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ESTIMATING SOYBEAN PRODUCTION EFFICIENCY IN IRRIGATED AREA OF BRANTAS RIVER BASIN

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ABSTRACT

Soybean has an important role in Indonesian diet, especially as source of protein, fat, mineral, and vitamin. Given the relatively stagnant technology, efficiency improvement at farm level would probably be an appropriate way to increase soybean production in the near future. The objective of this paper was to estimate the technical efficiency of soybean production in irrigated area of Brantas river basin and analyze factors affecting technical inefficiency level. The results indicated that the technical efficiency of soybean production in the sites was around 83%. The analysis, however, failed to identify the determinants of technical inefficiency because none of the parameters in the analysis was significant. Further study is required to identify the determinants such that the target groups of extension can be specifically determined. Since K_2O fertilizer significantly affected soybean production while P_2O_5 and N fertilizers did not, the first step to improve the technical efficiency of soybean production was to provide soybean farmers with recommendation regarding balanced amount of fertilizers. The recommendation, however, should be derived from local verification trial in each site.

[*Keywords*: Soybean, productivity, stochastic frontier production function, watersheds, Brantas]

INTRODUCTION

The role of soybean as a source of protein, fat, mineral, and vitamin in Indonesian diet is significant especially in the forms of tofu, soybean cake (*tempe*), and soysouce (*kecap*). The demand for soybean has been persistently increasing from time to time due to the population growth, the increase in per capita soybean consumption, and the growth of livestock subsector (Amang and Sawit 1996). Since domestic soybean production could not pace with soybean consumption, the difference between the two tends to be wider and wider and the gap between soybean consumption and production is covered by import that absorbs a large amount of foreign currencies.

The demand for soybean, as predicted, would increase by 2.92% per year, while the domestic production capacity remains low. Therefore, the import of soybean is predicted to be 1.04 million tons in 2000 and 1.22 million tons in 2010. Sudaryanto (1996) argued that domestic soybean production program is extremely important, but its implementation is problematic for various reasons. First, expansion of soybean production in new areas generally faces the salinity problem. Second, the new frontiers are generally hilly and therefore easily eroded. Third, availability of recommended varieties and quality seeds are limited. Fourth, recommended local specific technologies are not always available. Fifth, the low price levels of soybean, reflected in the farmers' term of trade, do not sufficiently give incentive for the farmers to grow soybean. Sixth, programs such as farmers' subsidy would be contradictory to the free market agreements.

In the near future, given the relatively stagnant technology, efficiency improvement at farm level would probably be an appropriate way to increase soybean production. Since the available resources (the government budget in particular) are limited, then it is imperative to determine priorities of alternative activities. This implies that, in an effort to improve the managerial capacity of the farmers, the Ministry of Agriculture should be able to identify the target groups of the extension service. In other words, it is important to have a map of technical efficiency levels of soybean farmers. The significance of this paper is based on that argument and, therefore, the objective of this paper is to estimate the technical efficiency that can be reached by soybean farmers and identify factors influencing technical inefficiency.

METHODS

Specification of the Model

A method frequently used in estimating the level of technical efficiency, which was introduced initially by Aigner *et al*. (1977) and Meeusen and van den Broeck

(1977), is the one that uses stochastic frontier production function approach. In the subsequent years, Jondrow *et al.* (1982), Waldman (1984), Schmidt (1986), Kumbhakar (1987), Battese and Coelli (1988, 1992, 1995), Bauer (1990), Greene (1993), and Neff *et al.* (1993) carried out a wide range of review and development in this approach. In the last five years, this approach has been applied, among others, by Wilson *et al.* (1998) and Yao and Liu (1998). Similar approach has been carried out by Siregar (1987) and Erwidodo (1992a, 1992b) for the cases in Indonesia.

