PROFIT MAXIMIZATION OF JUTE CROP ALLOCATION FOR FARMERS IN BANGLADESH USING THE LINEAR PROGRAMMING MODEL

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ABSTRACT: *Jute is one of the most important cash crops in Bangladesh, contributing significantly to the economy and rural livelihoods. This study presents an optimization model to maximize the profit of jute production by allocating land for three different types of jute: White jute, Tosha jute and Mesta jute across two distinct agricultural zones. Using a linear programming approach, the model incorporates key constraints such as land availability, labor, capital, and environmental limitations. The model has been solved using LINGO and optimal area allocations for each jute type are determined. To further enhance practical insights, sensitivity analysis is conducted to assess the impact of changes in labor, capital, and environmental factors on profitability. Results reveal that Tosha jute is the most profitable crop, with 400 hectares allocated in Zone 1 and 500 hectares in Zone 2, while White and Mesta jute were not selected due to lower profitability. The maximum profit achieved was BDT 90.9 million, demonstrating the potential of optimization-based planning to increase financial returns for farmers. Among all resources, the water limit emerged as the key binding constraint, fully utilized in both zones, while land, labor and capital showed surplus availability. These findings suggest that sustainable water management and improved irrigation practices are critical for maximizing profitability in jute cultivation and ensuring sustainable production and maximizing economic returns in Bangladesh.*

KEYWORDS: Jute Crop Allocation, Profit Maximization, Linear Programming, Jute Production.

INTRODUCTION

Jute remains a vital cash crop in Bangladesh, directly influencing farmers' income, rural livelihoods and national export earnings, while its profitability largely depends on optimal allocation of land, labor, capital, and water resources. Jute has maintained its relevance because of its eco-friendly properties, wide application in packaging, textiles, composites and geotextiles and its potential role in reducing plastic dependency. In recent years, the global demand for sustainable fibers has further increased the importance of jute as a strategic agricultural commodity.

Despite its potential, jute production in Bangladesh faces multiple challenges. Yields have declined in some regions, even as cultivated area expands raising concerns over land degradation and resource inefficiency. Crucially, water scarcity due to climate variability and competing uses has emerged as a pressing constraint, undermining year-on-year yield consistency (Rahman & Moniruzzaman, 2024). Meanwhile, cultivation decisions are influenced by the varied profitability of crop types: while Tosha jute generally commands higher returns due to its superior fiber quality and yield potential, White and Mesta jute have not kept pace and often remain less attractive economically (Ahmed *et al.*, 2023).

Historically, research efforts have concentrated on field trials, varietal development, and agronomic optimization (seeding rate, row spacing, harvesting time, etc.), which have yielded incremental improvements (Hossain *et al.*, 2025). On the other hand, production trends show that the expansion of cultivated land has not been sufficient to ensure consistent growth in jute output. Forecasting studies confirm that despite increasing area, jute production is highly influenced by water availability and climatic variability, creating uncertainty in supply (Rahman & Moniruzzaman, 2024). Earlier literature also emphasizes the potential of jute as a sustainable crop that could contribute to rural development and the global green economy, but highlights the need for technological interventions and better resource allocation to realize this potential (Rahman et al., 2017). However, there is a notable lack of high level decision support tools capable of helping policymakers and farmers allocate scarce resources such as land, labor, capital, and, crucially, water in order to maximize profitability while maintaining sustainability.

To address this gap, this study develops an integrated linear programming (LP) model using LINGO optimization software. Through the LP framework, it systematically captures the trade-offs between competing resource constraints and profitability across two key agricultural zones in Bangladesh. The model explicitly incorporates uncertain and binding environmental constraints, particularly water availability, which traditional agronomic studies often overlook. The goal is to determine the mix of jute types and corresponding land allocations that maximize profit under real-world resource limitations. The findings provide insights, not only for farmers but also for policymakers, by highlighting critical binding constraints, resource utilization patterns, and strategies for sustainable expansion of jute cultivation.

Bangladesh is a country whose economy is dominated by agriculture (Sultana et al. 2020). One of the most traditional and biggest agricultural industries is the jute industry (Moniruzzaman et al., 2008; Afroz & Islam, 2012). Jute, which is also known as golden fibre, is a major contributor to the economy (Moniruzzaman et al., 2008; Afroz & Islam, 2012). In Bangladesh, jute grows all over the country and is seen as the main cash crop, which is why the country is one of the largest global producers of jute, with only India cultivating more (Afroz & Islam,

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2012; Islam & Alauddin, 2012; Islam & Moniruzzaman, 2017; Rahman et al., 2017). Jute continues to be mainly used for obtaining fibre as a textile material for the packaging industry, but it can today be used for a variety of other products, such as ropes, mattresses, carpets, and bags (Islam & de Silva, 2011 as cited in Sheheli & Roy, 2014). In terms of global consumption, jute is the second most important natural fibre, following cotton only (Rahman et al., 2017). There are more than forty different types of jute, but the most commonly cultivated types are white jute and traditional jute (Islam & Alauddin, 2012; Islam & Ali, 2017b; Rahman et al., 2017). Both types of jute do not pose health hazards or environmental pollution. Additionally, jute is a cheap, durable, reusable and biodegradable fibre and therefore a superior alternative to synthetic fibre (Rahman et al., 2017). Overall, jute is known as a sustainable substitute of plastics in packaging (Islam & Alauddin, 2012; Rahman, 2016; Rahman et al., 2017).

As jute became a field crop, farmers learned the process of extracting the fibre and of spinning it into yarn by hand (Islam & Ali, 2017b). Jute crops require a warm and humid climate, with temperatures ranging from 24°C to 37°C and a humidity of 70% to 90% (Islam & Ali, 2017a).

Apart from environmental factors, successful agricultural production starts with the right seed. Traditional jute seed production, which includes sowing during the monsoon, has not proven to be sufficient to meet national needs (Islam & Ali, 2017b). Jute seeds need a long time to mature; thus, farmers prefer to grow other crops instead (Bhuyan, 2019). Therefore, jute seed production technology is used by governmental or research actors (Islam & Ali, 2017b), and the seeds are then distributed to farmers through open markets or the government (Moniruzzaman et al., 2008; Rahman et al., 2017). Here, Bhuyan (2019) points out a high dependency on India regarding jute seed, as Bangladesh imports almost 100% of the needed seed from India, which are often of lower quality.

Another very important part of jute production is the process of jute retting (Islam & Ali, 2017b), which determines the quality of jute fibre to a high degree (Ahmed & Akhter, 2001). As can be seen in Figure 1, jute stems are at first bundled and cut, and later placed in water (Sayed, 2014). This is done in preparation of the jute retting process, in which the jute plant absorbs water and swells (Ahmed & Akhter, 2001).

Figure 1: Preparation of jute stems for the retting process.

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Ultimately, the plant bursts at several places and fibre can be extracted (Ahmed & Akhter, 2001). If this process continues for too long, microorganisms begin to degrade the fibre, which is called over-retting (Ahmed & Akhter, 2001). This leads to a lower quality of jute fibre (Ahmed & Akhter, 2001).

Depending on the temperature of the water, the retting process is completed within fifteen to twenty days (Sayed, 2014). At the optimal time, the jute stems are loosened and fibre is removed from the stem by washing (Ahmed & Akhter, 2001; National Jute Board, 2016), as can be seen in Figure 2. In this last step of the jute retting process, one separates and extracts fibre from the wooden part of the stem of the jute plant (Ahmed & Akhter, 2001). The quality of water, as well as the speed of the water, influences the outcome of the process. Optimal retting conditions are found under slow running water (Ahmed & Akhter, 2001).

