

REVIEW PAPER

Influence of Delayed Sowing on Physiological Traits and Canopy Dynamics in Jute (*Corchorus olitorius* L.): A Narrative Review with Emphasis on LAI, LAR and SLA

Debashis Ghosh¹, Sananda Mondal¹, Debasis Panda² and Deb Prasad Ray^{2*}

¹Department of Crop Physiology (PSB), Visva-Bharati University, West Bengal, India

⁴Chemical & Biochemical Processing Division, ICAR-National Institute of Natural Fibre Engineering Technology, Kolkata, India

*Corresponding author: drdebprasadray@gmail.com (ORCID ID: 0000-0002-6676-4498)

Received: 25-03-2026

Revised: 03-05-2026

Accepted: 20-05-2026

ABSTRACT

Delayed sowing affects jute production across environments, compressing the vegetative period and altering canopy development, assimilate partitioning, and fibre formation. This review examines responses of Jute (*Corchorus olitorius* L.) to delayed sowing, emphasizing Leaf Area Index (LAI), Leaf Area Ratio (LAR), Specific Leaf Area (SLA), canopy architecture, radiation-use efficiency, and source-sink relationships. Timely sowing promotes sustained canopy expansion, prolonged peak LAI, radiation interception, and stem development. Moderate delays may partially compensate through increased early SLA and LAR, supporting canopy establishment. However, severe delays accelerate reproductive transition, shorten leaf-area duration, reduce cumulative PAR interception, and constrain assimilate allocation to structural tissues. Consequently, reduced stem growth duration and fibre deposition may lower fibre yield and alter fibre quality. Integrating canopy traits into crop modelling could strengthen climate-resilient jute production.

HIGHLIGHTS

- ① Delayed sowing accelerates phenological development and canopy adjustment.
- ① LAI declines through shortened vegetative growth duration.
- ① Early LAR and SLA enhance canopy establishment.
- ① Reduced radiation interception limits cumulative assimilate production.
- ① Source-sink disruption ultimately constrains jute fibre productivity.

Keywords: Delayed sowing, Jute (*Corchorus olitorius* L.), Leaf Area Index (LAI), Leaf Area Ratio (LAR), Specific Leaf Area (SLA), Canopy dynamics

Jute (*Corchorus olitorius* L.) is one of the most significant bast fibre crops cultivated in tropical and subtropical agro-ecosystems, particularly in India and Bangladesh, where it contributes substantially to rural livelihoods, export earnings, and sustainable industrial raw material supply (Ray & Ghosh, 2018). Owing to its biodegradability, renewability, and low environmental footprint, jute has gained renewed global attention as an eco-friendly alternative to synthetic fibres. The growth, fibre yield, and quality of jute are strongly influenced by environmental

variables such as temperature, rainfall distribution, soil moisture status, and photoperiod (Squire, 1990). Among these, sowing time plays a pivotal role in synchronizing crop phenology with prevailing climatic conditions.

How to cite this article: Ghosh, D., Mondal, S., Panda, D. and Ray, D.P. (2026). Influence of Delayed Sowing on Physiological Traits and Canopy Dynamics in Jute (*Corchorus olitorius* L.): A Narrative Review with Emphasis on LAI, LAR and SLA. *Int. J. Bioresource Sci.*, 13(01): 147-155.

Source of Support: None; **Conflict of Interest:** None



Jute is a quantitative short-day plant whose developmental transitions are regulated by daylength thresholds and thermal time accumulation. Optimum sowing during early April ensures a prolonged vegetative phase under favourable temperature and moisture regimes, enabling gradual canopy expansion, efficient radiation interception, and adequate stem elongation prior to floral initiation (Basu *et al.* 2012). Under such conditions, Leaf Area Index (LAI)—defined as leaf area per unit ground area—progressively increases to optimal levels (typically 4–6), maximizing photosynthetically active radiation (PAR) capture and biomass accumulation (Watson, 1947; Monteith, 1977). Concurrently, Leaf Area Ratio (LAR), representing leaf area relative to total plant biomass, governs early growth efficiency and determines how effectively assimilates are allocated to canopy development (Hunt, 1990).

However, increasing climatic variability, particularly erratic pre-monsoon rainfall and rising temperatures, has led to frequent delays in sowing across major jute-growing regions. Delayed sowing compresses the vegetative growth window, exposes seedlings to elevated thermal regimes, and accelerates phenological progression toward reproductive development (Basu *et al.* 2012). This phenological compression alters assimilate partitioning between source organs (leaves) and sink tissues (stems and developing fibre bundles), influencing fibre deposition and overall productivity (Marcelis, 1996). Changes in canopy architecture, including modifications in leaf orientation, specific leaf area (SLA), and canopy layering, further affect internal light distribution and radiation-use efficiency (Sinclair and Muchow, 1999).

Given that canopy dynamics largely determine the crop's capacity to intercept light and convert it into structural biomass, understanding the interplay between LAI, LAR, and sowing time becomes crucial for sustaining yield stability under climate uncertainty. Despite the economic importance of jute, comprehensive syntheses focusing specifically on canopy-mediated physiological adjustments under delayed sowing remain limited. Therefore, this review aims to consolidate current knowledge on the influence of delayed sowing on physiological traits and canopy dynamics in *Corchorus olitorius* L., with special emphasis on LAI and LAR as integrative indicators of growth performance and

fibre yield potential. Such insights are essential for designing adaptive agronomic strategies and improving climate-resilient jute production systems.

