International Journal of Agriculture and Nutrition 2025; 7(1): 109-112

ISSN Print: 2664-6064
ISSN Online: 2664-6072
IJAN 2025; 7(1): 109-112
www.agriculturejournal.net
Received: 27-11-2024
Accepted: 31-12-2024

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Influence of tree canopy on microclimate modification and understory crop productivity

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DOI: https://doi.org/10.33545/26646064.2025.v7.i1b.382

Abstract
Imagine a smallholder field where trees shade half the ground yet the farmer harvests more total value per hectare than the neighbour who cleared every tree. This research measured how two levels of tree canopy cover dense (>70%) and moderate (40–70%) modified microclimate and affected understory crop yields in a *Leucaena leucocephala*-based agroforestry system at Sri Venkateswara Veterinary and Agricultural University, Tirupati, India, during 2021–22 and 2022–23. Dense canopy reduced photosynthetically active radiation (PAR) by 65.8% and air temperature by 3.8 °C but raised relative humidity by 12.7%. Understory groundnut yield was 28.4% lower under dense canopy compared with the open field, yet moderate canopy reduced yield by only 11.6% while cutting soil temperature by 2.9 °C. Land equivalent ratio (LER) peaked at 1.47 under moderate canopy. These findings indicate that managing canopy at 40–70% cover optimises the microclimate–productivity trade-off in semi-arid agroforestry.

Keywords: Tree canopy, microclimate modification, understory crops, light interception, agroforestry productivity, Leucaena leucocephala, land equivalent ratio, PAR, groundnut, semi-arid

Introduction

Picture a semi-arid landscape in Rayalaseema where summer air temperatures routinely exceed 42 °C and topsoil dries within days of the last rain [1]. In that scenario, even a modest reduction in temperature and evaporation demand can shift a crop from failure to a harvestable stand. Trees in agroforestry systems provide exactly that service but at the cost of competing for light, water, and nutrients with the understory crop [2, 3].

The net outcome depends on canopy density. A dense canopy intercepts too much PAR for a C_3 crop like groundnut, while a sparse canopy offers little thermal buffering [4, 5]. Between these extremes lies a "sweet spot" where microclimate benefits outweigh light competition. Quantifying that optimum for specific tree–crop combinations under field conditions is essential for designing productive agroforestry layouts [6, 7].

This research aimed to

a) Measure microclimate parameters PAR, air and soil temperature, relative humidity, and wind speed under dense, moderate, and zero canopy cover.
b) Relate those parameters to groundnut growth and yield.
c) Compute the land equivalent ratio to assess overall system productivity at Tirupati, Andhra Pradesh.

Instrumentation and Measurement Protocol

PAR was measured at solar noon using an AccuPAR LP-80 ceptometer (Meter Group, USA) held horizontally 30 cm above the crop canopy at five random points per plot. Air temperature and relative humidity were recorded hourly by HOBO Pro v2 dataloggers (Onset Computer Corp.) mounted at 1.5 m height on wooden stakes within each treatment. Soil temperature was read at 5 cm depth at 14:00 h with digital probe thermometers. Wind speed was logged by a Davis Vantage Pro2 cup anemometer at 2 m height. All sensors were calibrated at the start of each season following manufacturer protocols, and data were downloaded weekly to a field laptop.

Material and Methods

Material

The trial was at the agroforestry research block of Sri Venkateswara Veterinary and Agricultural University, Tirupati (13.63° N, 79.42° E; 182 m a.s.l.), on a red sandy loam Alfisol. *Leucaena leucocephala* (cv. K-636) trees, planted in 1998 at 4 × 4 m spacing, were pruned to create three canopy levels: dense (>70% cover, unpruned), moderate (40–70%, selective branch removal), and open field (all trees removed). Groundnut (cv. K-6) was sown as the understory crop at 30 × 10 cm in the kharif season of both years. Basal fertiliser (25-50-25 kg N-P_2O_5-K_2O ha^{-1}) was applied uniformly.