After the retting process is complete, the accumulated fibre is air dried for two to three days, as can be seen in Figure 3 and then collected by a local jute trader (Sayed, 2014). Before any further processing of the raw jute is conducted, the jute is graded according to quality and later wound into larger balls, in preparation for manufacturers of jute products (Razzaque Jute Industries Ltd., 2022).

Figure 2: Farmers extracting jute fibre after the retting process.

Figure 3: Air drying of jute fibre by hanging it on bamboo poles.

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Jute production is highly labour intensive, and demands several other inputs, such as seed, fertilisers, and insecticides. Therefore, the costs of production can be overwhelming for farmers (Afroz & Islam 2012). As workers often go to urban areas to search for better or more stable jobs, seasonal high demand for agricultural labour in rural areas is common (Sheheli & Roy, 2014), which leads to high labour costs for farmers (Rifath, 2018). Also, farmers often lack knowledge regarding jute farming, which leads to an inefficient use of expensive inputs (Afroz & Islam, 2012).

Jute farmers also face trouble finding sufficient funds to cultivate their land efficiently as there is a lack of credit available, which leads to high interest rates, and to complex procedures to receive credits (Moniruzzaman et al., 2008). This limits farmers from being able to buy the necessary inputs and is a reason for the little change and development in production practices, whilst an intense development in product variety has occurred (Sheheli & Roy, 2014).

Natural challenges when farming jute can be insect and disease infestation (Sheheli & Roy2014), but also a lack of quality retting water due to droughts or overuse of water (Islam & Moniruzzaman, 2017). Often, farmers struggle with low health, caused by dirty water (Sheheli & Roy, 2014). Another natural challenge is a lack of suitable land due to the degradation of land, which threatens agricultural productivity (Helal & Hossain, 2013). Here, policies and regulations, as well as research on the topic, are missing (Helal & Hossain, 2013). Often, deforestation and urbanisation, but also intensive or improper farming practises, lead to a lower productivity of land. Droughts, extreme weather events, climate change and population challenges are additional pressures on land and farmers (Helal & Hossain, 2013). Nonetheless, studies indicate that the benefit-cost ratio of jute-production is generally positive for farmers, even though certain resources are used rather inefficiently (Afroz & Islam, 2012; Hossain et al., 2014).

Jute has been used for centuries to make various products and is known for its affordability, biodegradability, and eco-friendliness.

Figure 4: Diversified jute products are an impressive element for the export figures of Bangladesh, capturing a radical mark towards innovation.

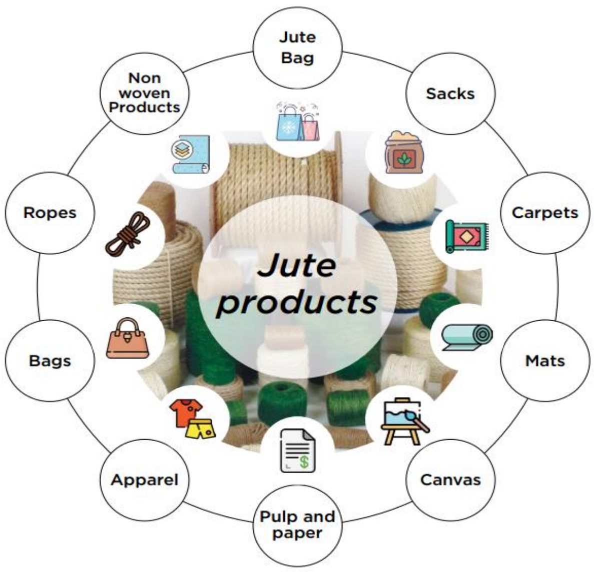

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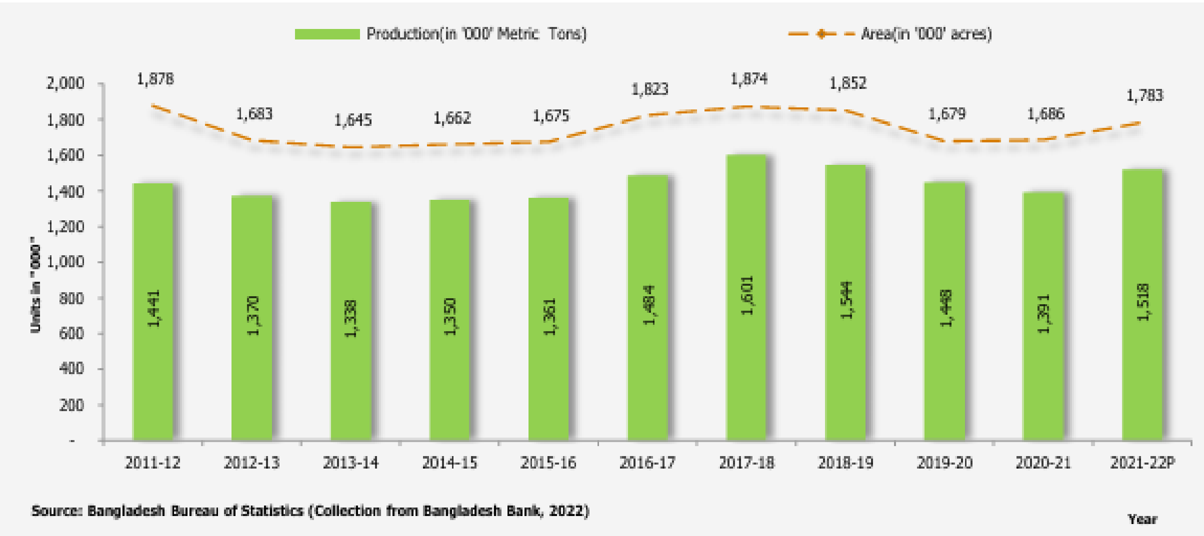
Figure 4 shows that diversified jute products contribute significantly to Bangladesh's export performance, reflecting continuous innovation and value addition in the sector.

According to the IMARC Group, the market size of jute bags is anticipated to reach $3.84 billion in 2027, with a CAGR of 10.4%. In Bangladesh, the jute industry contributes 1% to the country's GDP and accounts for 3% of the overall export earnings.

Bangladesh exports jute products to more than 100 countries around the world. Some of the major importing countries include Australia, Belgium, Brazil, China, Djibouti, Germany, India, Indonesia, Ivory Coast, the Republic of Korea, Pakistan, Russia, the United Arab Emirates, the United Kingdom, the United States and Vietnam.

The flooded land of Bangladesh is suitable for planting jute. So, the country can produce, on average, one million tons of jute annually, which helps it to be the second largest producer of jute globally, and the second largest export earning sector. According to the Bangladesh Jute Spinners Association (BJSA), the country has 291 jute mills, and 54 are closed. These active mills produce around 78 lakh bales of jute annually (The Business Standard, 2021). However, Figure 5 shows the yearly jute production and total land area. In FY12, Bangladesh produced 1,441 thousand metric tons of jute using 1,878 thousand acres of land; per acre production was 0.77 metric tons. On the other hand, in FY22, the total annual production was 1,518 thousand metric tons using 1,783 thousand acres of land, which indicates that per acre production was 0.85 metric tons of jute. The total production and per acre production increased in FY22 compared to FY12 and declined the total acres of land use.

Figure 5: Jute production and production area.



The Governments of Bangladesh should focus on this sector robustly because the whole world is turning to using eco-friendly products, which is why the jute market is expanding daily and the demand for Bangladeshi jute is high in the global market.

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The present study makes several important contributions to the existing body of knowledge on agricultural optimization and sustainable resource management. The main contributions of this study are fourfold:

1. **Novel Application of LP in Jute Agriculture:** While optimization has been widely applied in other agricultural sectors, this is one of the first comprehensive attempts to employ a **multi-constraint LP model** for the jute sector in Bangladesh, integrating land, labor, capital, and environmental limits.