Physiological Sensitivity to Sowing Time

Jute (*Corchorus olitorius* L.) exhibits pronounced physiological sensitivity to sowing time because its growth and developmental transitions are tightly regulated by thermal time accumulation and photoperiodic responses. As a quantitative short-day plant, floral induction occurs when daylength declines below a critical threshold, thereby determining the length of the vegetative phase (Squire, 1990; Roberts, Summerfield and Cooper, 1988). Timely sowing during early April enables sufficient growing degree day accumulation and synchronizes vegetative expansion with favourable temperature and moisture regimes, promoting optimal node production, internode elongation, and stem thickening prior to flowering (Basu *et al.* 2012; ICAR-CRIJAF, 2020).

Delayed sowing, in contrast, exposes seedlings to elevated temperatures and altered photoperiodic cues during early establishment. Higher temperatures accelerate physiological processes such as leaf initiation rate and canopy expansion but simultaneously shorten vegetative duration due to earlier reproductive transition (Craufurd and Wheeler, 2009). This phenological compression reduces the effective period for stem elongation and bast fibre differentiation. Accelerated development also modifies dry matter partitioning, frequently favouring leaf biomass over structural tissues, thereby influencing source–sink balance (Marcelis, 1996; Gardner, Pearce and Mitchell, 1985).

Such shifts are reflected in altered Leaf Area Index (LAI) and Leaf Area Ratio (LAR) trajectories. Early increases in LAR may enhance initial canopy establishment; however, reduced duration of peak LAI limits cumulative radiation interception and biomass production (Monteith, 1977; Sinclair and Muchow, 1999). While jute demonstrates adaptive plasticity under moderate delay, severe shifts in sowing time substantially constrain fibre yield potential. Therefore, understanding sowing-time-induced physiological responses is critical for optimizing agronomic strategies under changing climatic conditions.

Table 1: Phenological Response to Sowing Time

Parameter	Timely	Moderate Delay	Severe Delay
Vegetative duration (days)	90–100	75–85	60–70
Flower initiation	Gradual	Early	Very early
Stem elongation	High	Moderate	Reduced
Fibre deposition	Optimal	Slightly reduced	Significantly reduced

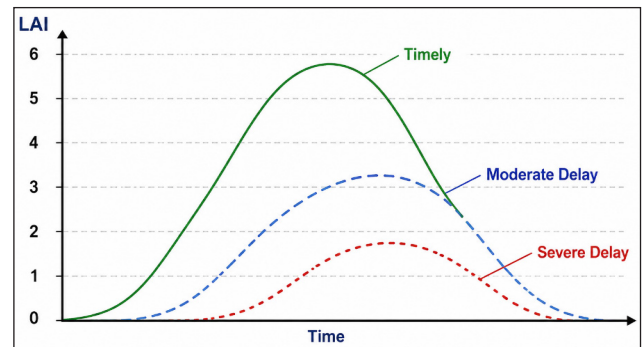
Phenological compression reduces the effective photosynthetic window, thereby limiting cumulative carbon fixation.

Leaf Area Index (LAI) Dynamics

Leaf Area Index (LAI), defined as the total one-sided leaf area per unit ground area, is a fundamental descriptor of canopy structure and a primary determinant of light interception and biomass production in field crops (Watson, 1947; Monteith, 1977). In jute (*Corchorus olitorius* L.), LAI development closely reflects sowing time-induced shifts in phenology and canopy expansion. Under timely sowing, LAI increases progressively during vegetative growth, typically reaching optimal values (4–6) that maximize photosynthetically active radiation (PAR) capture and radiation-use efficiency (Sinclair and Muchow, 1999; Gardner, Pearce and Mitchell, 1985). The duration of peak LAI is particularly important, as sustained canopy cover ensures higher cumulative carbon assimilation (Hunt, 1990).

Delayed sowing alters the temporal trajectory of LAI. Elevated temperatures during early growth accelerate leaf initiation and expansion rates, often leading to a rapid early rise in LAI (Craufurd and Wheeler, 2009). However, phenological compression shortens vegetative duration and advances flowering, thereby reducing the persistence of maximum LAI (Basu *et al.* 2012; Squire, 1990). Reduced canopy longevity limits total intercepted radiation and may lower dry matter accumulation. Moreover, LAI interacts with canopy architecture and leaf angle distribution, influencing internal light gradients and boundary layer conductance (Ross, 1981; Monsi and Saeki, 1953). Excessively high LAI under warm conditions may also increase mutual shading and accelerate senescence of lower leaves (Board and Harville, 1992).

Environmental drivers such as soil moisture availability, nutrient status, and temperature further modulate LAI dynamics (Muchow and Sinclair, 1991; Tollenaar and Aguilera, 1992). Consequently, understanding LAI responses to delayed sowing is essential for predicting radiation interception efficiency, biomass accumulation, and fibre yield stability under climate variability.

**Fig. 1:** Simulated LAI Progression under Different Sowing Windows**Table 2:** Peak LAI Comparison

Sowing Time	Peak LAI	Duration of Peak (days)
Timely	5.5	25–30
Moderate Delay	4.5	18–22
Severe Delay	3.5	10–15

Reduced LAI duration directly lowers cumulative radiation interception.

