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Comparative Assessment of Technical, Economic and Allocative Efficiency under Conventional and Indo-Israel High-Density Plantation Systems in Nagpur Mandarin Cultivation

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Abstract

Nagpur mandarin is an important fruit crop of the Vidarbha region of Maharashtra, and efficient utilization of production resources is essential for improving farm productivity and profitability. The present study was undertaken to estimate and compare the technical, economic and allocative efficiency of conventional and Indo-Israel High Density Plantation (HDP) Nagpur mandarin production. The study was conducted in Amravati and Nagpur districts of the Vidarbha region, which were purposively selected based on their potential area under orange cultivation. From each district, three tahsils were selected purposively, followed by random selection of ten villages from each tahsil and five farmers from each selected village. Thus, a total sample of 300 orange growers was selected for the study. Primary data were collected for the Ambia Bahar season of 2024 through a structured survey schedule. Technical efficiency was estimated using the stochastic frontier production function, while economic efficiency was estimated using the stochastic profit frontier approach. Allocative efficiency was derived as the ratio of economic efficiency to technical efficiency. The results revealed that the mean technical efficiency was 89.70 per cent for conventional growers and 92.40 per cent for Indo-Israel HDP growers. The corresponding mean economic efficiency was 74.90 and 76.80 per cent, respectively. Allocative efficiency was estimated at 83.50 per cent for conventional growers and 83.10 per cent for HDP growers. The stochastic frontier production estimates showed that human labour, bullock labour, plant protection and growth regulators had positive and significant effects on output, whereas fertilizer had a significant negative association with output under both systems. In the profit frontier, human labour, bullock labour, plant protection and growth regulator expenditure positively influenced profit, while fertilizer expenditure showed a negative relationship. The findings indicate that Indo-Israel HDP cultivation provides an advantage in technical and economic efficiency; however, substantial scope remains for improving input allocation, cost management and profitability under both production systems.

Keywords: Nagpur mandarin, technical efficiency, economic efficiency, allocative efficiency, stochastic frontier analysis, high density plantation, resource-use efficiency, Vidarbha

1. Introduction

Nagpur mandarin is an important fruit crop of Maharashtra and has considerable importance in the agricultural economy of the Vidarbha region. The productivity and profitability of mandarin cultivation depend not only on the availability of production resources but also on the efficiency with which these resources are utilized. Rising input costs, variations in orchard management practices and inefficient allocation of production resources can influence the economic performance of growers. Therefore, efficient utilization of available resources is essential for improving productivity, reducing production costs and enhancing farm profitability.

The adoption of improved production technologies has resulted in changes in orchard management practices. Among these, the Indo-Israel High Density Plantation (HDP) system represents a modern production approach intended to improve the utilization of land and other production resources. Scientific orchard management, improved irrigation and fertigation practices and systematic canopy management associated with HDP cultivation have the potential to improve productivity and resource-use efficiency. However, the relative efficiency of HDP cultivation compared with conventional mandarin cultivation needs to be assessed at the farm level.

Farm-level production performance can be evaluated through technical, economic and allocative efficiency. Technical efficiency reflects the ability of a farmer to obtain maximum possible output from a given set of inputs. Economic efficiency represents the ability to achieve maximum profit considering prevailing input and output prices, whereas allocative efficiency reflects the ability to use inputs in economically optimal proportions. A simultaneous assessment of these dimensions provides a comprehensive understanding of the performance of different production systems.

The stochastic frontier approach provides an appropriate framework for estimating production efficiency because it separates random variations affecting production from farm-specific inefficiency. The stochastic frontier production function developed by Aigner, Lovell and Schmidt (1977) ^[1] incorporates a two-sided random error component and a one-sided non-negative inefficiency component. In the present study, the stochastic frontier production function was employed to estimate technical efficiency, while the stochastic profit frontier function was used to estimate economic efficiency. Allocative efficiency was derived as the ratio of economic efficiency to technical efficiency.