The general form of stochastic frontier production function as presented by Aigner *et al.* (1977) can be rewritten as:

$$Q_i = Q(X_{ki},\beta)e^{\in_i} \qquad i = 1,\ldots, n \qquad (1)$$
$$k = 1,\ldots, k$$

Q_i = output produced by the i-th observation (farmer)
X_{ki} = vector of inputs applied by the i-th observation
β = vector parameter coefficients
$\in_i$ = specific error term of the i-th observation.

The other name for stochastic frontier model is composed error model since the error term consists of two elements:

$$\in_i = v_i - u_i \qquad i = 1,\ldots, n \qquad (2)$$

Component v_i is the random output variation due to external factors (such as climate) that has symmetric and normal distribution ($v_i \sim N(0, \sigma_u^2)$, while u_i is the error term due to internal factors that can be controlled by farmers and thus reflect farmers' managerial capability. This component is one-sided asymmetrically distributed ($u_i > 0$) and half-normal distributed ($u_i \sim |N(0, \sigma_u^2|)$. If the production process is perfectly efficient, the output level would coincide with maximum potential or $u_i = 0$. In contrast, if the output level is below the maximum potential, then $u_i > 0$. Aigner *et al.* (1977), Jondrow *et al.* (1982), and Greene (1993) defined σ^2 and λ as:

$$\sigma^2 = \sigma_v^2 + \sigma_u^2 \qquad (3)$$

$$\lambda = \frac{\sigma_u}{\sigma_v} \qquad (4)$$

Battese and Corra (1977) defined γ as total variation of actual output toward its frontier such that:

$$\gamma = \frac{\sigma_u^2}{\sigma^2} \qquad (5)$$

Consequently, $0 < \gamma < 1$ and one may obtain the estimated value of γ from σ^2 and λ.

Jondrow *et al.* (1982) has also proved that the individual technical efficiency can be measured from $\in_i$ (equation 1) and the expected value of u_i given $\in_i$ is:

$$E[u_i|\in_i] = \frac{\sigma_u\sigma_v}{\sigma}\left[\frac{f(\in_i\lambda/\sigma)}{1 - F(\in_i\lambda/\sigma)} - \frac{\in_i\lambda}{\sigma}\right] \qquad i = 1,\ldots, n \qquad (6)$$

where f (.) dan F (.) are the normal standard density function and normal standard distribution function, respectively. One can measure the technical efficiency (TE_i) from:

$$TE_i = \exp(- E[u_i|\in_i]) \qquad i = 1,\ldots, n \qquad (7)$$

such that $0 < TE_i < 1$

The general form of TE magnitude is $TE = E(Y_i^*|U_i, X_i) / E(Y_i^*|U_i = 0, X_i)$ (Coelli 1996).

To obtain an unbiased estimation of technical efficiency, maximum likelihood method should be used (Greene 1982). For the purpose of this paper, the frontier production function (equation 8) and its inefficiency function (equation 9) were simultaneously estimated by using FRONTIER program Version 4.1 (Coelli 1996).

- The frontier production function is specified as:

$$\ln y_i = \alpha_0 + \sum_i^n \beta_k \ln x_{ki} + \in_i \qquad (8)$$

where: y = production (in quintal of dried grain)
x_1 = land size cultivate for soybean (ha)
x_2 = soybean seed (kg)
x_3 = N-equivalent fertilizers (kg)
x_4 = P_2O_5-equivalent fertilizers (kg)
x_5 = K_2O-equivalent fertilizers (kg)
x_6 = pesticides (Rp)
x_7 = pump irrigation (Rp)
x_8 = labor (male-hours equivalent)

- The inefficiency function (effect model) is specified as:

$$|U_i| = a_0 + \sum_i^n b_k \ln z_{ki} + \in_i \qquad (9)$$

where: z_1 = number of land plots
z_2 = own irrigated land (ha)
z_3 = cultivated irrigated land (ha)
z_4 = income per capita (Rp $year^{-1}$)
z_5 = age (years)
z_6 = education (years)
z_7 = diversification index
z_8 = number of adult family members
z_9 = education of adult family members

Sampling Design and Data Analysis

The data and information used in this paper were drawn from a study on "Irrigation Investment, Fiscal Policy, and Water Resource Allocation in Indonesia". The scope of this study has initially been designed to represent the entire Brantas river basin in East Java (Table 1).

