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Evaluating the spatiotemporal relationship between crown architecture, leaf area index, and understorey light attenuation in a maturing gamhar (*Gmelina arborea* Roxb) based agroforestry system

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Abstract

Crown expansion and leaf area development jointly govern the amount of light that penetrates a tree canopy, yet the pace at which these three attributes co-develop within a young, maturing plantation is rarely quantified together, particularly under contrasting intercropping regimes. This study evaluated the spatiotemporal relationship between crown architecture (crown width and crown length), leaf area index (LAI) and sub-canopy light attenuation in a five-to-seven-year-old Gamhar (*Gmelina arborea* Roxb.) plantation established in a Randomized Block Design at the agroforestry research farm of Birsā Agricultural University, Ranchi, Jharkhand (Agroclimatic Zone VII, Sub-zone IV), across three consecutive years (2023, 2024 and 2025) and under three legume intercropping treatments pigeon pea (*Cajanus cajan*), cowpea (*Vigna unguiculata*) and black gram (*Vigna mungo*) compared against a sole Gamhar plantation. Crown width, crown length and LAI increased consistently with stand age in all treatments and were significantly ($p = 0.05$) greatest under pigeon pea and cowpea intercropping, exceeding sole Gamhar by 11-19% in crown dimensions and 10-18% in LAI depending on the year. This canopy development was mirrored by a progressive decline in sub-canopy light intensity, from a mean of 32-34 k Lux (36-39% of open-area intensity) at the start of the study to 17-22 k Lux (18-24% of open-area intensity) by the third year, with the sharpest attenuation recorded under the densest, pigeon-pea-associated canopies. LAI and sub-canopy light intensity were very strongly and negatively correlated across all treatment-year combinations ($r = -0.99$, $R^2 = 0.99$), indicating that canopy leaf area, itself driven by crown expansion, is a near-linear predictor of the understorey light climate regardless of intercrop identity. The tight, inverse coupling between expanding crown architecture, rising LAI and declining understorey irradiance observed here demonstrates that intercrop choice measurably accelerates canopy closure in Gamhar-based agroforestry, and that sub-canopy light is likely to fall below thresholds tolerable to shade-sensitive oilseed and pulse intercrops within the first three to four years of stand development. These findings offer a quantitative basis for timing intercrop transitions and canopy management interventions as Gamhar plantations mature.

Keywords: *Gmelina arborea*; crown architecture; leaf area index; light attenuation; agroforestry; canopy closure; understorey microclimate

Introduction

Agroforestry systems depend, in large part, on a favourable balance between the resources a tree canopy captures for itself and those it leaves available to the crops growing beneath it, and light is generally the resource whose partitioning changes fastest as a stand matures (Singh and Oraon, 2017) [19]. As a tree crown widens and lengthens, and as its leaf area accumulates, an increasing fraction of incident radiation is intercepted before it reaches the ground, so that the understorey light climate experienced by an intercrop in the establishment year of a plantation can differ sharply from that experienced only a few years later under the same trees. Crown architecture the three-dimensional arrangement of a tree's branches and foliage is widely recognised as a principal determinant of leaf area display and, through it, of canopy light interception (Broeckx *et al.*, 2012) [5], and recent work combining point-cloud and canopy-

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Analysing approaches has continued to refine how closely crown form, leaf area index (LAI) and within-canopy light transmittance track one another over a growing season (Zhou *et al.*, 2024; Zhao *et al.*, 2025) ^[29, 30].

Gmelina arborea Roxb. (Gamhar), a fast-growing, light-demanding deciduous species of the family Lamiaceae, is among the most widely planted agroforestry trees of South and South-East Asia on account of its rapid juvenile growth, coppicing ability and favourable timber and fodder returns (Nayak *et al.*, 2011) ^[15]. Under suitable soil and rainfall conditions the species can reach roughly 30 m in height and 60 cm diameter at breast height within fifteen years, with reported growth rates in the order of 40-50 m³ ha⁻¹ yr⁻¹ (Zeaser, 1998) ^[28], and mature stands have been reported to yield 250-300 t ha⁻¹ of standing biomass (Troup, 1921) ^[26]. Precisely because of this vigorous early growth, however, Gamhar develops a comparatively dense, spreading crown within the first few years after planting, and the associated canopy closure is frequently cited as the point beyond which shade-intolerant annual intercrops can no longer be sustained beneath the trees (Singh and Oraon, 2017) ^[19]. Quantifying how quickly this transition occurs and how it is modulated by the choice of companion intercrop is therefore of direct practical relevance to farmers and agroforestry planners deciding when to change intercrop species or thin the canopy.

