RESOURCE USE EFFICIENCY AND PROFITABILITY OF CUCUMBER CULTIVATION IN PROTECTED FIELD: A CASE OF KAITHAL, HARYANA.

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Abstract:
This study focuses on the economic analysis of cucumber cultivation under protected conditions in Haryana, a state once at the forefront of the Green Revolution. Today, Haryana faces serious challenges such as low farm returns, over-extraction of groundwater, climate variability, and rising input costs. Protected cultivation, especially of high-value crops like cucumber, offers a potential solution to these problems by improving water-use efficiency, reducing climatic risks, and increasing profitability.
The paper evaluates the viability and efficiency of cucumber farming in a one-acre protected field. Using farm-level data, we assess input use, gross revenue, and profitability. A Cobb-Douglas production function was used to estimate the contribution of each input, and Marginal Value Product (MVP) analysis was applied to measure resource use efficiency. The results show that irrigation cost is underutilized with an MVP/MFC ratio of 1.20, indicating a potential to increase yield by raising water use. In contrast, inputs like hired labour (MVP/MFC = 0.02), fertilizers (MVP/MFC = 0.12), and fixed costs (MVP/MFC = 0.01) were found to be highly overutilized, suggesting a need to reduce their usage for cost-effective production.
These findings highlight the importance of optimizing input use to improve profitability. The study concludes that cucumber cultivation under protected structures is economically viable when resource use is carefully managed. Policies promoting training, input management, and cost-effective technologies can help farmers transition to more sustainable and profitable production systems in Haryana.

Keywords: Resource Use Efficiency, Protected Cultivation, Cucumber Farming, Farm Profitability, Cost Analysis, Sustainable Agriculture, Agricultural Economics, Haryana Horticulture

JEL Codes: Q12, Q13, Q16, Q18, D24, O13, C21, Q01

Introduction

Agriculture remains the backbone of India's economy, contributing 16 per cent of the GDP and employing over 46 per cent of the workforce and register steady growth of 5% from financial year 2017 to 2023 (Economic Survey, 2024-25). According to the World bankagriculture should be the prime moving force of the economy becauseeconomic growth in a country driven by agriculture is moreimpactful in alleviating poverty than the other sectors. (World Bank Report, 2008).In India agriculture also has a significant effect on many indicators even a good monsoon season can help in 1% growth in economy.Vegetable is also the most important subsector of agriculture in India.
Vegetable contributedabout 28.3% share of agriculture in country with 28.77 million hectare and production of 355.25 million tonnes (2023-24 Estimates) and majority of farmers who

are engaged in vegetable cultivation are small farmers. According to (NHB, 2022) estimates there is a significant increase in the area of vegetable cultivation from the last 10 years either it is open field cultivation or protected field cultivation.China is the largest contributor in protected cultivation with 45% of share then along with the major producer include Turkey, Spain, Italy and Japan (FAO, 2023). India is also moving towards advanced agriculture.

In developing countries, vegetable farming is vital for boosting incomes, reducing poverty, and ensuring food and nutrition security for communities (Shrestha et al, 2022). In South Asian countries, most vegetable farmers are smallholders who must focus on high-yield production within limited land to maximize their productivity (Gurung et al, 2016). Capital to labour ratio for small holder farmers is very low and labour is more than enough (Rapsomanikis, 2015).In Indian agriculture lower cropping return, high production cost and low adoption of technology is a key issue which must be addressed for the conservation of agriculture. The combined effect of these practices promises higher productivity, profitability, and environmental benefits in medium to long-run-in different geographies and cropping systems (Jat et al, 2020).

There is a significant cropping pattern change in India from the mono-cropping pattern adopt during the times of green revolution to poly-cropping pattern. Producers have shifted from wheat and rice crops to commercial crops or horticultural crops (fruit, flower and vegetables crops) (Agri Statistics, 2023).From the last decade attraction towards protected horticulture crops specially vegetable has also increased, as vegetable grower can grow in off season as well as normal season which can generate higher income at small part of land in short time frame (Singh &Sirohi, 2006).