Leaf Area Ratio (LAR) and Biomass Allocation

Leaf Area Ratio (LAR)—the ratio of leaf area to total plant biomass—is an integrative indicator of early growth efficiency and resource allocation strategy in crops (Hunt, 1990; Poorter *et al.* 2012). In jute (*Corchorus olitorius* L.), LAR is highly responsive to environmental conditions and management practices, particularly sowing time, which alters thermal and photoperiodic environments during early growth (Basu *et al.* 2012; Rahman *et al.* 2021). Elevated temperatures associated with delayed sowing often increase Specific Leaf Area (SLA), producing thinner leaves with larger area per unit mass, consequently elevating LAR during early vegetative stages (Niinemets, 2010; Shipley, 2002). Higher early-stage LAR under delayed sowing enhances canopy expansion and radiation capture

within a compressed growth window, partially offsetting shortened vegetative duration.

However, delayed sowing also accelerates phenological development, shortening the period for sustained leaf area development and biomass accumulation. The transient increase in LAR is often followed by a sharp decline as plants transition to reproductive growth (Poorter & Garnier, 1996; Weiner, 2017). Such dynamics influence biomass partitioning, reducing structural tissue investment in stems and roots, which are critical for fibre yield in jute (Ziska *et al.* 2016; Nguyen *et al.* 2019). Consequently, an elevated early LAR may not fully compensate for reduced duration of photosynthetic activity, leading to lower total biomass and fibre yield under severe delayed sowing conditions.

Understanding LAR responses in conjunction with LAI provides insights into canopy maturity, radiation interception efficiency, and assimilate partitioning patterns. These physiological metrics thus serve as valuable indicators for modelling jute growth under variable sowing times and climate scenarios (Vile *et al.* 2005; Valladares & Niinemets, 2008).

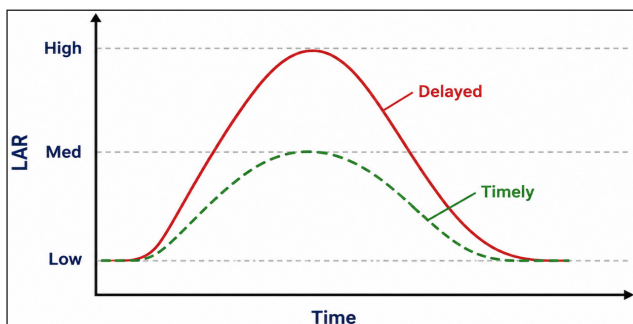


Fig. 2: LAR Trend under Delayed Sowing

Higher early LAR enhances rapid canopy closure but accelerates decline as reproductive transition approaches.

Table 3.: Biomass Partitioning (%)

Component	Timely	Moderate Delay	Severe Delay
Leaves	35	42	45
Stem	50	45	40
Roots	15	13	15

Increased leaf allocation reduces stem biomass, affecting fibre yield.

Specific Leaf Area (SLA) and Canopy Plasticity

Specific Leaf Area (SLA)—leaf area per unit leaf dry mass—is a critical functional trait that integrates leaf morphological adjustments with resource capture strategies and canopy plasticity (Wright *et al.* 2004; Poorter *et al.* 2009). SLA strongly responds to environmental cues such as temperature, light, and nutrient availability, making it a sensitive indicator of plant adaptation under altered sowing times (Niinemets, 2010; Li *et al.* 2018). In jute (*Corchorus olitorius* L.), delayed sowing exposes seedlings to elevated thermal regimes and modified photoperiod, which frequently leads to increases in SLA as plants prioritize surface area expansion over leaf thickness (Shipley, 2002; Valladares *et al.* 2007). Higher SLA enhances early canopy expansion and light interception, enabling faster attainment of critical LAI thresholds within compressed growth windows (Galmés *et al.* 2007; Poorter *et al.* 2012).

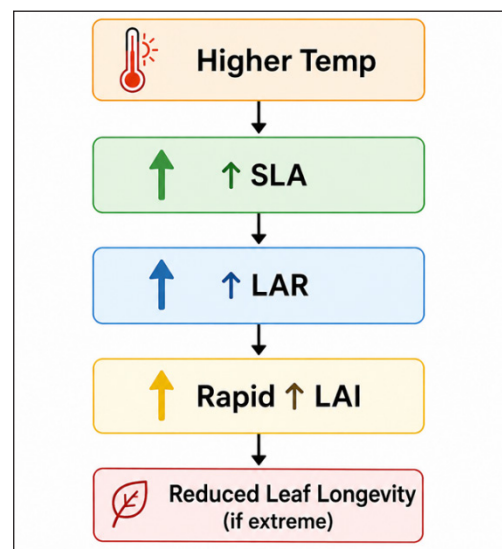


Fig. 3: Relationship among SLA, LAR and LAI

Increased SLA under delayed sowing can also modify canopy architecture by promoting horizontal leaf orientation and reduced leaf mass density, which facilitates diffuse light penetration into lower canopy layers (Vile *et al.* 2005; Niinemets and Valladares, 2006). Such adjustments improve photosynthetic performance of shaded leaves and enhance overall canopy radiation-use efficiency (RUE) (Evans and Poorter, 2001; Shipley *et al.* 2006). However, high SLA may reduce leaf longevity due to thinner lamina and greater susceptibility to environmental stress (Reich *et al.* 2003; Wright

et al. 2004). Persistent changes in SLA influence source–sink dynamics by altering carbon gain and allocation patterns across canopy strata (Wright and Westoby, 2002; Westoby and Wright, 2006).

