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RESEARCH ARTICLE

Low-density sowing of jute and jute-green gram intercropping: Enhancing farm economy, reducing labour bottlenecks

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Abstract

Jute (*Corchorus olitorius* L.) is a natural fibre crop of economic and ecological importance. However, jute farming is highly labour-intensive. Prevalent practice of broadcast high-density sowing (HDS) with a seed rate of 6.0 kg/ha results in overcrowding (240 plants/m^2) and high labour input. This study probed into the reduction of labour input *vis-à-vis* cost of cultivation through sowing density moderations in sole jute and jute-green gram intercropping at Eastern India and verified at farmers' fields of West Bengal, India, in 2020 and 2021. Low density sowing (LDS) of jute with 1.50-2.60 kg/ha seed rate in sole crop and intercropping with green gram (10.0 kg/ha) reduced labour input on major operations by 43 %-48 % (115-129 man-days/ha) over HDS. It achieved germination density of 60-103 plants/m^2 and eased in establishing 30-40 plants/m^2 at harvest. LDS produced a comparable fibre yield of 36.5-38.0 q/ha, enhanced net profit by 6.75 %-11.84 % and cost of cultivation reduced by Rs. 28208– Rs. 33500/ha over HDS. LDS of jute opened the scope of crop diversification. Jute-green gram intercrop generated 29.5 q/ha fibre, 5.0 q/ha green gram seed, reduced 108 man-days/ha, recorded a B:C ratio of 1.81 and improved soil health. In farmers' fields, with a jute seed rate of 2.25-2.60 kg/ha, 33-45 q/ha fibre yield was recorded, reduced labour by 70-100 man-days/ha and reduced cost up to Rs. 25000/ha. Farmers are rapidly adopting these friendly practices.

Keywords: broadcast; jute economy; jute-green gram intercropping; labour saving; low density sowing; soil health

Introduction

Jute (*Corchorus olitorius* L.) is an important bast fibre crop, grown in nearly 1 million hectares of the Indo-Bangla subcontinent, where it supports the rural economy. Jute farming is a low-profit but high labour-intensive venture with an ever-increasing share (54 % -59 %) of the total cost of cultivation (1). Three jute seeding rates of 1.20-2.60, 3.00-3.75 and 6.0 kg/ha form three categories, namely, LDS, moderate HDS and HDS respectively. Broadcast HDS with a 6.0 kg/ha seed rate is the extensive practice of jute farmers, which involves huge labourand has become a costly proposition today. LDS was thus studied to reduce labour in jute cultivation. Broadcast is an effective method for small areas where mechanical seeding is inconvenient (2). Recommended row sowing with 25-30 cm × 7-8 cm spacing intensifies plant competition within row and promotes crop-weed competition in wider spaces between rows, from the initial days. Jute seedlings have poor weed-competitive ability due to their limited external morphology, low growth rate during the initial 45 days after sowing (DAS) and dominance of C_4 grasses, broad-leaved weeds and sedges over the C_3 jute during warm climates with frequent drought spells. A higher degree of spatial uniformity in broadcast has an advantage for better crop growth and yield than the close distribution of plants within rows (3). Therefore, broadcast sowing appears advantageous under current farming system conditions.

Jute seeds are irregular in shape and tiny, with a test weight of 1.75 g. Jute seeds are mixed with fillers like rice bran, damp sand, vermiculite, etc. to ensure their even distribution over the field. A seed rate of 6.0 kg/ha recorded 31.5 lakhs of total seed count and viable seed counts over 25 lakhs (4). Subsequently, the number of seedlings germinated, survived after intercultural operations and matured plants at harvest remain around 17.0, 4.5-5.5 and 3.5-4.0 lakhs/ha respectively. Thus, out of a large proportion of sown seeds, only 3.5-4.0 lakh plants (12 %) ultimately matter at harvest. A plant density of 30-40 plants/m^2 yields 36 to 44 q/ha jute fibre (5). Fixed operations of jute cultivation (land preparation, sowing, management of water, plant nutrition and protection and harvesting) require 100-120 man-days/ha. High plant stand at emergence needs additional labour and care during weeding-thinning in successive phases until 45 DAS. It is a challenging process to downsize the copious plant population. Even with the best of efforts, the plant densities at harvest remain higher affecting overall plant growth and increase expenses cumulatively on major operations of weeding-thinning (since 15-45 DAS), post-harvest tasks of sorting and bundling of harvested plants (at 120 DAS), carrying the bulky bundles to water body for retting, steeping of bundles and fibre extraction (Fig. 1). Low seeding rate seems to be the key production strategy to regulate plant density at sowing that automatically reduce labour needs on all the successive tasks.