Protected cultivation is a farming technique where the growing conditions around plants are carefully managed, either partially or completely, to suit their needs throughout different growth stages. This approach helps increase crop yield while efficiently using resources like water, nutrients, and energy. (Nagarajan et al., 2002). Farmers using protected cultivation can avoid oversupply issues during peak harvest seasons. By carefully planning their production cycles, they can align their harvests with high-demand periods, ensuring better market prices and increased profits (Ashok & Parthasarathi, 2020).

India has diverse agro-climatic conditions, but protected cultivation enables farmers to grow vegetables year-round, regardless of seasonal limitations. This not only helps increase farmers' earnings by ensuring a steady supply but also reduces the country's dependence on vegetable imports, strengthening domestic production and market stability (Sharma et al, 2020). There are three vegetable crops Capsicum, Cucumber, and Tomato which are majorly grown in the protected field in India as well as globally(FAO, 2013).So, agriculture sub-sector needs to be efficient in view of government and return oriented from the farmer’s point of view.

In Haryana, cucumber holds the distinction of having the largest cultivation area among vegetables grown under protected farming systems (Horticulture Statistics, 2024). This study specifically examined Kaithal district, a region facing significant challenges due to rapidly declining groundwater levels and diminishing returns from conventional crops. The shift toward cucumber cultivation under protected structures offers a dual advantage—it not only helps mitigate environmental concerns such as groundwater depletion but also provides an opportunity to improve farmers’ incomes. One of the key benefits of this approach is the flexibility to grow crops across different seasons, enabling farmers to shield themselves from seasonal price fluctuations and unpredictable market trends. This research also delved into the economic aspects of cucumber farming, particularly focusing on cost-benefit analysis and resource use efficiency. It assessed how various input costs influence gross revenue and examined the efficiency of resource utilization in the production process—identifying which inputs are being used optimally, which are underutilized, and which may be contributing to inefficiencies through overuse.

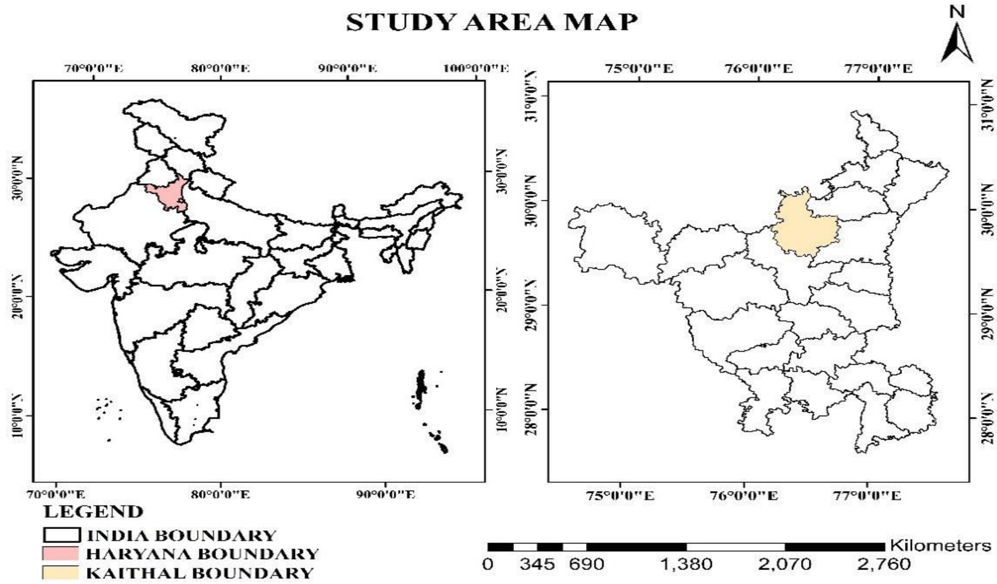
2. Research methods:

2.1 Study Area

The study area, Kaithal district, is located in the state of Haryana, North India, and lies at an elevation of approximately 250 meters above sea level. The district is known for its diverse agroclimatic conditions, which create a favourable environment for agricultural activities, particularly the cultivation of Cucumber. The region benefits from fertile soil, adequate irrigation facilities, and a moderate climate, making it one of the suitable areas for growing vegetables, including Cucumber, throughout different seasons.

