International Journal of Statistics and Applied Mathematics

ISSN: 2456-1452
Maths 2023; SP-8(6): 666-670

https://www.mathsjournal.com
Received: 20-09-2023
Accepted: 21-10-2023

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Technical efficiency of tomato cultivation under precision farming in Dharmapui District of Tamil Nadu: Stochastic frontier approach

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Abstract
The study was conducted to find out the technical efficiency of the precision farming in Dharmapuri District of Tamil Nadu. It employed a multistage purposive sampling method for the selection of sample households. Cost of cultivation method and stochastic frontier production approach were used to find out and compare the benefit cost ratio and technical efficiency of the both precision and conventional non-precision farming. The results revealed that the B:C ratio of precision farming and non-precision farming were 2.64 and 1.96 respectively. The estimated mean technical efficiency revealed that the farmers tended to realise only 93 per cent and 75 per cent of their technical abilities in tomato cultivation through precision and non-precision farming respectively and there was a potential to realize a further seven per cent and 25 per cent of their technical abilities in production respectively. High investment cost followed by smaller farm size, lack of credit facilities and lack of consensus in a joint family to adopt the precision farming system were found as the major constraints in adopting to precision farming to cultivate tomato cultivation in the study area. The study suggested that by providing better training, credit support and subsidy and promoting cooperative farming, the efficiency of tomato production through precision farming would improve in the water scarce study area.

Keywords: Technical efficiency, stochastic frontier, precision farming

Introduction
Agricultural production depends on the season and proper adoption of technology by farmers. The technology must be scientifically sound, knowledge of handling, ready to adoption, economically feasible and viable, and suitable for the farmers as their skills are the important for the successful farming. The existing variation in agro climatic factors and other climatic related factors do cause variations in the levels of adoption. The availability of land has decreased efficient application of fertilizers and pesticides become necessary to increase production. The major effect is that our agriculture has become inorganic cultivation. In this situation, it is essential to develop eco-friendly technologies for maintaining crop productivity. Since long, it has been recognized that crops and soils are not uniform within a given field. The farmers have always responded to such variability to take actions, but such actions are inappropriate and less frequent. Over the last decade, technical methods have been developed to utilize modern electronics to respond to field variability. Such methods are known as spatially variable crop production, Geographic Positioning System (GPS)-based agriculture, site specific application of fertilizer, drip and sprinkler irrigation and Precision Farming. The term ‘spatially variable crop production’ seems to be more accurate and descriptive than the term Precision farming. While the management of our natural resources is of paramount importance to save our agriculture from further deceleration, the use and adoption of some of the advanced technologies and practices would also be a potential tool in improving the efficiency of current production methods. Precision farming is on such technique, which has been advocated by technologists as a proven resource conserving and production enhancing technology to tackle the agrarian problems in rainfed regions of the country.

It is the hi-tech approach which consolidates available technologies relating to soil, water, inputs and varieties and integrates them in an appropriate order in order to enhance the productivity upto the genetic potential of the crop (Sangeetha *et al.*, 2013) [10]. It Ensure that the specific quantity of required farm input resources like fertilizers, insecticides, herbicides, water to plants and the reduction in farm labour activities are the key areas where the technology has been effective. These technologies also ensure improved soil fertility before planting to post-harvest activities (Abdullahi, *et al.*, 2015) [1]. It provides a new solution using a systems approach for today's agricultural issues such as the need to balance productivity with environmental concerns (Shibusawa, 2001) [11] and it reduces both seed and fertilizer rates on a site-specific basis. Still, the studies on its overall efficacy in terms of input use efficiency and productivity enhancement, under field conditions are relatively few to convince our farmers as well as policy makers.