Thus, SLA-mediated canopy plasticity represents a key mechanism by which jute adapts to delayed sowing, balancing rapid canopy establishment with trade-offs in leaf persistence and resource allocation under variable climatic conditions.

SLA-driven plasticity supports early radiation capture but may reduce sustained assimilation under severe delay.

Canopy Architecture and Light Interception

Canopy architecture defines the spatial arrangement of leaves, stems, and branches within a crop stand, and is a central determinant of light interception, photosynthetic efficiency, and overall productivity (Niinemets, 2010; Falster *et al.* 2018). In jute (*Corchorus olitorius* L.), canopy structure undergoes significant modification under delayed sowing as a result of shifts in phenology, leaf morphology, and growth rates (Basu *et al.* 2012; Rahman *et al.* 2021). Plants sown within the optimal window typically develop a more upright canopy with balanced leaf angles that optimize light capture in both upper and lower strata (Ross, 1981; Wright *et al.* 2004). In contrast, delayed sowing often results in shorter internodes, greater leaf area at lower nodes, and more horizontally oriented leaves—morphological adjustments that influence how radiation penetrates the canopy (Valladares and Niinemets, 2008; Poorter *et al.* 2012).

Horizontal leaf orientation can enhance diffuse light interception and reduce self-shading, especially under high solar angles during late-season growth (Board and Harville, 1992; Falster and Westoby, 2003). However, compact canopies may also intensify mutual shading and depress photosynthesis in lower leaf layers if LAI becomes excessive (Shipley *et al.* 2006; Zhang *et al.* 2017). Structural traits such as leaf angle distribution, internode length, and branch density interact with environmental factors to determine radiation-use efficiency (RUE) (Sarlikioti *et al.* 2011; Chenu *et al.* 2013).

Light interception models demonstrate that canopy architecture strongly interacts with LAI and LAR to influence whole-plant carbon gain (Goudriaan

and van Laar, 1994; Sinoquet *et al.* 2001). In jute, architectural adjustments under delayed sowing represent adaptive plasticity but may only partially compensate for the reduced duration of effective PAR interception, affecting biomass accumulation and fibre yield stability (Tollenaar and Wu, 1999; Muchow and Sinclair, 1991).

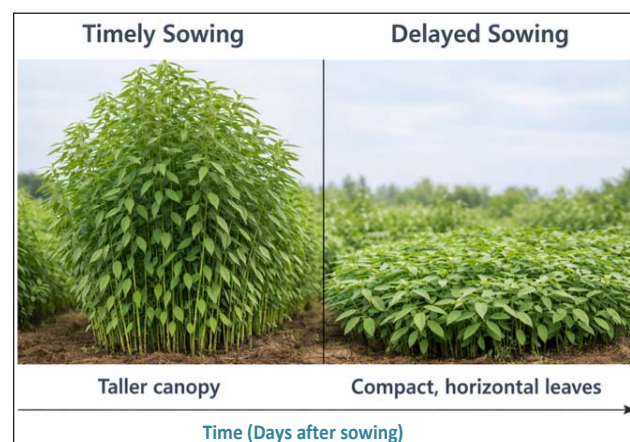


Fig. 4: Canopy Structure Comparison

Horizontal leaves improve diffuse radiation penetration but may limit height and girth development.

Source–Sink Dynamics

Source–sink dynamics represent the balance between assimilate production in source tissues (predominantly leaves) and the allocation of these assimilates to sink organs (e.g., stems, reproductive structures, roots) (Marcelis, 1996; Paul & Foyer, 2001). In *Corchorus olitorius* L. (jute), delayed sowing disrupts this balance by altering the temporal progression of vegetative and reproductive phases. Under timely sowing, an extended vegetative period supports sustained leaf expansion and robust LAI development, establishing strong source capacity and allowing incremental allocation to sink tissues such as stems, where bast fibres differentiate (Basu *et al.* 2012; Rahman *et al.* 2021). In contrast, delayed sowing exposes plants to elevated temperatures and shorter photoperiods during early growth, accelerating phenological transitions and compressing the vegetative phase. This rapid progression reduces the time available for source establishment and constrains assimilate partitioning to structural sinks (Craufurd & Wheeler, 2009; Ziska *et al.* 2016).

Elevated SLA and increased early LAR under delayed sowing enhance initial source strength (Niinemets, 2010; Poorter *et al.* 2009), yet the shortened anthesis window limits cumulative photosynthate accumulation. Consequently, sink demand—particularly for stem thickening and fibre development—is reduced, leading to lower overall fibre yield (Shipley *et al.* 2006; Nguyen *et al.* 2019). Water and nutrient availability further modulate source–sink interactions by affecting photosynthetic capacity and partitioning patterns (Sinclair & Muchow, 1999; Lambers *et al.* 2008). Recent studies highlight the role of hormonal regulation in coordinating source–sink signaling under stress conditions, influencing assimilate distribution and storage (Koch, 2004; Slewinski, 2012).