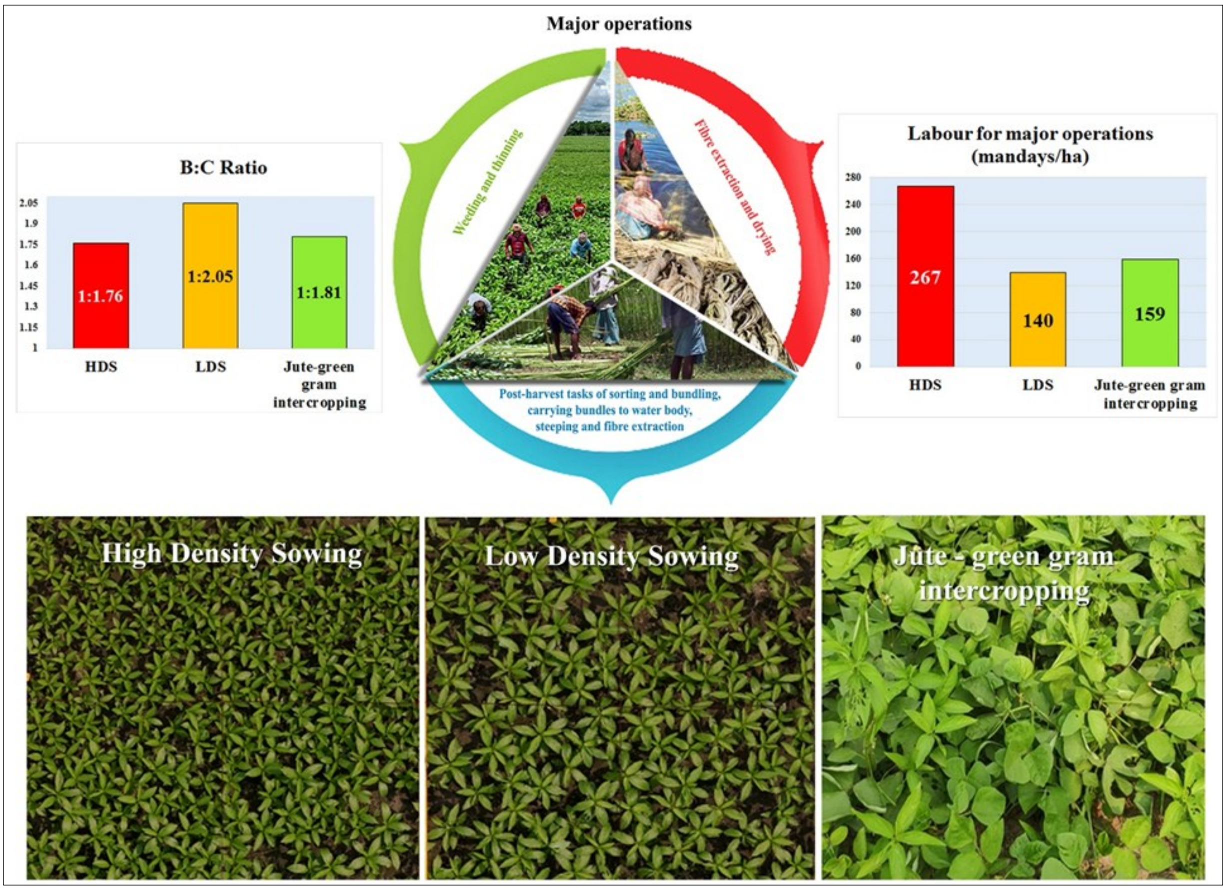

Fig. 1. Schematic diagram of major operations and economics of low-density sowing of jute.

Hence, reducing the seed rate can directly regulate plant density, lowering labour requirements for subsequent operations.

Problematic labour input (rising labour costs and scarcity of labour during the peak labour-absorbing periods) is a persistent constraint of low profitability in jute farming (6). Plant density-dependent major operations are physically demanding, executed under harsh weather conditions of hot (36 ^{0}C-40 ^{0}C) and humid (80 % -95 %) summer days (April-May) for weeding-thinning operations, rainy season (July-September) for post-harvest operations and demand for completion in a short period. Presently, there is no viable alternative to reduce manual labour dependency. Jute harvest and post-harvest operations period (July-September) overlaps with the primary growing season of *Kharif* crops when labour demand reaches its peak (7). Labour scarcity in the agricultural sector is intensifying with heightened migration from rural to urban regions and reluctance to undertake strenuous fibre extraction tasks under difficult conditions, particularly among younger generations (8-10).

LDS opened the scope and also offers opportunities for crop diversification with short-duration cultivars. Intercropping jute with short-duration green gram provides live mulch to suppress weeds without compromising fibre yield due to minimal competition (11). It derives substantial benefits to local farming systems, including dependability of return and ensuring nutritional needs. It has created a great prospect of increasing green gram area and production. Green gram canopy suppresses weeds by 30 DAS, thereby reducing or eliminating the need for further weeding (12, 13). In view of the above, a study with LDS of sole jute and LDS of jute intercropped with short-duration green gram was taken up to reassess the jute seeding rates to strengthen the farm economy by minimising labour input.

Materials and methods

The study was conducted at the research farm of the Indian Council of Agricultural Research - Central Research Institute for Jute and Allied Fibres, Barrackpore, West Bengal, India (22^{0}45' N, 88^{0}25' E; 9.69 m above mean sea level). The soil was Gangetic alluvium (inceptisol), with pH 7.23 (1:2.5 w/v), organic carbon 5.50 g/kg and medium fertility (available N, P, K = 178, 30 and 135 kg/ha respectively). The climate was humid tropical with total rainfall of 964.0 mm in 2020 and 979.9 mm in 2021 during the jute growing season (Fig. 2). The experiment involved premature flowering resistant jute (cv. JROBA-3) and green gram (cv. Virat), sown between 16-19 March and harvested at 120 DAS. The field trial followed a randomised block design with 11 treatments, each replicated thrice in 3.5 × 3.5 m^2 plots (Table 1). At 7 DAS, for initial weeding the plots with T2 were operated with the CRIJAF nail weeder, a low-draft multi-tasking small tool, effective for intercultural intervention in jute (14).

Pre-emergence herbicide Pretilachlor 50 EC at 0.9 kg a.i./ha was applied at 48 hr following sowing with irrigation to control initial composite weeds. The germination rate of jute seeds was around 95 % in petri dishes. Weeding-thinning and line arrangement of seedlings in broadcast jute, was done using CRIJAF Nail Weeder used in T_2. In the jute-green gram intercropping (1:1) treatment (T_8), fertilisers were applied at N:P:K= 80:70:70. A basal dose of 20:70:70 was applied, followed by top dressing of 60 kg N/ha after green gram harvest (55-60 DAS). In all other treatments, N:P:K = 60:30:30 was applied, with 20:30:30 as basal and two top dressings of 20 kg N/ha at 21 and 45 DAS, each followed by irrigation.