A substantial body of work has examined the growth response of Gamhar and other agroforestry trees to different intercropping regimes, generally reporting equal or improved height, girth, volume and biomass accumulation under legume intercropping particularly pigeon pea, cowpea and black gram relative to sole tree plantation, an effect usually attributed to the residual fertiliser, tillage and biologically fixed nitrogen that the companion legume leaves in the shared rhizosphere (Swamy *et al.*, 2008; Vanlalngurzaiva *et al.*, 2010; Banerjee and Dhara, 2009; Momin *et al.*, 2017; Kumar *et al.*, 2026) ^[3, 11, 14, 22]. Comparatively few of these studies, however, extend the same treatment comparison to the crown, leaf area and sub-canopy light regime together, even though these three attributes are mechanistically the most direct link between tree growth and the intercrop's growing environment. Working with Gamhar and Alder-based agroforestry systems in the Eastern Himalayas, Choudhury *et al.* (2025) ^[6] recently demonstrated that measurable differences in canopy leaf area and photosynthetically active radiation transmittance between tree species translated directly into different physiological and yield responses of the understorey crop, underscoring the value of tracking canopy structure and sub-canopy light jointly rather than treating tree growth and intercrop performance as separate outcomes. What remains comparatively less documented is the temporal trajectory of this crown-LAI-light relationship within a single, young-to-maturing Gamhar stand evaluated under a realistic range of pulse intercrops on the lateritic soils of the eastern Indian plateau. The present study therefore examines, over three consecutive years, how crown width and crown length, leaf area index, and sub-canopy light attenuation co-vary in a Gamhar-based agroforestry system intercropped with pigeon pea, cowpea and black gram, in comparison with a sole Gamhar plantation, with the specific objectives of (i) quantifying the spatial (treatment-wise) and temporal (year-wise) variation in crown architecture and LAI, (ii) quantifying the corresponding decline in sub-canopy light intensity, and (iii) evaluating the extent to which intercrop-mediated differences in canopy development translate into a differential understorey light environment as the plantation matures.

2. Materials and Methods

2.1 Study site

The study was carried out at the agroforestry research farm adjoining the Ranchi Veterinary College campus of Birsa Agricultural University, Ranchi, Jharkhand, India, situated at approximately 23°26'55" N and 85°18'53" E at an elevation of about 625 m above mean sea level, on the southern margin of the Chotanagpur plateau within Agroclimatic Zone VII, Sub-zone IV (Central and North-Eastern Plateau Zone). The area experiences a humid subtropical climate under the Köppen classification, with three well-marked seasons summer (March-June), the south-west monsoon (June-October) and winter (November-February) and a mean annual rainfall of approximately 1,300-1,400 mm, more than 80% of which is received during the four monsoon months. The soil of the experimental block is a lateritic, sandy-loam derivative of granite-gneiss, free-draining but structurally weak, acidic in reaction and of moderate inherent fertility, characteristics broadly typical of the red and lateritic soils of the Chotanagpur plateau.

2.2 Plant material and experimental design

The trial made use of an existing stand of Gamhar (*Gmelina arborea*) planted on 4 July 2018 at a spacing of 8 m × 2.5 m. The experiment followed a Randomized Block Design comprising seven treatments replicated three times (21 plots in total, 16 trees per plot), of which four treatments form the basis of the present analysis: sole Gamhar, and Gamhar intercropped separately with pigeon pea (*Cajanus cajan* cv. UPAS-120), cowpea (*Vigna unguiculata* cv. Swarna Mukut) and black gram (*Vigna mungo* cv. Birsa Urd-1). Intercrops were sown following the onset of the south-west monsoon each year, with fertiliser, organic amendments and plant-protection inputs applied according to locally recommended package-of-practice for each crop. Observations were recorded at baseline (2023) and after the first (2024) and second (2025) year of active intercropping, corresponding to Gamhar stands of approximately five to seven years of age.