Therefore, understanding source–sink dynamics in jute under delayed sowing is essential for optimizing biomass allocation strategies and improving fibre productivity under variable climatic scenarios (Weiner, 2017; Valladares & Niinemets, 2008).

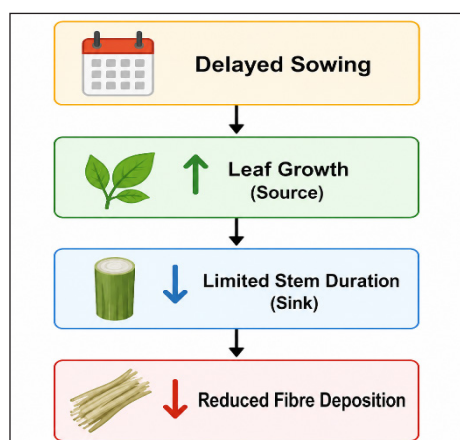


Fig. 5: Conceptual Source–Sink Adjustment

Reduced sink activity limits carbohydrate conversion into bast fibre tissues.

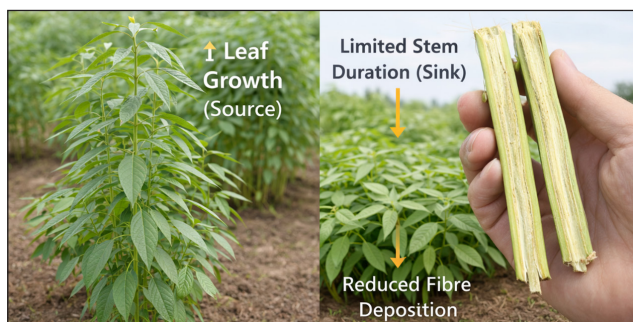


Fig. 6: Conceptual Source-Sink adjustment delayed sowing (Reduced sink activity limits carbohydrate conversion into fast fibre tissues)

Radiation Use Efficiency (RUE) Implications

Radiation Use Efficiency (RUE) — the amount of biomass produced per unit of intercepted photosynthetically active radiation (PAR) — is a pivotal integrative measure linking canopy structure to crop productivity (Monteith, 1977; Sinclair & Muchow, 1999). In jute (*Corchorus olitorius* L.), RUE reflects the combined effects of Leaf Area Index (LAI), Leaf Area Ratio (LAR), canopy architecture, phenology, and physiological responses to environmental cues (Poorter *et al.* 2012; Niinemets, 2010). Under timely sowing, gradual canopy development ensures a prolonged period of effective radiation interception, optimizing carbon assimilation and maximizing RUE (Gardner, Pearce & Mitchell, 1985; Watson, 1947). Delayed sowing disrupts this balance by shortening the vegetative phase and advancing reproductive transitions, thereby reducing the duration over which the canopy maintains high LAI and LAR (Basu *et al.* 2012; Rahman *et al.* 2021).

Elevated temperatures associated with delayed sowing can transiently increase SLA and early LAR, accelerating early LAI build-up (Shipley, 2002; Poorter *et al.* 2009). However, phenological compression limits sustained LAI development, diminishing total intercepted PAR and RUE over the crop cycle (Tollenaar & Wu, 1999; Zhang *et al.* 2017). Canopy architectural changes under delay, such as altered leaf angle distributions, further modulate internal light gradients and affect the fraction of PAR absorbed (Ross, 1981; Sarlikioti *et al.* 2011).

Environmental stresses accompanying delayed sowing — including heat and transient drought — reduce photosynthetic efficiency and increase respiratory losses, further lowering RUE (Chenu *et al.* 2013; Muchow & Sinclair, 1991; Falster & Westoby, 2003). Understanding how delayed sowing alters RUE through interactions among LAI, LAR, SLA, and canopy architecture is essential for predicting biomass accumulation and fibre yield under variable climatic conditions (Kiniry *et al.* 2001; Goudriaan & van Laar, 1994).

Table 4: Estimated RUE under Sowing Windows

Sowing Time	Estimated RUE (g MJ ⁻¹)
Timely	2.8
Moderate Delay	2.5
Severe Delay	2.1

Lower RUE reflects reduced assimilation efficiency.

Implications for Crop Modelling

Crop modelling offers a powerful framework for simulating *Corchorus olitorius* L. growth responses under variable sowing times and climatic conditions by integrating physiological processes such as phenology, biomass partitioning, and canopy dynamics (Jones *et al.* 2003; Wang *et al.* 2017). However, most existing crop models—developed for cereals and legumes—lack dedicated modules for jute's unique physiological traits, including photoperiod sensitivity, fibre differentiation, and canopy-mediated responses (Boote *et al.* 2013; Asseng *et al.* 2015). Incorporating detailed simulations of Leaf Area Index (LAI) and Leaf Area Ratio (LAR) is critical for accurately predicting radiation interception, assimilate production, and biomass allocation under delayed sowing (Goudriaan & van Laar, 1994; Poorter *et al.* 2012).

