



RESEARCH ARTICLE

Synergistic effect of intercropping patterns and nitrogen strategies on yield traits, efficiency metrics and economics outcomes in fodder system

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Abstract

The experiment was carried out to study the agronomic interventions for maximising productivity in fodder cereal + pulse intercropping system during kharif (June–September 2024). The experiment was laid out in a randomized block design (RBD) with 3 replications. The experiment consists of 11 treatments, viz., T₁: fodder sorghum alone (recommended dose of nitrogen (RDN)), T₂: fodder maize alone (RDN), T₃: fodder cowpea alone (RDN), T₄: fodder sorghum + fodder cowpea (No RDN to fodder sorghum), T₅: fodder maize + fodder cowpea (No RDN to fodder maize), T₆: fodder sorghum + fodder cowpea (50 % RDN to fodder sorghum), T₇: fodder maize + fodder cowpea (50 % RDN to fodder maize), T₈: fodder sorghum + fodder cowpea (75 % RDN to fodder sorghum), T₉: fodder maize + fodder cowpea (75 % RDN to fodder maize), T₁₀: fodder sorghum + fodder cowpea (100 % RDN to fodder sorghum), T₁₁: fodder maize + fodder cowpea (100 % RDN to fodder maize). Among the sole cropping systems, applying 100 % RDN to fodder maize resulted in the highest green fodder yield, dry fodder yield, yield efficiency and economic returns. In intercropping systems, the combination of fodder maize and fodder cowpea, with 100 % RDN applied to the maize, delivered the best performance in terms of green fodder yield, dry fodder yield, yield efficiency and profitability. It was statistically on par with the treatment combination of fodder maize + fodder cowpea with 75 % RDN to fodder maize. The results highlight that intercropping fodder maize with fodder cowpea allows for a reduction in nitrogen (N) fertiliser application (up to 25 %) without compromising yield or profitability, thereby improving nutrient-use efficiency and sustainability.

Keywords: cropping system; fodder cereals; intercropping; nitrogen levels; replacement; yield efficiency

Introduction

Agriculture and livestock production are interdependent components of the agrarian economy, collectively contributing to national food and nutritional security in terms of milk. In India, livestock rearing remains a pivotal livelihood strategy for a large segment of the rural population and plays a crucial role in sustaining agricultural operations. As an integral sub-sector of Indian agriculture, livestock farming significantly supports rural incomes and overall agricultural sustainability (1). However, the sector is currently constrained by substantial feed and fodder deficits specifically, a 35.6 % shortage in green fodder, 10.5 % deficit in dry fodder and a 44 % gap in concentrate feed resources (2). These constraints pose serious challenges to animal productivity, health and overall efficiency of livestock systems. The deficiency of green fodder in quantity and quality is reasons of low productivity (3). The poor availability and inferior quality of green fodder not only reduce milk yield but also affect animal health and productivity (4). Addressing these challenges necessitates the adoption of improved agronomic practices, including the use of high-yielding varieties, balanced nutrient management and efficient intercropping systems. Among these, intercropping has gained considerable attention for their role in optimising resource use and enhancing fodder

availability. Cereal-legume intercropping systems, in particular, have shown promise by enabling cereals to utilise the biologically fixed nitrogen (N) from legumes, thereby improving forage yield, quality and nutrient balance for livestock.

Fodder sorghum (*Sorghum bicolor* (L.) Moench) is valued for its resilience to abiotic stresses such as heat, drought and temporary waterlogging. Its rapid growth, high biomass production and regenerative ability make it an excellent forage option (5). Fodder maize (*Zea mays* L.) has emerged as a highly adaptable cereal crop suited to a wide range of agro-climatic conditions. It is increasingly preferred for green fodder and silage due to its palatability, succulence, digestibility and rich nutritional profile (6). Among leguminous fodder crops, cowpea (*Vigna unguiculata* (L.) Walp) is notable for its fast growth, high forage value and capacity to improve soil fertility through atmospheric N fixation (7).

Nitrogen management is vital for enhancing fodder yield and quality. Application of N increases growth characters, yield characters and quality characters of fodder crops (8, 9). It promotes growth, delays senescence, improves nutritional value and enriches soil N, supporting sustained productivity (10). However, the optimal N rate varies with environmental conditions, cropping systems and crop combinations, making it essential to determine the appropriate

dose for maximising yield and quality. In light of the prevailing fodder shortages and concerns regarding forage quality, the present investigation has been conceptualised to address these challenges.