Administratively, the district is divided into several blocks, out of which the study focuses on two primary blocks—Kaithal and Kalayat. These blocks are significant agricultural hubs where a large number of farmers are engaged in vegetable farming under both open-field and protected cultivation systems.

Figure 1. Map of the Study Area (Source: Authors).



2.2 Sampling and Sample Design

The study focuses on two blocks from Kaithal district—Kaithal and Kalayat, selected based on the predominance of Cucumber cultivation under protected farming systems. According to data obtained from the District Horticulture Department, there are a total of 387 Cucumber farmers across these two blocks. Among them, 163 farmers are in Kaithal block, while 224 farmers are in Kalayat block.

To determine the actual sample size, the Taro Yamane (1973) formula was applied, ensuring a statistically valid and representative selection of farmers for the study. This approach helps in drawing meaningful conclusions about protected Cucumber farming practices, farmer adoption trends, and economic impacts within the region.

$$n = \frac{N}{1 + N.e^2}$$

Where N= Population

e = Level of Significance at 10% level.

Total sample size was calculated 80 at (10% level). The sample size for Kaithal was thus calculated to be $\frac{163}{387} \times 80 = 34$ and for Kalayat it was calculated $\frac{224}{387} \times 80 = 46$ upon using the proportionate sampling.

2.3 Data Collection and Data Analysis

A structured interview schedule was created for data collection, and verbal consent was obtained from the sampled farmers after receiving ethical approval. To structure the interview schedule, a pilot study was conducted to address key components such as cost, yield, and the price of the respective vegetable crops.

The collected data was entered into MS Excel and then cleaned to address any missing values and outliers before analysis. Descriptive statistics were used to present the socio-demographic characteristics, costs incurred, and the different input shares in cucumber cultivation. Socio-demographic characteristics, including age, education, experience, farm size, and area under vegetable cultivation, were considered important for assessing the costs incurred, resource utilization, and their distribution. Data analysis was performed using SPSS version 26, where cost-benefit analysis and resource use efficiency were calculated to determine the profitability of protected cucumber cultivation.

2.3.1 Cost benefit Analysis

For cost benefit analysis total variable cost (TVC), total fixed cost and other cost were accessed per acre. Price of crops were calculated at the average level for the whole season per farmer and on the basis of whole production total return was calculated per farmer with the help of average method.

Variable cost consist of total material cost (which is sum of seed, FYM, chemical and fertilizers), labour cost (sum of hired labour and family labour), transportation cost and irrigation cost were considered. TVC was calculated on the ongoing market price of respective inputs used in cultivation as shown in Eq. (1)

$$\textit{Total Variable Cost} = C_{Material\ Cost} + C_{Labour\ Cost} + C_{TransportationCost} + C_{Irrigation\ Cost} \quad (1)$$

Where $C_{\text{Material Cost}}$= Cost of Material used (INR/acre), $C_{\text{Labour Cost}}$= cost of labour used in cultivation either it is hired or family labour (INR/acre), $C_{\text{Transportation Cost}}$= transportation used for farm to market (INR/acre), $C_{\text{Irrigation Cost}}$ = total cost used in irrigation (fuel or electricity) (NPR/acre).

Gross revenue were calculated with the multiplication of ongoing price of cucumber in the market with total production of the crop as shown in Eq. (2).

$$\textit{Gross Revenue} = \textit{Price of Cucumber at market} \times \textit{Total production of the crop} \quad (2)$$

Gross margin (NPR/acre) were calculated from the gross revenue and total variable cost. The calculation is explained in Eq. (3).

$$\textit{Gross Margin} = \textit{Gross Revenue} - \textit{Total Variable Cost} \quad (3)$$

BC ratiowas calculated with the help of gross revenue and total variable cost. Calculation has been shown in Eq. (4).

$$Benefit\ Cost\ Ratio\ (BCR) = \frac{Gross\ Revenue}{Total\ variable\ Cost} \quad (4)$$

2.3.2 Resource Use efficiency based on the cobb- Douglas production function

The study is based on the regression analysis using cobb Douglas production function for analysing the resource use efficiency of in protected cucumber cultivation. Cobb Douglas was used because of the its self-dual nature which is convenient for both cost and production function. This production function has been widely used for calculating the efficiency in agriculture in both developing and developed nation. (Bravo-Ureta & Evenson, 1994).