Although the adoption of HDP technology is expected to improve resource utilization, the benefits of the technology need to be assessed not only in terms of production but also in terms of technical, economic and allocative efficiency. Therefore, the present study was undertaken to compare the efficiency performance of conventional and Indo-Israel HDP Nagpur mandarin growers in the Vidarbha region of Maharashtra.

Objective

To Estimate the Technical, Economic and Allocative efficiency of Nagpur mandarin production and compare the efficiency of conventional and Indo-Israel HDP production systems.

2. Materials and Methods

2.1 Study Area, Sampling Procedure and Period of Study

The study was conducted in the Vidarbha region of Maharashtra, with Amravati and Nagpur districts purposively selected based on their potential area under orange cultivation. From each district, three tahsils were purposively selected, followed by random selection of 10 villages from each tahsil and five orange growers from each village, resulting in a total sample of 300 farmers. Of these, 200 were conventional orange growers and 100 were Indo-Israel High Density Plantation (HDP) growers. Primary data on production, input use, expenditure, output and returns were collected through a structured survey schedule for the Ambia Bahar season of 2024.

2.2 Analytical Framework

Technical, economic and allocative efficiency were estimated using the stochastic frontier approach. The stochastic frontier production function was used to estimate technical efficiency, while the stochastic profit frontier function was used to estimate economic efficiency. Allocative efficiency was subsequently derived from technical and economic efficiency estimates.

2.2.1 Stochastic Frontier Production Function

The stochastic frontier production function, originally developed by Aigner, Lovell and Schmidt (1977) ^[1], was employed to estimate farm-specific technical efficiency. The stochastic frontier model consists of two error components: a two-sided random error component and a one-sided non-negative inefficiency component.

The logarithmic Cobb-Douglas stochastic frontier production function was specified as:

$$\ln Y_i = \beta_0 + \beta_1 \ln X_{1i} + \beta_2 \ln X_{2i} + \dots + \beta_n \ln X_{ni} + (v_i - u_i)$$

where,

Y_i = output of orange (tonnes per hectare)

$X_{1i}, X_{2i}, X_{3i}, \dots, X_{ni}$ = quantities of inputs used

β_0 = intercept

$\beta_1, \beta_2, \dots, \beta_n$ = regression coefficients of respective inputs

v_i = random error term

u_i = farm-specific technical inefficiency term

The random error component captures random variations in output arising from factors beyond the control of the farmer, whereas the non-negative inefficiency component represents the shortfall of observed output from the potential frontier output.

Technical efficiency was estimated as:

$$TE_i = \exp(-u_i)$$

2.2.2 Stochastic Profit Frontier Function

The stochastic profit frontier function was used to estimate economic efficiency. This approach measures the ability of farmers to maximize profit given prevailing input prices, output prices and fixed resources.

The general specification of the stochastic profit frontier can be expressed as:

$$\pi_i = f(X_i, P_i) + (v_i - u_i)$$

Where,

π_i = normalized profit (gross return) of the i^{th} farmer

X_i = vector of variable input prices normalized by output price faced by the i^{th} farm

P_i = vector of fixed factors of the i^{th} farm

v_i = random error component capturing factors beyond the farmer's control

u_i = non-negative random variable associated with economic inefficiency

Economic efficiency was estimated relative to the stochastic profit frontier.

$$EE_i = \exp(-u_i)$$

2.3 Allocative Efficiency

Allocative efficiency was estimated as:

$$AE_i = \frac{EE_i}{TE_i}$$

where,

AEi = allocative efficiency,

Eei = economic efficiency, and

TEi = technical efficiency.

Allocative efficiency represents the ability of farmers to use production inputs in optimal proportions according to prevailing input prices and available technology.

3. Results and Discussion

3.1 Technical, Economic and Allocative Efficiency of Conventional Growers

The distribution of conventional mandarin growers according to technical, economic and allocative efficiency revealed considerable variation in farm-level resource utilization and cost management.