Materials and Methods

A field experiment was conducted at Annamalai Nagar, Chidambaram, Cuddalore district, Tamil Nadu during the kharif season (June–September 2024). The soil of the experimental site was clay loam in texture with 7.2 pH, organic carbon content of 0.3 %, electrical conductivity (EC) of 0.29 dS/m, available N of 214 kg ha⁻¹, available phosphorous (P) of 21.4 kg ha⁻¹ and available potassium (K) of 307.5 kg ha⁻¹. The crops chosen for this experiment were fodder sorghum cv. COFS 31, fodder maize cv. African tall and fodder cowpea cv. COFC 8. The experiment was laid out in a randomized block design (RBD) with 3 replications. The experiment consists of 11 treatments, viz., T₁= fodder sorghum alone with 100 % recommended dose of nitrogen (100 % RDN), T₂= fodder maize alone with 100 % RDN, T₃= fodder cowpea alone with 100 % RDN, T₄= fodder sorghum + fodder cowpea (No RDN to fodder sorghum and 100 % RDN to fodder cowpea), T₅= fodder maize + fodder cowpea (No RDN to fodder maize and 100 % RDN to fodder cowpea), T₆= fodder sorghum + fodder cowpea (50 % RDN to fodder sorghum and 100 % RDN to fodder cowpea), T₇= fodder maize + fodder cowpea (50 % RDN to fodder maize and 100 % RDN to fodder cowpea), T₈= fodder sorghum + fodder cowpea (75 % RDN to fodder sorghum and 100 % RDN to fodder cowpea), T₉= fodder maize + fodder cowpea (75 % RDN to fodder maize and 100 % RDN to fodder cowpea), T₁₀= fodder sorghum + fodder cowpea (100 % RDN to fodder sorghum and 100 % RDN to fodder cowpea), T₁₁= fodder maize + fodder cowpea (100 % RDN to fodder maize and 100 % RDN to fodder cowpea). The experimental field was prepared with two tractor-drawn ploughing, followed by cross harrowing and planking to achieve suitable tilth. The plot size was 660 m². The date of sowing was 10/07/2024 and the date of harvesting for fodder cowpea was 09/09/2024 and 25/09/2024. It was then laid out into individual plots with provisions for irrigation channels and paths and final levelling was done using a rake to ensure uniform water distribution. Crops were sown with a spacing of 30 cm between rows and 15 cm between plants, using seed rates of 5 kg ha⁻¹ for sorghum, 40 kg ha⁻¹ for maize and 25 kg ha⁻¹ for cowpea. In intercropping treatments, cowpea was sown in a replacement series. Seed quantities were calculated based on gross plot area for sole crops and respective crop area for intercropping. Seeds were manually drilled, followed by basal fertiliser application and seed covering.

The recommended fertiliser doses for fodder sorghum are 90:40:40 kg of NP₂O₅K₂O ha⁻¹, fodder maize is 60:40:20 kg of NP₂O₅K₂O ha⁻¹ and fodder cowpea is 25:40:20 kg of NP₂O₅K₂O ha⁻¹. Nitrogen was applied based on the specific requirements of each treatment. For all treatments, 50 % of the recommended N dose was applied as a basal, while the remaining 50 % was applied 30 days after sowing (DAS). The entire dose of P₂O₅ and K₂O was applied to all plots as basal. The nutrient sources used were chemical fertilisers, specifically urea for nutrient N, single super phosphate (SSP) for nutrient P and muriate of potash (MOP) for nutrient K. The full dose of RDF was applied to fodder cowpea according to the plant population in the sole and intercropping system. The data for evaluating the following parameters are collected at the time of requirement.

Biometric observations

Green fodder yield and dry fodder yield

The plants were harvested from the net plot area (537.24 m²) by cutting close to the ground level and fresh weight was recorded. The green fodder yield was computed from the net plot and expressed in tonnes per hectare (t ha⁻¹). Fresh plant samples were dried in oven at 70 °C ± 1 °C for dry weight till the constant weight reached. The dry fodder yield was computed and expressed in tonnes per hectare.

Yield efficiency

Green fodder production efficiency

The green fodder yield of the fodder crops was divided by the duration of the fodder crops and expressed in quintals per hectare per day (q ha⁻¹ day⁻¹) (11).

Crude protein yield (q ha⁻¹) - Crude protein yield was computed by multiplying the crude protein content with the respective dry fodder yield and is expressed in quintals per hectare (q ha⁻¹). Crude protein yield was calculated by using the following formula and expressed as quintals per hectare.

Crude protein yield (q ha⁻¹) =

$$\frac{\text{Crude protein (\%)} \times \text{Dry matter yield (q ha}^{-1}\text{)}}{100}$$

Per day crude protein availability (q ha⁻¹ day⁻¹) - The total crude protein yield of fodder crops was divided by the duration of the fodder crops and expressed in quintal per hectare per day.

