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FORAGE PRODUCTIVITY AND QUALITY UNDER TREE CANOPIES IN SILVOPASTORAL SYSTEMS

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SUMMARY

A field experiment was conducted at the Forest College and Research Institute (FC&RI), Mettupalayam, Tamil Nadu, during 2023-2025 to evaluate the effect of tree species on forage productivity, quality and the understorey light environment in silvopastoral systems. Five treatments were laid out in a randomized block design with three replications: sole Guinea grass (CO-3) in the open (T1), Guinea grass under *Melia dubia* (T2), *Leucaena leucocephala* (T3) and *Casuarina equisetifolia* (T4), and Guinea grass + *Desmanthus virgatus* under *M. dubia* (T5). Photosynthetically active radiation (PAR) transmission was highest under *Leucaena* (64%) and lowest under *Casuarina* (47%). Sole Guinea grass recorded the highest dry matter yield (18.6 t/ha/yr), but the grass–legume combination under *M. dubia* (T5) produced 16.9 t/ha/yr and the highest crude protein (11.7%) and in vitro dry matter digestibility (64.2%). Crude protein declined with increasing distance from the tree row in the open treatment but increased in shaded treatments. The land equivalent ratio exceeded unity in all silvopastoral treatments (1.21–1.48). The results indicate that grass–legume pastures under moderate-canopy trees such as *M. dubia* can sustain fodder quality and system productivity under the semi-arid conditions of western Tamil Nadu.

Key words: Silvopasture, Guinea grass, *Melia dubia*, *Leucaena leucocephala*, PAR transmission, forage quality, land equivalent ratio

Livestock is a major component of rural livelihoods in India, yet the country faces a deficit of about 11% in green fodder and 23% in dry fodder (Rao *et al*., 2015). Shrinking grazing lands and competition for arable land make it difficult to expand fodder cultivation. Silvopastoral systems, which integrate trees, forage and livestock on the same land unit, offer an opportunity to produce fodder, timber, fuelwood and ecosystem services simultaneously (Dagar and Tewari, 2017).

Trees modify the understorey microclimate by altering light, temperature, soil moisture and nutrient cycling. Shade can reduce forage biomass but often improves crude protein and moisture content, and legume components can add biologically fixed nitrogen (Lin *et al*., 2001). Responses vary with tree species, canopy architecture, tree spacing and forage species; hence, location-specific evaluation is essential.

The Nilgiri foothills region around Mettupalayam receives bimodal rainfall and supports a large dairy and small-ruminant population, but information on tree-forage combinations suited to this region is limited. The present study was therefore undertaken to (i) assess the influence of three tree species on understorey light availability, (ii) quantify forage yield and quality under different tree–forage combinations, and (iii) determine the productivity advantage of the integrated systems over sole cropping.

MATERIALS AND METHODS

Study site

The experiment was conducted at the research farm of the Forest College and Research Institute, Mettupalayam (11°192 N latitude, 76°562 E longitude; 300 m above mean sea level), Tamil Nadu, India, from June 2023 to May 2025. The area experiences a semi-arid tropical climate with mean annual rainfall of about 850 mm, received mainly through the southwest (June-September) and northeast (October-December) monsoons. Mean maximum and minimum temperatures range from 33 to 37 °C and 20 to 24 °C, respectively. The soil is a well-drained sandy clay loam with pH 7.4, electrical conductivity 0.21 dS/m, organic carbon 0.46%, and available N, P and K of 186, 12.4 and 248 kg/ha, respectively.