2.3 Measurement of crown architecture

Crown width was recorded on tagged sample trees in each plot as the mean canopy spread along two perpendicular directions, and crown length as the vertical extent of the live crown from the lowest live branch to the apex, following standard field mensuration practice. Annual increment in crown width and crown length was computed as the difference between successive years' observations for each sample tree.

2.4 Leaf area index

Leaf area index the one-sided leaf area per unit ground area (Bréda, 2003) ^[4] was estimated non-destructively for sample trees in each treatment following the specific-leaf-area (SLA) approach of Mason *et al.* (2012) ^[13] as adapted by Tenorio *et al.* (2019) ^[23]. Fresh foliage from sample trees was weighed, a 500 g sub-sample was taken to derive SLA, and LAI was computed by applying the resulting SLA-to-weight ratio to the total estimated canopy leaf mass of the sample tree.

2.5 Sub-canopy light intensity

Light intensity beneath the tree canopy was recorded with a digital lux meter (Lutron LX-107HA) at 1:00 pm under full-sun conditions in each of the three observation years, with a corresponding open-area (unshaded) reading taken as reference at the same time. Sub-canopy readings are expressed both in k

Lux and as a percentage of the concurrent open-area light intensity, following the approach used for tree-crop systems of this region by Das *et al.* (2017) ^[8], Johar *et al.* (2017) ^[10] and Dalal *et al.* (2019) ^[17].

2.6 Statistical analysis

Data on crown width, crown length, LAI and sub-canopy light intensity, together with their annual increments, were subjected to analysis of variance appropriate to the Randomized Block Design, and treatment means were separated using Duncan's Multiple Range Test at $p = 0.05$. Standard error of the mean ($S.E.m \pm$), critical difference ($CD, p = 0.05$) and coefficient of variation ($CV\%$) are reported alongside treatment means in the corresponding tables.

3. Results

3.1 Crown width and crown length

Crown width and crown length of Gamhar trees, together with their annual increments, differed significantly ($p = 0.05$) among treatments in every year of observation and in the pooled analysis of increments (Table 1). Crown width was consistently

greatest under Gamhar intercropped with pigeon pea (3.42, 4.93 and 6.64 m during 2023, 2024 and 2025, respectively), exceeding sole Gamhar (2.95, 4.13 and 5.88 m) by 15.93, 19.37 and 12.93 per cent in the respective years, followed by cowpea intercropping (8.14-4.93% over sole) and black gram intercropping (7.80-1.36% over sole). Crown length followed an analogous pattern, being greatest under pigeon pea intercropping (3.92, 5.25 and 6.72 m) and 10.73, 12.18 and 10.89 per cent higher than sole Gamhar (3.54, 4.68 and 6.06 m) across the three years. Annual increment in both crown dimensions was generally highest under pigeon pea intercropping, although sole Gamhar recorded a comparatively large increment in crown width during 2024-25 (1.75 m), suggesting some lateral canopy compensation by the more openly grown, unshaded sole trees in the later part of the observation period. The trajectories in Fig. 1 make this divergence clear: crown width and crown length climbed steadily in all four treatments between 2023 and 2025, but the gap between the pigeon-pea and cowpea lines and the sole-Gamhar line widened rather than narrowed with each successive year, indicating a cumulative, not merely a one-off, effect of legume intercropping on crown expansion.