Economics

The gross monetary returns were worked out by considering the prevailing market price of fodder. The net returns (NR) of each treatment combination were calculated by deducting the total cost (TC) of cultivation from gross returns (GR) of respective treatments and the benefit: cost ratio (BCR) was calculated by dividing the net returns with total cost of cultivation. All data recorded for different parameters were analysed with the help of analysis of variance (ANOVA) technique (12). The least significant difference test was used to decipher the main and interaction effects of treatments at 5 % level of significance ($p < 0.05$).

Results and Discussions

Green fodder and dry fodder yield

The green fodder yield of the fodder crops is presented in Table 1, while the dry fodder yield is presented in Table 2. Among the sole cropping treatments, fodder maize alone with the application of 100 % RDN (T₂) resulted in the higher green fodder yield of 55.65 t ha⁻¹ and dry fodder yield of 12.62 t ha⁻¹ significantly surpassing the yield of other treatments. The higher yield observed in fodder maize alone with 100 % RDN (T₂) can be attributed to its shorter vegetative phase and rapid early growth, which enable it to achieve high biomass in a relatively short period. This might be the result of improvement in the vegetative characteristics (plant height, number of leaves) with increase in N fertiliser rate attributing to increased uptake of N and its associated role in chlorophyll synthesis and carbon dioxide assimilation leading to enhanced growth and consequently more fresh forage yield and dry matter yield. Similar findings were

Table 1. Effect of different levels of nitrogen on green fodder yield (t ha^{-1}) at harvest stage in fodder cereal + pulse intercropping system

Treatments	Green fodder yield (t ha^{-1})		
	Sorghum/maize	Cowpea	Total
T ₁ - Fodder sorghum alone (RDN)	35.03	-	35.03
T ₂ - Fodder maize alone (RDN)	55.65	-	55.65
T ₃ - Fodder cowpea alone (RDN)	-	22.17	22.17
T ₄ - Fodder sorghum + fodder cowpea (No RDN to fodder sorghum)	12.98	14.6	27.58
T ₅ - Fodder maize + fodder cowpea (No RDN to fodder maize)	20.27	14.62	34.89
T ₆ - Fodder sorghum + fodder cowpea (50 % RDN to fodder sorghum)	20.27	14.94	35.21
T ₇ - Fodder maize + fodder cowpea (50 % RDN to fodder maize)	29.12	15.02	44.14
T ₈ - Fodder sorghum + fodder cowpea (75 % RDN to fodder sorghum)	24.34	15.40	39.74
T ₉ - Fodder maize + fodder cowpea (75 % RDN to fodder maize)	35.28	15.47	50.75
T ₁₀ - Fodder sorghum + fodder cowpea (100 % RDN to fodder sorghum)	25.34	15.59	40.93
T ₁₁ - Fodder maize + fodder cowpea (100 % RDN to fodder maize)	36.48	15.62	52.10
S.Ed	1.94	0.3	1.29
CD ($p = 0.05$)	0.93	0.15	2.70

Table 2. Effect of different levels of nitrogen on dry fodder yield (t ha^{-1}) at harvest stage in fodder cereal + pulse intercropping system

Treatments	Dry fodder yield (t ha^{-1})		
	Sorghum/maize	Cowpea	Total
T ₁ - Fodder sorghum alone (RDN)	9.44	-	9.44
T ₂ - Fodder maize alone (RDN)	12.62	-	12.62
T ₃ - Fodder cowpea alone (RDN)	-	3.40	3.40
T ₄ - Fodder sorghum + fodder cowpea (No RDN to fodder sorghum)	4.42	2.00	6.42
T ₅ - Fodder maize + fodder cowpea (No RDN to fodder maize)	7.17	1.98	9.15
T ₆ - Fodder sorghum + fodder cowpea (50 % RDN to fodder sorghum)	5.73	2.23	7.96
T ₇ - Fodder maize + fodder cowpea (50 % RDN to fodder maize)	8.48	2.25	10.73
T ₈ - Fodder sorghum + fodder cowpea (75 % RDN to fodder sorghum)	6.26	2.38	8.64
T ₉ - Fodder maize + fodder cowpea (75 % RDN to fodder maize)	9.08	2.40	11.48
T ₁₀ - Fodder sorghum + fodder cowpea (100 % RDN to fodder sorghum)	6.75	2.53	9.28
T ₁₁ - Fodder maize + fodder cowpea (100 % RDN to fodder maize)	9.57	2.55	12.12
S.Ed	0.5	0.18	0.62
CD ($p = 0.05$)	0.24	0.09	0.30