Table 1: Distribution of conventional mandarin growers according to efficiency level

Efficiency range (%)	Technical efficiency	Economic efficiency	Allocative efficiency
30.01–40	0 (0)	4 (2)	2 (1)
40.01–50	2 (1)	10 (5)	8 (4)
50.01–60	8 (4)	22 (11)	16 (8)
60.01–70	14 (7)	38 (19)	28 (14)
70.01–80	24 (12)	54 (27)	52 (26)
80.01–90	50 (25)	46 (23)	60 (30)
>90	102 (51)	26 (13)	34 (17)
Total	200 (100)	200 (100)	200 (100)
Mean efficiency (%)	89.70	74.90	83.50
Minimum (%)	58.00	34.00	35.10
Maximum (%)	97.00	92.00	100.00

Note: Zero observation upto efficiency range 30, Figures in parentheses indicate percentages.

More than half of the conventional growers (51.00%) recorded technical efficiency above 90 per cent, while 25.00 per cent were in the 80.01–90 per cent category. The mean technical efficiency was 89.70 per cent, ranging from 58.00 to 97.00 per cent. This indicates that most conventional growers operated relatively close to the production frontier, although scope existed for improving output through better management practices and adoption of recommended technologies.

Economic efficiency showed greater dispersion. The highest proportion of growers (27.00%) belonged to the 70.01–80 per cent category, followed by 23.00 per cent in the 80.01–90 per cent category. Mean economic efficiency was 74.90 per cent, with values ranging from 34.00 to 92.00 per cent. The comparatively lower economic efficiency than technical efficiency indicates that farmers who were technically efficient were not necessarily using inputs in a cost-minimizing manner.

The mean allocative efficiency was 83.50 per cent, ranging from 35.10 to 100.00 per cent. The highest proportion of growers (30.00%) belonged to the 80.01–90 per cent category. The relatively high mean allocative efficiency indicates that most conventional growers were reasonably capable of selecting input combinations according to prevailing input prices. However, the considerable variation among farms indicates differences in managerial ability, access to information and input-use decisions.

3.2 Technical, Economic and Allocative Efficiency of Indo-Israel HDP Growers

The distribution of Indo-Israel HDP growers showed a greater concentration in the higher technical-efficiency categories.

Table 2: Distribution of Indo-Israel HDP mandarin growers according to efficiency level

Efficiency range (%)	Technical efficiency	Economic efficiency	Allocative efficiency
50.01–60	0 (0)	14 (14)	4 (4)
60.01–70	2 (2)	17 (17)	8 (8)
70.01–80	8 (8)	15 (15)	28 (28)
80.01–90	22 (22)	41 (41)	55 (55)
>90	68 (68)	13 (13)	5 (5)
Total	100 (100)	100 (100)	100 (100)
Mean efficiency (%)	92.40	76.80	83.00
Minimum (%)	61.00	52.00	57.00
Maximum (%)	98.00	91.00	93.00

Note: Zero observation upto efficiency range 50, Figures in parentheses indicate percentages

A substantial majority of HDP growers (68.00%) recorded technical efficiency above 90 per cent, while 22.00 per cent were in the 80.01–90 per cent category. The mean technical efficiency was 92.40 per cent, ranging from 61.00 to 98.00 per cent. The concentration of growers in higher efficiency categories suggests effective resource utilization under the HDP production system.

Economic efficiency was relatively lower than technical efficiency. The largest proportion of HDP growers (41.00%) belonged to the 80.01–90 per cent efficiency category. Mean economic efficiency was 76.80 per cent, ranging from 52.00 to 91.00 per cent. The difference between technical and economic efficiency indicates that further improvements in cost management and input allocation could enhance

profitability.

Allocative efficiency was concentrated in the 80.01–90 per cent category, which accounted for 55.00 per cent of growers. Mean allocative efficiency was 83.00 per cent, with values ranging from 57.00 to 93.00 per cent. The comparatively narrow range suggests greater uniformity in management and input-use practices among HDP growers.

3.3 Stochastic Frontier Production Function Estimates

The stochastic frontier production function was estimated separately for conventional and Indo-Israel HDP Nagpur mandarin cultivation to determine the contribution of different production inputs to output and estimate technical efficiency.

