynthesis and forage quality. As the primary sites of photosynthesis, leaves enhance the plant's capacity to produce photosynthates, supporting overall growth and development (Nihad *et al.* 2023). This finding aligns with the work of Patidar *et al.* (2023), who emphasized the importance of leaf biomass in forage quality. Studies by Kumhar *et al.* (2021) and Singh *et al.* (2023) further highlight the importance of genetic potential in determining plant growth and biomass production. The notable increase in plant height and the leaf-to-stem ratio with higher nutrient levels (150% RDN) underscores the role of adequate nutrition in promoting vegetative growth. Nutrients, particularly nitrogen, are critical for cell division and elongation, as well as chlorophyll synthesis, which enhances photosynthetic activity (Nihad *et al.* 2023). These trends are consistent with findings by Sannagoudar and Murthy (2018), who demonstrated that increased nitrogen availability leads to enhanced plant height and biomass production. Higher nutrient levels (150% RDN) also resulted in a significantly improved leaf-to-stem ratio, suggesting that adequate nutrition supports balanced growth between leaves and stems, enhancing overall forage quality.

Green fodder and crude protein yield of grasses: The productivity of grasses heavily depends on effective nutrient management, which is a vital agronomic practice for maximizing green fodder yields. Grasses are known to require substantial nutrients and due to their C_4 photosynthetic pathway, they excel at converting solar energy into dry matter. This high efficiency, coupled with their nutrient needs, necessitates careful management to achieve the best possible yields. The green forage yield (GFY) of forage grasses was significantly affected by different nutrient levels (Table 3). Pooled data from three years showed that among the grasses, the Bajra Napier hybrid produced the highest green forage yield (832.14 q/ha), significantly outperforming Guinea grass (590.01 q/ha) and Signal grass (427.13 q/ha). Similarly, dry matter and crude protein yield (CPY) were reported higher in case of Bajra Napier hybrid followed by Guinea grass and Signal grass. This substantial difference can be attributed to the inherent characteristics of the Bajra Napier hybrid, which includes its robust growth habit, extensive root system, and superior nutrient uptake efficiency (Nihad *et al.* 2023). The superior performance of the Bajra Napier hybrid in terms of dry matter and CPY further reinforces its suitability as a high-yield forage crop. The hybrid's ability to produce more biomass and higher quality fodder is crucial for meeting the nutritional needs of livestock, especially in regions where forage resources are limited.

The application of 150% RDN resulted in a significantly higher green forage yield (694.09 q/ha), dry matter yield (163.88 q/ha), and crude protein yield (12.81 q/ha) due to the increased nutrient levels. This was mainly due to fact that higher level of nutrients leads rapid division and elongation of cells due to improved photosynthesis and assimilation of photosynthates resulting in improved plant height (107.28 cm), leaf stem ratio (0.66) and more light interception (Fig. 2) and dry matter production per plant. An increase in nutrient concentration in plant parts is responsible for improvements in plant growth metrics, as they are components of proteins, chlorophyll, and other substances. The availability of more minerals and nutrients has resulted in increased source activity, greater leaf areas, and an improved supply of photosynthates for plant growth and development (Sannagoudar *et al.* 2021). Nitrogen is also a structural constituent and amino acids, amides, alkaloids protein and protoplasm of the cell which are essential for growth and development of plant cells thereby resulting in higher GFY, DMY, CPY and content (Supplementary Fig. 2). These results are in confirmation with findings of Deepak *et al.* 2015. Phosphorus is a component of ribonucleic acid (RNA) and ATP, which regulate essential metabolic processes in plants, promoting root development, nitrogen fixation, and ultimately enhancing quality. These findings align with those of Carruthers *et al.* (2000) and Zhang *et al.* (2008).