Functional-structural plant models (FSPMs) capture 3D canopy architecture and light distribution, enabling finer simulations of how leaf angle, internode length, and leaf distribution influence light interception (Sarlikioti *et al.* 2011; Vos *et al.* 2010). Coupling FSPMs with process-based models could improve predictions of how early increases in SLA and LAR under delayed sowing translate into canopy development and biomass production (Niinemets, 2010; Li *et al.* 2018). Advances in remote sensing and machine learning further enable dynamic calibration of LAI and canopy traits at field scale, enhancing model validation and real-time decision support (Ferreira *et al.* 2019; Zhang *et al.* 2020).

Integration of genotype × environment × management (G×E×M) interactions into jute models would facilitate selection of optimal sowing windows and resilient cultivars (Hammer *et al.* 2019; Messina *et al.* 2018). Improved modelling of source-sink dynamics, radiation-use efficiency, and stress responses will strengthen prediction of fibre yield under climate variability (Chenu *et al.* 2013; Reymond *et al.* 2003). Robust crop models incorporating canopy traits are therefore essential for climate-smart jute agronomy and strategic planning (Rotter *et al.* 2015; Thornton *et al.* 2017).

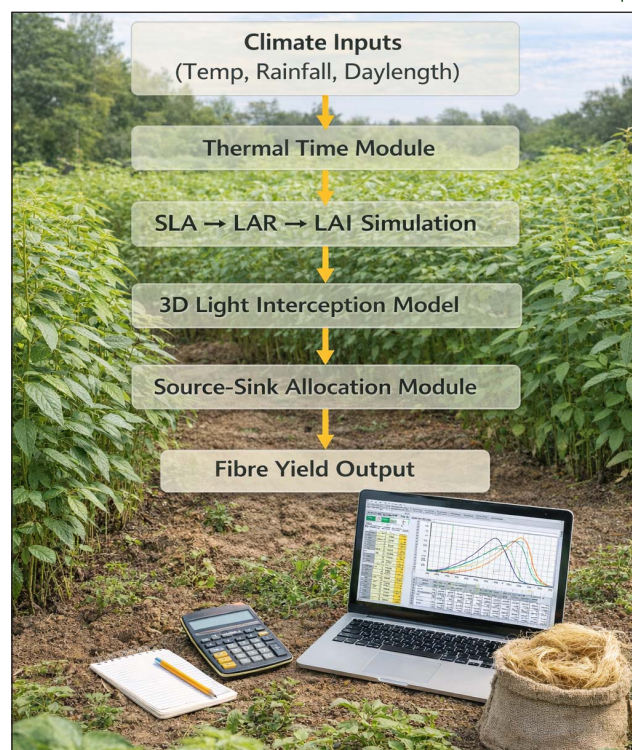


Fig. 7: Proposed Jute Canopy Modelling Framework

Remote sensing tools can estimate LAI in real time, improving sowing window optimization.

CONCLUSION

Delayed sowing exerts profound impacts on the physiological traits and canopy dynamics of jute (*Corchorus olitorius* L.), primarily through modification of phenology, canopy architecture, and assimilate partitioning (Basu *et al.* 2012; Rahman *et al.* 2021). Shifts in sowing time alter Leaf Area Index (LAI) and Leaf Area Ratio (LAR) trajectories, affecting radiation interception and photosynthetic efficiency (Poorter *et al.* 2012; Niinemets, 2010). While elevated SLA and early LAR under delayed sowing can partially compensate for reduced vegetative duration, shortened peak LAI and compressed source-sink dynamics often limit cumulative biomass and fibre yield (Shipley, 2002; Sinclair & Muchow, 1999).

Integrating canopy traits such as LAI and LAR into crop modelling frameworks is essential for predicting crop performance under climate variability (Goudriaan & van Laar, 1994). Future

research should focus on genotype-specific responses and model refinement to support adaptive sowing strategies and climate-resilient jute production systems.