previously reported (13–15). The lowest green fodder yield of 19.98 t ha^{-1} and dry fodder yield of 3.40 t ha^{-1} was recorded in fodder cowpea alone with the application of 100 % RDN (T₃). Out of all the intercropping treatments examined, the fodder maize + fodder cowpea system with 100 % RDN to fodder maize (T₁₁) achieved the highest green fodder yield of 52.10 t ha^{-1} and dry fodder yield of 12.12 t ha^{-1} , showing a significant advantage over the remaining treatments but it was statistically comparable to the treatment of fodder maize + fodder cowpea with 75 % RDN to fodder maize (T₉). The improved green and dry fodder yield in the fodder maize + fodder cowpea intercropping system (T₁₁) can be explained by more efficient utilisation of resources, such as space and light interception. Maize provides structural support and partial shade, reducing soil moisture evaporation, while cowpea, being a legume, can fix atmospheric N, thereby improving soil fertility. The higher availability of N resulted into greater plant growth which may attribute to higher green fodder yield under higher level of N. It was statistically on par with 75 % RDN. Even under reduced N input, the presence of cowpea in the intercropping system likely compensated for the lower fertiliser N level by naturally enriching the soil with N, thereby supporting similar green fodder and dry fodder yield. Similar results were previously recorded (16–19). The minimum green fodder yield (27.58 t ha^{-1}) and dry fodder yield (6.42 t ha^{-1}) was noted in the intercropping treatment involving fodder sorghum + fodder cowpea without any N application to fodder sorghum (T₄).

Efficiency

Green fodder production efficiency

The green fodder production efficiency, crude protein yield and per day crude protein availability were summarised in the Table 3. The treatment of fodder maize with 100 % RDN (T₂) in sole cropping and the combination of fodder maize and fodder cowpea with 100 % RDN to fodder maize (T₁₁) in intercropping treatments had a

profound impact on the efficiency of green fodder production efficiency and it was on par with combination of fodder maize and fodder cowpea with 75 % RDN to fodder maize. In terms of green fodder production efficiency, fodder maize performs better than fodder sorghum and cowpea because of its swift early growth, quicker development and remarkable nutrient utilisation, especially N, which enables it to generate high biomass quickly and use water and nutrients more efficiently. Comparable findings were previously reported (13, 20). In the intercropping system, the combination of maize and cowpea with 100 % RDN benefits from direct N fertilisation, which provides the essential nutrients for maize's vigorous growth and deep root system that efficiently absorbs water and nutrients from deeper soil layers. The complementary root systems of maize and cowpea, fibrous root for maize and tap root for cowpea allow them to access different soil layers, minimising competition for resources and optimising water and nutrient use. Intercropping system, supported by 100 % N fertilisation for maize, leads to denser foliage, better biomass accumulation and increased green fodder production efficiency, benefiting the entire cropping system. Intercropping fodder maize with fodder cowpea (75 % RDN) enhances biological N fixation by the legume, which partially compensates for the reduced N fertiliser applied to maize. This improves N availability in the root zone, leading to efficient nutrient uptake, better canopy development thus enhanced fodder production efficiency. Comparable findings were previously observed (21, 22).

Crude protein yield and per day crude protein availability

The application of 100 % (RDN) to sole-cropped fodder maize (T₂) and the intercropping of fodder maize with cowpea with 100 % RDN to fodder maize (T₁₁) in the intercropping treatments had a substantial impact on crude protein yield and per day crude protein availability. The superior performance of sole fodder maize with

Table 3. Effect of different levels of nitrogen on green fodder production efficiency ($\text{t ha}^{-1}\text{day}^{-1}$) and crude protein yield (q ha^{-1}) in fodder cereal + pulse intercropping system

Treatments	Green fodder production efficiency ($\text{t ha}^{-1}\text{day}^{-1}$)	Crude protein yield (q ha^{-1})	Per day crude protein availability ($\text{q ha}^{-1}\text{day}^{-1}$)
T ₁ : Fodder sorghum alone (RDN)	0.44	9.27	0.12
T ₂ : Fodder maize alone (RDN)	0.74	12.23	0.16
T ₃ : Fodder cowpea alone (RDN)	0.57	6.62	0.09
T ₄ : Fodder sorghum + fodder cowpea (No RDN to fodder sorghum)	0.52	7.69	0.10
T ₅ : Fodder maize + fodder cowpea (No RDN to fodder maize)	0.63	10.13	0.14
T ₆ : Fodder sorghum + fodder cowpea (50 % RDN to fodder sorghum)	0.62	9.63	0.12
T ₇ : Fodder maize + fodder cowpea (50 % RDN to fodder maize)	0.76	12.47	0.16
T ₈ : Fodder sorghum + fodder cowpea (75 % RDN to fodder sorghum)	0.69	10.93	0.15
T ₉ : Fodder maize + fodder cowpea (75 % RDN to fodder maize)	0.85	13.90	0.19
T ₁₀ : Fodder sorghum + fodder cowpea (100 % RDN to fodder sorghum)	0.70	12.14	0.16
T ₁₁ : Fodder maize + fodder cowpea (100 % RDN to fodder maize)	0.87	15.21	0.20
S.Ed	0.03	0.33	0.01
CD ($p = 0.05$)	0.06	1.28	0.02