2. **Identification of Critical Constraints:** The study provides a quantitative demonstration that water availability is the most binding constraint in jute cultivation, in contrast to land, labor, and capital, which showed significant slack.

3. **Policy-Oriented Insights:** Beyond technical modeling, the paper translates optimization results into policy-relevant strategies, such as promoting Tosha jute, introducing water-saving irrigation, and redirecting excess labor and capital into value-added activities along the jute value chain.

4. **Scalable Decision-Support Tool:** The proposed model is designed to be replicable across different regions and crops, offering a flexible framework for agricultural resource planning under sustainability constraints.

By combining rigorous optimization modeling with real-world applicability, this study contributes both academically and practically, providing actionable insights for policymakers, farmers, and stakeholders seeking to ensure the profitability and sustainability of the jute sector.

LITERATURE/THEORETICAL UNDERPINNING

The application of mathematical optimization in agriculture has gained prominence as it provides structured methods for allocating limited resources efficiently. Among these methods, the linear programming model is widely recognized for solving problems of crop allocation, farm planning, and resource distribution. Linear programming has been successfully applied to determine optimal land allocation that maximizes crop returns under constraints such as land, water, labor, and capital (Hazell & Norton, 1986). More recently, researchers have demonstrated its effectiveness in developing farm-level and regional strategies that improve profitability while ensuring sustainability. For example, Charnes et al. (2020) showed that linear programming models are particularly useful for decision making under resource scarcity by incorporating multiple constraints that reflect real-world farming conditions.

Mathematics is the foundation of linear programming (Chen, Y. et al., 2020), providing the theoretical framework and tools necessary for its application (Suárez, J. Let al., 2021). Linear programming is a mathematical optimization technique (An J. et al., 2021) that falls under the broader field of mathematics (Kleinert, T. et al., 2021). It involves formulating real-world problems into mathematical models with linear constraints (Kumar, A. et al., 2020) and a linear objective function (Khalilpourazari, S., 2019).

Linear programming utilizes mathematical concepts such as linear equations (Vaccari, M. et al., 2019), inequalities, and matrices (Dadush, D. et al., 2020, June) to represent constraints

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(Ajay, P. et al., 2022) and optimize the objective function. It employs mathematical algorithms and techniques (Menabde et al., 2018), such as the simplex method or interior point methods, to find the optimal solution (Chowdhury A et al., 2022).

When it comes to applications in agriculture, linear programming plays a crucial role (Rodger, J. A. & George, J. A., 2017) in optimizing crop selection (Sharma, A. et al., 2020) and production planning (Gupta, A et al., 2020). By utilizing mathematical models and techniques (Mooney, D. D. et al., 2021), linear programming helps farmers (Kharisma, A. & Perdana, T., 2019) and agricultural decision-makers allocate limited resources (Li, M.; Fu, Q., et al., 2020), such as land, labor, and machinery, effectively (Abraham, M. & Pingali, P., 2022). Technological Interventions in Indian Food Systems and the Future of Food Security (Pingali, P. et al., 2019). It takes into account factors like crop yields (Mwangagi, E. C., 2021), market prices, resource availability, and constraints to determine the optimal crop mix and resource allocation strategies (Nouri, A., et al., 2019).

Through the application of linear programming in agriculture (Mitlif, R. J., et al., 2021), farmers can make informed decisions to maximize profits, minimize costs, and optimize resource usage (Lubna, et al., 2022). It aids in identifying the most profitable crops to cultivate (Alotaibi, A. & Nadeem, F. 2021), determining the optimal planting areas, and allocating resources efficiently to achieve higher yields and profitability (Zhang, H. et al., 2022). Linear programming (LP) is a mathematical technique that aims to optimize performance in terms of combinations of resources (Yahya, Garba, & Ige, 2012). According to Sharma (2016), linear programming is useful for the allocation of scarce or limited resources to several competing activities on the basis of given criterion of optimality. LP is also known as a mathematical technique to achieve profit maximization or cost minimization in a mathematical model whose requirements are represented by linear relationship (Gunasekaran et al., 2015).

Linear programming helps in making optimum use of productive resources (Ogbeide, 2018). Linear programming techniques also offer practical and viable solutions as there may be different constraints operating beyond the problem that needs to be considered. If there are some changes on the conditions, whether decision variables or constraints, when the linear programming model is partially achieved, the model can be controlled by changing or altering the conditions for the optimal results (Ezema & Amakom, 2012).

Uddin, M. F. and Sano, K. (2010) considered an integrated multi-product, multi-facility, and multi-customer location production problem. By formulating a Mixed Integer Linear Fractional Programming (MILFP) model, they maximize the ratio of return on investment of the distribution network. Uddin, M. F. and Sano, K. (2011) developed a Mixed Integer Programming (MIP) problem-based vendor-buyer multiple products-consumers, facility selection problem with a price-sensitive linear demand function. They assumed that a coordinated mechanism among the members of the supply chain could achieve the optimal solution and the optimal location for the warehouse.

Linear programming is a mathematical technique that is widely used in operation research or management science, in finding solutions to complex managerial decision problems that allow options between alternative courses of action (Yahya et al., 2012). Linear programming can be used in solving product mix problems, production planning problems, assembly line balancing problems, and transportation and assignment problems.

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The present study builds upon their work by introducing a more comprehensive model that includes environmental constraints, such as water availability, along with land, labor and capital. The use of the LINGO software for solving LP models adds to the computational efficiency and accuracy of the optimization process.

While previous studies have established the usefulness of linear programming in optimizing crop allocation across a range of agricultural contexts, research focused specifically on the jute sector remains very limited. Most applications in Bangladesh and elsewhere have centered on staple crops such as rice, wheat, and maize, with comparatively little attention given to high-value cash crops like jute that contribute significantly to rural livelihoods and export earnings. Addressing this gap, the present study develops a linear programming model that incorporates multiple constraints including land, labor, capital, and water availability to determine the optimal allocation of white jute, tosha jute and mesta jute across two agricultural zones. By doing so, it not only extends the application of linear programming to an underexplored but economically vital crop but also provides a practical decision-support tool for policymakers and farmers to enhance profitability while promoting sustainable resource use.

METHODOLOGY

The methodology of this study is based on the application of linear programming (LP) as a quantitative decision-making tool to optimize jute production in Bangladesh. The approach begins with the identification of the research problem, focusing on maximizing profitability while considering multiple resource constraints such as land, labor, capital, and environmental constraints, such as water availability, to ensure sustainability in the production process. Relevant data were collected from secondary sources, including agricultural reports, national statistics, and international databases (BBS, 2023; FAO, 2022), to parameterize the model with realistic values. The LP model has been formulated by defining the objective function of profit maximization and incorporating all relevant constraints that reflect the ground realities of jute farming in different zones. The model has been solved using LINGO optimization software, which is widely used for solving complex resource allocation and supply chain problems due to its efficiency and accuracy (LINDO Systems, 2022). Finally, sensitivity analysis has been conducted to evaluate the robustness of the solution, ensuring that the findings are applicable to both policymakers and practitioners in the agricultural sector. This systematic methodology provides a rigorous framework for understanding and improving the efficiency of resource utilization in the jute value chain.

This section details the steps involved in developing and solving the model, including the formulation of the objective function, constraints, data collection, and the use of LINGO software to find the optimal solution.

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Important Notations

This section outlines the critical notations used throughout the mathematical model. To ensure clarity and consistency in the model formulation, key notations are introduced to represent decision variables, parameters, and constraints. These notations provide a structured way to express crop allocation, resource requirements, and profitability calculations. By defining them systematically, the model avoids ambiguity and enables accurate substitution of real-world data into mathematical models, which is essential for solving and interpreting the optimization results.