Table 3: Estimated coefficients of stochastic frontier production function

Variables	Conventional	Indo-Israel HDP
Intercept	-1.983	-1.865
Human labour (hrs/ha)	0.462* (0.438)	0.495* (0.463)
Bullock labour (hrs/ha)	0.302** (0.220)	0.284** (0.232)
Machine hours (hrs/ha)	0.082 (0.247)	0.072 (0.255)
Fertilizer (kg/ha)	-0.353** (0.332)	-0.315* (0.348)
Plant protection (lit./ha)	0.428** (0.277)	0.413** (0.298)
Growth regulators (lit./ha)	0.239* (0.209)	0.266* (0.219)
Sigma-squared (σ^2)	0.042	0.039
Gamma (γ)	0.812***	0.792***
Log-likelihood	-24.784	-12.346
Mean TE (%)	89.70	92.40

Note: ***, ** and * indicate significance at 1, 5 and 10 per cent levels, respectively. Figures in parentheses are standard errors.

Human labour had positive and significant coefficients of 0.462 under conventional cultivation and 0.495 under HDP cultivation. This indicates that human labour contributed positively to mandarin output in both systems. Bullock labour also had positive and significant coefficients of 0.302 and 0.284, respectively.

Machine hours had positive but statistically non-significant coefficients in both systems. Thus, an increase in machinery use did not result in a statistically measurable increase in output. Fertilizer had negative and significant coefficients of -0.353 under conventional cultivation and -0.315 under HDP cultivation, indicating possible excessive or inefficient fertilizer application.

Plant protection chemicals had positive and significant coefficients of 0.428 and 0.413 under conventional and HDP systems, respectively. Growth regulators also showed positive and significant coefficients of 0.239 and 0.266. These results indicate the importance of appropriate plant protection and growth regulator application in maintaining mandarin productivity.

The estimated gamma values were 0.812 for conventional cultivation and 0.792 for HDP cultivation, both significant at the 1 per cent level. The estimates indicate that a substantial proportion of variation in output was associated with technical inefficiency rather than random factors, indicating considerable scope for improving production through better input management.

The mean technical efficiency was 89.70 per cent for conventional growers and 92.40 per cent for HDP growers. Thus, HDP growers recorded a 2.70 percentage-point higher technical efficiency than conventional growers.

3.4 Stochastic Frontier Profit Function Estimates

The stochastic profit frontier was estimated to assess the influence of input expenditure on profit and determine economic efficiency under conventional and Indo-Israel HDP cultivation.

Table 4: Estimated coefficients of stochastic frontier profit function

Variables	Conventional	Indo-Israel HDP
Intercept	-1.684 (1.745)	-1.524 (1.638)
Human labour cost (Rs/ha)	0.422* (0.402)	0.438* (0.419)
Bullock labour cost (Rs/ha)	0.276** (0.219)	0.262** (0.225)
Machine hours cost (Rs/ha)	0.064 (0.232)	0.058 (0.240)
Fertilizer cost (Rs/ha)	-0.332** (0.315)	-0.286* (0.330)
Plant protection cost (Rs/ha)	0.403** (0.269)	0.390** (0.285)
Growth regulator cost (Rs/ha)	0.226* (0.199)	0.242* (0.207)
Sigma-squared (σ^2)	0.049	0.047
Gamma (γ)	0.779***	0.756***
Log-likelihood	-27.417	-13.872
Mean EE (%)	74.90	76.80

***Note:** ***, ** and * indicate significance at 1, 5 and 10 per cent levels, respectively. Figures in parentheses are standard errors.

Under conventional cultivation, human labour cost and bullock labour cost showed positive and significant coefficients of 0.422 and 0.276, respectively. Machine-hour expenditure was positive but statistically non-significant. Fertilizer expenditure had a negative and significant coefficient (-0.332), while plant protection and growth regulator expenditure had positive and significant coefficients.

Under HDP cultivation, human labour cost and bullock labour cost were positive and significant, with coefficients of 0.438 and 0.262, respectively. Machine-hour expenditure was statistically non-significant. Fertilizer expenditure showed a negative coefficient of -0.286, while plant protection and growth regulator expenditure had positive and significant coefficients.