Gross revenue was termed as dependent variable and other cost incurred in the production process was termed as independent variable in the regression variable. CD function calculates marginal value of productivity, return to scale and other indicators to calculate the efficiency of input using in production process or how they affect the revenueas shown in Eq. (5).

$$Y = \alpha X_1^{\beta_1} X_2^{\beta_2} X_3^{\beta_3} X_4^{\beta_4} X_5^{\beta_5} X_6^{\beta^6} X_7^{\beta^7} e^u \qquad (5)$$

Y (Gross revenue) is dependent variable and other cost included in the production process are independent variable where X_1 = Cost of FYM, X_2= Cost of Chemical used(Manure +NPK), X_3= Cost of fertilizers, X_4 = Cost of family labour, X_5 = Cost of labour (Hired), X_6 = cost of Irrigation and X_7 = transportation cost, e = base of natural logarithm, u = random error term, α = Constant and β_1 β_2….β_7 are the coefficient of respective variable.
The Cobb-Douglas production function is in non-linear form to make it pragmatic we have to change it into linear form using a log function. Now CD production function can be expressed as shown in Eq. (6).

$$\ln Y = \ln\alpha + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta l_4 n X_4 + \beta_5 \ln X_5 + \beta_6 \ln X_6 + \beta_7 \ln X_7 + u \qquad (6)$$

Where ln = Natural Logarithm and u = error term
β is coefficient of elasticity for input used and summation of all elasticity used is termed as Return to Scale (RTS)Eq. (7).

$$\text{RTS} = \sum_{i=1}^{7} \beta i$$

Where, $\beta_i$are termed as coefficients for each input obtained from the regression model. The RTS value is calculated with the help of coefficient value. Returns to scale is greater than 1meansincreasing returns to scale, if less than 1, decreasing returns to scale and if equal to 1 constant returns to scale. In other terms if RTS>1 means production can have a potential of increase, by increasing inputs, RTS=1 means optimum use of inputs, RTS<1 inefficient use of resource, input use is high with less gain in production.
The RUE was assessed by calculating the ratio of the Marginal Value of Product (MVP) of a variable input and Marginal Factor Cost (MFC), which has been a popularly used approach (Gujarati, 2014). Thus, the resource use efficiencyEq. (8).

$$(\text{r}) = \frac{MVP}{MFC}$$

The geometric mean (GM) provides a more accurate value in the context of production. Since our variables are measured in terms of cost, a monetary measure, we calculate the marginal value product (MVP) for individual inputs by multiplying the $\beta_i$coefficient with the geometric mean (GM) of the respective input (Xi) and then dividing it by the GM of the total output (Y) (Rabbani et al., 2013). This approach ensures a more precise estimate of the MVP in terms of the cost and output relationship.
MFC (Marginal Factor Cost) refers to the additional cost incurred when using one more unit of input. In this study, the cost of inputs is considered based on their use, such as the cost of 1 kg of fertilizers and manure, 1 litre of chemicals, the daily cost of family and hired labour working in the field, transportation cost per kilogram of cucumber to the market, and the total daily cost of fuel or electricity used. These costs are all factored in to assess the marginal cost associated with each input in the production process.

$$MVP = \beta_i \, x \frac{GM \; of \; gross \; revenue \; (Y)}{GM \; of \; ith \; inputs \; used \; X_i}$$

Finally, the relative percentage change (D) in MVP was calculated using Eq. (9).

$$D = (1 - \frac{1}{R}) \times 100$$

Where D = Absolute value of percentage change in input used, r = resource use efficiency
Value of r can be different in any scenario if r>1, r =1 or r <1 underutilized, optimal utilized and overutilized. So, RUE can be used in estimating profitability and efficiency of a crop cultivation.