Table 1: Crown width (m) and crown length (m) of Gamhar trees and their respective annual increments under a Gamhar-based agroforestry system

Treatment	Crown width (m)			Increment in crown width (m)			Crown length (m)			Increment in crown length (m)		
	2023	2024	2025	2023-24	2024-25	Pooled	2023	2024	2025	2023-24	2024-25	Pooled
G. arborea + C. cajan	3.42 ^a	4.93 ^a	6.64 ^a	1.51 ^a	1.71 ^a	1.60 ^a	3.92 ^a	5.25 ^a	6.72 ^a	1.33 ^a	1.47 ^a	1.41 ^a
G. arborea + V. unguiculata	3.19 ^{ab}	4.61 ^{ab}	6.17 ^b	1.42 ^{ab}	1.56 ^b	1.48 ^b	3.68 ^{ab}	5.00 ^b	6.48 ^{ab}	1.32 ^{ab}	1.48 ^{ab}	1.42 ^{ab}
G. arborea + V. mungo	3.18 ^{bc}	4.54 ^{bc}	5.96 ^{bc}	1.36 ^{bc}	1.42 ^b	1.39 ^{bc}	3.57 ^b	4.84 ^{bc}	6.27 ^{bc}	1.27 ^{bc}	1.43 ^{bc}	1.34 ^{bc}
Sole G. arborea	2.95 ^c	4.13 ^c	5.88 ^c	1.18 ^c	1.75 ^c	1.47 ^c	3.54 ^b	4.68 ^c	6.06 ^c	1.14 ^c	1.38 ^c	1.24 ^c
S.E.m±	0.02	0.04	0.08	0.02	0.04	0.03	0.03	0.04	0.07	0.02	0.03	0.02
CD (p=0.05)	0.06	0.12	0.25	0.06	0.13	0.10	0.08	0.13	0.21	0.05	0.08	0.07
CV (%)	6.19	7.32	8.21	8.81	9.54	9.30	6.63	7.07	7.83	8.54	9.73	9.22

Means followed by the same letter(s) within a column do not differ significantly at $p = 0.05$ as per Duncan's Multiple Range Test.

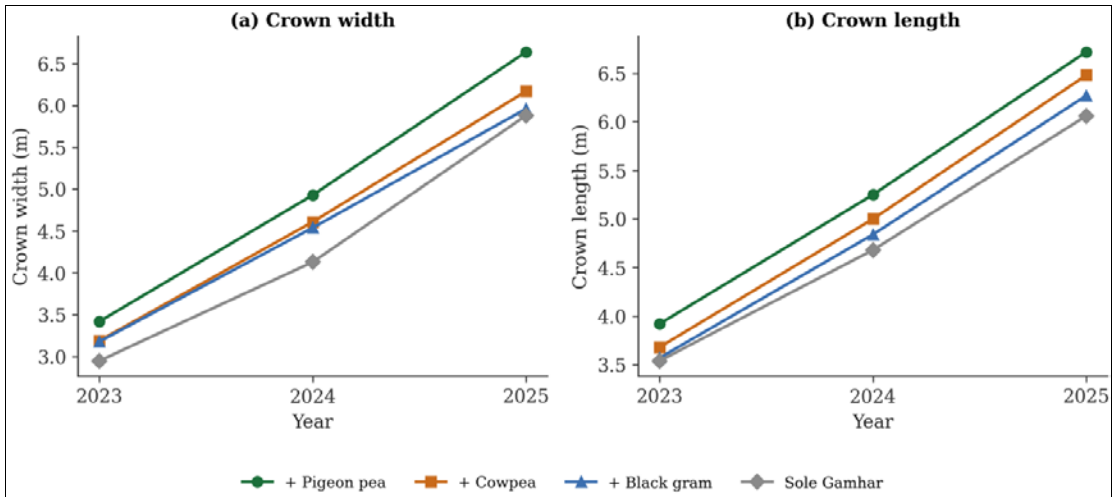


Fig 1: Temporal trend (2023-2025) in (a) crown width and (b) crown length of Gamhar trees under sole planting and three legume intercropping treatments

3.2 Leaf area index

LAI varied significantly ($p = 0.05$) among treatments in every year of observation (Table 2). LAI was consistently greatest under Gamhar intercropped with pigeon pea (2.17, 2.61 and 3.37 during 2023, 2024 and 2025, respectively), exceeding sole Gamhar (1.89, 2.37 and 2.86) by 14.81, 10.13 and 17.83 per cent, respectively, and remained statistically at par with the cowpea treatment (2.03, 2.56 and 3.25) throughout the study. LAI increment was not, however, always greatest under pigeon

pea: black gram intercropping recorded the highest increment during 2023-24 (0.57, 18.75% over sole), whereas pigeon pea intercropping recorded the highest increment during 2024-25 (0.76, 55.10% over sole) and in the pooled analysis (0.57, 18.75% over sole).

