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Comparative analysis of resource-use efficiency in conventional and high-density planting system cotton cultivation

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Abstract

Cotton (*Gossypium Hirsutum*) is one of the major commercial crops cultivated in Telangana, and improving its productivity and profitability is essential for enhancing farmers' income. The present study was carried out in Nagarkurnool district of Telangana to assess the economic impact of the High Density Planting System (HDPS) in comparison with the conventional cotton production system. Primary data were collected from 90 cotton farmers, comprising 45 HDPS adopters and 45 conventional cotton growers, through personal interviews during the agricultural year 2025–26. The present study assessed the economic impact of the High Density Planting System (HDPS) in cotton cultivation compared with the conventional planting system in Nagarkurnool district of Telangana. Primary data were collected from 90 farmers, comprising 45 HDPS adopters and 45 conventional cotton growers. The Cobb–Douglas production function analysis showed differences in resource-use efficiency between conventional and HDPS cotton cultivation. In conventional cotton, the model explained 58 per cent of the variation in output ($R^2 = 0.58$). Human labour (0.26649) and machine labour (0.33718) had positive and significant coefficients, while the MVP/MFC ratios of human labour (1.29673), machine labour (4.18716), bullock labour (1.85525) and plant protection chemicals (4.26025) were greater than unity, indicating under-utilization. Seed (−6.02200) and fertilizers (−1.79932) recorded negative MVP/MFC ratios. In HDPS cotton, the model explained 29 per cent of the variation in output ($R^2 = 0.29$). Machine labour (0.32478) was positively significant, while fertilizers (−0.35872) showed a significant negative coefficient. The MVP/MFC ratios indicated under-utilization of machine labour (5.93260), bullock labour (1.19322) and plant protection chemicals (9.30406), whereas human labour (0.13972) was relatively over-utilized. Seeds (−2.10357) and fertilizers (−4.82740) showed negative MVP/MFC ratios. Overall, plant protection chemicals and machine labour showed greater scope for improving resource-use efficiency and profitability in HDPS cotton cultivation.

Keywords: HDPS, conventional, production, profitability, resource use efficiency

Introduction

Cotton (*Gossypium* spp.) is an important commercial fibre crop and plays a major role in the agricultural and textile economy of India. Despite its importance, cotton production is associated with considerable expenditure on labour, machinery, seed, fertilizers and plant protection chemicals. Efficient allocation of these resources is therefore essential for improving productivity and profitability. Studies on cotton production have shown that the contribution of individual production inputs varies considerably and that inefficient use of resources can adversely affect farm returns (Kumar *et al.*, 2021; Gayathri & Karunakaran, 2022) [5, 3].

The High-Density Planting System (HDPS) has emerged as an alternative production technology aimed at increasing cotton productivity through higher plant population and closer spacing. Under HDPS, the increased plant population enables more efficient utilization of land and other available

production resources compared with conventional planting systems. Kumar *et al.* (2017) [4] reported that closer spacing under HDPS significantly increased seed cotton yield and economic returns, with the 45 × 15 cm spacing recording 2,063 kg ha^{−1} yield and a benefit-cost ratio of 2.33. Similarly, Ramanjaneyulu *et al.* (2024) [7] reported higher yield and economic returns for suitable cotton cultivars under HDPS in Telangana.

Recent field studies have also demonstrated the economic potential of HDPS under farmers' conditions. Laxman *et al.* (2024) [6], in Vikarabad district of Telangana, reported an average yield of 24.51 q ha^{−1} under HDPS compared with 18.03 q ha^{−1} under farmers' conventional practice. HDPS also generated higher net returns of ₹77,999 ha^{−1} and a benefit-cost ratio of 1.79 compared with ₹43,489.50 ha^{−1} and 1.49, respectively, under conventional practice. These findings indicate that HDPS can improve both productivity and

profitability when appropriate plant geometry and crop management practices are followed.