Pilot-scale demonstrations were conducted in 2020 and 2021 to verify the merits of LDS of sole jute and jute-green gram intercropping under farmers' conditions. A total of 115 farmers across six blocks in three districts of West Bengal (Murshidabad,

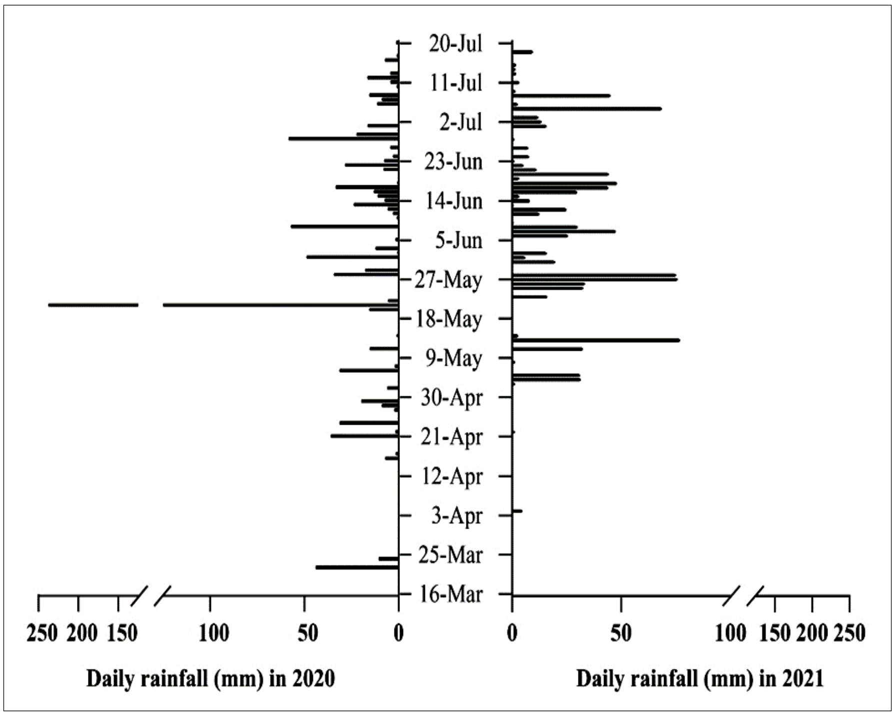

Fig. 2. Daily rainfall (mm) at ICAR-CRIJAF experimental station during the jute cultivation period (March-July) for the years 2020 and 2021.

Table 1. Treatment set-up of the experiment.

Code	Treatment	Jute Sowing Density
T_1	Jute Seed (6.00 kg/ha) broadcast + 2 HW (Farmers' practice)	HDS
T_2	Jute Seed (6.00 kg/ha) broadcast + CRIJAF Nail Weeder (5-10 DAS) + 1 HW	
T_3	Jute Seed (1.20 kg/ha) broadcast + Filler (4.80 kg/ha) + Pretilachlor 50 EC at 0.9 kg a.i./ha + 1 HW	LDS
T_4	Jute Seed (1.50 kg/ha) broadcast + Filler (4.50 kg/ha) + Pretilachlor 50 EC at 0.9 kg a.i./ha + 1 HW	
T_5	Jute Seed (1.90 kg/ha) broadcast + Filler (4.10 kg/ha) + Pretilachlor 50 EC at 0.9 kg a.i./ha + 1 HW	
T_6	Jute Seed (2.25 kg/ha) broadcast + Filler (3.75 kg/ha) + Pretilachlor 50 EC at 0.9 kg a.i./ha + 1 HW	
T_7	Jute Seed (2.60 kg/ha) broadcast + Filler (3.40 kg/ha) + Pretilachlor 50 EC at 0.9 kg a.i./ha + 1 HW	
T_8	Jute Seed (2.20 kg/ha) broadcast + Filler (3.80 kg/ha) + Pretilachlor 50 EC at 0.9 kg a.i./ha + Green gram (10.00 kg/ha) + 1 HW	
T_9	Jute Seed (3.00 kg/ha) broadcast + Filler (3.00 kg/ha) + Pretilachlor 50 EC at 0.9 kg a.i./ha + 1 HW	Moderate HDS
T_{10}	Jute Seed (3.75 kg/ha) broadcast + Filler (2.75 kg/ha) + Pretilachlor 50 EC at 0.9 kg a.i./ha + 1 HW	
T_{11}	Jute Seed (6.00 kg/ha) broadcast as Unweeded Control	HDS

Paschim Medinipur and North 24 Parganas) participated, covering 13.90 ha. To ensure even distribution of jute seeds, active seeds (1.20, 1.50, 1.90, 2.25, 2.60, 3.00 and 3.75 kg/ha) were mixed homogeneously with a complementary amount of river sand, keeping the total mixture weight to 6.0 kg/ha. Half of the mixture was broadcast in one direction and the remaining half in a perpendicular direction, forming a crisscross pattern. Farmers used either river sand or fried jute seeds as filler material. A few of them crisscrossed twice by doubling the filler in the mixture to broadcast one quarter of the mixture each time. After seed sowing, the plots were planked lightly and irrigated. Other recommended production practices are applied uniformly. The crop was harvested at 120 DAS on 16-18 July. Uniformity of the crop stand was assessed visually. Data were recorded on manpower use (operation-wise), plant density (at emergence, after final thinning and at harvest), uneconomic plants ('chad'), plant biometry, fibre yield, light transmission (above/ below green gram canopy, using LX-102 light meter, Lutron model L620942) and soil nutrient status using standard methods.