REFERENCES

- Asseng, S. et al. 2015. Rising temperatures reduce global wheat production. *Nature Climate Change*, **5**(2): 143–147.
- Basu, G., Bandyopadhyay, P.K., Biswas, S., Roy, A. and Mahapatra, B.S. 2012. Effect of sowing date on growth and fibre yield of jute (*Corchorus olitorius* L.). *Indian Journal of Agronomy*, **57**(3): 259–263.
- Biscoe, P.V. and Gallagher, J.N. 1977. Weather, dry matter production and yield. In: *Environmental Effects on Crop Physiology*. London: Academic Press, pp. 75–100.
- Board, J.E. and Harville, B.G. 1992. Explanations for greater light interception in narrow vs wide row soybean. *Crop Science*, **32**: 198–202.
- Boote, K.J., Jones, J.W. and Pickering, N.B. 2013. Potential uses and limitations of crop models. *Agronomy Journal*, **105**(8): 2557–2566.
- Campbell, G.S. and Norman, J.M. 1998. *An Introduction to Environmental Biophysics*. New York: Springer.
- Chenu, K., Chapman, S.C. and Hammer, G.L. 2013. Large-scale characterization of drought pattern: A continent-wide modelling approach applied to the Australian wheatbelt. *Environmental Modelling & Software*, **41**: 98–114.
- Craufurd, P.Q. and Wheeler, T.R. 2009. Climate change and flowering time of annual crops. *Journal of Experimental Botany*, **60**: 2529–2539.
- Evans, J.R. and Poorter, H. 2001. Photosynthetic acclimation of plants to growth irradiance: The relative importance of specific leaf area and nitrogen partitioning in maximizing carbon gain. *Plant, Cell & Environment*, **24**(8): 755–767.
- Falster, D.S. and Westoby, M. 2003. Leaf size and angle vary widely across species: What consequences for light interception? *New Phytologist*, **158**(3): 509–525.
- Falster, D.S., Brännström, Å., Dieckmann, U. and Westoby, M. 2018. *Plant Form–Functional Ecology and Evolution*. Cambridge: Cambridge University Press.
- Ferreira, L.G., Góes, R.M., Silva, T.S.F. and Castro, J.F. 2019. Remote sensing for crop monitoring. *International Journal of Applied Earth Observation and Geoinformation*, **80**: 1–10.
- Galmés, J., Flexas, J., Savé, R. and Medrano, H., 2007. Water relations and stomatal characteristics of Mediterranean plants with different growth forms and leaf habits: Responses to water stress and recovery. *Plant and Soil*, **290**(1–2): 139–155.
- Gardner, F.P., Pearce, R.B. and Mitchell, R.L., 1985. *Physiology of Crop Plants*. Ames: Iowa State University Press.
- Goudriaan, J. and van Laar, H.H. 1994. *Modelling Potential Crop Growth Processes*. Dordrecht: Kluwer Academic Publishers.
- Hammer, G.L. et al. 2019. Crop design for specific adaptation in variable environments. *Field Crops Research*, **234**: 115–128.
- Hay, R.K.M. and Walker, A.J. 1989. *An Introduction to the Physiology of Crop Yield*. London: Longman.
- Hunt, R., 1990. *Basic Growth Analysis*. London: Unwin Hyman.
- ICAR-CRIJAF, 2020. Annual Report 2019–20. Barrackpore: ICAR-Central Research Institute for Jute and Allied Fibres.
- Jones, J.W. et al. 2003. The DSSAT cropping system model. *European Journal of Agronomy*, **18**(3–4): 235–265.
- Kiniry, J.R. et al. 2001. Radiation-use efficiency in biomass accumulation. *Field Crops Research*, **68**: 199–214.
- Koch, K.E. 2004. Sucrose metabolism: Regulatory mechanisms and pivotal roles in sugar sensing and plant development. *Current Opinion in Plant Biology*, **7**(3): 235–246.
- Lambers, H., Chapin, F.S. and Pons, T.L. 2008. *Plant Physiological Ecology*. 2nd ed. New York: Springer.
- Li, Y., Shipley, B. and Lechowicz, M.J. 2018. Are plant ecological strategies consistent across environments? Evidence from a multispecies test. *New Phytologist*, **218**(1): 272–283.
- Loomis, R.S. and Williams, W.A., 1969. Productivity and the morphology of crop stands. *Annual Review of Plant Physiology*, **20**: 289–312.
- Marcelis, L.F.M., 1996. Sink strength as a determinant of dry matter partitioning in the whole plant. *Journal of Experimental Botany*, **47**(Special Issue): 1281–1291.
- Messina, C.D. et al. 2018. Crop modelling strategies for precision agriculture. *Agronomy Journal*, **110**(6): 1–12.
- Monsi, M. and Saeki, T. 1953. Über den Lichtfaktor in den Pflanzengesellschaften. *Japanese Journal of Botany*, **14**: 22–52.
- Monteith, J.L. 1977. Climate and efficiency of crop production in Britain. *Philosophical Transactions of the Royal Society B*, **281**: 277–294.
- Muchow, R.C. and Sinclair, T.R. 1991. Water deficit effects on maize yields modeled under current and climate change scenarios. *Agronomy Journal*, **83**: 105–112.
- Nguyen, H.T., Bousser, J., Roumet, C. and Garnier, E. 2019. Biomass allocation in relation to plant size, light, and nutrient availability. *Functional Ecology*, **33**(9): 1645–1655.
- Niinemets, Ü. and Valladares, F. 2006. Tolerance to shade, drought, and waterlogging of temperate northern hemisphere trees and shrubs. *Ecological Monographs*, **76**(4): 521–547.
- Niinemets, Ü. 2010. A review of light interception in plant canopies: Physical models and underlying concepts. *Annals of Botany*, **105**(3): 369–389.
- Paul, M.J. and Foyer, C.H. 2001. Sink regulation of photosynthesis. *Journal of Experimental Botany*, **52**(360): 1383–1400.
- Poorter, H. and Garnier, E. 1996. Plant growth analysis: An evaluation of experimental design and computational