For better understanding, the detailed descriptions of all variables and parameters used in this study are presented in Table 1.

Table 1: Model Component Descriptions

Category	Variables/ Parameters	Description	Units
Decision Variables	A_{ij}	Area allocated for jute type i in zone j	Hectares
Parameters	P_{ij}	Market price of jute type i in zone j	BDT '000 per ton
	Y_{ij}	Yield per hectare of jute type i in zone j	Tons per hectare
	C_{ij}	Production cost per hectare of jute type i in zone j	BDT '000/hectare
	L_{ij}	Labor requirement per hectare for jute type i in zone j	Labor (Man-days)/hectare
	K_{ij}	Capital requirement per hectare for jute type i in zone j	BDT '000/hectare
	E_{ij}	Environmental requirement per hectare for jute type i in zone j	Hectares
	L_j	Total land available in zone j	Hectares
	$\overline{L}_j$	Total available labor in zone j	Labor (Man-days)/hectare
	$\overline{K}_j$	Total available capital in zone j	BDT '000/hectare
	$\overline{E}_j$	Environmental capacity in zone j	Hectares

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Model Formulation

This study formulates a linear programming model to maximize the profitability of jute cultivation in Bangladesh by optimally allocating land among White jute, Tosha jute, and Mesta jute across two agricultural zones in Bangladesh: Zone 1 (Jessore) and Zone 2 (Mymensingh). The objective function captures total profit based on per-hectare returns, while the constraints reflect real-world limitations on land, labor, capital, and water usage. In particular, land and labor constraints ensure feasible allocation within available resources, capital constraints address financial requirements of production, and environmental constraints regulate water consumption to maintain sustainability. Non-negativity conditions guarantee realistic solutions. By integrating economic, resource, and environmental dimensions, the model provides a robust decision-support tool for policymakers and farmers, ensuring both profitability and long-term sustainability of jute production.

Objective Function

Maximize Z (Total Profit):

$$Z = \sum_{i=1}^{3} \sum_{j=1}^{n} (P_{ij} . Y_{ij} - C_{ij}) . A_{ij}$$

where:

P_{ij} = Market price of jute type i in zone j

Y_{ij} = Yield per hectare of jute type i in zone j

C_{ij} = Production cost per hectare of jute type i in zone j

A_{ij} =Area allocated for jute type i in zone j

Constraints

1. Land Availability Constraints:

$$\sum_{i=1}^{3} A_{ij} \leq L_j, \quad \forall j = 1, 2, 3, \ldots, n$$

where:

L_J =Total land available in zone j

2. Labor Constraints:

$$\sum_{i=1}^{3} L_{ij} . A_{ij} \leq \bar{L}_j, \quad \forall j = 1, 2, 3, \ldots, n$$

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where:

L_{ij} = Labor requirement per hectare for jute type i in zone j

$\overline{L}_J$ = Total available labor in zone j

3. Capital Constraints:

$$\sum_{i=1}^{3} K_{ij} . A_{ij} \leq \overline{K}_j, \quad \forall j = 1, 2, 3, \ldots, n$$

where:

K_{ij} = Capital requirement per hectare for jute type i in zone j

$\overline{K}_J$ = Total available capital in zone j

4. Environmental Constraints:

$$\sum_{i=1}^{3} E_{ij} . A_{ij} \leq \overline{E}_j, \quad \forall j = 1, 2, 3, \ldots, n$$

where:

E_{ij} = Environmental requirement per hectare for jute type i in zone j

$\overline{E}_J$ = Environmental capacity in zone j

5. Non-Negativity Constraints:

$$A_{ij} \geq 0, \quad \forall i, j$$

where:

$i = 1$ for White jute,

$i = 2$ for Tosha jute,

$i = 3$ for Mesta jute,

$j = 1$ to n for different zones.

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Model Implementation

The formulated linear programming model has been implemented using LINGO 19.0 optimization software, which is widely recognized for solving large-scale linear, nonlinear, and integer programming problems with high computational efficiency. The direct variable method was employed to define decision variables explicitly for each crop type and zone, ensuring flexibility in allocation and transparent interpretation of results. All constraints including land, labor, capital and environmental limits were encoded into the model to reflect the actual resource availability and sustainability considerations in Bangladesh.

The implementation process involved three key steps:

1. Encoding the mathematical model into LINGO syntax, where the objective function was set to maximize net profit from jute cultivation.

2. Running the optimization solver, which applied the simplex algorithm to efficiently identify the global optimal solution.

3. Extracting results and sensitivity analysis, which provided not only the optimal land allocation and maximum achievable profit but also insights into binding constraints and resource utilization.

By adopting this approach, the model offers evidence-based recommendations for policymakers, farmers, and stakeholders in the jute value chain, ensuring that the optimization outcomes are practical, resource-efficient, and environmentally sustainable in the Bangladeshi context.

Data Collection

The reliability of any optimization model depends on the accuracy and relevance of its input data. Data collection for this study was conducted through both secondary sources and expert consultation. Secondary data on land availability, labor requirements, production costs, market prices, water consumption, and capital investment for White jute, Tosha jute, and Mesta jute were obtained from government reports, statistical yearbooks, and published research. Specifically, information was extracted from the Bangladesh Bureau of Statistics (BBS) for agricultural production and labor availability, the Department of Agricultural Extension (DAE) for jute cultivation practices and water use, and recent peer-reviewed studies for cost and profitability parameters.

In addition, expert opinions and field consultations with agricultural officers and jute farmers were used to validate and adjust the secondary data to better reflect current production practices across different agricultural zones. These datasets reflect the current production environment of Bangladesh and ensure that the model captures both economic and environmental realities. By incorporating zone-specific information, the data enable realistic constraint settings and allow the linear programming model to generate solutions aligned with ground-level conditions.

Model Input Data

The accuracy and reliability of any optimization model depend on the quality of the input data. For this study, data were collected from multiple sources, including government agricultural reports, published research articles and field surveys, to ensure robustness and practical relevance. The model input data encompass crop-specific parameters such as market price, yield per hectare, production cost, labor requirement, capital investment, and water consumption. In addition, resource availability data for each agricultural zone, including land area, labor supply, capital allocation, and water resources, were incorporated. These inputs allowed the linear programming model to capture the real constraints faced by jute farmers and to determine the optimal allocation of land among White jute, Tosha jute, and Mesta jute. By integrating both economic and environmental parameters, the model provides a comprehensive framework for decision-making in sustainable jute production.

Table 2 summarizes the crop-related input parameters used in the model, including market prices, crop yields, production costs, labor, capital and water requirements for each jute type.

Table 3 summarizes the resource-related input parameters, including the availability and unit cost of land, labor, capital and water used in the production process.

Table 2: Jute Crop Allocation (Zone 1 & Zone 2)

Type of Jute	Market Price (BDT/ ton)	Yield (Tons/ha)	Cost (BDT/ha)	Labor Requirement (Person-days/ha)	Capital Requirement (BDT/ha)	Water Requirement (Litres/ha)
Zone 1						
White Jute	30,000	2.5	15,000	120	15,000	1,200,000
Tosha Jute	40,000	3.0	12,000	100	12,000	1,000,000
Mesta Jute	35,000	2.0	10,000	90	10,000	900,000
Zone 2						
White Jute	28,000	2.2	14,000	120	15,000	1,200,000
Tosha Jute	38,000	2.8	11,000	100	12,000	1,000,000
Mesta Jute	34,000	2.1	9,000	90	10,000	900,000

Table 3: Resource Availability (Zone 1 & Zone 2)

Resource	Zone 1	Zone 2
Land (ha)	500	600

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Labor Requirement (Person-days/ha)	60,000	70,000
Capital Requirement (BDT/ha)	6,000,000	8,000,000
Water Requirement (Litres/ha)	400,000,000	500,000,000

Graphical Representation of Input Data

To provide a clearer understanding of the model parameters, the input data have been visually presented through a graph. This graphical representation highlights the comparative differences across jute types and agricultural zones, making the resource distribution patterns easier to interpret. The following graph illustrates these variations effectively:

Figure 6: Comparison of jute yield between Zone 1 and Zone 2.