3. Results

3.1. Socio Demographic Characteristics

The socio demographic characteristics; age of famer, years of education, family size in number, farm size in acre, area under vegetable cultivation and experience of the grower has been shown in the table 1.Age of farmers engaged in the vegetable cultivation of cucumber was 42 years, average age of education was 10 years, average farm size was 6.73 acre, and farmers who have adopted vegetable cultivation in their respective field was of average of 1.73 acre per farmer and years of experience of cultivation was 3.58 years.

Table 1. Socio Demographic Characteristics of sampled Farmers.

Variables	Mean(Standard Deviation)
Age(Years)	42.78 (10.453)
Education (Years)	10.16 (4.150)
Family size(Number)	7.81 (3.457)
Farm Size (Acre)	6.73 (2.392)
Area vegetable(Acre)	1.75 (1.108)
Experience (Years)	3.58 (2.260)

Source: Author's Calculation (Note SD= Standard Deviation)

3.2. Average cost of Cucumber Cultivation

The table 2. presents a breakdown of the total costs in cucumber cultivation. Material costs make up the largest share at 34.72%, with a mean cost of ₹166,990. Labour costs follow closely at 33.97% of the total, with a mean cost of ₹163,403.55. Fixed costs account for 25.54% of the total, with a mean of ₹122,865.19. Irrigation costs represent 2.79% of the total, with a mean of ₹13,418.93. Finally, transportation costs contribute 2.96% of the total, with a mean of ₹14,236.10. These figures highlight the varying contributions of different cost items, with material and labour costs being the most significant.

Table 2. Average Cost used in the cultivation.

Items	Share of total cost (%)	Mean Cost (SD)
Material cost	34.72	166990 (9882.732)
Labour cost	33.97	163403.55 (7814.578)
Fixed cost	25.54	122865.19 (7339.528)
Irrigation cost	2.79	13418.93 (1950.776)
Transportation cost	2.96	14236.10 (2146.460)
Total Cost	100.00	480914.63 (14372.701)

Source: Author's Calculation

3.3Profitability of Cucumber Cultivation.

Table 3. Yield and Profitability in the Cucumber Cultivation.

Economic Measure	Mean (SD)
Yield (Quintal per Acre)	381.315 (80.99)
Price per KG	21.30 (4.178)
Gross Return(INR/acre)	780063.5 (31739.21)
Total Variable Cost (INR/acre)	358049.44 (12572.52)
Gross profit (INR/acre)	422014.14 (28738.06)
B:C ratio	2.18 (.08)

Source: Author's Calculation

The table 3. presents various economic measures related to cucumber cultivation. The average yield is 381.32 quintals per acre, with a price of ₹21.30 per kilogram. The gross return per acre is ₹780,063.50, while the total variable cost per acre amounts to ₹358,049.44. This results in a gross profit of ₹422,014.14 per acre. The benefit-cost (B:C) ratio is 2.18, indicating that for every rupee spent, the farmer earns ₹2.18 in return, demonstrating a positive profitability for cucumber cultivation.

3.4 Estimates of Cobb-Douglas production function in cucumber cultivation

The table 4. presents the regression results for various input variables in cucumber cultivation. The coefficients represent the impact of each variable on the output in INR per acre. For instance, FYM (Farm Yard Manure) has a coefficient of 0.929, indicating that an increase in its use by one unit will increase the output by ₹0.929 per acre, and this relationship is statistically significant with a t-value of 4.117. Chemical costs and fertilizers show similarly significant relationships with coefficients of 0.871 and 0.919, respectively, and t-values of 5.732 and 15.872, respectively, suggesting strong influences on the output. Family labour (coefficient 0.729, t-value 6.775) and hired labour (coefficient 1.463, t-value 6.938) also significantly contribute to production, with hired labour having a higher impact. Fixed costs, irrigation costs, and transportation costs also show significant positive effects, with t-values of 3.087, 8.225, and 6.983, respectively.

Table 4. Results of Cobb Douglas production function Estimated.