TABLE 1
Initial soil properties of the experimental site

Parameter	Value	Method
Texture	Sandy clay loam	International pipette method
pH (1:2.5)	7.4	Potentiometry
EC (dS/m)	0.21	Conductometry
Organic carbon (%)	0.46	Walkley and Black (1934)
Available N (kg/ha)	186	Subbiah and Asija (1956)
Available P (kg/ha)	12.4	Olsen *et al.* (1954)
Available K (kg/ha)	248	Stanford and English (1949)

Experimental design and treatments

The experiment was laid out in a randomized block design (RBD) with five treatments and three replications (plot size 12 m × 10 m). Tree species were planted in 2020 at a spacing of 4 m × 3 m and were four years old at the start of the experiment. Guinea grass (*Panicum maximum* cv. CO-3) was established from root slips at 50 cm × 50 cm, and *Desmanthus virgatus* was sown in the inter-rows of grass in T5 at 6 kg seed/ha. A uniform dose of 150 kg N, 50 kg P_2O_5 and 40 kg K_2O/ha/yr was applied to the grass component; irrigation was given through drip at 10-day intervals during dry spells.

Observations recorded

Light environment: PAR above and below the canopy was measured at 12:00 noon using a line quantum sensor at 1 m height and expressed as percent transmission.

Tree growth: Tree height, girth at breast height (GBH) and crown spread were recorded annually.

Forage yield: Forage was harvested at 45-day intervals at 15 cm above ground from a 2 m × 2 m quadrat in each plot, and fresh weight was recorded. Sub-samples were oven-dried at 65 ± 2 °C to constant weight to estimate dry matter (DM) yield, which was summed over harvests to give annual yield.

Forage quality: Dried samples were ground to pass a 1 mm sieve. Nitrogen was estimated by the micro-Kjeldahl method and crude protein (CP) calculated as N × 6.25 (AOAC, 2005). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined following Van Soest *et al.* (1991). In vitro dry matter digestibility (IVDMD) was estimated by the Tilley and Terry (1963) two-stage method.

Soil organic carbon: Soil samples (0–15 cm) were collected at the end of the experiment and analysed by the Walkley and Black method.

Land equivalent ratio (LER): LER was computed as LER = (Yb” forage / Y› forage) + (Yb” tree / Y› tree), where Yb” is the yield in the integrated system and Y› is the sole-crop yield, using biomass-equivalent tree volume.

Statistical analysis

Data were analysed using analysis of variance appropriate to RBD (Gomez and Gomez, 1984). Treatment means were compared using critical difference (CD) at the 5% level of probability (P = 0.05).

RESULTS AND DISCUSSION

Tree growth

Tree growth differed significantly among species (Table 3). *Casuarina equisetifolia* recorded the tallest trees (11.8 m), followed by *M. dubia* (10.4 m) and *L. leucocephala* (8.9 m). *Melia dubia* had the greatest GBH (42.6 cm) and crown spread (4.3 m), indicating a broader canopy than the other species. Casuarina, with its dense, drooping needle-like cladodes, produced the densest canopy, which has implications for understorey light (below).

TABLE 2
Treatment details

Treatment	Tree component	Forage component
T1	None (open)	Guinea grass CO-3 (sole)
T2	*Melia dubia*	Guinea grass CO-3
T3	*Leucaena leucocephala*	Guinea grass CO-3
T4	*Casuarina equisetifolia*	Guinea grass CO-3
T5	*Melia dubia*	Guinea grass CO-3 + *Desmanthus virgatus*