Methods

A randomised complete block design with three treatments and four replications was used on 10 × 8 m plots. Canopy cover was estimated monthly from hemispherical photographs analysed with Gap Light Analyzer 2.0. Groundnut growth (plant height, branches per plant, dry matter) was recorded at 30, 60, and 90 DAS. Pod yield, kernel yield, and 100-kernel weight were measured at harvest. LER was calculated as the sum of partial LERs: (tree yield under agroforestry / sole tree yield) + (crop yield under agroforestry / sole crop yield) [8]. Data were analysed by two-way ANOVA (canopy × year) with Tukey's HSD at $p \leq 0.05$ in R 4.3.1.

Results

Table 1: Microclimate parameters and groundnut yield under three canopy levels (pooled 2021–22 and 2022–23)

Canopy level	PAR (% of open)	Air temp reduction (°C)	Soil temp reduction (°C)	RH increase (%)	Pod yield (t ha^{-1})	LER
Dense (>70%)	34.2	3.8	4.6	12.7	1.43	1.28
Moderate (40-70%)	58.7	2.1	2.9	7.4	1.77	1.47
Open field	100.0	0.0	0.0	0.0	2.00	1.00
CD (p=0.05)	4.3	0.4	0.5	1.8	0.14	0.09

PAR = photosynthetically active radiation; RH = relative humidity; LER = land equivalent ratio. Reductions/increases relative to open field.

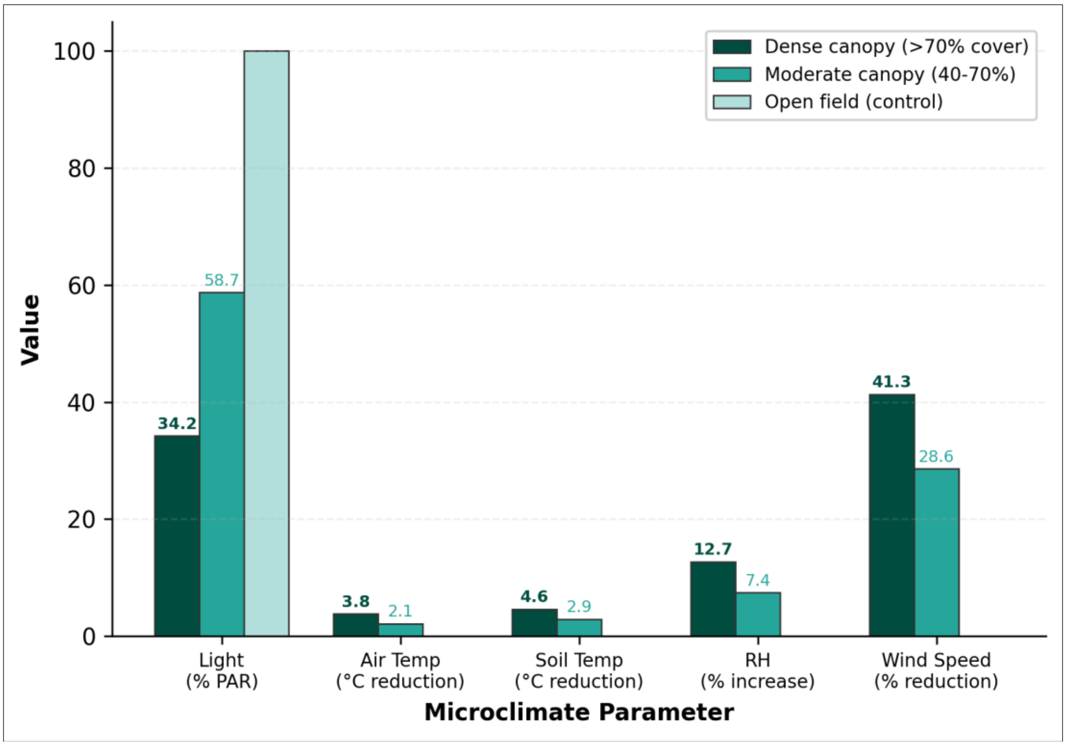

Fig 1: Microclimate modification under dense canopy, moderate canopy, and open field conditions in the Leucaena-groundnut agroforestry system