The purpose of the sampling was to have representative farm households in irrigated area of the basin as a whole. In other words, since the sampling was not specifically designed for a particular crop, the samples were expected to represent farm households in general. A farm household as a sampling unit of analysis was defined as a group of individuals having one expenditure management unit and cultivating at least a piece of land to earn income.

The first step of the sampling was the selection of 12 tertiary blocks of irrigated area in the basin (three tertiary blocks in Tulung Agung district representing upstream region, five tertiary blocks in Nganjuk and Kediri districts representing middle-stream region, and four tertiary blocks in Sidoarjo district representing downstream region). The second step was to have a list of all farmers in each tertiary block, including their size of cultivated land and cropping pattern. The last step was the selection of 40 sample farm households in each tertiary block using stratified random sampling based on the three strata of irrigated land size (L) as follows:

Stratum 1 (small) : $L < \{Avg - 1/2\ (StD)\}$
Stratum 2 (medium) : $\{Avg - 1/2\ (StD)\} < L < \{Avg + 1/2\ (StD)\}$
Stratum 3 (large) : $L > \{Avg + 1/2\ (StD)\}$
Avg = average; StD = standard deviation

As the number of the samples in each tertiary block was 40 farm households, the total number of the samples was 480 farm households. From this number, 129 farm households grew soybean in the third season of 2000, and they were taken as the samples of soybean farmers for the analysis.

RESULTS AND DISCUSSION

Land Holding and Cropping Patterns

If land is simply classified into irrigated field and non-irrigated field, the average sizes of land ownership of farm households was 0.34 ha of irrigated field and 0.09 ha of non-irrigated field, totaling 0.43 ha. The proportion of farmers who did not have their own irrigated fields (their cultivated irrigated fields were rented-in or sharecropped-in from other farmers) was around 23% (Table 2).

The distribution of irrigated field ownership was somewhat skewed since its Gini Index was equal to 0.664. The lowest half (50%) of farm households only had 12% of the total irrigated field ownership. Inversely, the highest 50% of farm households had 88% of the total irrigated field ownership. The

Table 1. Study sites in Brantas river basin, East Java.

Regions	Sources of water	Tertiary blocks	Area (ha)	Villages	Subdistrict	Districts
Upstream	Wlingi Dam (12,321 ha)	RW.2.A.	64	Tanen and Pakis Rejo	Rejo Tangan	Tulungagung
		NT Kanan	72	Boyolangu and Kendal Bulur	Boyolangu	
		CD.1. Kiri	103	Tanggung and Pojok	Campur Darat	
Middlestream	Mrican Barrage (28,904 ha)	BPP12	67	Ngampel and Papar	Papar	Kediri
		BPP17	136	Jontok and Puh Jajar	Purwoasri and Papar	
		KW6	102	Watu Dandang	Prambon	Nganjuk
		KW16	115	Kampung Baru and Waru Jayeng	Tanjung Anom	
		KW23	86	Jambi and Kedung Rejo	Baron and Tanjung Anom	
Downstream	Lengkong Dam (27,362 ha)	P.23	36	Tanjeg Wagir	Krembung	Sidoarjo
		Pj.5.LB	22	Balong Tani	Jabon	
		Mg2.Kanan	30	Mindu Gading	Tarik	
		Kp.16.Kiri	44	Segodo Bancang	Tarik	

Table 2. Average size of irrigated fields in Brantas river basin by the groups of ownership, 1999/2000.

Size (L) of irrigated field ownership (ha)	Sample farmers[1]		Ownership	
	N	%	Number of land plots	Total size (ha)
L = 0	111	23.13	0.0	0.000
0 < L < 0.5	257	53.54	1.7	0.255
0.5 < L < 1.0	85	17.71	3.5	0.647
1.0 < L < 1.5	20	4.17	4.4	1.213
L > 1.5	7	1.46	4.3	2.546
Total	480	100.0	1.8	0.339

[1] 129 farmers who grew soybean in the third cropping season, 1999/2000, were taken as the samples for the analysis

highest 10% of farm households even had at least 37% of the total irrigated fields in the sites.