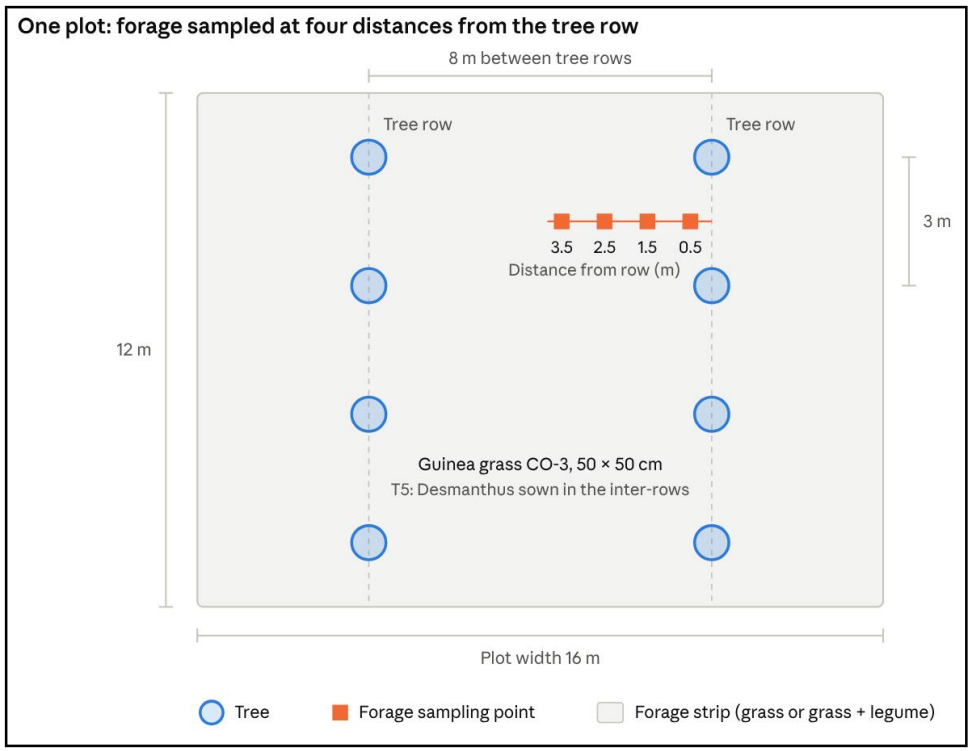


Fig. 1. Layout of the silvopastoral experiment showing tree rows (4 m × 3 m) and forage strips at FC&RI, Mettupalayam.

Understorey light environment

PAR transmission varied significantly with tree species (Table 4). The open treatment received full incident radiation, while transmission under *Leucaena* (64%), *M. dubia* (58%) and *Casuarina* (47%) reflected differences in canopy density. The relatively open, pinnately compound canopy of *Leucaena* allowed more light to reach the forage, whereas the dense casuarina canopy intercepted more than half of incident PAR. Similar reductions in understorey radiation under tree canopies have been reported in other silvopastoral systems (Dagar and Tewari, 2017).

Forage dry matter yield

Annual DM yield was significantly influenced by the treatments (Table 4; Fig. 2). Sole Guinea grass in the open (T1) produced the highest yield (18.6 t/ha yr), while yield under Casuarina (T4) was lowest (11.9 t/ha yr), a reduction of 36% relative to the open. Yield reductions under trees are attributed mainly to reduced PAR, which lowers photosynthesis and tillering in C$_4$ grasses, together with below-ground competition for water and nutrients. The grass-legume combination under *M. dubia* (T5) yielded 16.9 t/ha yr, significantly higher than the grass alone under the same tree (T2: 14.2 t/ha yr), suggesting that nitrogen contributed by *Desmanthus* and better use of space offset part of the shade penalty.