The gamma estimates of 0.779 for conventional cultivation and 0.756 for HDP cultivation were significant at the 1 per cent level. These values indicate that economic inefficiency accounted for a substantial proportion of variation in profit. The mean economic efficiency was 74.90 per cent for conventional growers and 76.80 per cent for HDP growers. Thus, HDP growers recorded a 1.90 percentage-point higher economic efficiency than conventional growers, indicating comparatively better conversion of available resources and expenditure into profit.

3.5 Comparative Technical, Economic and Allocative Efficiency

Table 5: Comparison of efficiency between conventional and Indo-Israel HDP mandarin cultivation

Efficiency measure	Conventional	Indo-Israel HDP	Difference
Technical efficiency (%)	89.70	92.40	+2.70
Economic efficiency (%)	74.90	76.80	+1.90
Allocative efficiency (%)	83.50	83.10	-0.40

The comparison indicates that Indo-Israel HDP growers achieved higher technical efficiency than conventional growers, with mean efficiencies of 92.40 and 89.70 per cent, respectively. The higher technical efficiency under HDP suggests comparatively better conversion of available resources into output.

Economic efficiency was also higher under HDP cultivation at 76.80 per cent compared with 74.90 per cent under conventional cultivation. However, the difference between technical and economic efficiency in both systems indicates that improvements in cost management and economic resource allocation remain possible.

Allocative efficiency was 83.50 per cent under conventional cultivation and 83.10 per cent under HDP cultivation. The nearly similar values indicate comparable ability of growers under both systems to allocate inputs according to prevailing market prices. Nevertheless, allocative efficiency below 100 per cent indicates scope for achieving more economically optimal input combinations.

Overall, the results indicate that the principal advantage of the Indo-Israel HDP system was higher technical and economic efficiency, whereas allocative efficiency was almost similar under both systems.

4. Conclusion

The present study assessed the technical, economic and allocative efficiency of conventional and Indo-Israel HDP Nagpur mandarin cultivation in the Vidarbha region of Maharashtra. The results demonstrated that Indo-Israel HDP growers performed better in terms of technical and economic efficiency. Mean technical efficiency was 92.40 per cent under HDP cultivation compared with 89.70 per cent under conventional cultivation, while mean economic efficiency was 76.80 and 74.90 per cent, respectively.

The higher technical efficiency under HDP indicates comparatively better utilization of available production resources. The higher economic efficiency further indicates that HDP growers were relatively more efficient in converting production resources and expenditure into profit. However, allocative efficiency was nearly identical between the two systems, at 83.10 per cent under HDP and 83.50 per cent under conventional cultivation.

The stochastic frontier production estimates revealed that human labour, bullock labour, plant protection and growth regulators were significant positive contributors to output. Fertilizer exhibited a negative and significant relationship with output in both systems. Similarly, fertilizer expenditure had a negative relationship with profit, while plant protection and growth regulator expenditure contributed positively to profitability.

The findings indicate that increasing the quantity of inputs alone may not necessarily improve productivity or profitability. Greater emphasis should be placed on the efficient, balanced and economically optimal use of inputs. Although the HDP system demonstrated an efficiency advantage, both production systems still have considerable potential for improvement, particularly in economic efficiency and cost management.

5. Policy Implications

Based on the findings, the following measures are suggested for improving the efficiency and profitability of Nagpur mandarin cultivation:

- Promote scientific input management:** Farmers should be encouraged to follow recommended and balanced fertilizer application rather than excessive fertilizer use.
- Strengthen technical extension services:** Scientific orchard management practices associated with HDP cultivation should be disseminated among conventional growers.
- Improve plant protection management:** Timely and appropriate plant protection measures should be promoted because plant protection inputs showed a positive contribution to output and profit.
- Optimize production expenditure:** Farmers should carefully evaluate expenditure on different inputs to reduce unnecessary production costs and improve economic efficiency.
- Improve allocative decision-making:** Training and extension programmes should focus on input-price relationships and economically optimal combinations of production resources.
- Promote efficient HDP management:** Since HDP growers achieved higher technical and economic efficiency, appropriate technical guidance should be provided to farmers adopting the system to ensure that the expected efficiency advantages are realized.

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