Alkaline $KMnO_4$-oxidizable nitrogen (available N) was estimated by using a standard procedure (15). Available phosphorus was extracted with 0.5 M $NaHCO_3$ (pH 8.5) and determined spectrophotometrically (16). Available potassium was extracted using neutral 1N ammonium acetate and measured with a flame photometer (17). Soil organic carbon was determined by using the wet oxidation method (18). Economic evaluation was based on prevailing minimum support prices: jute fibre Rs. 5500/q, green gram seed Rs. 7200/q, jute stick Rs. 140/q, pulse husk Rs. 2000/q and labour wage Rs. 250/man-day. The benefit: cost (B: C) ratio was calculated as the ratio of gross return to cost of cultivation.

The significant differences in treatments were tested using the two-way analysis of variance (ANOVA) to assess the impact of germination percentage and plant population at harvest with changes in jute seed rate, labour cost, cost of cultivation, net and gross return. For mean separation ($p < 0.05$), the DMRT test was used. Data on plant population at germination and at harvest are subjected to log transformation and for the chad population, data are subjected to square root transformation before comparison. All statistical analysis was carried out using SAS 9.3 software.

Results and Discussions

Plant stand establishment at different seed rates

Plant density at emergence and harvest under different sowing densities is presented in Table 2. On an average, about 69 % of the sown seed established successfully. In *olitorius* jute, conventional seed rate for the broadcast and line sown methods had been 6.00 and 3.50-4.00 kg/ha respectively. These contain 31.6 lakh and 18.4-21.1 lakh seeds and potential plants. Whereas, the seed rates under LDS (1.20, 1.50, 1.90, 2.25 and 2.60 kg/ha) account for 6.3, 7.9, 10.0, 11.8 and 13.7 lakh seeds respectively. Plant density at emergence steadily increased from 45-103 to 118-139 and to 229-234 plants/m^2, corresponding to the LDS treatments (T_3 to T_8), moderate HDS treatments (T_9, T_{10}) and HDS treatments (T_1, T_2 and T_{11}) respectively. Accordingly, HDS treatments (T_1, T_2, T_9 and T_{10}) needed additional manpower for thinning. It was a tedious task with a relatively slow work rate to downsize the copious plant population before settling down to a uniformly targeted density (30-40 plants/m^2) in successive phases. Even with the best of efforts and thinning rigour, it was found that plant densities at harvest were a little higher (45-54 plants/m^2) for the treatments T_1 and T_2 and around 46-53 plants/m^2 for treatments T_9 to T_{11}. The presence of excess plants affected overall plant growth, increased the share of uneconomic plants and cumulatively increased man-days for weeding-thinning, sorting and fibre extraction (Table 3). Whereas, in the case of LDS treatments (T_3 to T_7), the emerged plant density was sufficient and fair enough to settle down easily to an effective plant density of 29-40 at harvest, required no manpower for thinning and sorting tasks and reduced man-days for fibre extraction. These differences were observed in both the study years. This highlights how higher sowing density not only increased competition but also added to the labour burden, thereby reducing profitability.

Effect of sowing density on plant height, basal diameter, plant weight and single plant fibre weight

Average jute plant height under LDS (T_3 to T_7) was comparable with that under HDS (T_1 and T_2) (Table 2). The basal diameter of jute plants in LDS recorded 1.80 to 2.02 cm and was comparable to HDS irrespective of broadcast or line-sown crops (T_1 and T_2). Average green biomass and single plant fibre weight ranged between125 to 175 g/plant and 9.11 to 13.00 g/plant respectively, for LDS treatments (T_3 to T_8). Whereas, in HDS (T_1 and T_2), average green biomass varied in the range 121.3 to 138.0 g/plant and single plant fibre weight from 7.63 to 8.73 g/plant. Plant height, basal diameter, single plant weight and fibre yield attained maximum for T_7,having a seed rate of 2.60 kg/ha. This suggests that moderate LDS (2.60 kg/ha) optimises resource use efficiency and plant vigour, balancing stand density with individual plant growth. These results of LDS tallied with the earlier study (5, 6). Similarly, low-density planting in industrial hemp (*Cannabis sativa* L.) resulted in longer plants and thicker stems at harvest than for the high-density planting and raw fibre yields were maximum at 300 plant/m^2 and the stem biomass decreased with an increase in plant density (19, 20). Similar density-growth trade-offs in jute reinforce the general principle observed across bast fibre crops.

Effect of sowing density on fibre yield and green biomass

Unweeded control (T_{11}) has the highest chad population, resulting in a 53.3 % fibre yield loss compared with managed plots. Plant density at harvest affected fibre yield. A plant density of around 30 to 35 plants/m^2 at harvest resulted in better plant growth and minimised

Table 2. Plant population, biometry and fibre yield of jute under low-density sowing.