3.3 Sub-canopy light attenuation

As a direct counterpart of the progressively denser canopy associated with higher LAI, light transmittance beneath the canopy declined most sharply under pigeon pea intercropping,

where sub-canopy light intensity fell from 29.85 k Lux in 2023 to 24.52 k Lux in 2024 and 16.67 k Lux in 2025 (equivalent to 33.79, 27.12 and 18.54 per cent of open-area intensity, respectively) a reduction of 13.07, 11.29 and 22.52 per cent relative to sole Gamhar, which recorded the least shading throughout (34.34, 27.64 and 21.52 k Lux, i.e., 38.87, 30.57 and 23.93 per cent of open-area intensity). Open-area (unshaded) light intensity itself measured 88.34, 90.43 and 89.92 k Lux

during 2023, 2024 and 2025, respectively, against which the sub-canopy readings in Table 2 were benchmarked. Fig. 2 places the LAI and light-attenuation trends side by side: panel (a) shows LAI rising in every treatment across the three years, while panel (b) shows sub-canopy light falling almost as a mirror image of panel (a), with the treatment that gained LAI fastest (pigeon pea) also losing transmitted light fastest.

Table 2: Leaf area index and sub-canopy light intensity (k Lux), with light intensity as a percentage of open-area intensity, under a Gamhar-based agroforestry system

Treatment	LAI			Increment in LAI			Light intensity under canopy (k Lux)			Light intensity, % of open area		
	2023	2024	2025	2023-24	2024-25	Pooled	2023	2024	2025	2023-24	2024-25	Pooled
G. arborea + C. cajan	2.17 ^a	2.61 ^a	3.37 ^a	0.44 ^a	0.76 ^a	0.57 ^a	29.85 ^b	24.52 ^c	16.67 ^c	33.79 ^b	27.12 ^c	18.54 ^c
G. arborea + V. unguiculata	2.03 ^{ab}	2.56 ^{ab}	3.25 ^b	0.53 ^b	0.69 ^b	0.56 ^b	32.01 ^{ab}	25.14 ^{bc}	17.71 ^b	36.24 ^{ab}	27.80 ^{bc}	19.69 ^b
G. arborea + V. mungo	1.91 ^{bc}	2.48 ^b	3.00 ^b	0.57 ^b	0.52 ^b	0.53 ^b	33.99 ^{ab}	26.17 ^b	20.06 ^b	38.48 ^{ab}	28.94 ^b	22.31 ^b
Sole G. arborea	1.89 ^c	2.37 ^c	2.86 ^c	0.48 ^c	0.49 ^c	0.48 ^c	34.34 ^a	27.64 ^a	21.52 ^a	38.87 ^a	30.57 ^a	23.93 ^a
S.Em±	0.02	0.02	0.04	0.01	0.01	0.01	1.19	1.10	0.98	1.36	1.25	1.13
CD (p=0.05)	0.05	0.07	0.11	0.02	0.04	0.03	3.65	3.38	3.01	4.18	3.86	3.47
CV (%)	5.87	6.37	7.08	8.66	9.83	9.42	5.09	5.81	7.13	5.09	5.81	7.13

Means followed by the same letter(s) within a column do not differ significantly at $p = 0.05$ as per Duncan's Multiple Range Test. Open-area light intensity averaged 88.34, 90.43 and 89.92 k Lux in 2023, 2024 and 2025, respectively