Among the grasses and nutrient levels, significantly higher interception of light was reported at both bottom and middle of the canopy in BN hybrid + 150% RDF over other cropping systems and nutrient levels (Fig. 2). Notably, Bajra Napier hybrid intercepted more light both at middle (25%) and bottom (35%) of the canopy under higher nutrients (150% RDF) application followed by 125% RDF. More number of tillers with dense foliage of Bajra Napier hybrid possibly enhanced the light interception over guinea and signal grasses. Higher light interception might be associated to the optimum plant nutrition which resulted in rapid division and elongation of cells lead to increased plant height, larger leaf area and higher dry matter production per plant which in turn resulted in the higher interception of the solar radiation (Zhang *et al.* 2008, Trouwborst *et al.* 2010, Haque *et al.* 2006, Sannagoudar and Murthy 2018). Higher light interception is directly correlated with increased photosynthetic efficiency. When plants capture more light, they can produce more photosynthates through photosynthesis, which are then used for growth and development. This process leads to an increase in biomass production, which is essential for forage crops like the Bajra Napier hybrid. The additional light intercepted by the dense canopy translates into higher rates of carbon assimilation. This increased carbon assimilation supports greater growth rates, enhanced leaf area and more robust plant development (Kumhar *et al.* 2021). Consequently, the Bajra Napier hybrid's ability to intercept more light results in superior growth metrics such as increased plant height, higher leaf-to-stem ratios and greater overall biomass.

Economics of grass cultivation under coconut orchards: The final criterion for accepting and widely implementing any technology in agriculture is economics. Net returns and the B:C ratio, two measures of economic efficiency in any production system, have a stronger influence on the technology's applicability and farmers' adoption of it. In this study, cultivation of bajra napier hybrid recorded the highest net returns (44,371 ₹/ha) and B:C ratio (₹3.09) (Supplementary Fig. 3). The improved net returns and BC ratio with Bajra Napier hybrid were possibly due to higher production of green fodder yield and dry matter with good crude protein yield. Likewise, application of 150% RDN recorded higher net returns and B: C ratio (35,901 ₹/ha and 2.54, respectively). This improvement was mainly due to higher green biomass with application of higher nutrient levels. These results are consistent with the findings of Shekara *et al.* (2010). Therefore, cultivation of Bajra Napier hybrid with 150% of recommended dose of nutrients in the interspace of established coconut orchards could supply protein rich green fodder that leads to efficient utilization of land and other natural resources.

Availability of land for the cultivation of fodder crops is the main constraint in the modern agriculture. Thus, vertical intensification is very much required to improve the land use efficiency. Based on the study, feasibility of intercropping in coconut depends upon the judicious management of the intercrops to avoid excessive competition. Addressing the nutrient requirements of these intercropping systems is another key to creating compatibility intercropped systems. Selection of potential grasses and application of required quantities of nutrients would enhance productivity of coconut-based fodder production systems. It can be concluded that cultivation of Bajra Napier hybrid grass in coconut garden with 150% of recommended dose of nutrients is found suitable and profitable for production of

Table 2 Growth parameters of various forage crops as impacted by nutrient levels in coconut garden

Treatment	Plant height (cm)				Leaf: Stem ratio			
	2020	2021	2022	Mean	2020	2021	2022	Mean
Grasses (C)								
C_1	96.94	96.37	128.54	107.28	0.70	0.66	0.61	0.66
C_2	73.67	76.31	107.80	85.93	0.61	0.67	0.55	0.61
C_3	39.39	53.08	75.11	55.86	0.42	0.52	0.55	0.50
SEm±	1.25	1.48	4.58	2.44	0.01	0.02	0.02	0.02
CD (*P*=0.05)	3.75	4.44	13.63	7.27	0.03	0.05	0.06	0.05
Nutrient levels (N)								
N_1	58.89	63.00	83.12	68.34	0.50	0.56	0.52	0.52
N_2	67.91	72.42	106.84	82.39	0.58	0.58	0.57	0.57
N_3	83.23	90.35	121.49	98.36	0.64	0.67	0.61	0.64
SEm±	1.25	1.45	4.58	2.43	0.01	0.02	0.02	0.02
CD (*P*=0.05)	3.75	7.32	13.63	8.23	0.58	0.05	0.06	0.23
Interaction								
SEm±	15.31	18.14	22.56	17.98	0.03	0.04	0.02	0.03
CD (*P*=0.05)	44.98	53.31	NS	53.56	NS	NS	NS	NS

NS, Non-significant; *, Significant; RDN, Recommended dose of nutrients.
Treatment details are given under Materials and Methods.

