Pak. J. Agri. Sci., Vol. 49(4), 583-588; 2012
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
http://www.pakjas.com.pk

ENVIRONMENTAL AND TECHNICAL EFFICIENCY ANALYSIS IN BITTER GOURD PRODUCTION

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The present research article is designed to determine technical and environmental efficiency using a data set of bitter gourd growers taken from two districts of the Punjab province of Pakistan. Fertilizer and pesticide inputs are treated as environmental detrimental inputs in bitter gourd production. Stochastic frontier production function is used to measure technical efficiency whereas environmental efficiency is estimated as the input-oriented technical efficiency of inputs, fertilizer and pesticide. The mean technical efficiency is found to be 0.64 and the mean environmental efficiency scores are 0.69 for chemical fertilizer and 0.06 for pesticide, showing huge potential to reduce the application of these inputs. Results show that bitter gourd growers can make less use of environmental contaminating inputs while without any impact on yield. Since environmentally friendly produced vegetables are getting preference of consumers and policymakers, this paper provides an insight into production of such type of vegetable production in the country.
Keywords: Chemical fertilizer, environmental efficiency, pesticide, Stochastic frontier

INTRODUCTION

With the onset of the Green Revolution, agricultural productivity was increased. The factors that increased agricultural production and productivity include technological development, introduction of high yielding varieties, increased use of fertilizers and pesticides and more availability of water. This increased productivity helped in solving the problem of food security to a great extent. Statistics indicate that the use of fertilizers and pesticides has increased substantially from 1970 to 2007 (Government of Punjab, 2008), thereby creating environmental side-effects (Vink, 2003). Studies show that the use of fertilizers and pesticides could enhance agricultural production to a certain limit (Sharif and Dar, 1996), thus it is not possible to increase production of crops with more use of inputs such as fertilizer and chemicals. So the time has reached to adopt sustainable agricultural practices, such as best management practices (Tamini and Larue, 2009) because there is significant scope to make the current agricultural production system more environmentally sustainable (Hoang and Allauddin, 2011). Instead of using more inputs, adopting best management practices would make our current agricultural system competitive in the world market as well. However, after the Green Revolution, no and or little efforts have been made to promote environmental friendly practices. In Pakistan, different production systems exist. They include crop production, livestock production, fruit production, etc. However, vegetable production system is one of the production systems where fertilizers and pesticides are used more frequently. Studies conducted by Bakhsh (2002) and Ahmad *et al.* (2004) identified the use of fertilizers above the recommended levels in vegetable production. Similar pattern of chemicals (pesticides) can be found in vegetable production.

Fertilizers cause environmental pollution among which nitrogen pollution is the crucial. Reinhard *et al.* (1999) reported several environmental problems created by nitrogen pollution. In addition to these impacts, residue presence in the vegetables including bitter gourd leads to widespread health risks to the consumers. Moreover, if current agricultural practices continue in the same fashion, soil and water will be less suitable for future production in the long run, creating severe food security problem and rising cost of production as well.

One of the solutions to provide safe food and healthy environment is to optimize the use of chemical fertilizers and pesticides especially in vegetable production in general and bitter gourd production in particular. The vegetable growers including those of bitter gourd can optimize outputs by minimizing the use of environmental detrimental inputs, such as fertilizers and pesticides, thereby reducing environmental health hazards. All this shows that studies need to be conducted determining technical and environmental efficiency in vegetable production. Bitter gourd is one of the vegetables where substantial amounts of fertilizer and pesticide are used. Many studies are conducted in Pakistan, estimating technical efficiency in vegetable production (Bakhsh *et al.*, 2006, Abedullah *et al.*, 2006, Bakhsh *et al.*, 2007), however, very little is known about environmental efficiency. Thus the present study has been designed to determine technical efficiency and environmental efficiency for fertilizer and pesticide inputs in bitter gourd production, since fertilizer and pesticides are considered two critical inputs causing adverse effect on environmental quality. The results of the study will help to identify how the producers can optimize output by minimizing environmental detrimental inputs-fertilizer and pesticides, although fertilizers and pesticides increase bitter gourd production. Balanced use of fertilizer nutrients and timely spray of pesticides coupled with pest scouting are assumed to increase productivity of bitter gourd. The present study provides evidence whether these two farm inputs are used efficiently or not.

MATERIALS AND METHODS

***Empirical analysis*:** The present study has used two methods. In the first method, technical efficiency was estimated by using stochastic frontier production function initially developed by Meeusen and van den Broeck (1977) and Aigner *et al*. (1977) separately. The second method dealt with environmental efficiency. Environmental efficiency was investigated by employing the method developed by Reinhard *et al.* (1999).