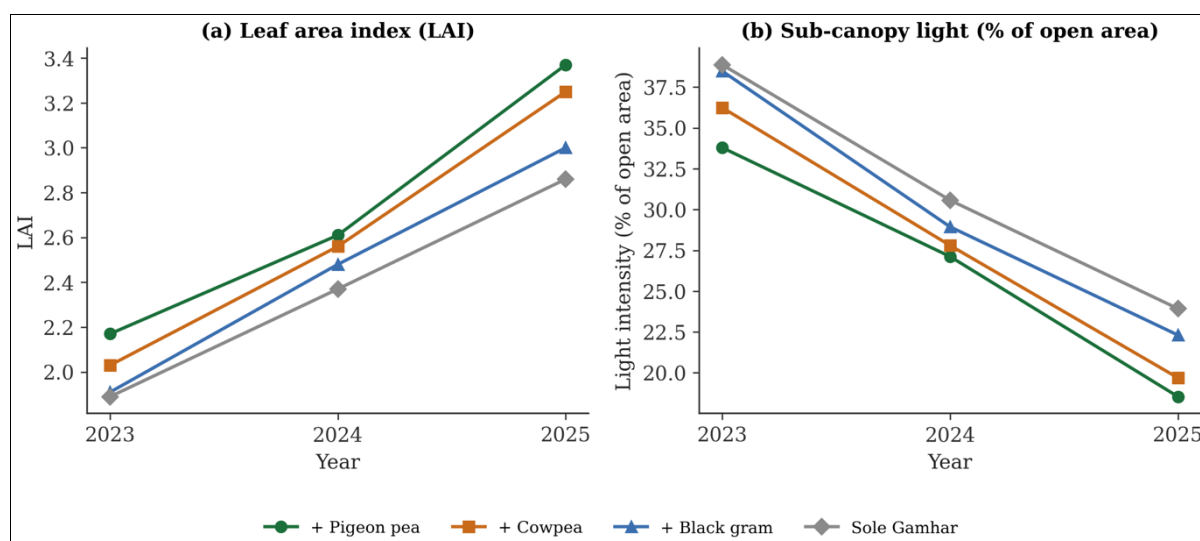


Fig 2: Temporal trend (2023-2025) in (a) leaf area index and (b) sub-canopy light intensity (percentage of open-area intensity) of Gamhar trees under sole planting and three legume intercropping treatments. Note the mirrored trajectories of panels (a) and (b) across treatments and years.

3.4 The spatiotemporal crown-LAI-light relationship

Considered jointly, Tables 1 and 2 show a consistent spatiotemporal pattern: in every treatment, crown width, crown length and LAI increased year-on-year between 2023 and 2025, and in every year the treatment ranking for all three canopy variables was the same pigeon pea intercropping $\geq$ cowpea intercropping $\geq$ black gram intercropping $>$ sole Gamhar. Sub-canopy light intensity, both in absolute (k Lux) and relative (% of open-area) terms, followed the inverse of this ranking in every year, with the pigeon-pea-associated canopy which had the largest crown dimensions and highest LAI in all three years also recording the lowest sub-canopy light in all three years, and the sole, unintercropped canopy with the smallest crown and lowest LAI recording the highest sub-canopy light throughout. This treatment-consistent, year-consistent inverse pairing indicates that the rate at which the understorey light environment deteriorates as the Gamhar stand matures is set jointly by how fast the crown expands radially and vertically and by how fast leaf area accumulates within that expanding crown volume, with

the two intercrops that most favoured tree growth (pigeon pea and cowpea) also most accelerating the loss of transmitted light beneath the canopy. Plotting LAI against sub-canopy light intensity for all twelve treatments $\times$ year combinations (Fig. 3) makes this relationship explicit: the two variables were very strongly and negatively associated (Pearson $r = -0.99$, $R^2 = 0.99$, based on the twelve treatment-year mean pairs in Tables 1 and 2), with sub-canopy light declining by approximately 13.9 percentage points of open-area intensity for every unit increase in LAI across the observed range ($LAI \approx 1.9$ -3.4). Because this relationship held with essentially the same slope across all four treatments, canopy LAI itself the product of the crown-dimension trends in Fig. 1 emerges as a strong single predictor of the understorey light climate in this Gamhar system, regardless of which intercrop was responsible for driving LAI upward. This treatment-independent LAI-light relationship, rather than the intercrop identity per se, is therefore what determines the light environment available to the associated crop at any given stage of stand development.