- methods. *Journal of Experimental Botany*, **47**(305): 1343–1351.
- Poorter, H., Niinemets, Ü., Poorter, L., Wright, I.J. and Villar, R. 2012. Biomass allocation to leaves, stems and roots: Meta-analyses of interspecific variation and environmental control. *New Phytologist*, **193**(1): 30–50.
- Poorter, H., Niinemets, Ü., Poorter, L., Wright, I.J. and Villar, R. 2009. Causes and consequences of variation in leaf mass per area (LMA): A meta-analysis. *New Phytologist*, **182**(3): 565–588.
- Rahman, M.S., Amin, M.R. and Hassan, M.M. 2021. Phenological responses of jute to sowing time and climate variability. *Journal of Crop Science and Biotechnology*, **24**(2): 101–113.
- Ray, D.P. and Ghosh, R.K. 2018. Perspective of Jute in a New Realm beyond Sacking, *Economic Affairs*, **63**(4): 981–986.
- Reich, P.B., Walters, M.B. and Ellsworth, D.S. 2003. From tropics to tundra: Global convergence in plant functioning. *Proceedings of the National Academy of Sciences*, **94**(25): 13730–13734.
- Reymond, M. *et al.* 2003. Combining QTL analysis and ecophysiological modelling to study genetic variability of rice. *Field Crops Research*, **87**(2–3): 85–104.
- Ritchie, J.T. and Otter, S. 1985. Description and performance of CERES models. In: *ARCP Wheat Simulation Modeling Workshop Proceedings*, pp. 159–175.
- Roberts, E.H., Summerfield, R.J. and Cooper, J.P. 1988. Photoperiod and flowering in crop plants. *Advances in Agronomy*, **41**: 1–61.
- Ross, J. 1981. *The Radiation Regime and Architecture of Plant Stands*. The Hague: Dr W. Junk Publishers.
- Rotter, R.P. *et al.* 2015. Crop–climate models need an overhaul. *Nature Climate Change*, **5**(9): 768–774.
- Sarlikioti, V., De Visser, P.H.B., Buck-Sorlin, G.H. and Marcelis, L.F.M. 2011. How plant architecture affects light absorption and photosynthesis in tomato: Towards an ideotype for plant architecture using a functional–structural plant model. *Annals of Botany*, **108**(6): 1065–1073.
- Shipley, B. 2002. *Cause and Correlation in Biology: A User's Guide to Path Analysis, Structural Equations and Causal Inference*. Cambridge: Cambridge University Press.
- Shipley, B., Meziane, D. and Wright, I.J. 2006. The evolutionary ecology of leaf economics. *Functional Plant Biology*, **33**(12): 1151–1161.
- Sinclair, T.R. and Muchow, R.C. 1999. Radiation use efficiency. *Advances in Agronomy*, **65**: 215–265.
- Sinoquet, H., Le Roux, X. and Adam, B. 2001. Analysis of the spatial distribution of leaf area index (LAI) at tree and canopy scales in a broad-leaved forest. *Plant, Cell & Environment*, **24**(2): 195–211.
- Slewinski, T.L. 2012. Diverse functional roles of monosaccharide transporters in vascular plants: A physiological perspective. *Molecular Plant*, **5**(3): 787–797.
- Squire, G.R. 1990. *The Physiology of Tropical Crop Production*. Wallingford: CAB International.
- Thornton, P.K. *et al.* 2017. Response of agricultural systems to climate change. *Annual Review of Environment and Resources*, **42**: 205–226.
- Tollenaar, M. and Aguilera, A., 1992. Radiation use efficiency of maize under stress conditions. *Crop Science*, **32**: 221–227.
- Tollenaar, M. and Wu, J. 1999. Yield improvement in temperate maize is attributable to greater stress tolerance. *Crop Science*, **39**(6): 1597–1604.
- Valladares, F. and Niinemets, Ü. 2008. Shade tolerance, a key plant feature of complex nature and consequences. *Annual Review of Ecology, Evolution, and Systematics*, **39**: 237–257.
- Valladares, F., Wright, S.J., Lasso, E., Kitajima, K. and Pearcy, R.W. 2007. Plastic phenotypic response to light of 16 congeneric shrubs from a tropical dry forest. *Ecology*, **88**(11): 1–11.
- Vile, D., Garnier, E., Shipley, B. and Laurent, G. 2005. Specific leaf area and dry matter content estimate thickness in laminar leaves. *Annals of Botany*, **96**(6): 1129–1136.
- Vos, J. *et al.* 2010. Functional–structural plant models: A growing paradigm for crop science. *Trends in Plant Science*, **15**(6): 304–312.
- Watson, D.J. 1947. Comparative physiological studies on growth of field crops. *Annals of Botany*, **11**: 41–76.
- Weiner, J. 2017. Applying plant ecological knowledge to increase agricultural sustainability. *Journal of Ecology*, **105**(4): 865–870.
- Westoby, M. and Wright, I.J. 2006. Land-plant ecology on the basis of functional traits. *Trends in Ecology & Evolution*, **21**(5): 261–268.
- Wright, I.J. and Westoby, M. 2002. Leaves at low versus high rainfall: Coordination of structure, lifespan and physiology. *New Phytologist*, **155**(3): 403–416.
- Wright, I.J., Reich, P.B., Westoby, M. *et al.* 2004. The worldwide leaf economics spectrum. *Nature*, **428**(6985): 821–827.
- Zhang, C. *et al.* 2020. Machine learning for crop yield prediction and climate adaptation. *Computers and Electronics in Agriculture*, **175**: 105592.
- Zhang, Y., Fincke, B.G., Zhang, K. *et al.* 2017. Effects of canopy structure and light interception on stem growth and yield formation in soybean (*Glycine max* L.). *Field Crops Research*, **212**: 170–180.
- Ziska, L.H., Gebhard, D.E. and Frenkel, C. 2016. Temperature effects on biomass allocation patterns in annual crops. *Agricultural and Forest Meteorology*, **226–227**: 165–173.