Tr No	Treatments	Plant population at germination (lakh/ha)	Plant population at harvest (lakh/ha)	*Chad* population at harvest (lakh/ha)	Average plant height (cm)	Average basal diameter (cm)	Average green weight/plant (g)	Average fibre weight/plant (g)	Green biomass yield (t/ha)	Fibre yield (q/ha)
T_1	Seed (6.0 kg/ha) + 2 HW (Farmers' practice)	1.36^{i} (22.87)	0.73^{e} (5.38)	0.76^{bcd} (0.58)	346.83^{ab}	1.81^{ab}	121.3^{cd}	7.63^{cd}	64.88^{abc}	40.81^{a}
T_2	Seed (6.0 kg/ha) + CRIJAF Nail Weeder (5-10 DAS) + 1 HW	1.37^{i} (23.21)	0.65^{cde} (4.46)	0.78^{bcd} (0.61)	340.00^{ab}	1.98^{a}	138.2^{bc}	8.73^{bc}	54.75^{abc}	38.28^{ab}
T_3	Seed (1.20 kg/ha) + Filler (4.80 kg/ha) + Herbicide + 1 HW	0.65^{a} (4.51)	0.46^{a} (2.87)	0.31^{a} (0.10)	361.50^{ab}	1.80^{ab}	174.5^{a}	13.00^{a}	49.85^{c}	37.12^{ab}
T_4	Seed (1.50 kg/ha) + Filler (4.50 kg/ha) + Herbicide + 1 HW	0.78^{b} (5.96)	0.58^{c} (3.76)	0.32^{a} (0.10)	363.83^{ab}	2.02^{a}	168.0^{ab}	9.93^{b}	66.16^{ab}	37.07^{ab}
T_5	Seed (1.90 kg/ha) + Filler (4.10 kg/ha) + Herbicide + 1 HW	0.85^{c} (7.16)	0.59^{c} (3.87)	0.46^{ab} (0.21)	353.83^{ab}	1.86^{ab}	144.5^{abc}	9.42^{bc}	52.59^{bc}	36.53^{ab}
T_6	Seed (2.25 kg/ha) + Filler (3.75 kg/ha) + Herbicide + 1 HW	0.93^{e} (8.53)	0.61^{cd} (4.03)	0.93^{cd} (0.87)	365.00^{a}	1.67^{b}	125.2^{c}	9.18^{bc}	50.54^{c}	36.83^{ab}
T_7	Seed (2.60 kg/ha) + Filler (3.40 kg/ha) + Herbicide + 1 HW	1.01^{f} (10.31)	0.59^{c} (3.88)	0.54^{abc} (0.29)	363.50^{ab}	1.87^{ab}	143.7^{abc}	9.11^{bc}	69.15^{a}	37.99^{ab}
T_8	Seed (2.25 kg/ha) + Filler (3.80 kg/ha) + Herbicide + Green gram + 1 HW	0.91^{d} (8.04)	0.49^{b} (3.10)	0.46^{ab} (0.21)	333.17^{bc}	1.84^{ab}	166.8^{ab}	9.70^{b}	51.55^{bc}	29.47^{c} (5.0)*
T_9	Seed (3.00 kg/ha) + Filler (3.00 kg/ha) + Herbicide + 1 HW	1.07^{g} (11.80)	0.66^{cde} (4.55)	1.00^{d} (1.01)	360.00^{ab}	1.85^{ab}	127.3^{c}	8.27^{bc}	56.13^{abc}	37.35^{ab}
T_{10}	Seed (3.75 kg/ha) + Filler (2.75 kg/ha) + Herbicide + 1 HW	1.14^{h} (13.89)	0.72^{e} (5.27)	0.54^{abc} (0.29)	349.17^{ab}	1.81^{ab}	115.8^{cd}	6.50^{d}	61.13^{abc}	34.05^{bc}
T_{11}	Seed (6.00 kg/ha) Unweeded control	1.37^{i} (23.40)	0.67^{de} (4.72)	2.37^{e} (5.62)	296.67^{c}	1.66^{b}	91.6^{d}	4.16^{e}	34.89^{d}	19.08^{d}

Means followed by the same letter are not significantly different based on DMRT (p=0.05). Plant population at germination and harvest are log-transformed values and chad population values are square root transformed values and figures in parentheses are their corresponding untransformed mean values. * indicates average green gram grain yield (q/ha). ***Chads*** are the uneconomic plants having <150 cm plant height.

the share of uneconomic plants (5). Fibre yields were comparable for all three categories of sowing densities. Fibre yield of 40.8 q/ha was highest for the farmers' practice (T_1). Whereas, with LDS treatments (T_3 to T_7), fibre yield varied in the range of 36.5 to 38.0 q/ha (Table 2), reaching the numerical maximum for the seed rate 2.60 kg/ha (T_7), having 29 to 40 plants/m^2 at harvest. For moderate HDS (T_9 and T_{10}), fibre yields were 37.4 and 34.1 q/ha (Fig. 3a) and with the conventional HDS (T_1 and T_2), plant densities recorded 45 and 54 plants/m^2 at harvest and fibre yields of 40.8 and 38.3 q/ha respectively. Thus, jute row development by CRIJAF nail weeder operation on broadcast sowing, resembled drill sowing for row formation but the process was more efficient as it was easier and labour-saving (14). Studies in fertile soil recorded almost equal fibre yield with varying plant density (4).

In T_8, LDS jute intercropped with green gram (1:1) produced 29.5 q/ha jute fibre and 5.0 q/ha green gram seed, equivalent to 36.0 q/ha jute fibre yield (Table 2). For LDS (T_3 to T_7), the total jute green gram biomass yield varied from 49.9-69.2 t/ha and attained a maximum for T_7 with a comparable biomass yield (68.9 t/ha) for HDS broadcast (T_1). These findings suggest that LDS is an efficient process for ensuring plant density, ease of management practices and yield optimisation. Average net return and yields were similar for broadcast and drill sowing in wheat (21). Beyond fibre yield, intercropping with green gram diversifies farm output, improves soil fertility through biological nitrogen fixation and reduces labour needs by suppressing weeds.

Effect of sowing density on labour requirements and cost savings for major operations

Labour requirements were strongly influenced by sowing density, with LDS reducing the need for labour-intensive operations such as weeding-thinning and sorting. Plant density from differential sowing density directly influenced the manpower requirement. Reducing the seeding rate significantly reduced manpower requirements for major operations and the total manpower requirement. Around 115 man-days/ha were required on account of common operations of jute farming consisting of land preparation, sowing, irrigation, plant nutrition, protection measures and harvesting (Table 3).