However, higher productivity alone does not necessarily indicate efficient resource utilization. Resource-use efficiency refers to the extent to which production inputs are utilized in relation to their contribution to output and economic returns. In cotton cultivation, excessive use of an input may increase production costs without a corresponding increase in output, whereas inadequate use may restrict the production potential of the crop. Kumar *et al.* (2021) ^[5] found that human labour and phosphatic fertilizer were under-utilized in cotton production in Haryana, while several other resources were used beyond their economically efficient levels. Similarly, Das *et al.* (2022) ^[1] reported significant contributions of fertilizer, pesticides, human labour and machine labour to cotton production in Odisha, highlighting the importance of efficient input allocation.

The Cobb–Douglas production function is widely used to assess the contribution of different production inputs and their resource-use efficiency in agricultural production. The marginal value product (MVP) of an input can be compared with its marginal factor cost (MFC) to determine whether the input is under-utilized, over-utilized or optimally utilized. Daud and Shiyani (2018) ^[2] used the Cobb–Douglas production function and MVP approach to estimate resource-use efficiency in long-staple cotton cultivation in Gujarat. Similarly, research on Bt cotton in Rajasthan demonstrated that human labour, machine labour, seed and irrigation had MVP/MFC ratios greater than unity, indicating scope for increasing their use.

Although several studies have examined the productivity, profitability and agronomic performance of HDPS cotton, comparatively limited attention has been given to the comparative economic efficiency of individual production resources under HDPS and conventional cotton systems. Recent evidence from Telangana indicates that HDPS can substantially improve cotton yield and profitability over conventional farmer practices, while studies on resource-use efficiency demonstrate that the optimal allocation of inputs differs across production environments. This creates a need to assess not only the productivity advantage of HDPS but also whether the major production resources are being utilized efficiently under the two planting systems.

Therefore, the present study was undertaken to assess and compare the resource-use efficiency of conventional and HDPS cotton cultivation. The study employs the Cobb–Douglas production function to estimate the contribution of major inputs and uses the marginal value product to marginal factor cost (MVP/MFC) ratio to determine their economic efficiency. The analysis focuses on human labour, machine labour, bullock labour, seed, fertilizers and plant protection chemicals, with the objective of identifying under-utilized and over-utilized resources and suggesting appropriate input allocation strategies for improving the productivity and profitability of cotton cultivation.

Materials and Methods

Cobb–Douglas Production function

The Cobb–Douglas production function was used to analyze the resource use efficiency of HDPS in comparison with the conventional planting system in cotton cultivation. This model was applied to examine the relationship between

cotton output and various production inputs used by the farmers.

The functional form of the Cobb–Douglas production function was specified as:

$$Y = aX_1^{b_1}X_2^{b_2}X_3^{b_3}X_4^{b_4}X_5^{b_5}X_6^{b_6}e^u$$

where,

Y= Cotton yield (kg/ha)

a = constant term

X1 = Human labour (Man days/ha)

X2 = Machine labour (hours/ha)

X3 = Seed cost (₹/ha)

X4 = Fertilizer cost (₹/ha)

X5 = Plant protection chemicals (₹/ha)

X6 = Irrigation cost (₹/ha)

b1 to b₆ = Production elasticities of respective inputs

u = Random error term

For estimation purposes, the above function was transformed into a linear form using logarithmic transformation. Separate production functions were estimated for HDPS adopters and conventional farmers.

The regression coefficients obtained from the model represented the elasticity of output with respect to each input. Resource use efficiency was evaluated by comparing the marginal value product (MVP) of each input with its marginal factor cost (MFC). An MVP to MFC ratio greater than unity indicated underutilization of the resource, a ratio less than unity indicated overutilization, and a ratio equal to unity indicated optimal utilization of the input.

Results and Discussion

Estimates of Cobb–Douglas production function in conventional Cotton cultivation

The Cobb–Douglas production function was employed to examine the contribution of different production inputs and their resource-use efficiency in conventional cotton cultivation. The estimated coefficient of determination was 0.58, indicating that about 58 per cent of the variation in cotton output was explained by the selected explanatory variables, while the remaining variation could be attributed to other factors not included in the model. Among the different inputs, Human labour had a positive regression coefficient of 0.26649 and was statistically significant at the 1 per cent level, with a t-value of 3.25771. This indicates that an increase in labour use, while keeping other inputs constant, would have a positive effect on cotton output. Its MVP/MFC ratio was 1.29673, which was greater than unity, suggesting that labour was relatively under-utilized and there was scope for increasing its use to improve returns.