Cropping pattern is a reflection of choices made by farmers about what, how much, and when to produce. A farmer might apply more than one cropping pattern, particularly if the farmer had more than one land plot. Consequently, the cropping patterns considerably varied from one site to another. In 1999/2000, there were 84 cropping patterns which covered 22 crops grown (Table 3). The largest cropping pattern was rice-rice-soybean (20%), followed by rice-rice-fallow (17%), and rice-rice-maize (13%).

Input Use, Costs and Returns in Soybean Production

In the use of soybean seed, farmers usually broadcast more seed than the normal quantity of seed required. Not only does it relates to the viability of the seed that seldom reaches 95%, but it also reflects farmers' attempt to anticipate stall replacement after planting. Among material inputs, the cost proportions for seeds, fertilizers, and pesticides were respectively 28%, 33%, and 39% (Table 4). About 65% of male labors and 71% of female labors were hired labors.

The major cost components in soybean production were the costs of hired labors and material inputs (Table 5). The shares of the two cost components in the total revenue were 25% and 21%, respectively. Since the share of the total cash costs in the total revenue was about 52%, then the proportion of net returns to farmers as landowner-operators was about

Table 3. Dominant cropping patterns in irrigated fields of Brantas river basin, 1999/2000.

Cropping patterns	Area	
	ha	%
Rice-rice-soybean	43.6	19.8
Rice-rice-fallow	37.0	16.9
Rice-rice-maize	28.1	12.8
Rice-maize-maize	13.2	6.0
Rice-rice-mungbean	12.4	5.6
Rice-tobacco	10.2	4.6
Rice-rice-rice	9.3	4.2
Rice-*bengkoang*-maize	6.7	3.1
Sugar cane	6.4	2.9
Rice-rice-squase	5.4	2.5
Others (74 types of cropping patterns)	47.3	21.5
Total	219.6	100.0

Table 4. Productivity and input use in soybean production, Brantas river basin, third cropping season 2000.

Material inputs and labors	Quantity	Values (Rp000)
Productivity (kg ha^{-1})	1,310	2,518
Land (ha)	0.39	380[1]
Seed (kg ha^{-1})	51	148
Fertilizers (kg ha^{-1})		
Urea	40	42
AS	38	38
TSP	12	20
SP-36	5	7
KCl	19	34
Others (Rp000)	-	33
Insecticides/herbicides (Rp000)	-	207
Labors (hr ha^{-1})		
Male labor		
Hired	644	520
Family	354	0
Female labor		
Hired	257	116
Family	104	0
Hired tractor (hr ha^{-1})	6	55
Hired irrigation pump (hr ha^{-1})	3	17

[1] Value of land rent in the season

Table 5. Costs and returns in soybean production, Brantas river basin, third cropping season 2000.

Costs and returns	Values (Rp000 ha^{-1})	Factor shares (%)
Material input	531	21
Hired labors	637	25
Hired hand tractor	55	2
Hired irrigation pump	17	1[1]
Irrigation fees	32	1
Other equipment	9	1[1]
Land tax	36	1
Total costs (cash + in kind)	1,317	52
Total revenue	2,517	100
R/C	(1.91)	na
Returns to landowner -operator	1,200	48
Land rent	552	22
Returns to tenant	648	26
Imputed costs of family labors	597	24
Interest rates	107	4
Returns to management	-56	-2

[1]Less than 1%; na = not applicable

48%. Although the proportion of net returns was relatively high, it was obviously small in absolute terms, which was Rp1.2 million per hectare for about three months of one production cycle of soybean. The net returns would even be much smaller for an average cultivated land size of 0.39 ha per farm household.