Total manpower requirement was maximum (382 man-days/ha) in farmers' practice of HDS broadcast (T_1), wherein major operations shared 70 % (267 man-days/ha). In the line-sown HDS treatments (T_2) with CRIJAF Nail Weeder, the manpower requirement for total and major operations was 283 and 177 man-days/ha respectively. For the treatment of moderate HDS (T_9 and T_{10}), the requirements were also significantly larger. Whereas, the LDS at 1.20 to 2.60 kg/ha of seeding treatments (T_3 to T_7), needed only one hand weeding at 15 DAS and required no thinning and sorting operations and thereby manpower requirements were significantly low at 138 to 157 man-days/ha on major operations and total man-days/ha were at 248 to 272 (Table 3). It reduced labour use by 43 %-48 % on major operations and 29 %-35 % on total manpower use over farmers' practice (T_1). In the case of LDS with green gram intercropping treatment (T_8), the green gram crop management and harvesting process required an additional 30 man-days/ha. These additional labour inputs, commonly women and family labour, pertained to the green gram harvesting process during summer. It mitigates the negative impacts of labour absorption troughs (22). Intercropping ensured a well-distributed income in the jute crop cycle and labour absorption in lean periods, particularly for rural women.

Hence, broadcast LDS with a seed rate of 1.20 to 2.60 kg/ha is a reasonable option to reduce dependency on human labour (Fig. 3b) to achieve a comparable fibre yield of 36.5-38.0 q/ha. Cost of production in LSD reduced by Rs. 27625 to Rs. 33500, i.e. 21 %-25 % low, over farmers' practice (T_1) (Fig. 3c) and recorded Rs. 94562 to Rs. 113027/ha in net return for an optimum plant density of 40 plants/m^2 (Fig. 3d). The B: C ratio of LDS (T_3 to T_8) varied between 2.00 and 2.13 (Fig. 4). Whereas, the B: C ratio was 1.76 in farmers practice (T_1) due to relatively higher cost of cultivation of Rs. 133700/ha. CRIJAF nail weeder operation (T_2) at 5-10 DAS and one manual weeding at 15 DAS, reduced major operations by 90 man-days/ha with 2.02 in B: C ratio.

Jute and green gram intercropping

In jute-green gram intercropping (1:1), green gram (T_8) moderately covered the open ground space around jute plants by 35 days of crop age. Thereby, further weed control measures became redundant. Reduction in weed biomass up to 76 % by jute-green gram intercropping over sole jute was reported earlier (12). At 45 DAS, light penetration was reduced by 90 % to the understory weeds below the green gram canopy in between the two rows of jute. It produced 29.47 q/ha jute fibre and 5.0 q/ha mung grain, reduced manpower use by 108 man-days/ha on major operations of jute cultivation compared to the farmers' practice of HDS (T_1), recorded net return of Rs. 94562/ha and B:C ratio of 1.8 (Table 3). The available nitrogen, phosphorus, potassium and organic carbon content (214.0, 30.8, 141.0 kg/ha and 0.60 %) in post-harvest jute-mung intercropped soil were higher than that in sole jute soil (204.0, 26.4, 109.0 kg/ha and 0.57 %). Soil N, P, K in intercropped plots and sole jute crops varied significantly ($p < 0.05$) with calculated t values 2.6, 3.6, 5.7 respectively. But carbon percentage was found to be non-significant at 5 % level of significance. It added a high amount (2-3 t/ha) of nitrogen-rich biomass (2.35 % total nitrogen) in the form of pulse waste to soil (12). For large-scale intercropping, jute seed: river sand (1:10) and green gram seed: river sand (1:3) can be sown using a zero till seed drill.

Field-level demonstrations of low-density sowing technology

Conducted pilot scale studies with 115 farmers for two years (2020 and 2021) over 13.9 ha area of three districts of West Bengal, India (Table 4). Farmers broadcast a homogeneous mixture of active jute seeds at 2.25 to 2.6 kg/ha and a complementary amount of filler material at 3.40 to 3.75, keeping the total weight of the mixture to 6.0 kg/ha and irrigated the field following sowing. For weed control, apply either Pretilachlor 50 EC at 0.9 l/ha at 48 hours after irrigation + one hand weeding at 15 DAS or quizalofop ethyl 5 % EC at 60 g/ha at 15 DAS. The fibre yield varied from 33 to 45 q/ha. In comparison to HDS, labour use was reduced by 70 to 100 man-days/ha (Rs. 15000 to Rs. 25000/ha monetarily) on weeding-thinning, sorting and fibre extraction activities. Farmers reported that with low initial population, the plants were better in vigour and growth and can tolerate waterlogging stress to some extent than in high density sowing (6.0 to 8.0 kg/ha seed rate) of jute and fibre yield was 15-27 q/ha under waterlogged situation since 30-50 DAS. In Paschim Medinipur, LDS jute was found suitable in zero-till conditions after summer rice harvest.

Field demonstration of green gram along with LDS of jute were held at Murshidabad (Block Nowda), Jalpaiguri and North 24 Parganas (Blocks: Swarup Nagar, De Ganga, Amdanga and Habra 1). Farmers reported jute fibre yield of 27 to 35 q/ha and mung grain