Machine labour also showed a positive and statistically significant coefficient of 0.33718, with a t-value of 2.84255, indicating its important contribution to conventional cotton production. As presented in Table 1, the marginal product of machine labour was 1.16010 quintals, resulting in an MVP of ₹8,374.32 against an MFC of ₹2,000. The resulting MVP/MFC ratio of 4.18716 indicates considerable under-utilization of machine labour, suggesting that greater use of machinery could potentially enhance farm productivity and economic returns.

The coefficient for bullock labour was positive (0.16153) but

statistically non-significant, with a t-value of 0.66943. Its MVP of ₹1,484.20 exceeded the corresponding MFC of ₹800, resulting in an MVP/MFC ratio of 1.85525, as shown in Table 1. This indicates that bullock labour was being used below its economically optimal level, although its estimated statistical contribution to output was not significant.

In contrast, seed recorded a negative coefficient of -0.25343 and a negative marginal product of -1.33490 quintals. The corresponding MVP was -₹9,635.20, giving an MVP/MFC ratio of -6.02200. Similarly, fertilizers showed a negative coefficient of -0.21143 and a marginal product of -0.01795 quintals, with an MVP/MFC ratio of -1.79932. As indicated in Table 1, both coefficients were statistically non-significant. The negative marginal productivity suggests that, at the sample mean, additional use of these inputs was not associated with an increase in output under the estimated production relationship. These negative values should be interpreted as outcomes of the fitted model rather than as literal recommendations for negative input use.

Plant protection chemicals had a positive coefficient of 0.06560, although it was statistically non-significant, with a t-value of 0.63858. Its marginal product was 0.23611 quintals, generating an MVP of ₹1,704.10 against an MFC of ₹400. Consequently, the MVP/MFC ratio was 4.26025, as reported in Table 4.16, indicating that plant protection chemicals were relatively under-utilized and that increased use, within economically and technically appropriate limits, could potentially improve returns.

Overall, the resource-use analysis indicates that labour total, machine labour, bullock labour and plant protection chemicals had MVP/MFC ratios greater than unity, suggesting scope for increasing their use. Among these, machine labour and plant protection chemicals exhibited particularly high ratios, indicating greater potential for additional use. On the other hand, the negative MVP/MFC ratios observed for seed and fertilizers reflect their negative estimated marginal productivity in the fitted function.

Table 1: Estimates of Cobb-Douglas production function in conventional cotton cultivation

Sl. No.	Explanatory Variables	Parameters (Coefficient ± SE)	't' Value	Geometric Mean (GM)	MP	MVP	MFC	MVP/MFC
1.	Human Labour	0.26649***	3.25771	76.15233	0.07187	518.69	400	1.29673
2.	Machine labour	0.33718***	2.84255	5.96902	1.16010	8,374.32	2,000	4.18716
3.	Bullock labour	0.16153	0.66943	16.13032	0.20566	1,484.20	800	1.85525
4.	Seeds	-0.25343	-1.37775	3.89942	-1.33490	-9,635.20	1,600	-6.02200
5.	Fertilizers	-0.21143	-1.26884	241.85370	-0.01795	-129.55	72	-1.79932
6.	Plant protection chemicals	0.06560	0.63858	5.70600	0.23611	1,704.10	400	4.26025
	R ²	0.58						

*** Significant at 1 per cent level ($P < 0.01$). ** Significant at 5 per cent level ($P < 0.05$)

Estimates of Cobb-Douglas production function in HDPS Cotton cultivation

The Cobb-Douglas production function was estimated for HDPS cotton cultivation to assess the contribution of major production inputs and their economic efficiency. The estimated value was 0.29, indicating that approximately 29 per cent of the variation in cotton output was explained by the selected explanatory variables included in the model. The remaining variation may be attributed to other production, environmental and farm-specific factors that were not included in the function.

Among the inputs, Human labour had a positive regression coefficient of 0.01902, with a t-value of 0.27806, indicating a positive but statistically non-significant relationship with output. Its marginal product was 0.00776 quintals, generating an MVP of ₹55.89 against an MFC of ₹400. As presented in Table 2, the MVP/MFC ratio was 0.13972, which was less than unity, indicating that labour was relatively over-utilized compared with its economically efficient level.