Variables (INR/Acre)	Coefficient	Standard Error	t-value
FYM	.929	.226	4.117
Chemical Cost	.871	.152	5.732
Fertilizers	.919	.058	15.872
Family Labour	.729	.108	6.775
HiredLabour (Machine + manual)	1.463	.211	6.938
Fixed Cost	.638	.207	3.087
Irrigation Cost	.725	.088	8.225
Transportation	.592	.085	6.983
Constant	43.085	5.069	8.500
Observations	80		
F-value	60.945		
Prob>F	.000[b]		
R^2	.873		
Adjusted R^2	.859		
RTS	5.212		

Source: Author's Calculation

The F-value of 60.945 and a Prob>F value of 0.000 indicate that the overall model is statistically significant. The R^2 value of 0.873 suggests that 87.3% of the variation in output is explained by the model, and the Adjusted R^2 of 0.859 indicates that the model is well-fitting after adjusting for the number of variables. Finally, the RTS (Returns to Scale) of 5.212 suggests increasing returns to scale in cucumber production, meaning that as inputs are increased, the output increases at a higher rate.

3.5Resource use efficiency in Cucumber Cultivation

The table 5. provides an analysis of the efficiency of various inputs used in cucumber cultivation based on their Marginal Value Product (MVP) and Marginal Factor Cost (MFC). Most inputs, including FYM, Chemical cost, Fertilizers, Family labour, Hiredlabour, Fixed cost, and Transportation, are overutilized, with MVP/MFC ratios below 1, indicating inefficiency in their usage. FYM has an efficiency of 44.17%, Chemical cost has 60.87%, Fertilizers show 87.56% efficiency, Family labour shows 79.36%, Hired labour has an efficiency of 97.46%, and Fixed cost shows the highest efficiency at 98.74%. In contrast, Irrigation cost is underutilized with an MVP/MFC ratio of 1.204, indicating its inefficient use, and it has an efficiency of only 20.43%. Transportation is also overutilized with a low efficiency of 12.3%. This analysis suggests that while most inputs are being used excessively, irrigation and transportation are underutilized, resulting in suboptimal efficiency.

Table 5. Estimates of resource use efficiency in Cucumber Cultivation.

Variables (INR/Acre)	Coefficient	MVP	MFC	MVP/MFC	Efficiency	Percent adjustments
FYM	.929	32.94	59	0.558305	Overutilized	44.17
Chemical Cost	.871	26.22	67	0.391343	Overutilized	60.87
Fertilizers	.919	15.30	123	0.12439	Overutilized	87.56
Family Labour	.729	17.54	85	0.206353	Overutilized	79.36
Hired Labour (Machine + manual)	1.463	8.71	343	0.025394	Overutilized	97.46
Fixed Cost	.638	4.05	322	0.012578	Overutilized	98.74
Irrigation Cost	.725	42.15	35	1.204286	Underutilized	20.43
Transportation	.592	32.45	37	0.877027	Overutilized	12.3

Source: Author's Calculation

4. Discussion

4.1. Average Cost of Cucumber Cultivation

Total average cost was 480914 INR/acrein our study. Total average cost was higher than compared to the previous studies reported by (Nimbrayan & Tanwar, 2018) and (Kumar et al, 2017) in Haryana. A study done by (Patil et al, 2018) also confirm this notion as cost was 200000 INR/acre in shade net house. Fixed cost and hired labour contributed maximum to the cost in our study. The higher cost in protected cultivation tellsabout the majority of the farmers who cannot afford this type of agriculture without subsidy (Jadhav & Rosentrater, 2017).

Material cost which consist of Seeds, chemical, fertilizers and manure attain the highest cost in our study. Labour cost was also around 1/3rd of total cost. In our study seeds cost was common for every farmers because for protected cultivation need specialised seed which were around 70k INR/acre for each farmers. In vegetable cultivation under we need labour at different stage as land preperation, sowing, application of FYM, hand weeding and harvesting which is a basic challenge for agriculture farmers. Mechanisation of vegetable cultivation can help in reduce labour cost.

4.2 Factors affecting profitability

Profitability in cucumber cultivation is influenced by a range of input costs and farm-level management practices. In the present study, the cost of fertilizers, farmyard manure (FYM), and labour was found to positively affect gross revenue, primarily due to their direct contribution to enhancing productivity. Fertilizer application improves nutrient availability, leading to higher yields, while FYM improves soil health and water retention, resulting in long-term productivity gains. Labor costs, although significant, are crucial for the timely application of these inputs and other essential field operations. Additionally, expenditure on chemical inputs such as pesticides and fungicides also contributed positively, as they prevent yield losses due to pest infestations and diseases, thereby stabilizing production and income.