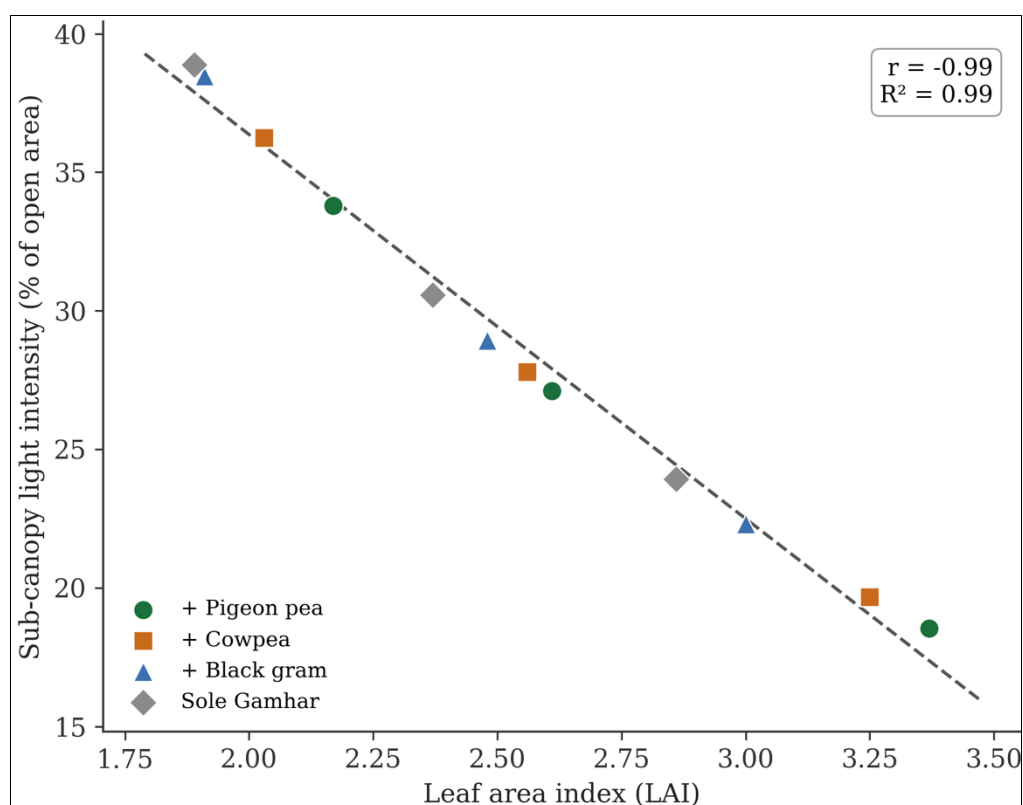


Fig 3: Relationship between leaf area index (LAI) and sub-canopy light intensity (percentage of open-area intensity) across all treatment $\times$ year combinations ($n = 12$). The dashed line is the fitted linear trend ($r = -0.99$, $R^2 = 0.99$)

4. Discussion

The parallel, treatment-consistent increase in crown width, crown length and LAI recorded here is in agreement with the general understanding that crown architecture is a principal determinant of leaf area display in trees, and that leaf area display in turn governs the amount of light intercepted by the canopy (Broeckx *et al.*, 2012) [5]. More recent canopy-structure work on plantation species has reached the same conclusion using higher-resolution instrumentation: point-cloud-based LAI inversion in apple canopies has been used to derive light-transmittance relationships directly from three-dimensional crown geometry (Zhou *et al.*, 2024) [30], while canopy-structure manipulation in poplar plantations has been shown to alter the within-stand light environment sufficiently to change growth outcomes (Zhao *et al.*, 2025) [29]. The present results extend this general crown-LAI-light coupling to a maturing, intercropped Gamhar stand and show that it holds not only across years, as the trees age, but also across intercropping treatments within a single year.