This technology is being implemented by Government of Tamil Nadu through Tamil Nadu Precision Farming Project (TNPFP) since 2004-05. In the state, it was first implemented in Dharmapuri and Krishnagri districts in about 400 ha of land with a total budget of Rs. 720 lakhs for the period of three years as a pilot project, as these two districts together are the major vegetable and other horticultural crops producing region in the state (Vadivel, 2006) [12]. The significant advantage of the technology is that the application of the fertilizer is through drip irrigation which might reduce the quantity of input use, weed growth and hence the cost of cultivation (Miller and Paice, 1998) [8]. At the same time, this would also increase the production (Godwin *et al.*, 2003) and productivity of crops. Hence, the famers could earn higher income through the crop cultivation (Cetin *et al.*, 2004) [3].

India is the second largest producer of vegetables next to China in the world, it is grown in an area of 9.575 million hectares with the productivity of 17.7 mt/ha which contributes 14% of the total world production of vegetables. During 2021-22, India produced 204.61 million metric tonnes of vegetables (Indiastat, 2022) [6]. Tamil Nadu is one among the leading states (Karnataka, Andhra Pradesh and Gujarat are the other states) in India contributing nearly 60 per cent of total output of vegetables.

Out of total production in India, Tamil Nadu contributes 6% in vegetable production. The major vegetables grown in the state are tomatoes, onions, brinjal and drumsticks. Tamil Nadu accounts for nearly 4.59% of the area under fruits and 3.36% of area under Vegetables in the Country. The total area under vegetable production in Tamil Nadu has increased from 25.15 lakh ha in 2013-14 to 33.98 lakh ha in 2021-22, which is mainly due to adoption of advanced technology like precision farming in the state.

Among the vegetables, tomato occupies a prime place in terms of its cultivation in Tamil Nadu and is being undertaken in the months of August - September during which it fetches lower prices for the farmers on account of high supply. On the other hand, the off-season tomato fetches higher prices for the farmers due to its constant demand and lower supply. This supply-side constraint could be effectively tackled by stabilizing the production in off-season through precision farming technology. Since this technology has been widely practiced in Dharmapuri and Krishnagiri districts and potential for tomato cultivation and its marketing in major cities nearby, under this context, the objective of the study is estimate the technical efficiency of precision farming and compare with those farms practicing conventional non-precision farming in one of the districts cultivating tomato for better understanding.

Data and Methodology

Commensurate with the objectives of the study, Dharmapuri district of Tamil Nadu was selected purposively since it is one of the districts where Tamil Nadu Precision Farming Project (TNPFP) was implemented. A multistage purposive sampling method was employed for the selection of sample households. The respondents were selected randomly from the selected block in such a way that there were 50 adopters and 50 non-adopters of precision farming in tomato cultivation, making total sample as 100 farmers. The other information about the study area such as land use pattern and cropping pattern were also collected from Directorate of Economics and Statistics of the district to corroborate the findings of field survey.

Tabular analysis was used to estimate the cost of cultivation of tomato produced under both precision and non-precision farming. The following concepts were used in this study to evaluate and compare the cost of cultivation per unit of product (Palanisami *et al.*, 2002) [9].

Cost A1: Value of hired human labour + Value of bullock labour (both hired and owned) + Value of machine power (both hired and owned) + Value of seeds (both and owned and purchased) + Value of insecticides and pesticides + Value of manure (both owned and purchased) + Value of fertilizers + Depreciation of implements and farm buildings + Irrigation charges + Land revenue cess and other taxes + Interest on working capital + Miscellaneous expenses (electricity charges etc.).

Cost A2: Cost A1 + Rent paid for leased in land
Cost B1: Cost A2 + Interest on value of owned capital assets (excluding land)
Cost B2: Cost B1 + Rental value of owned land
Cost C1: Cost B1 + Imputed value of family labour
Cost C2: Cost B2 + Imputed value of family labour
Cost C3: Cost C2* 1.10 (10% of cost C2 added to cost C2)

Note: This is recently added concept to provide allowance for managerial functions undertaken by the farmer

Cost of Production = (Cost C3 - Value of by-product) / Yield
Net income = Gross return – Cost C3.