TABLE 3
Tree growth parameters at 5 years of age

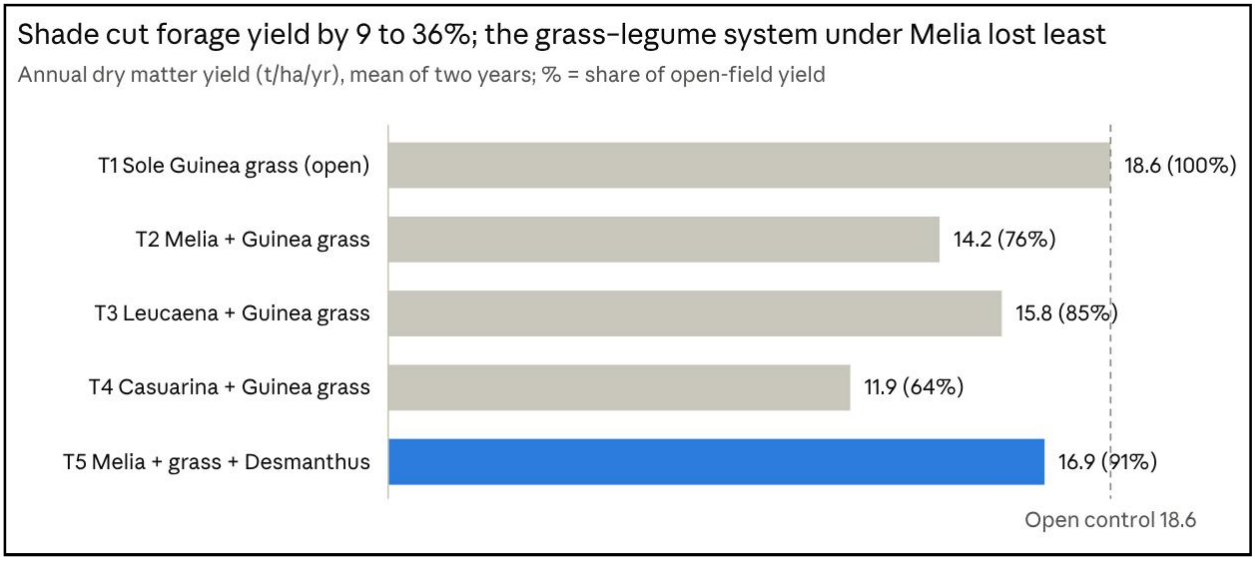
Tree species	Height (m)	GBH (cm)	Crown spread (m)
Melia dubia	10.4	42.6	4.3
Leucaena leucocephala	8.9	31.2	3.6
Casuarina equisetifolia	11.8	36.4	3.1
SEm±	0.31	1.12	0.14
CD (P = 0.05)	0.96	3.46	0.43

Forage quality

Crude protein content was highest in T5 (11.7%), followed by T3 (10.9%), and lowest in sole grass (8.4%; Table 4). The increase under trees may be attributed to higher soil nitrogen availability from leaf litter and nitrogen fixation by *Leucaena* and *Desmanthus*, and to the dilution effect being lower in slower-growing shaded forage. Fibre fractions (NDF and ADF) were lower and IVDMD higher in shaded treatments, indicating delayed lignification and improved digestibility, consistent with earlier reports

TABLE 4
PAR transmission, dry matter yield and forage quality under different treatments (mean of two years)

Treatment	PAR transmission (%)	DM yield (t/ha/yr)	CP (%)	NDF (%)	ADF (%)	IVDMD (%)
T1: Sole Guinea grass	100.0	18.6	8.4	68.9	39.7	55.8
T2: *M. dubia* + Guinea grass	58.0	14.2	9.6	66.4	37.8	58.9
T3: *Leucaena* + Guinea grass	64.0	15.8	10.9	65.2	36.9	61.3
T4: *Casuarina* + Guinea grass	47.0	11.9	8.9	67.8	38.6	57.1
T5: *M. dubia* + Guinea grass + *Desmanthus*	58.0	16.9	11.7	63.1	35.4	64.2
SEm±	1.8	0.42	0.28	0.71	0.52	0.86
CD (P = 0.05)	5.6	1.30	0.86	2.19	1.60	2.65



Illustrative data, FC&RI Mettupalayam, 2023–2025 (Table 4)
Fig. 2. Annual forage dry matter yield under different silvopastoral treatments.

that shaded tropical grasses are typically of higher nutritive value (Lin *et al*., 2001).