If a farmer is a tenant, farmer has to pay the land rent. In this case, the net returns to the tenant would be Rp648,000 ha^{-1} or about 26% of the total revenue. When imputed family labor costs and interest rate were taken into account, the returns to a farmer, as the manager of soybean production, would even be negative. This information explains that, given the present state of technology, soybean would not be produced by a large company when all costs, including land rent and interest rate, have to be paid by the company. In other words, soybean production is only feasible for smallholders, especially for landowner-operators.

Technical Efficiency Level of Soybean Production

In the last ten years, irrigated field in Brantas river basin has become one of soybean producing regions in Indonesia. The soybean productivity in the third season of 1999/2000 was approximately 1.3 t ha^{-1}, ranging from 0.9 to 1.9 t ha^{-1}. Such a low productivity might be the major determinant of the weak comparative and competitive advantages of soybean production in Indonesia (Siregar 2001). Moreover, the range of soybean productivity among farmers is larger than that of rice or maize. This may be interpreted that the risk in soybean production is higher than that in rice or maize production (Sumaryanto *et al.* 2002).

From now on, the problems facing the soybean farmers would be more complicated since the problems always relates to two things. First, the impacts of international free trade on food crops in general and soybean in particular would be significant. Its impact would be the increasing pressure of competitors from abroad: (1) for agricultural output markets, prices would be pressed down because farmers in some exporting countries may sell their commodities at lower prices; (2) for agricultural inputs, the real prices tend to go up since all input subsidies would be lessened or even eliminated. Second, the scarcity and degradation of resources, particularly of land and water, are getting worse. The population growth and economic development would increase the demand for land and water. On the other hand, if the use of resources (based on sustainability principles) does not directly bring about an adequately short run profitability to farmers, then the rate of resource degradation cannot be reduced. Ultimately, the real problem would be the increasing competition in the use of declining-quality resources.

The extent to which farmers may respond to the challenges is dependent upon their capability to increase farm efficiency. In other words, the challenge the farmers are facing is to produce more output given their resources, or to produce the same level of output by using less quantity of inputs. In practice, attempt to increase farm efficiency is not simple since it depends on their managerial capability and the dynamics of the environment. Managerial capability itself is not only determined by economic variables, but also by social dimensions.

The results of simultaneous estimation of equations (8) and (9) are presented in Table 6. The value of gamma, which was equal to 0.79, implied that 79% of variation in the dependent variable was explained by the variations of independent variables. Computed from all samples, the average level of technical efficiency of soybean production in Brantas river basin was 0.83. Compared with the results of previous study, it was obviously high because the level was in the range of technical efficiency of rice production (Sumaryanto 2001). In spite of the high level of technical efficiency, the proportion of soybean

Table 6. Parameter estimates of stochastic frontier production function of soybean in irrigated land of Brantas river basin, second dry season 2000.

Parameters	Coefficient	t-ratio
Production function		
Intercept	1.7300	2.9855
x_1 Land for soybean (ha)	0.7043	6.0234*
x_2 Seed (kg)	0.2957	2.5344*
x_3 N-equivalent fertilizer (kg)	0.0051	0.7218
x_4 P_2O_5-equivalent fertilizer (kg)	0.0094	1.3052
x_5 K_2O-equivalent fertilizer (kg)	0.0180	2.2896*
x_6 Pesticides (Rp)	0.0202	3.2407*
x_7 Pump irrigation (Rp)	0.0113	1.6047
x_8 Labor (male-hours equivalent)	0.0098	0.1423
Inefficiency function		
Intercept	0.5771	0.8129
z_1 Number of land plots	-0.7242	-1.2447
z_2 Own irrigated land (ha)	-0.2382	-0.4615
z_3 Cultivated irrigated land (ha)	0.2933	0.7152
z_4 Income per capita (Rp/yr)	0.2921	1.3906
z_5 Age (yr)	-0.0096	-1.1090
z_6 Education (yr)	-0.0614	-0.6114
z_7 Diversification index	0.0044	0.0073
z_8 Number of adult family members	0.2468	1.6292
z_9 Education of adult family members	-0.0728	-1.2314
Sigma-squared	0.2453	3.2852
Gamma	0.7933	7.3411