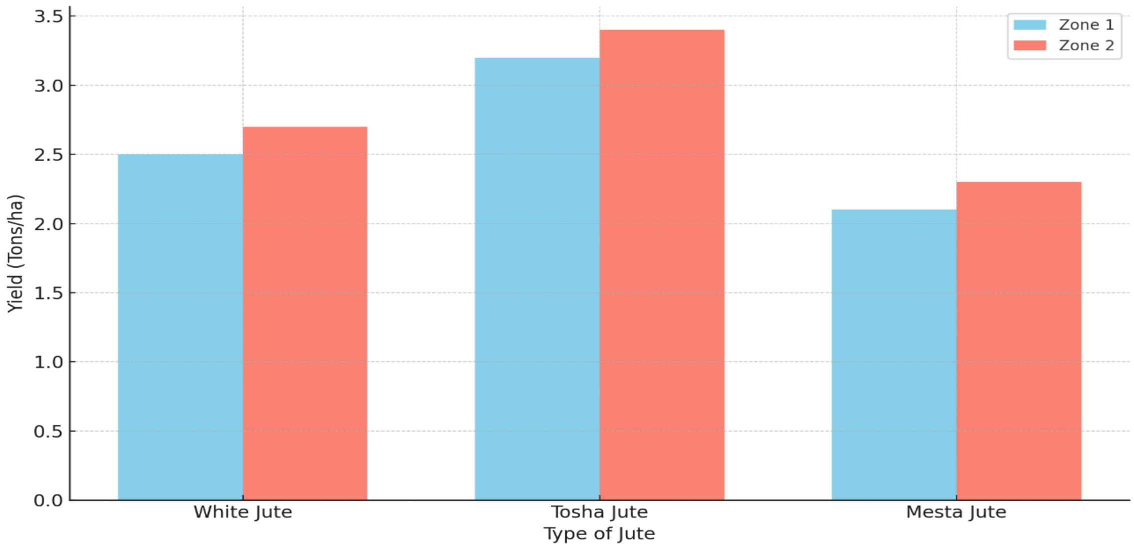

Figure 6 shows that the yield of Tosha jute is consistently higher across both Zone 1 and Zone 2, compared to White jute and Mesta jute. This demonstrates that Tosha jute not only provides better productivity but also shows stability across different agricultural zones. White jute and Mesta jute, on the other hand, yield significantly less, which makes them less profitable in comparison. The figure clearly supports the model's finding that Tosha jute is the optimal choice for maximizing profitability in both regions.

Model Application and Optimal Solution

The collected input data are applied to the formulated linear programming model to generate the optimal crop allocation and profit results. This section presents the required input parameters, including market prices, yields, production costs, labor, capital, water requirement and resource availability, which are then substituted into the model to derive the optimal solution. This step provides the foundation for presenting the results and conducting the sensitivity analysis in the following sections.

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Objective Function

The objective is to maximize the total profit, Z, given by:

$$Z = \sum_{i=1}^{3}\sum_{j=1}^{2}\left(P_{ij} \,.\, Y_{ij} \,.\, A_{ij} - C_{ij} \,.\, A_{ij}\right)$$ where:

$i=1$ for White jute, $i=2$ for Tosha jute, $i=3$ for Mesta jute

$j=1$ for Zone 1, $j=2$ for Zone 2

Substitute numerical values for the market prices (P_{ij}) yields (Y_{ij}), production cost (C_{ij}) and allocated area (A_{ij}):

For Zone 1:

White jute: $P_{11}=30{,}000,\ Y_{11}=2.5,\ C_{11}=15{,}000$

Tosha jute: $P_{21}=40{,}000,\ Y_{21}=3.0,\ C_{21}=12{,}000$

Mesta jute: $P_{31}=35{,}000,\ Y_{31}=2.0,\ C_{31}=10{,}000$

For Zone 2:

White jute: $P_{12}=28{,}000,\ Y_{12}=2.2,\ C_{12}=14{,}000$

Tosha jute: $P_{22}=38{,}000,\ Y_{22}=2.8,\ C_{22}=11{,}000$

Mesta jute: $P_{32}=34{,}000,\ Y_{32}=2.1,\ C_{32}=9{,}000$

The objective function becomes:

$$Z = (30{,}000\times 2.5\times A_{11} - 15{,}000\times A_{11}) + (40{,}000\times 3.0\times A_{21} - 12{,}000\times A_{21}) + (35{,}000\times 2.0\times A_{31} - 10{,}000\times A_{31}) + (28{,}000\times 2.2\times A_{12} - 14{,}000\times A_{12}) + (38{,}000\times 2.8\times A_{22} - 11{,}000\times A_{22}) + (34{,}000\times 2.1\times A_{32} - 9{,}000\times A_{32})$$

Simplified:

$$Z = (75{,}000A_{11} - 15{,}000A_{11}) + (120{,}000A_{21} - 12{,}000A_{21}) + (70{,}000A_{31} - 10{,}000A_{31}) + (61{,}600A_{12} - 14{,}000A_{12}) + (106{,}400A_{22} - 11{,}000A_{22}) + (71{,}400A_{32} - 9{,}000A_{32})$$

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Simplified:

$$Z = 60,000A_{11} + 108,000A_{21} + 60,000A_{31} + 47,600A_{12} + 95,400A_{22} + 62,400A_{32}$$

Final Linear Programing Model

Maximize:

$$Z = 60,000A_{11} + 108,000A_{21} + 60,000A_{31} + 47,600A_{12} + 95,400A_{22} + 62,400A_{32}$$

Subject to:

1. Land Constraints:

$$A_{11} + A_{21} + A_{31} \leq 500$$

$$A_{12} + A_{22} + A_{32} \leq 600$$

2. Labor Constraints:

$$120A_{11} + 100A_{21} + 90A_{31} \leq 60,000$$

$$120A_{12} + 100A_{22} + 90A_{32} \leq 70,000$$

3. Capital Constraints:

$$15,000A_{11} + 12,000A_{21} + 10,000A_{31} \leq 6,000,000$$

$$15,000A_{12} + 12,000A_{22} + 10,000A_{32} \leq 8,000,000$$

4. Environmental Constraints:

$$1,200,000A_{11} + 1,000,000A_{21} + 900,000A_{31} \leq 400,000,000$$

$$1,200,000A_{12} + 1,000,000A_{22} + 900,000A_{32} \leq 500,000,000$$

Additionally, $A_{ij} \geq 0$ for all i and j (non-negative area allocation).

This model, after incorporating all input data and computations, is now ready to generate the optimal solution for jute crop allocation, using optimization software LINGO to find the optimal values of A_{11}, A_{12}, A_{21}, A_{22}, A_{31}, A_{32}.

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RESULTS

The linear programming model developed in this study has been successfully implemented using LINGO to optimize the allocation of land for jute cultivation across two agricultural zones in Bangladesh. The findings reveal that Tosha jute emerged as the most profitable crop, while White jute and Mesta jute were excluded from the optimal solution due to their relatively low profitability. The model achieved a maximum profit of BDT 90.9 million, highlighting the strong economic potential of resource-optimized cultivation strategies. Among the constraints, the water/environmental limit was binding in both zones, confirming that water availability is the most critical factor restricting production expansion. In contrast, land, labor, and capital resources were found to be underutilized, indicating that they are not binding in the current optimization scenario. This suggests that any future policy or technological interventions should focus on efficient water use and sustainable environmental management to unlock higher profitability in the jute sector.