Labour recorded a positive coefficient of 0.32478 and was statistically significant at the 1 per cent level, with a t-value of 2.99685. The marginal product of machine labour was 1.64843 quintals, while its MVP was ₹11,865.19 against an MFC of ₹2,000. The MVP/MFC ratio of 5.93260, as shown in Table 2, was substantially greater than unity, indicating considerable under-utilization of machine labour. This suggests that greater and economically appropriate use of machinery could improve the productivity and profitability of HDPS cotton cultivation.

The coefficient of bullock labour was positive (0.07061) but

statistically non-significant, with a t-value of 0.34367. Its marginal product was 0.13262 quintals, resulting in an MVP of ₹954.58. Since the MFC was ₹800, the MVP/MFC ratio was 1.19322. As indicated in Table 2, the ratio being slightly greater than unity suggests that bullock labour was marginally under-utilized and that a modest increase in its use could potentially improve economic returns, subject to practical farm conditions.

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Seeds showed a negative regression coefficient of -0.07610 and a negative marginal product of -0.46760 quintals. Consequently, the MVP was $-\text{₹}3,365.71$, resulting in an MVP/MFC ratio of -2.10357 . The coefficient was statistically non-significant, with a t-value of -1.07289 . The negative marginal productivity, as reported in Table 2, indicates that additional seed use was not associated with an increase in output at the sample mean under the estimated production relationship. This negative value should be interpreted as a statistical outcome of the fitted model rather than as a recommendation for negative seed use.

Fertilizers had a negative coefficient of -0.35872 , which was statistically significant at the 5 per cent level, with a t-value of -2.38317 . Its marginal product was -0.04829 quintals, resulting in an MVP of $-\text{₹}347.57$ and an MVP/MFC ratio of -4.82740 . The results presented in Table 2 suggest a negative estimated marginal contribution of fertilizer use at the sample mean. This may indicate that fertilizer application levels were relatively high in relation to the output response under the

prevailing production conditions.

Plant protection chemicals recorded a positive coefficient of 0.15084 , which was statistically significant at the 5 per cent level, with a t-value of 2.02699 . The marginal product was 0.51705 quintals, and the corresponding MVP was $\text{₹}3,721.63$ against an MFC of $\text{₹}400$. As reported in Table 2, the MVP/MFC ratio was 9.30406 , the highest among all the inputs considered. This indicates substantial under-utilization of plant protection chemicals and suggests considerable scope for increasing their use at economically and technically appropriate levels.

Overall, the results indicate considerable variation in the economic efficiency of resource use under HDPS cotton cultivation. Machine labour, bullock labour and plant protection chemicals recorded MVP/MFC ratios greater than unity, indicating under-utilization, whereas labour total had a ratio below unity, suggesting over-utilization. Seeds and fertilizers recorded negative marginal products due to their negative estimated coefficients. Among all the inputs, plant protection chemicals showed the highest MVP/MFC ratio (9.30406), followed by machine labour (5.93260), highlighting these inputs as the major areas where improved resource allocation could contribute to better economic performance in HDPS cotton cultivation.

Table 2: Estimates of Cobb-Douglas production function in HDPS Cotton cultivation

Sl. No.	Explanatory Variables	Parameters (Coefficient $\pm$ SE)	't' value	Geometric Mean (GM)	MP	MVP	MFC	MFC/MVP
1.	Labour total	0.01902	0.27806	74.22060	0.00776	55.89	400	0.13972
2.	Machine labour	0.32478***	2.99685	5.96902	1.64843	11,865.19	2,000	5.93260
3.	Bullock labour	0.07061	0.34367	16.13032	0.13262	954.58	800	1.19322
4.	Seeds	-0.07610	-1.07289	4.93048	-0.46760	-3,365.71	1,600	-2.10357
5.	Fertilizers	-0.35872***	-2.38317	225.06050	-0.04829	-347.57	72	-4.82740
6.	Plant protection chemicals	0.15084***	2.02699	8.83829	0.51705	3,721.63	400	9.30406
7.	R ²	0.29						

*** Significant at 1 per cent level ($p < 0.01$) ** Significant at 5 per cent level ($P < 0.05$)

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