At first we describe stochastic frontier production function briefly. It can be written as (Battese and Coelli, 1995, 1992)

$$y_i = f(x_i, \beta)\exp\{v_i - u_i\} \qquad (1)$$

In the above function, y denotes the production level of i-th firm, x is a vector of inputs, β is unknown parameters to be estimated. v is a random error term, independently and identically distributed and u is a nonrandom error term capturing technical inefficiency obtained by truncation of the normal distribution. Thus we can write technical efficiency as follows

$$TE = y_i / [f(x_i, \beta)\exp\{v\}] \text{ or } TE = \exp\{-u_i\} \qquad (2)$$

We have adopted translog production function to estimate environmental efficiency suggested by Reinhard *et al*. (1999). Stochastic frontier production function of translog form used for the present study is as under:

$$\ln Y_i = \beta_0 + \sum_{i=1}^{n} \beta_i \ln x_i + \sum_{i=1}^{n}\sum_{j=1}^{n} \beta_{ij} (\ln x_i)(\ln x_j) + \upsilon_i - \mu_i \qquad (3)$$

y_i represents the yield of bitter gourd at i-th farm, x_i ranges from 1 to 5. x_1 is the quantity of seed used (kg/acre), x_2 shows plant protection measures (Rs/acre), number of irrigation hours used to irrigate one acre of land are given by x_3. x_4 is the labour hours for performing various practices and x_5 is the quantity of chemical fertilizer (nutrients kg/acre). Since translog functional form has been used, the production elasticities were estimated for each input level.

Environmental efficiency index is the ratio of minimum feasibility to an observed input which is environmental detrimental (Reinhard *et al*., 2000, 2002). According to Reinhard *et al.* (1999)

$$EE = \min[\theta : f(X, \theta Z) \geq Y] \leq 1 \qquad (4)$$

Here $f(X, \theta Z)$ is the frontier function, X is a vector of inputs, Z is a vector of environmental contaminating input (chemical fertilizer and pesticides) and Y is output of bitter gourd. For one environmental contaminating input (chemical fertilizer), we can write a stochastic version of environmental efficiency by setting $\mu_i = 0$ and replacing observed input (Z) with θZ (Reinhard *et al.*, 1999)

$$0.5\beta_{55}[\ln\theta Z - \ln Z]^2 + [\beta_5 + \beta_{15}\ln x_1 + \beta_{25}\ln x_2 + \beta_{35}\ln x_3 + \beta_{45}\ln x_4 + \beta_{55}\ln x_5] \qquad (5)$$

$$\ln EE = \ln\theta = \ln(\theta Z / Z) = \ln\theta Z - \ln Z$$

The above function can be written as

$$0.5\beta_{55}[\ln EE]^2 + [\beta_5 + \beta_{15}\ln x_1 + \beta_{25}\ln x_2 + \beta_{35}\ln x_3 + \beta_{45}\ln x_4 + \beta_{55}\ln x_{55}]\ln EE + \mu_i = 0$$

$$\ln EE = [-\{\beta_5 + \beta_{15}\ln x_1 + \beta_{25}\ln x_2 + \beta_{35}\ln x_3 + \beta_{45}\ln x_4 + \beta_{55}\ln x_5\} \pm \{(\beta_5 + \beta_{15}\ln x_1 + \beta_{25}\ln x_2 + \beta_{35}\ln x_3 + \beta_{45}\ln x_4 + \beta_{55}\ln x_5)^2 - 2\beta_{55}\mu_i\}^{0.5} / \beta_{55} \qquad (6)$$

The environmental efficiency index was estimated by using $EE = Exp(\ln EE) = \theta = (\theta Z / Z)$ where θ is the environmental efficiency. The same process has been used to estimate environmental efficiency for other environmental detrimental-pesticides.

***Data and source*:** The input and output data related to bitter gourd production collected by the Department of Environmental and Resource Economics, University of Agriculture, Faisalabad, Pakistan during 2003-04 were used to estimate technical and environmental efficiency. Environmental detrimental variables, namely chemical fertilizer and pesticide are substantially applied in bitter gourd production. The data comprised of 90 bitter gourd growers selected from two districts of Punjab, Pakistan. Four stage sampling technique was applied to choose the bitter gourd growers.

Five variables were taken in translog production function. They include seed, plant protection measures, irrigation, labour and chemical fertilizers. Chemical fertilizer and pesticides are the most important environmental contaminating inputs because the environmental pollution mostly results from these inputs in agriculture. Nevertheless, prices of nitrogenous fertilizers and pesticides are increasing sky rocketing. Limited financial resources possessed by vegetable growers especially bitter gourd growers create problems to purchase and apply these inputs timely. In this study, we would show that how much possibility there is to reduce the use of fertilizer and pesticides without decreasing the level of output. Summary statistics of the variables included in the model are given in Table 1.