A summary of the results, including optimal crop allocation, profit, and resource utilization status, is presented in Table 4.

Table 4: Result Summary of the Jute Crop Optimization Model

Parameter	**Zone 1 (A11, A21, A31)**	**Zone 2 (A12, A22, A32)**	**Optimal Allocation**	**Binding/Slack Status**
White Jute (A11, A12)	0 ha	0 ha	Not selected	High reduced cost (unprofitable)
Tosha Jute (A21, A22)	400 ha	500 ha	Selected	Optimal crop choice
Mesta Jute (A31, A32)	0 ha	0 ha	Not selected	Low profitability
Land Availability	400 ≤ 500 (slack 100)	500 ≤ 600 (slack 100)	Not binding	Sufficient land
Labor Availability	40,000 ≤ 60,000 (slack 20,000)	50,000 ≤ 70,000 (slack 20,000)	Not binding	Surplus labor
Capital Availability	4.8M ≤ 6M (slack 1.2M)	6M ≤ 8M (slack 2M)	Not binding	Excess capital
Water/Environmental Limit	400M = 400M (binding)	500M = 500M (binding)	Binding	Key limiting factor
Max Profit (BDT)	–	–	90.9 million	Achieved

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Graphical Representation on Result Summary

The optimization results are presented through graphical representations to provide a comprehensive understanding of the outcomes. These visual summaries highlight the optimal crop allocation, profitability, and the binding as well as non-binding constraints.

Figure 7: Optimization result and strategic recommendations.

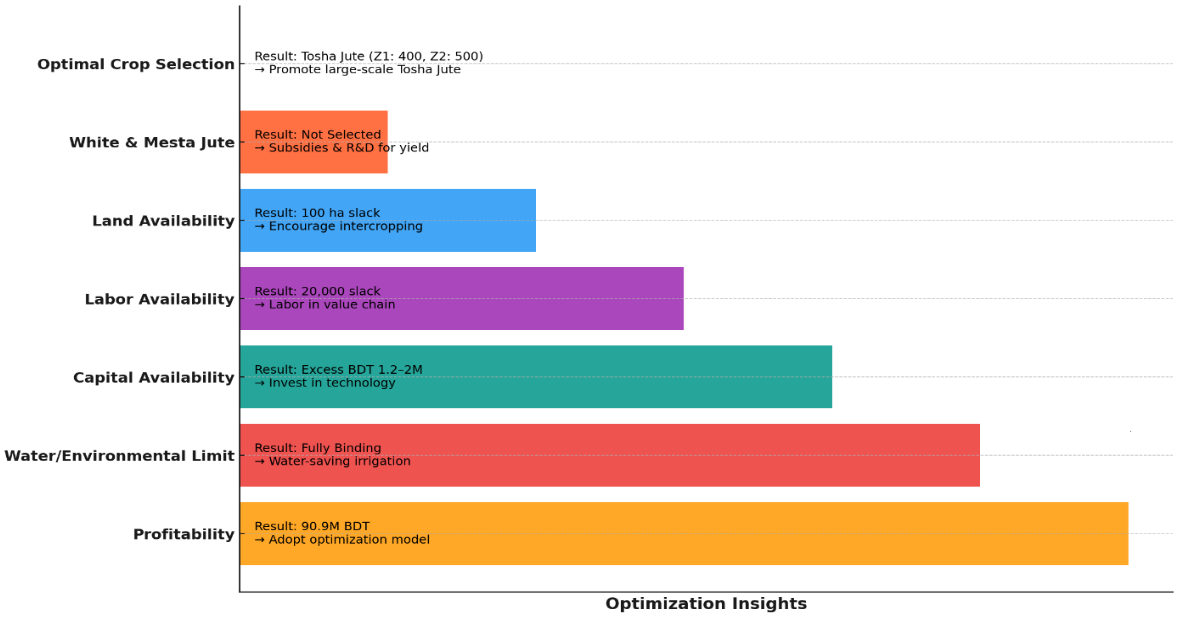

Figure 7 describes the optimization results of jute crop allocation in Bangladesh, highlighting both the binding and non-binding constraints. The figure clearly shows that Tosha jute dominates as the optimal crop, with full land allocation in both zones, while White and Mesta jute were excluded due to low profitability. It further illustrates that land, labor, and capital resources are not binding constraints, as they remain underutilized with considerable slack, whereas the water/environmental constraint is fully binding in both zones, emerging as the key limiting factor for production expansion. The figure also emphasizes that a maximum profit of BDT 90.9 million is achievable under the optimal allocation strategy. These results suggest the need for strategic interventions such as water-efficient irrigation, subsidies and R&D for yield improvement of less competitive jute types, and better utilization of surplus labor and capital in downstream value chain activities.

Sensitivity Analysis

Sensitivity analysis has been performed to evaluate how variations in key input parameters, particularly environmental capacity (water usage), influence the optimal profit and resource allocation decisions. The results indicate that environmental constraints play a decisive role in determining the profitability of jute cultivation across different zones. The shadow prices reveal the marginal contribution of scarce resources such as water, labor, and capital to the objective function (profit). When a constraint is binding, its shadow price is positive, meaning that even a small relaxation could increase total profit. Conversely, once the constraint becomes non-binding, the shadow price drops to zero, suggesting no additional economic benefit from further

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expansion of that resource. This analysis is critical for policymakers and stakeholders as it identifies which resources are bottlenecks and where investments in capacity expansion (e.g., water-saving technology, labor efficiency, or capital input) will have the greatest impact on improving overall profitability in the Bangladesh jute sector.

Graphical Representation of Sensitivity Analysis

The graphical presentation of the sensitivity analysis provides a clear and comprehensive understanding of how variations in key resource constraints, such as land, labor, capital and water, affect the profitability of jute production in Bangladesh. The figures illustrate that land, labor, and capital resources are non-binding constraints, as changes in their availability have little to no impact on overall profit. This suggests that these resources are underutilized and can be redirected to other productive activities within the jute value chain. In contrast, water availability emerges as the most critical and binding factor; even slight reductions in water lead to a sharp decline in profitability, whereas increases beyond the current allocation do not enhance returns, since the model already operates at the water constraint limit. These findings highlight the need for resource-specific strategies, particularly emphasizing sustainable water management, to ensure optimal jute production.

Figure 8: Sensitivity of profit to land availability.