The technical efficiency of precision and non-precision farms was estimated by using the stochastic frontier production function proposed by Aigner *et al.* (1977) [2], Meeusen and Vanden Broeck (1977) [7] and Hazarika and Subramanian (1999) [5]. By the use of this approach, it is possible to find out whether the deviation in technical efficiencies from the frontier output is due to farm specific factors or due to external random factors.

$$\log Y_i = \beta_0 + \beta_1 \log X_1 + \beta_2 \log X_2 + \beta_3 \log X_3 + \beta_4 \log X_4 + \beta_5 \log X_5 + \beta_6 \log X_6 + \beta_7 \log X_7 + \beta_8 \log X_8 + Vi - Ui$$

i = 1, 2, ……n.

Y_i = Total tomato production in kg in ha.

X_1 = Seed rate in grams per ha.

X_2 = FYM in kg per ha.

X_3 =Total labour in man days per ha.

X_4 =Total nitrogen in kg per ha.

X_5 =Total phosphorus in kg per ha.

X_6 =Total potash in kg per ha.

X_7 =Total plant protection chemical in grams per ha.

X_8 =Total quantity of water used in ha cm.

Ui =Farm technical efficiency related factor, and

Vi =Random variable.

Technical efficiency (TE)

$$TE_i = Exp(-u)$$

i = 1,2 ……n. $0 \leq TE \leq 1$

Mean Technical Efficiency = $1-\sigma\mu[2/\pi]^{1/2}$

Results and Discussion

Cost of Cultivation

The cost of cultivation was worked out separately for precision and non-precision farming. The results were presented in Table-1.

Table 1: Cost of cultivation of Tomato, (in Rs /ha)

Particulars	Precision Farming	Non-Precision Farming
Operational cost		
Human labour	46,076(19.20)	34,716(24.48)
Machine power	8,614(3.59)	8,614(6.07)
Seedlings	12,438(5.18)	11,874(8.37)
Manures	6,134(2.56)	4,080(2.88)
Plant protection	3,972(1.66)	3,736(2.63)
Fertilizers	60,600(25.25)	25,950(18.30)
Depreciation cost		
Sticks	4,040(1.68)	4,040(2.85)
Investment on drip system		
Tubes	7,200(3.00)	0(0.00)
Tank system	6,074(2.53)	0(0.00)
Total	1,55,154(64.65)	93,011(65.60)
Cost A1	1,73,772(72.41)	1,02,404(72.22)
Cost B1	1,94,550(81.06)	1,04,669(73.82)
Cost B2	2,17,050(90.44)	1,27,169(89.69)
Cost C1	1,95,674(81.53)	1,06,400(75.04)
Cost C2	2,18,174(90.91)	1,28,900(90.91)
Cost C3	2,39,994(100.00)	1,41,791(100.00)
Returns		
Main product (kg)	75,315	38,625
Value of main product	5,27,205	2,31,750
Average price per kg	7	6
Gross income	5,27,205	2,31,750
Net income	3,27,210	1,13,591
Benefit-Cost Ratio	2.64	1.96

Notes: Figures in parentheses indicate percentages to total cost

It could be seen from the Table 1 that the per hectare cost of cultivation was

Rs. 2,39,994 and Rs. 1,41,791 (including managerial cost at 10 per cent) in precision and non-precision farms respectively. The paid out cost (Cost A1) of Rs. 1,73,772 and Rs. 1,02,404 per ha in precision and non-precision farms revealed that the cultivators under precision farming incurred higher amount on variable cost than their counterparts under non-precision farming. This might be due to the installation of drip system (water saving tool) and higher expenses towards application of water soluble fertilizers which are costlier. But the net return realized per ha of tomato was found to be Rs. 3,27,210 and Rs. 1,13,591 in precision farming and non-precision farming respectively. The benefit cost ratio of precision farming and non-precision farming were 2.64 and 1.96 respectively. It indicated that the cost effectiveness of the precision farming would be more than non-precision farming. It was found that though the cost of production under precision farming was higher, the farmers practicing it were getting more profit due to higher yield in off-season period that fetches better price for the produce on account of its uniformity in size, colour and delicious taste of the fruits cultivated under precision farming as compared to non-precision farming.