Table 1. Summary statistics of variables

Variables	Mean	Minimum	Maximum	SD
Seed (kg/acre)	2.76	1	5	0.96
Plant protection measures (Rs/acre)	1911.11	0	12000	1888.44
Irrigation (hours/acre)	29.40	0.5	72	14.04
Labour (hours/acre)	462.69	86	1210.5	211.24
Fertilizer (NPK kg/acre)	140.87	33.31	361.89	60.08

RESULTS AND DISCUSSION

The software FRONTIER 4.1 developed by Coelli (1994) was used to estimate maximum likelihood estimates of the stochastic frontier production function. Truncated normal distribution was considered for technical efficiency estimation. A generalized likelihood ratio statistic was carried out for possibility of existence of stochastic translog frontier function. It is written as

$$\lambda = -2\ln[L(H_o / L(H_1)]$$

This test statistic indicated that there existed technical inefficiency and therefore, stochastic frontier production function is applicable to the data set of bitter gourd vegetable.

Out of 20 variables of translog production function, 10 variables are statistically significant (Table 2). However, it is much more difficult to describe the coefficients of translog production function individually. Therefore, we have estimated output elasticities of five input variables. Elasticities of seed, plant protection measures and fertilizer inputs are according to our expectation, however, negative elasticities for two inputs, namely labour and irrigation have been found (Table 3). The reasons for negative elasticity for irrigation could be due to the fact that quality of underground water would not be fit for irrigation, since vegetables, especially bitter gourd are more sensitive to quality of underground water. Consultation with agricultural officers in the selected districts confirms my argument that underground water is not suitable for purpose especially for vegetable production. Similar results are found by Ahmad *et al.* (2006) in vegetable production. Negative elasticity for labour input could be due to more use of surplus family labour. Bakhsh (2007) and Coelli *et al.* (2002) argue that large families totally depends on small chunk of agricultural landholdings and the use of labour on such farms is not optimum. The estimated elasticities of output with respect to the chemical fertilizer and pesticide are particularly important in this research article. A mean value of 0.002 indicates that a 1 percent reduction of plant protection measures induce a 0.002 percent decrease in output value. The average output elasticity for fertilizer input is 0.019, indicating that a 1 percent decrease in chemical fertilizer decrease output level by 0.019 percent. Although the coefficients of environmental detrimental variables are small, the signs are according to the expectation and these signs provide an evidence of detrimental impact on environment with an increase use of these farm inputs. It is commonly observed that vegetable growers commonly make use of nitrogenous fertilizers. This imbalanced use of fertilizer nutrients does not increase vegetable yield compared to balanced use of fertilizer nutrients. Similarly, sprays against pests and insects without pest scouting can add to total cost in bitter gourd production.

The estimated technical efficiency of bitter gourd growers is given in Table 4. Results show that the technical efficiency of bitter gourd production was very low with a minimum of 0.12 and maximum of 1 and the mean technical efficiency was 0.64, implying that there existed severe problem of technical inefficiency in bitter gourd production. A mean technical efficiency score of 0.64 show that large amount of output is sacrificed to resource waste. Frequency distribution of technical efficiency show that 59 percent of bitter gourd growers were operating below 70 percent level of technical efficiency. So, there is a need to address this problem in order to increase vegetable production and income of vegetable growers in the country. Mkhabela (2011), Bakhsh (2007), Wossink and Denaux (2006) and Bakhsh *et al.* (2007) also determined the lower level of technical efficiency.

Environmental efficiency results for fertilizer input are shown in Table 5. The mean environmental efficiency is estimated to be 0.69. EE estimate in the present study is higher by that of Wossink and Denaux (2006) in cotton production and lower than that of Mkhabela (2011). Further, the maximum EE in the present study is 0.95 and minimum is found to be 0.05. Farms having EE below 0.70 are 49 percent. Environmental efficiency scores for fertilizer input were quiet higher than technical efficiency scores. Zhang and Xue (2005) found lower EE score compared to TE scores. Moreover, technical efficiency scores for Chinese vegetables were far higher than that of bitter gourd vegetable in the present study.