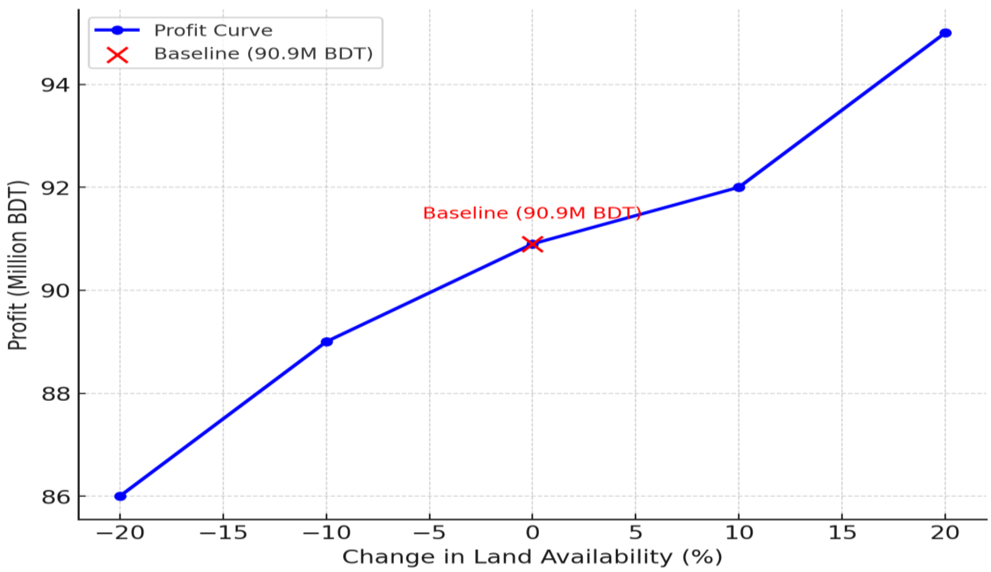

Figure 8 illustrates that profit is largely insensitive to changes in land availability within the range of −20% to +20%. The curve is nearly flat around the baseline (90.9 million BDT), showing only small deviations (about ±5% at the etremes). This confirms that land is a non-binding constraint in the optimal plan; additional land does not raise profit materially, and moderate land reductions can be absorbed without significant loss, given that water is the binding constraint in the model.

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Figure 9: Sensitivity of profit vs labor availability.

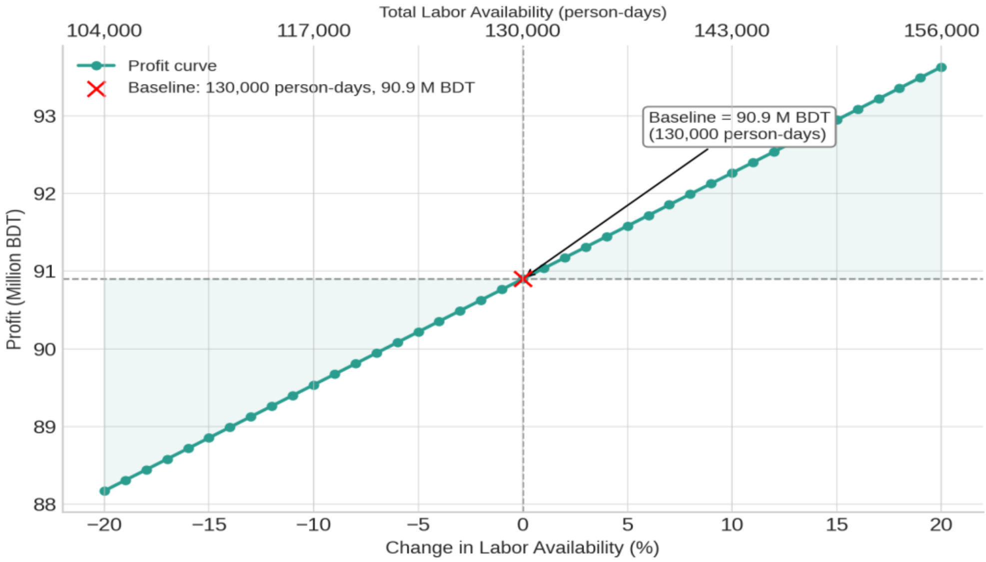

Figure 9 illustrates the sensitivity of total profit to changes in labor availability. The baseline point (130,000 person-days; 90.9 million BDT) is highlighted in red. The curve shows that profit is only modestly sensitive to labor variations within ±20 percent (approximately ±3 percent change in profit), indicating that labor is a non-binding resource in the current model. The secondary axis translates percent changes to absolute total labor (person-days) to aid interpretation.

Figure 10: Sensitivity of profit vs capital availability.

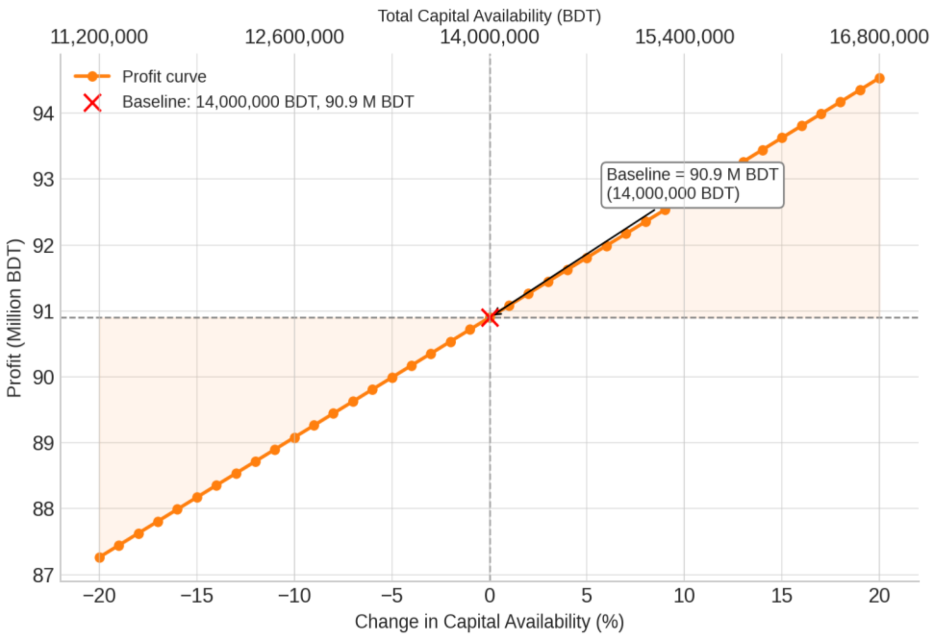

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Figure 10 illustrates the sensitivity of total profit to changes in capital availability. The baseline point (14,000,000 BDT total capital; 90.9 million BDT profit) is highlighted in red. The curve shows modest responsiveness of profit to capital changes within ±20 percent, approximately ±4 percent change in profit, indicating that capital is not a binding constraint under current conditions. The secondary axis maps percent changes to absolute capital values to aid interpretation.

Figure 11: Sensitivity of profit and shadow price to environment capacity.

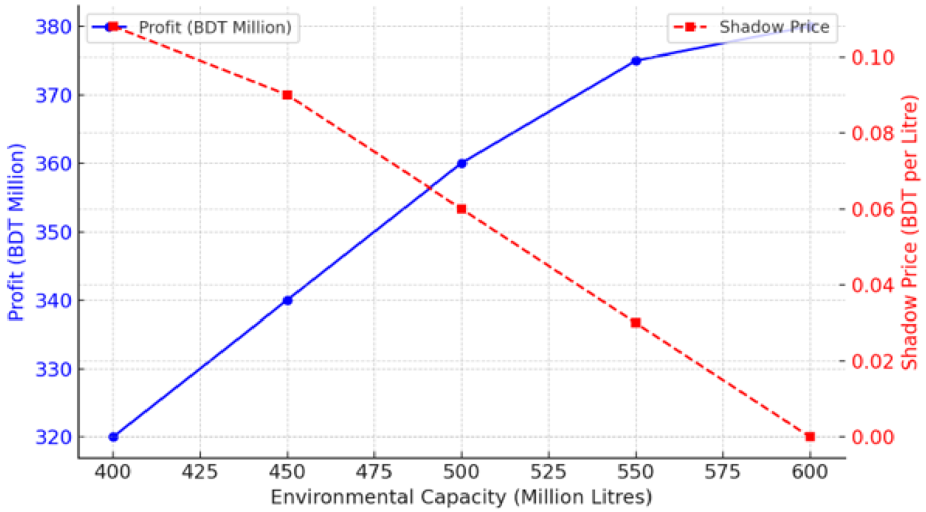

Figure 11 illustrates the relationship between environmental capacity (measured in million litres) and the resulting profit (in BDT million), along with the corresponding shadow prices of water resources. The profit curve shows a steady increase with additional water availability up to the binding capacity, after which it plateaus, indicating that further expansion of water resources does not contribute to higher returns. The shadow price line highlights the marginal value of each additional unit of water, which is initially positive and decreases to zero once the constraint becomes non-binding. This analysis demonstrates that water is a critical limiting factor in the jute production system; however, beyond a certain threshold, additional water does not yield extra profit.