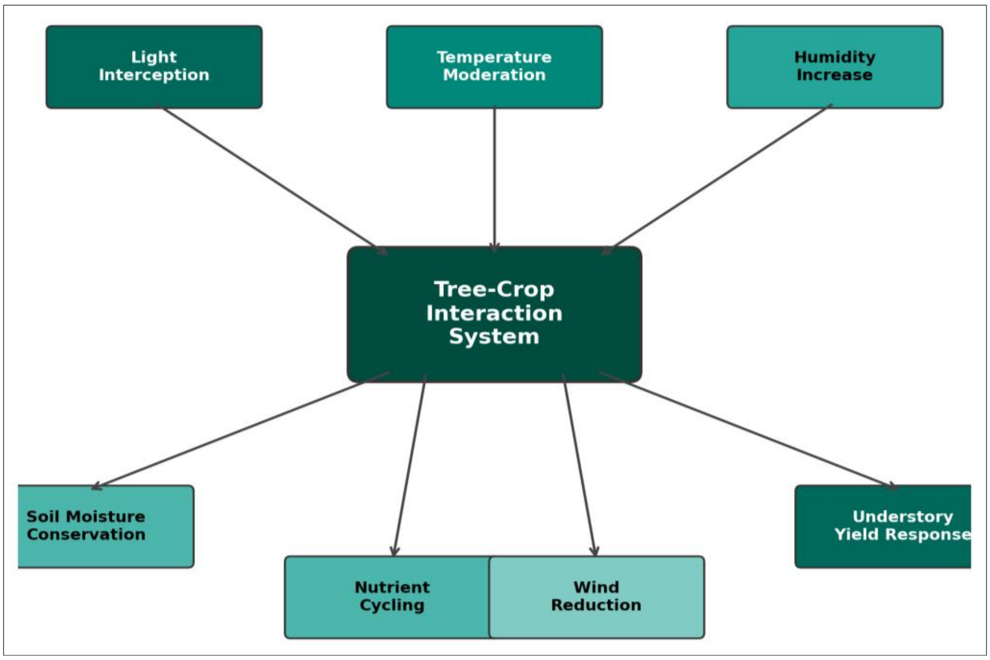

Fig 2: Network of tree-crop interactions in the agroforestry system, showing microclimate and resource-cycling pathways

Comprehensive Interpretation

Moderate canopy offered the best trade-off: PAR remained at 58.7% of open-field levels above the light-saturation point of groundnut (~400 µmol m^{-2} s^{-1}) while air and soil temperatures dropped enough to reduce evaporative stress during the critical pegging phase [4]. The LER of 1.47 means that 47% more land would be needed in sole cropping to match the combined output of the moderate-canopy agroforestry system. Dense canopy depressed groundnut yield by 28.4% but still achieved an LER of 1.28, because the tree component (fodder and fuelwood) compensated.

Discussion

The LER of 1.47 under moderate canopy compares favourably with published values of 1.2–1.6 for tropical agroforestry systems [2, 6]. The mechanism is primarily thermal: by lowering soil temperature by 2.9 °C, the moderate canopy extended the soil moisture depletion curve by an estimated 3–4 days between irrigations, allowing deeper groundnut root penetration [3, 9].

The dense canopy's PAR reduction (65.8%) pushed below the threshold for optimal groundnut photosynthesis, triggering etiolation and lower pod set [4]. Managing *Leucaena* canopy through biannual pruning to maintain 40–70% cover is therefore a practical recommendation and the harvested branches provide livestock fodder worth an estimated 8,000–12,000 INR ha^{-1} yr^{-1} [10].

A limitation is the single tree species and single crop; results may differ with deeper-rooted trees or shade-tolerant crops like turmeric [11]. Multi-species and multi-crop trials across agro-climatic zones would expand the recommendation domain.

Conclusion

Moderate canopy cover (40–70%) in a *Leucaena*-based agroforestry system reduced air temperature by 2.1 °C and soil temperature by 2.9 °C while retaining 58.7% of open-field PAR. Groundnut yield dropped by only 11.6%, and the system's LER of 1.47 confirmed strong complementarity. Dense canopy (>70%) over-shaded the crop and should be avoided unless the primary objective is timber or fodder. Pruning to maintain moderate cover is the recommended management strategy for semi-arid agroforestry in Andhra Pradesh.

Acknowledgements

This research was supported by Sri Venkateswara Veterinary and Agricultural University. Mr. K. Ravi assisted with datalogger maintenance and canopy photography.

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