Environmental efficiency scores for pesticide input are quiet different from those of fertilizer input (Table 6). The mean score is very low (0.06), implying that farmers were not optimizing pesticide use input whereas the use of fertilizer was more efficient at bitter gourd farms compared to pesticide use. Very low environmental efficiency score for pesticide input represents that current pesticide use on bitter gourd is excessive and there is a great potential to reduce pesticide use in this vegetable production. The sign of the coefficient of pesticide variable is according to the

Table 2. Estimation of parameters of stochastic frontier production function

Parameter	Coefficient	Parameter	Coefficient
Constant	1.310 (0.978)	LnSEED x LnLBR	-0.295 (0.219)***
LnSEED	2.976* (1.060)	LnSEED x LnFRT	0.034 (0.348)
LnPPM	0.514 (0.309)**	LnPPM x LnIRR	-0.0438 (0.033)***
LnIRR	-1.242 (0.895)***	LnPPM x LnLBR	-0.078*** (0.058)
LnLBR	0.631 (0.803)	LnPPM x LnFRT	0.062 (0.050)
LnFRT	1.684 (0.957)**	LnIRR x LnLBR	-0.198 (0.186)
LnSEED x LnSEED	-0.264 (0.270)	LnIRR x LnFRT	0.506* (0.192)
LnPPM x LnPPM	-0.005 (0.004)	LnLBR x LnFRT	-0.027 (0.207)
LnIRR x LnIRR	0.022 (0.485)	σ^2	0.439 (0.043)
LnLBR x LnLBR	0.096 (0.161)	Log likelihood	-29.258
LnFRT x LnFRT	-0.395 (0.152)*	Number of observation	90
LnSEED x LnPPM	-0.155 (0.102)***		
LnSEED x LnIRR	0.117 (0.299)		

Table 3. Elasticities of the Output with Respect to each Input

Inputs	Elasticities
Seed	0.097
Plant protection measure	0.002
Irrigation	-0.001
Fertilizer	0.019
Labour	-0.002

Table 4. Technical Efficiency Estimates of the Respondents

Value	Count	Percent	Cumulative count	Cumulative percent
Up to 0.40	14	16	14	16
0.40-0.50	10	11	24	27
0.50-0.60	15	16	39	43
0.60-0.70	14	16	53	59
0.70-0.80	14	16	67	75
0.80-0.90	7	8	74	83
0.90-1	16	17	90	100
Mean				0.64
Minimum				0.12
Maximum				1.00

Table 5. Environmental Efficiency Estimates for Fertilizer Input

Value	Count	Percent	Cumulative count	Cumulative percent
Up to 0.50	6	7	6	7
0.50-0.60	8	9	14	16
0.60-0.70	30	33	44	49
0.70-0.80	33	37	77	86
0.80-0.90	11	12	88	98
0.90-1	2	2	90	100
Mean				0.69
Minimum				0.05
Maximum				0.95

Table 6. Environmental Efficiency Estimates for Pesticide Input

Value	Count	Percent	Cumulative count	Cumulative percent
0.0-0.10	74	82.2	74	82.2
0.10-0.20	10	11.1	84	93.3
0.20-0.30	4	4.5	88	97.8
0.30-0.50	2	2.2	90	100
Mean				0.06
Minimum				0.0
Maximum				0.43

expectation although it is statistically non-significant. The mean score (0.69 for fertilizer input and 0.06 for pesticide input) shows that the output level of bitter gourd could be maintained with using other inputs, however, a reduction of 32 percent in chemical fertilizer input and 99 percent in chemicals (pesticides) will not affect the output level. Thus bitter gourd growers can increase net revenues by decreasing the use of chemical fertilizer and pesticide on one hand and environmental improvement on the other hand.

Conclusions: Vegetables come next after cotton in terms of pesticide use in Pakistan. Indiscriminate use of pesticide in vegetables poses serious threats to human health in addition to adverse impacts on environment, since vegetables are consumed directly. Similarly, chemical fertilizer use is also intensive resulting in financial burden on vegetable growers and detrimental effects on natural resources, such as ground water. All these issues point out judicious use of such detrimental inputs in order to make environment safe and sustainable. Results of the present study provide the evidence to reduce the use of fertilizer and pesticide in bitter gourd production. There will be two outcomes of reduced use of fertilizer and pesticide in bitter gourd production. They include sustaining of bitter gourd production on one hand and declining health hazard in animal and human lives on the other hand. Sustainable resource use can be made possible if vegetable growers are trained and educated about optimal use of chemical fertilizer and pesticide use on vegetable farms and there is a dire need to discourage indiscriminate use of chemical uses in vegetable production. Extension department may have a significant role in this respect (Although the present study does not make an attempt to estimate determinants of environmental and technical efficiency, future research should focus on determining factors having influence on technical and environmental efficiency). Moreover, vegetable growers can earn huge amount through following environmentally friendly practices on the farms in vegetable production, since demand for such products is increasing with the passage of time within country and in international market. The need is to make aware farming community in such type of production. Further, the present study focuses on one vegetable however its results can be an indication for other vegetables as well. It also hints for conducting future studies on this issue in other vegetables, since vegetable consumption in Pakistan is increasing with the passage of time.

***Acknowledgement*:** The author is thankful to Dr Bashir Ahmad for providing data collected in a project funded by PARC under ALP, Pakistan.

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