DISCUSSION

The results of this study provide important insights into the optimization of jute production in Bangladesh through the application of linear programming techniques. The findings highlight that Tosha jute is the most profitable crop under current economic and resource conditions, whereas White jute and Mesta jute were excluded from the optimal allocation due to their comparatively lower returns. This indicates that focusing on high-yield and high-profitability varieties is crucial for maximizing farmers' income.

The optimization results demonstrate that the maximum attainable profit from jute crop allocation is BDT 90.9 million, achieved by exclusively allocating land to Tosha jute (A21 in Zone 1 and A22 in Zone 2)**.** Other crop varieties (White jute and Mesta jute) are not selected in the optimal solution because of lower profitability relative to resource use.

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While land, labor, and capital resources exhibit considerable slack, the binding constraints are environmental (water usage limits) in both agricultural zones. This highlights the pivotal role of environmental sustainability in profit maximization. Shadow prices indicate that relaxing water availability by 1 million liters would increase profits by BDT 108,000 in Zone 1 and BDT 95,400 in Zone 2, demonstrating strong sensitivity of profits to environmental limits.

A key observation is that water and environmental constraints emerged as the binding factors, limiting further expansion of cultivation. In contrast, land, labor, and capital resources were not fully utilized, suggesting that improvements in water management and the adoption of water-efficient technologies could significantly enhance jute productivity. This aligns with previous studies that have emphasized the increasing scarcity of water as a major challenge in agricultural production in South Asia (Rahman et al., 2022).

The model's outcomes also demonstrate the practical utility of optimization tools like LINGO in policy formulation and farm-level decision making. By quantifying trade-offs between resources and profitability, the model equips policymakers, researchers, and farmers with evidence-based strategies for efficient resource allocation. Importantly, the findings underscore the need for sustainability-oriented interventions, ensuring that profit maximization does not compromise long-term ecological balance.

Overall, the discussion confirms that a linear programming-based approach provides a robust decision support system for addressing agricultural resource allocation challenges in Bangladesh, with significant implications for both farm management and national agricultural policies.

A summary of the key implications of the optimization results, by comparing the resources used, binding constraints, and strategic recommendations for sustainable jute production, is presented in Table 5.

Table 5: Key Discussion Insights from the Jute Crop Optimization Model

Parameter/Constraint	Optimization Result	Implication for Jute Production in Bangladesh	Strategic Recommendation
Optimal Crop Selection	Only Tosha Jute selected (Zone 1: 400 ha, Zone 2: 500 ha)	Tosha Jute offers the highest profitability compared to White and Mesta Jute	Promote large-scale Tosha Jute cultivation and improve seed quality
White & Mesta Jute	Not selected due to low returns	Less profitable, not competitive under current resource costs	Provide subsidies, R&D (Research and Development) for yield improvement
Land Availability	Not binding (100 ha slack in each zone)	Land is available but not fully utilized	Encourage intercropping or diversify cash crops

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Labor Availability	Not binding (20,000 person-days slack per zone)	Surplus labor exists in rural areas	Deploy labor into value chain (processing, packaging)
Capital Availability	Not binding (excess BDT 1.2–2M)	Capital resources sufficient for expansion	Redirect excess capital toward technology adoption
Water/Environmental Limit	Binding (fully utilized in both zones)	Major limiting factor for jute expansion	Introduce water-saving irrigation & eco-friendly farming
Profitability	90.9 million BDT (maximum profit)	High profitability achievable with optimal allocation	Scale model adoption at farm and policy level

IMPLICATION TO RESEARCH AND PRACTICE

The findings of this study have several important implications for both academic research and practical policy-making in Bangladesh's jute sector.

Advancement in Research:

1. The study demonstrates the practical applicability of linear programming (LP) techniques in addressing real-world agricultural optimization problems.
2. By incorporating multiple constraints such as land, labor, capital, and environmental limits, the model enriches the methodological framework for future research in agricultural economics and operations research.
3. It provides a replicable model that other researchers can adapt for different crops, regions, or value chain analyses, thereby contributing to the broader body of optimization-based agricultural studies.

Policy and Decision-Making Practice:

1. The results highlight that Tosha jute is currently the most profitable crop option, while White and Mesta jute are less attractive without intervention. This offers policymakers evidence-based guidance to prioritize resource allocation.
2. The identification of water and environmental limits as binding constraints indicates the urgent need for policies that encourage water-efficient technologies and sustainable farming practices.
3. Recommendations such as providing subsidies and investing in R&D (Research and Development) for yield improvement can help diversify jute production, improve competitiveness, and enhance resilience against climate change.

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Practical Impact for Farmers and Industry:

1. Farmers gain insights into the profitability of different jute types, helping them make informed land allocation decisions.
2. Industry stakeholders, including processors and exporters, can use the results to forecast supply trends and design sustainable sourcing strategies.
3. This model can serve as a decision-support tool for agricultural extension services, promoting efficient resource utilization at the grassroots level.

CONCLUSION

This study has successfully developed and applied a linear programming model to optimize jute production in Bangladesh, focusing on efficient resource allocation across different agricultural zones to maximize profitability. The model, formulated and solved using LINGO optimization software, provides valuable insights into the optimal allocation of land for jute cultivation. The results clearly indicate that Tosha jute is the most profitable and sustainable crop, with 400 hectares allocated in Zone 1 and 500 hectares in Zone 2, whereas White jute and Mesta jute are excluded due to their comparatively lower profitability and high reduced costs. The findings reveal that Tosha jute emerges as the most profitable crop, with substantial land allocated in both zones, while White jute and Mesta jute are excluded due to their lower profitability and higher reduced costs. The model achieves a maximum profit of BDT 90.9 million, clearly demonstrating the effectiveness of optimization-based approaches in agricultural planning. Sensitivity analysis reveals that while land, labor, and capital resources remain underutilized with considerable slack, the water and environmental constraint is the key limiting factor in jute production, restricting further expansion of cultivation and dictating the optimal solution.

These outcomes suggest that enhancing water-use efficiency and environmental sustainability will be crucial for future improvements in jute productivity and profitability. Overall, the study demonstrates that linear programming can serve as a powerful decision-support tool for policymakers, researchers, and stakeholders in the agricultural sector, enabling them to design strategies that balance economic growth with sustainable resource management. Therefore, policies aimed at improving water-use efficiency, eco-friendly farming practices, and sustainable irrigation could significantly enhance profitability and ensure long-term sustainability in the jute sector.

FUTURE RESEARCH

Future research on jute crop optimization can be extended in several important directions. At first, incorporating stochastic modelling and uncertainty analysis would allow the model to capture the impacts of unpredictable factors such as climate variability, rainfall fluctuations, and market price volatility, which strongly influence jute production in Bangladesh. Secondly, the model can be expanded to include multi-objective optimization, balancing not only profit maximization but also environmental sustainability, employment generation, and export

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competitiveness. Third, future studies could integrate GIS-based spatial data to identify region-specific resource endowments and optimize production at a more granular level. Moreover, including value chain linkages such as processing, transportation, and export channels would provide a more holistic framework for decision-making. Finally, comparative studies across multiple crops, or the integration of jute with crop diversification strategies, can offer insights into improving farm resilience and long-term sustainability.

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