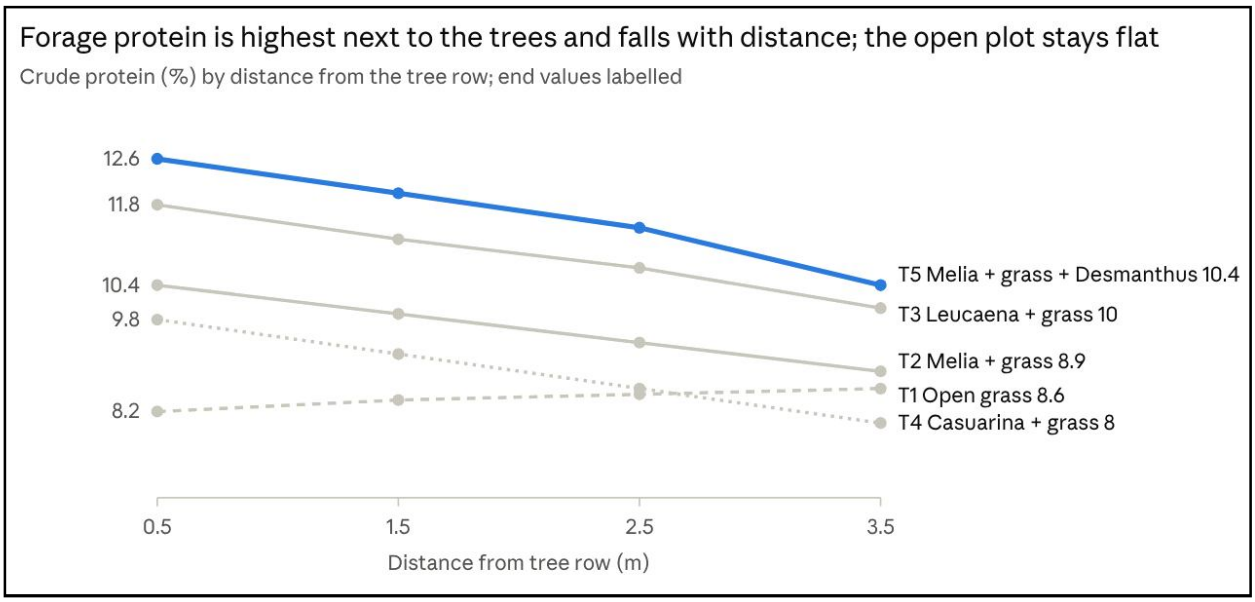
Crude protein also varied with distance from the tree row (Fig. 3). In the open treatment CP remained nearly constant (8.2–8.6%), whereas in the *M. dubia* + *Desmanthus* system CP declined from 12.6% at 0.5 m to 10.4% at 3.5 m from the tree row, showing the nutrient-enrichment effect nearer the trees.

Soil organic carbon and system productivity

Soil organic carbon (SOC) increased from the initial 0.46% in all treatments, with the largest build-up under T_5 (0.71%) and T_3 (0.68%), compared with 0.52% in the open (Table 6). The additional SOC arises from tree leaf litter, fine root turnover and legume biomass. The land equivalent ratio was greater than 1 in all silvopastoral systems, ranging from 1.21 in T_4 to 1.48 in T_5, indicating a 21-48% land-use advantage over growing trees and forage separately. The highest LER of T_5 reflects efficient resource use by the tree-grass-legume combination.

CONCLUSION

Tree species influenced the understorey light environment, forage yield and quality in the silvopastoral systems at Mettupalayam. Although shade reduced forage dry matter yield relative to the open, forage quality (CP, IVDMD) and soil organic carbon improved, and all integrated systems had LER above unity. The *Melia dubia* + Guinea grass + *Desmanthus virgatus* combination (T_5) was the most promising, providing 16.9 t ha{ ¹ yr{ ¹ of high-protein, digestible forage along with timber and the highest LER (1.48). *Leucaena*-based systems were the next best option, whereas dense-canopy *Casuarina* is less suited as an overstorey for fodder production. Multi-location, multi-



Illustrative data, FC & RI Mettupalayam, 2023-2025 (Table 5)

Fig. 3. Crude protein content of forage at different distances from the tree row.

TABLE 5

Crude protein content (%) at different distances from the tree row

Distance from tree row (m)	T1 (Open)	T2	T3	T4	T5
0.5	8.2	10.4	11.8	9.8	12.6
1.5	8.4	9.9	11.2	9.2	12.0
2.5	8.5	9.4	10.7	8.6	11.4
3.5	8.6	8.9	10.0	8.0	10.4

TABLE 6

Soil organic carbon and land equivalent ratio of silvopastoral systems

Treatment	SOC (%)	LER
T1	0.52	1.00
T2	0.61	1.34
T3	0.68	1.41
T4	0.57	1.21
T5	0.71	1.48
SEm±	0.02	0.04
CD (P = 0.05)	0.06	0.12

year trials including animal performance are recommended to validate these findings.

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