The superior crown and LAI development recorded under pigeon pea and cowpea intercropping mirrors the growth advantage of Gamhar under legume intercropping reported widely in the agroforestry literature: pigeon pea intercropping has been shown to maximise the height, diameter and volume of Gamhar in Gamhar-mango systems (Momin *et al.*, 2017) [14], black gram intercropping has been associated with the greatest height and diameter of Gamhar in West Bengal trials (Vanlalngurzaiva *et al.*, 2010; Banerjee and Dhara, 2009) [3], and tree growth under legume-based intercropping more generally has been linked to the residual soil nitrogen, tillage and moisture conservation that these companion crops leave behind (Swamy *et al.*, 2008) [22]. The present findings suggest that this same facilitation extends beyond stem and biomass growth to the lateral and vertical dimensions of the crown itself,

and hence to the pace of canopy closure a link that, to the authors' knowledge, has not previously been made explicit for Gamhar-based systems, although a broadly comparable canopy-understorey coupling has recently been reported for *Gmelina arborea* and *Alnus nepalensis* agroforestry systems in the Eastern Himalayas, where measurable differences in tree canopy leaf area and transmitted radiation between tree species were shown to carry through directly to the physiological and yield performance of the understorey crop (Choudhury *et al.*, 2025) [6]. From a management perspective, the magnitude of light attenuation recorded under the most vigorously growing treatments is of practical significance. By the third year of intercropping, sub-canopy light under pigeon-pea-associated Gamhar had fallen to under 19 per cent of open-area intensity, a level that approaches or falls below the light compensation range tolerated by many shade-intolerant pulse and oilseed intercrops, including toria/mustard and, to a lesser extent, pigeon pea and cowpea themselves in their later growth stages. This is consistent with the broader observation, made for tree-crop systems elsewhere in Jharkhand, that although overall resource-use efficiency of an agroforestry system can remain favourable as canopy shade increases, crop yield beneath the tree canopy is progressively constrained by declining light once canopy closure advances (Singh and Oraon, 2017) [19]. The present data indicate that, for Gamhar-based systems on similar lateritic soils, this constraint is likely to become binding within three to four years of intercropping onset, particularly where the companion legume is one that also accelerates tree crown development, and that a switch to more shade-tolerant intercrops, or scheduled canopy thinning/pruning, may need to be planned on a correspondingly short time-scale. The present study relied on a specific-leaf-area-based, non-destructive estimate of LAI and on point-in-time lux-meter readings of sub-canopy light rather than continuous or hemispherical-photography-based canopy characterisation; more

automated, geometry-based approaches such as terrestrial LiDAR or convex-hull point-cloud analysis, recently applied to derive light-transmittance relationships directly from crown structure in other plantation species (Zhou *et al.*, 2024) ^[30], could offer a finer-grained description of the crown-LAI-light relationship documented here, and represent a natural extension of the present single-site, three-year dataset to longer rotations and a wider range of tree-crop combinations.

5. Conclusion

This study shows that a maturing Gamhar plantation does not drift toward canopy closure gradually and unpredictably it does so along a tight, near-linear trajectory in which crown expansion, leaf area accumulation and understorey light loss move together with remarkable consistency. The same treatment ranking (pigeon pea > cowpea > black gram > sole Gamhar) held for crown width, crown length and LAI in every single year, and its mirror image held for transmitted light, culminating in a pooled LAI-light relationship strong enough ($r = -0.99$) to function as a practical predictor in its own right: once LAI at a given stand age is known, the sub-canopy light environment can be anticipated to within a narrow margin, independent of which legume intercrop produced that LAI. Legume intercropping pigeon pea most of all did not just grow bigger trees; it measurably compressed the window during which shade-sensitive intercrops remain viable, pushing sub-canopy light below one-fifth of open-area intensity within three years of establishment.

Beyond the specific case of Gamhar, this points to a broader and still under-exploited opportunity in agroforestry research: crown architecture is comparatively cheap and non-destructive to measure, yet it emerges here as a strong proxy for two variables LAI and understorey light that are far more laborious to quantify directly. If the crown-LAI-light coupling demonstrated in this three-year Gamhar system generalises to other fast-growing agroforestry species and other soil-climate zones, simple, repeatable crown measurements could underpin low-cost decision-support tools for timing intercrop transitions, scheduling canopy thinning, or selecting shade-tolerant successor crops questions of growing importance as agroforestry is increasingly promoted for carbon sequestration and climate-resilient land use across the tropics. Testing the stability of this relationship across a wider range of species, stand ages, planting densities and remote-sensing-based canopy metrics (e.g., LiDAR- or point-cloud-derived crown geometry) represents a natural and, in the authors' view, a genuinely promising next step for agroforestry science.

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