This aligns with findings from (Srivastava et al, 2023), who reported that judicious use of labour and chemicals improved resource efficiency and farm profitability. Similarly, (Mishra et al, 2023) emphasized that input combinations that optimize both yield and crop protection measures result in better returns for farmers. Therefore, input allocation—especially for fertilizers, FYM, and labournot only influences productivity but also determines the overall profitability of cucumber cultivation.

4.3 Yield and profitability

Yield and profitability are key indicators of the economic viability of cucumber cultivation. In the current study, the observed yield and net returns were aligned with trends from controlled cultivation systems. Tripathy et al. (2019) reported yields of 300–600 quintals per acre under protected cultivation, significantly higher than 150–250 quintals per acre typically seen in open-field systems. This yield advantage translated into higher net profits. Srivastava et al. (2023) highlighted farmers under protected systems earned net profits up to ₹120,000 per acre, compared to ₹58,000 in traditional setups.

Additionally, Gadge et al. (2018) reported benefit-cost (B:C) ratios of 2.3 under fertigation systems, indicating high profitability. Singh et al. (2020) noted a B:C ratio of 1.46 without subsidy, suggesting that profitability remains positive even without external financial support. These studies collectively reinforce that protected cultivation and modern agronomic practices significantly enhance profitability when managed efficiently.

4.4 Resource Use efficiency

Resource use efficiency plays a vital role in maximizing returns from cucumber cultivation. Analysis based on Cobb-Douglas production function and Data Envelopment Analysis (DEA) has indicated that land and labour are the most productive resources (Srivastava et al., 2023). The marginal value productivity (MVP) to cost ratio was greater than one for these inputs, suggesting underutilization and potential for increased efficiency. Fertilizer and pesticide usage, however, showed diminishing returns when applied beyond the optimal threshold.

Ashfaq et al. (2016) further supported these findings by applying DEA in off-season cucumber production, concluding that only a small proportion of farmers were operating at optimal efficiency levels. There is clear scope for improving input allocation through training, extension services, and the use of precision agriculture tools. Enhancing resource use efficiency not only improves profitability but also ensures long-term sustainability in cucumber farming. These suggestions should include with proper caution when applying to production process.

Conclusion:

Investment in vegetable cultivation, particularly in the Indian context, holds immense potential not only for enhancing the income of farmers but also for contributing positively to ecological sustainability. The prevailing mono-cropping patterns, especially the continuous cultivation of cereal crops like wheat and rice, have led to serious concerns such as declining groundwater levels, increased input costs, and long-term soil degradation. Diversification into vegetable crops can serve as a strategic intervention to mitigate these challenges.

In Haryana, the scope for expanding vegetable cultivation is especially promising, particularly through the adoption of protected cultivation systems like polyhouses and net houses. These structures allow for controlled growing environments, leading to better yields, reduced pesticide use, and off-season production advantages. The benefit-cost (B:C) ratio of 2.18 reported in our study reflects a highly profitable return on investment under such systems, signalling strong economic viability.

However, a major challenge lies in the high initial investment costs associated with protected cultivation, particularly in crops like cucumber. Costs related to infrastructure setup, irrigation systems, fertilizers, and skilled labour often become prohibitive for small and marginal farmers, limiting their participation in such high-return ventures. This creates a disparity where only medium or large-scale farmers can fully leverage the benefits of advanced cultivation techniques.

To make protected vegetable cultivation more inclusive and accessible, policy interventions are urgently required. Government support should not only focus on capital subsidies but also identify and subsidize the key cost components that disproportionately impact overall expenditure—such as greenhouse construction materials, fertigation units, and labour-intensive operations. Moreover, promoting custom hiring centres, facilitating credit support, and providing technical training can empower smallholder farmers to adopt protected cultivation practices, thereby ensuring equitable growth and sustainable agricultural development.

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