Regression analysis

Pooled regression analysis was carried to find out the significant difference between the precision and non-precision farming in fertilizer use and the results are depicted in Table 2.

Table 2: Pooled Regression Analysis with Dummy Variables

S. No	Variables	Coefficient
1	Intercept	4.671**(5.116)
2	Intercept dummy	-3.451(-1.875)
3	Seed rate (grams per ha)	0.182**(2.274)
4	FYM (kg per ha)	0.006(0.943)
5	Total labour (mandays per ha)	0.207**(4.575)
6	Fertilizer (kg per ha)	0.093(0.696)
7	Slope dummy	0.949**(2.975)
8	Total plant protection chemical (grams per ha)	0.099(1.706)
9	Total Quantity of water used (ha cm)	0.135**(2.372)
	R^2	0.98

Notes: **, * indicate significance at 1 per cent and 5 per cent levels respectively

Figures in parentheses are T Values

It could be seen from the table that the coefficient of determination (R^2) was 0.98 which indicated that 98 per cent of the variation in total tomato production was explained by the explanatory variables. All explanatory variables had expected signs, among which seed rate, total labour mandays per ha, slope dummy (fertilizer) and total quantity of water used in ha cm were positively and significantly related to the production of tomato in the study area. The coefficient of the fertilizer slope dummy was 0.949 and it implied that one kg of increase in fertilizer would result in 0.949 kg increase in total tomato production keeping other factors constant at their mean level. Similarly, the coefficient for total quantity of water used in ha cm showed that for every one ha cm increase in water used would increase the tomato production by 0.135 kg.

Estimation of Frontier Production function

To estimate the mean technical efficiency in tomato cultivation under both precision and non-precision farming, stochastic frontier production function was used. On the basis of the frontier, the efficiency of management practices in tomato cultivation in the study area was estimated. The parameter estimates of maximum likelihood method for the frontier production function are shown in Table 3.

Table 3: Maximum likelihood estimates of stochastic frontier production model in Dharmapuri District-2006-07

S. No	Variables	Precision farm	Non-Precision farm
1	Intercept	1.670 (1.711)	8.951** (7.151)
2	Seed rate in grams per ha	0.051 (0.632)	0.097 (0.956)
3	FYM in kg per ha	0.058** (2.564)	-0.0005 (-0.085)
4	Total labour in mandays per ha	0.233** (5.630)	-0.201* (-1.854)
5	Total nitrogen in kg per ha	0.808* (2.132)	0.0891 (1.081)
6	Total phosphorus in kg per ha	0.424** (3.878)	-0.037 (-0.286)
7	Total potash in kg per ha	0.024 (0.084)	-0.038 (-0.560)
8	Total plant protection chemical in grams per ha	0.097* (2.094)	0.128 (1.380)
9	Total quantity of water used in ha cm	0.166* (2.307)	-0.059 (-0.769)
	R^2	0.93	0.43

Notes: **, * indicate significance at 1 per cent and 5 per cent levels respectively

Figures in parentheses are t values

The results revealed that the FYM, total labour, total nitrogen, total phosphorus, total plant protection chemical and total quantity of water used contributed positively and significantly towards the production of tomato under the precision farming. These indicated that there was scope for increasing the production of tomato by enhancing the level of these inputs. The total nitrogen has the highest elasticity (0.808), followed by total phosphorus (0.424), total labour (0.233), total quantity of water used (0.166), total plant protection chemical (0.097) and FYM (0.058). The nitrogen and phosphorus fertilizers were showing higher elasticities and it indicated that these fertilizers had the scope to enhance the yield further, especially through promoting the root growth by phosphorus fertilizer and thereby increasing the capacity of the plants to absorb the nutrients from other fertilizers.