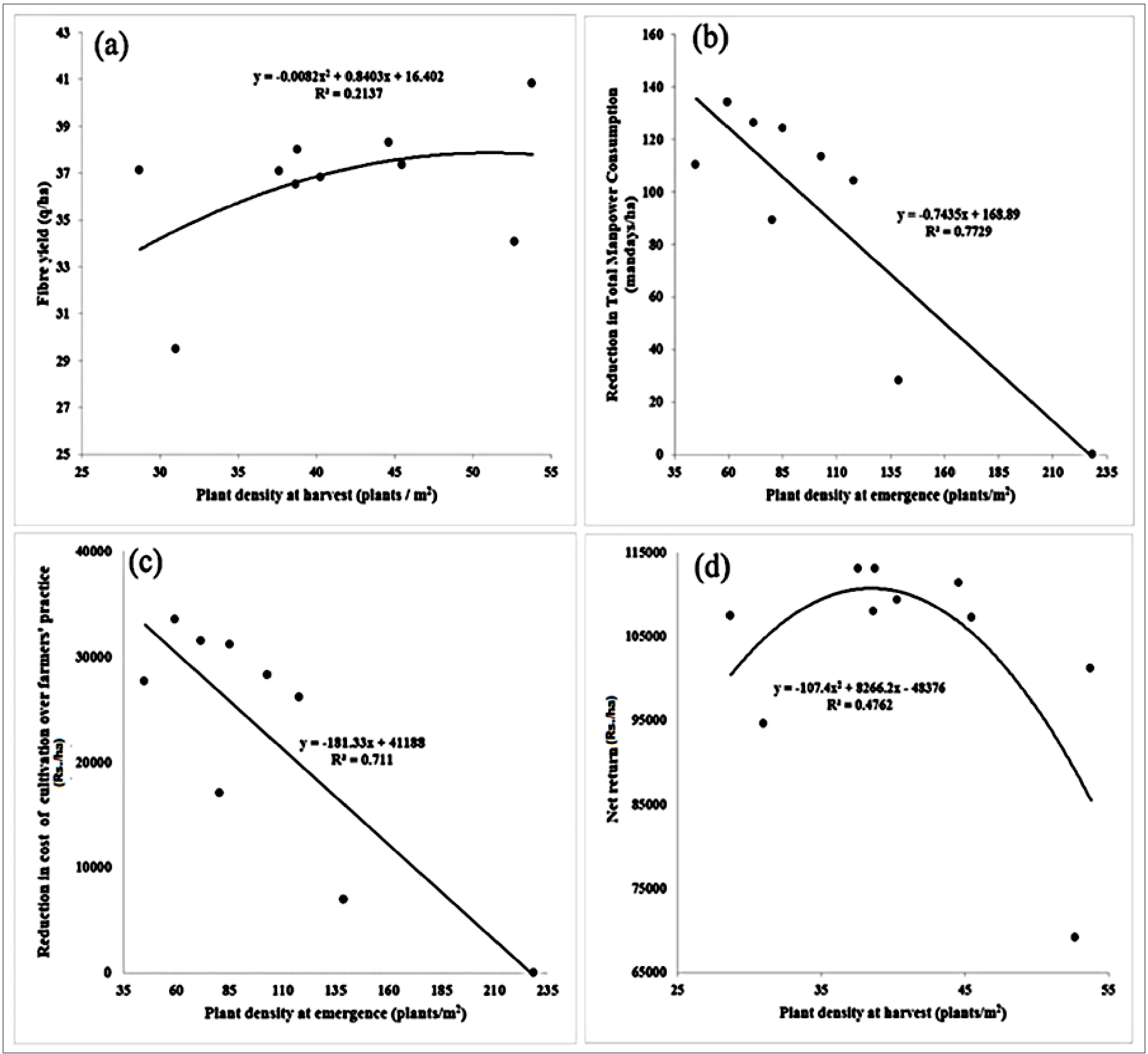

Fig. 3. Effect of plant density (plants/m²) on: **a.** Fibre yield, **b.** Reduction of total manpower, **c.** Cost of cultivation, **d.** Net return.

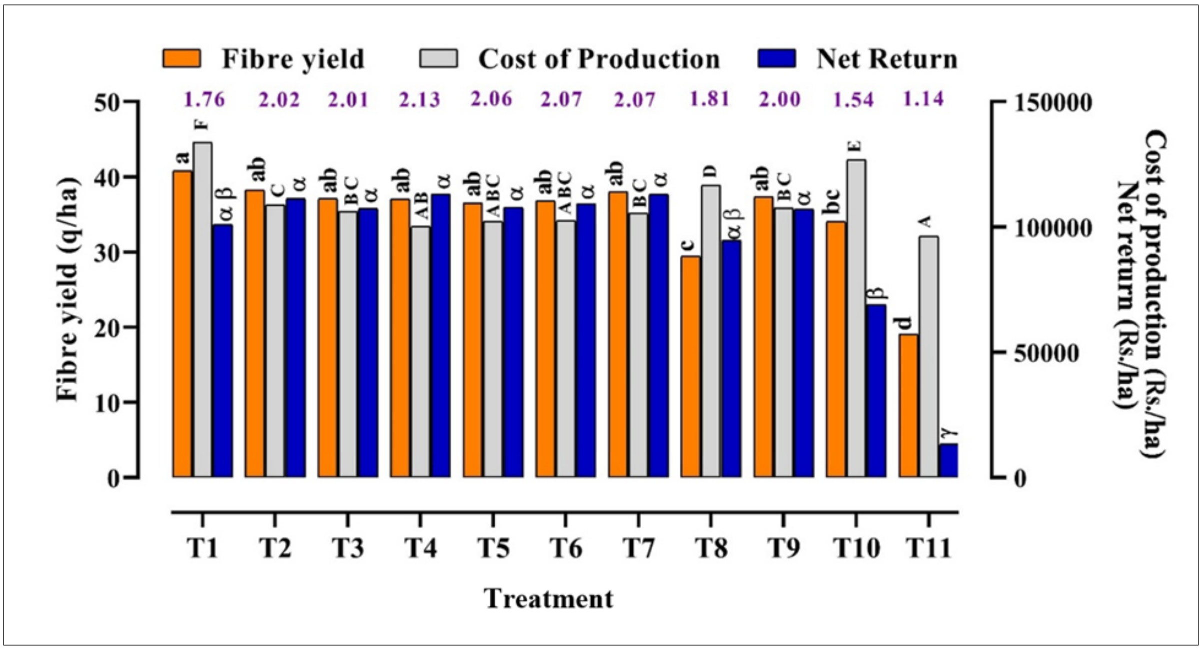

Fig. 4. Jute fibre yield, cost of production and net return under different sowing densities. Numbers in line above the bar charts indicate the B:C ratio for the corresponding treatments.