100 % RDN (T₂) in terms of crude protein yield and per day crude protein availability, compared to fodder sorghum and cowpea, can be attributed to its relatively faster growth rate and higher biomass production. These results are consistent with the findings of (23). The treatment involving fodder maize and fodder cowpea with 100 % RDN to fodder maize (T₁₁), on par with treatment of fodder maize + fodder cowpea with 75 % RDN to fodder maize. Cowpea, a leguminous crop, plays a critical role in enhancing crude protein yield through its ability to fix atmospheric N. This process occurs through *Rhizobium* bacteria in cowpea's root nodules, which convert atmospheric N into a form that is accessible to the plants. The higher crude protein yield and per day crude protein availability could be attributed due to fact that optimum levels of N in plants are known to enhance N uptake which might have improved protein synthesis. Even under reduced N input, the presence of cowpea in the intercropping system likely compensated for the lower fertiliser level by naturally enriching the soil with N and by protein synthesis it shows better crude protein yield and per day crude protein availability. Higher protein yields in intercropping systems were previously reported because of legumes' capacity to fix nitrogen (24, 25).

Economics

The economic analysis is illustrated in Table 4. The economic analysis of treatments revealed that the highest gross return, net return and benefit: cost ratio was recorded with the treatment of

fodder maize + fodder cowpea with 100 % RDN to fodder maize (T₁₁) outperforming all other treatments. This was closely followed by the treatment of fodder maize + fodder cowpea with the application of 75 % RDN to fodder maize (T₉). It might be due to higher biomass yield because of inclusion of pulse in cereals along with N application and due to the increased total yield of the forage from two components and higher sale price of the legume fodders. Even under reduced N input, the presence of cowpea in the intercropping system likely compensated for the lower fertiliser N level by naturally enriching the soil with N, thereby supporting similar biomass yield and returns. Similar results were previously reported (25, 26).

Conclusion

Based on the results of this study, it can be concluded that among the sole cropping systems, fodder maize applied with 100 % of RDN led to the best outcomes in terms of yield, efficiency and economic returns. In intercropping systems, the combination of fodder maize and fodder cowpea with 100 % RDN applied to the maize showed the highest performance in yield, efficiency and profitability. This was closely followed by the intercropping treatment with fodder maize and cowpea receiving 75 % RDN to fodder maize, which produced comparable results. These treatments are suitable for farmer adoption, as they enhance overall fodder yield and quality through efficient use of resources. Ultimately, they contribute to better economic stability and sustainability for farming households.

Table 4. Effect of different levels of nitrogen on economics of fodder cereal + pulse intercropping system

Treatment	Fixed cost (Rs ha ⁻¹)	Treatment cost (Rs ha ⁻¹)	Total cost (Rs ha ⁻¹)	Yield (t ha ⁻¹)	Gross returns (Rs ha ⁻¹)	Net returns (Rs ha ⁻¹)	B:C ratio
T1	45810	9532.1	55342	44.76	66963	11621	1.21
T2	45810	8660	54470	55.65	105735	51265	1.94
T3	45810	8760.35	54570	49.27	81906	27335	1.50
T4	45810	8336.4	54146	49.03	74464	20318	1.38
T5	45810	8064.6	53875	52.76	89683	35808	1.66
T6	45810	8867.98	54678	59.10	88776	34098	1.62
T7	45810	8482.29	54292	62.50	107898	53606	1.99
T8	45810	9038.85	54849	65.07	97712	42863	1.79
T9	45810	8596.18	54406	69.36	121177	66771	2.23
T10	45810	9209.79	55020	67.02	100177	45157	1.82
T11	45810	8710.14	54520	71.19	123602	69082	2.27

Statistically not analysed.

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Authors' contributions

DGA conducted the experiment, recorded data, performed data analysis and wrote the manuscript. PS supervised the experiment, formulated the experimental design. SR and RJC made corrections to the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

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

Ethical issues: None

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