Notes: Log likelihood function = -20.0988
LR test of the one-sided error = 20.0276
*: significantly different from zero at $\alpha = 0.01$
Number of the samples is 129 soybean farmers

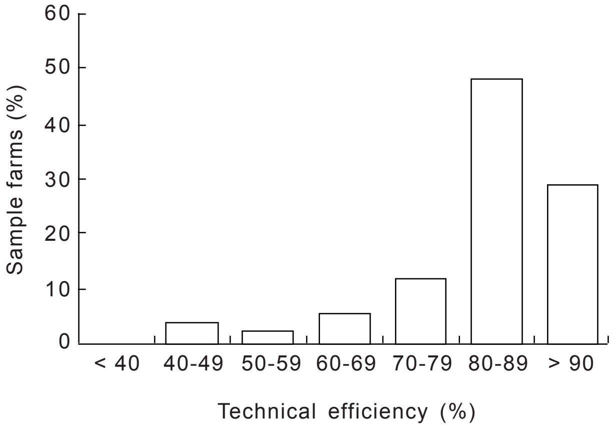

Fig. 1. Distribution of farmers by technical efficiency rating of soybean production in irrigated area of Brantas river basin, 1999/2000.

farmers having technical efficiency less than 0.80 was about 23%, which was still relatively high (Fig. 1). In other word, there is still a relatively large opportunity to improve the technical efficiency.

Land size, seed, K_2O fertilizer, and pesticides positively and significantly affected soybean production, while N and P_2O_5 fertilizers, pump irrigation, and labor did not (Table 6). The production elasticity of land size was 0.70, meaning that an increase in land size by 10% would increase soybean production by 7%. The production elasticity of seed, which was somewhat high (30%), indicated that soybean farmers need more seed than the normal amount to replace soybean stall due to pest damage and drought in the third season. Although the production elasticities of pesticides (1.8%) and K_2O fertilizer (2%) were low, their impacts were still significant at 99% level of confidence.

It is worthwhile to note that while K_2O fertilizer significantly affected soybean production, N and P_2O_5 fertilizers did not. It seems that soybean in the study sites does not need additional N and P_2O_5 fertilizers because of its accumulation in the soil. Note that *Rhyzobium* bacteria in soybean roots also contribute N for soybean crop through N fixation. The insignificant effects of N and P_2O_5 fertilizers on production implied that the soybean farmers need a recommendation about a balanced amount of fertilizers, and this recommendation should be based on local verification trial in each site.

In spite of the high level of technical efficiency in soybean production, there is still possibility to improve the efficiency if factors affecting technical inefficiency could be identified. Unfortunately, the results of estimating inefficiency function presented in Table 6 cannot indicate the factors because none of the nine parameters was significant. It is likely that experience in soybean production and the role of agricultural extension might be the important determinant, but such variables were not available for this paper.

CONCLUSION

The computed average level of technical efficiency of soybean production in Brantas river basin was 0.83. In spite of the high level of technical efficiency, the proportion of soybean farmers having technical efficiency less than 0.80 was relatively high, about 23%. In other word, there is still a relatively large opportunity to improve the technical efficiency. The analysis, however, failed to identify factors affecting technical inefficiency in soybean production because nine determinants included in the analysis did not significantly affect the inefficiency. Further study is required to identify the determinants in a such a way that the target groups of extension can be specifically determined.

Land size, seed, K_2O fertilizer, and pesticides significantly affected soybean production, while N and P_2O_5 fertilizers, pump irrigation, and labors did not. Since K_2O fertilizer affected production while N and P_2O_5 fertilizers did not, the realistic and operational way to improve the efficiency was to recommend soybean farmers to apply fertilizers in balanced proportion. The recommendation, however, should be based on local verification trial in each site.

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