The estimated coefficients of non-precision farming revealed that the total labour had significantly negative relationship with the tomato cultivation. All other variables were not significantly related with the dependent variable. The results showed the over utilization of inputs such as fertilizers and water in non-precision farming. The coefficient of multiple regression determinations (R^2) was 0.93 and 0.43 indicating that 93 per cent and 43 per cent of the variation in total tomato production were explained by the explanatory variables in precision farming and non-precision farming respectively.

Technical efficiency

The mean technical efficiency of tomato cultivators in precision farming and non-precision farming was calculated and given in Table 4.

Table 4: Level of technical efficiency in precision and non-precision farming

S. No	Particulars	Mean Technical Efficiency (%)
1	Precision Farming	93
2	Non-Precision Farming	75

It could be observed from the table that the estimated mean technical efficiency in precision and non-precision farming in the study area as a whole was 93 pre cent and 75 per cent respectively. It was implying that the sample farmers tended to realize only 93 per cent and 75 per cent of their technical abilities in tomato cultivation and the remaining seven per cent and 25 per cent of their technical abilities were not realized respectively and hence there exists more scope for the non-adopters to increase their income by adopting precision faming system and for adopters to follow the best management practices by the frontier farmers. The reason for the high technical efficiency by precision farming adopters could be due to better fertilizer use efficiency and water use efficiency and the reasons could be vice-versa for non-adopters of precision farming.

Constraints in adoption of precision farming

Reasons for non-adoption of precision farming as ranked by the farmers, were analyzed through frequency distribution technique. Table 5 shows that the high initial investment for establishing the drip system of irrigation was the most limiting constraint for adoption of precision farming system. Another important issue here was that the cost effectiveness of the drip irrigation was high in large farm size and hence, the marginal and small farmers are not adopting precision faming system. Accordingly, smaller farm size was the next limiting constraint in adoption of precision farming in the study area. Among the various constraints, 36 per cent of the farmers had indicated the high investment cost followed by smaller farm size (28 per cent), lack of credit facilities (24 per cent) and lack of consensus in a joint family to adopt the precision farming system (12 per cent). It is observed that the marginal and small farmers were more in Dharmapuri district because of the fragmentation of land. Hence, it is suggested that subsidies for water soluble fertilizers and drip irrigation system could be given. Apart from these, co-operative farming could be the better solution to consolidate the land holdings as well as to be eligible for enhanced credit support and hence to adopt the precision farming by the tomato cultivators in the study area.

Table 5: Constraints in adopting precision farming

S. No	Reason	No. of Farmers	Per cent of Farmers (%)
1	High investment cost	18	36
2	Smaller farm size	14	28
3	Lack of credit facilities	12	24
4	Lack of consensus in a joint family to adopt to the system	6	12
	Total	50	100

Conclusions

The study has concluded that the yield of tomato under precision farming was two times higher than non-precision farming. The benefit-cost ratio of precision farming and non-precision farming was 2.64 and 1.96 per cent respectively. It was found that though the cost of production under precision farming was higher, the farmers practicing it were getting more profit due to higher yield in off-season period that fetches better price for the produce on account of its uniformity in size, colour and delicious taste of the fruits cultivated under precision farming as compared to non-precision farming. The results of frontier production function indicated that the nitrogen and phosphorus were significantly influencing the tomato yield in precision farming and the total quantity of water used was positive and significantly influenced the yield of tomato. The mean technical efficiency of precision farming was 93 per cent as compared to non-precision farming (75 per cent). It was implying that the sample farmers tended to realise only 93 per cent and 75 per cent of their technical abilities in tomato cultivation and the remaining seven per cent and 25 per cent of their technical abilities were not realised respectively and hence there exists more scope for the non-adopters to increase their income by adopting precision faming system and for adopters to follow the best management practices by the frontier farmers. The study revealed that high initial investment for establishing the drip system of irrigation, smaller farm size, lack of credit facilities and lack of consensus in a joint family to adopt to the system were identified as the major constraints in adopting the precision farming. The study suggested that by providing better training, credit support and subsidy and promoting cooperative farming, the efficiency of production by adopting the precision farming would improve in the water scarce study area.

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