Table 3 Green forage yield and quality of various forage crops as influenced by nutrient levels in coconut garden

Treatment	Green forage yield (q/ha)				Dry matter yield (q/ha)				Crude protein yield (q/ha)			
	2020	2021	2022	Mean	2020	2021	2022	Mean	2020	2021	2022	Mean
Grasses (C)												
C_1	384.18	645.93	1466.31	832.14	86.47	132.86	325.12	181.48	4.74	9.41	23.49	12.55
C_2	249.91	492.64	1027.47	590.01	73.36	117.76	225.72	138.95	4.51	9.91	17.46	10.63
C_3	131.44	455.38	694.58	427.13	34.72	115.72	158.32	102.92	1.96	8.06	13.08	7.62
SEm±	7.35	11.78	33.84	17.66	2.26	4.11	9.09	5.15	0.12	0.23	0.72	0.36
CD (*P*=0.05)	22.04	35.30	101.40	52.91	6.79	12.33	27.23	15.45	0.36	0.70	2.16	1.07
Nutrient levels (N)												
N_1	177.40	479.22	927.68	528.10	42.91	113.79	190.94	115.88	2.24	7.99	13.44	7.87
N_2	261.42	525.18	1094.67	627.09	66.83	120.90	243.02	143.58	3.28	9.32	18.04	10.19
N_3	326.72	589.55	1166.01	694.09	84.81	131.63	275.20	163.88	5.68	10.16	22.43	12.73
SEm±	7.35	11.78	33.84	17.66	2.26	4.11	9.09	5.15	0.12	0.22	0.72	0.35
CD (*P*=0.05)	22.04	35.30	101.42	52.92	6.79	12.32	27.23	15.45	0.36	0.70	2.16	1.07
Interaction												
SEm±	47.13	56.87	98.97	63.12	18.11	8.65	41.31	39.66	0.10	0.78	1.23	0.61
CD (*P*=0.05)	135.26	169.74	NS	187.31	53.27	25.92	122.50	117.89	0.31	NS	NS	1.79

NS, Non-significant; *, Significant; RDN, Recommended dose of nutrients.
Treatment details are given under Materials and Methods.

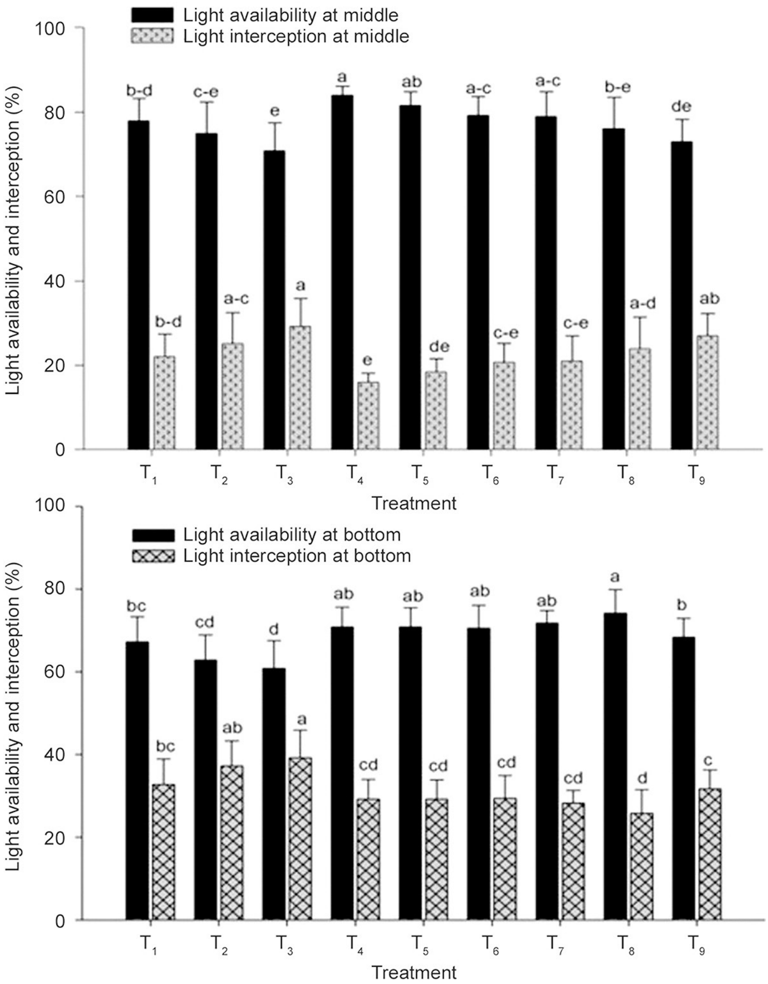

Fig. 3 Light interception by different forage crops as influenced by nutrient levels in coconut garden (pooled data of 3 years).
Treatment details are given under Materials and Methods.

quality green forage yield.

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