Table 3. Economic performance of jute under low-density sowing.

Code	Total manpower requirement (man-days/ha)	Reduction in total manpower (man-days/ha)	Manpower for major operations (man-days/ha)	Reduction in manpower for major operations (man-days/ha)	Share of manpower on major operation (%)	Hand weeding (man-days/ha)		Thinning (man-days/ha)		Sorting (man-days/ha)	Fibre extraction (man-days/ha)	Cost of manpower (Rs/ha)	Cost of cultivation (Rs/ha)	Reduction in the cost of cultivation over the Farmers' practice (%)	Gross return (Rs/ha)	Net return (Rs/ha)	Benefit-cost ratio
						15 DAS	21 DAS	15 DAS	21 DAS								
T_1	382^{f}	0	267^{d}	0	70	30	53	21	31	18	114	95500^{f}	133700^{F}	0	234758^{a}	$101058^{\alpha\beta}$	1.76
T_2	283^{cd}	99	177^{c}	90	63	54	0	10	0	9	104	70667^{cd}	108867^{C}	19	220206^{ab}	111338^{α}	2.02
T_3	272^{bcd}	110	157^{bc}	110	58	71	0	0	0	0	86	67875^{bcd}	106075^{BC}	21	213485^{ab}	107411^{α}	2.01
T_4	248^{ab}	134	138^{ab}	129	56	58	0	0	0	0	80	62000^{ab}	100200^{AB}	25	213227^{ab}	113027^{α}	2.13
T_5	256^{abc}	126	141^{ab}	126	55	50	0	0	0	0	91	64042^{abc}	102242^{ABC}	24	210121^{ab}	107879^{α}	2.06
T_6	258^{abc}	124	143^{ab}	124	55	45	0	0	0	0	98	64375^{abc}	102575^{ABC}	23	211827^{ab}	109252^{α}	2.07
T_7	269^{bcd}	113	152^{bc}	115	57	47	0	3	0	1	101	67292^{bcd}	105492^{BC}	21	218509^{ab}	113017^{α}	2.07
T_8	293^{d}	89	159^{bc}	108	54	37	0	7	0	0	115	73292^{d}	116692^{D}	13	211254^{ab}	$94562^{\alpha\beta}$	1.81
T_9	278^{bcd}	104	163^{bc}	104	59	56	0	8	0	3	96	69417^{bcd}	107617^{BC}	20	214818^{ab}	107201^{α}	2.00
T_{10}	354^{e}	28	240^{d}	27	68	89	0	12	17	17	105	88583^{e}	126783^{A}	5	195846^{b}	69063^{β}	1.54
T_{11}	233^{a}	149	119^{a}	148	51	0	0	0	0	0	119	58208^{a}	96408^{a}	28	109729^{c}	1332^{γ}	1.14

Mean followed by same letter are not significantly different based on DMRT (p=0.05).

Table 4. Results of field-level demonstration with low-density sowing of jute (2020-2021).

Districts	Blocks	Number of farmers involved	Jute seed rate (kg/ha)	Area covered (ha)	Jute fibre yield (q/ha)	Manpower reduction (man-days/ha)	Net reduction in manpower (Rs/ha)
Murshidabad	Nowda	25	2.25-3.75	3.4	33-36	70	15000
24 Parganas (North)	Bagdah, Amdanga, Swarup Nagar, Habra 1	30	2.25- 2.60	3.0	37-45	68-90	17000 to 22500
Paschim Medinipur	Pingla, Moyna	60	2.25	7.5	33-37	90-100	22500-25000
Total		115		13.9			

yield of 3 to 5 q/ha, eliminating the second and third weeding reduced 60-90 man-days/ha (Rs. 15000 to Rs. 22500/ha monetarily) over manual weeding twice for sole jute in different locations. Due to very high rainfall at the pod maturity stage, green gram grain yield reduced to 1.5 to 2.0 q/ha. Plant waste from green gram (inter- or mixed cropping) added 2.0-3.0 t/ha nitrogen-rich biomass into the soil. Household labour, generally, women carried out green gram harvest and post-harvest tasks for middle and small peasants (22).

Conclusion

Low-density sowing with a 1.50-2.60 kg/ha seed rate is the most important first step to reduce labour requirements in jute cultivation. It ensures optimum plant density (30-40 plants/m^2), optimises fibre yield (36.5-38.0 q/ha) and reduces labour use by 43 %-48 % to enhance net profit by 6.75 %-11.84 % over high-density sowing of 6.0 kg/ha seeds. LDS also opened the scope of jute-green gram intercropping with substantial benefits. Regular training programmes were organised for state- and district-level agricultural officers and farmers in West Bengal, India, to promote the adoption of LDS and intercropping. Adoption of these farmer-friendly methods is gaining momentum among jute farmers across West Bengal. Adoption of these methods in other costly hybrid small-seeded field and horticultural crops will benefit farmers.

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Authors' contributions

AKG conceived of the study, perceived its design, participated its coordination, carried out the experiment and drafted the manuscript. AKC performed the statistical analysis, participated in its design and helped in draft preparation of the manuscript. SR participated in the design of plant physiological studies and draft preparation thereof. SPM participated in the design of the soil health study and draft preparation thereof. 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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