ANALYSIS OF TECHNICAL EFFICIENCY OF RICE PRODUCTION IN PUNJAB (PAKISTAN)
Implications for Future Investment Strategies

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Abstract. The study employed a Stochastic Frontier Production approach to determine the future investment strategies that can enhance the production of rice in Punjab, Pakistan. The data is collected from 200 farmers in the year of 2005 from two Tehsils of Sheikhupura district which is one of the major rice growing districts of Punjab province. The results of stochastic production function indicate that coefficient of pesticide is non significant probably due to heavy pest infestation while fertilizer is found to have negative impact on rice production mainly because of improper combination of N, P, and K nutrients. The improper combination of input use indicates poor dissemination of extension services. Therefore, the role of extension department should be strengthened to enhance the productivity of rice and to protect the major natural resource, ground water for future generations. The results of inefficiency model suggest that investment on tractor (mechanization) could significantly contribute to improve farmer's technical efficiency, implying that the role of agricultural credit supply institutes (such as banks) needs to be redefined. Rice farmers are 9 percent technically inefficient, implying that little potential exists that can be explored through improvement in resource use efficiency. As a long run strategy, the investment on research related activities should be increased to shift the production technology.

I. INTRODUCTION

Rice is one of the most important cash crops that play a vital role in uplifting the country's economy. It contributes more than two million tons to our food

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requirements and is an important source of employment and income generation for rural areas in the rice zone. It also contributes significantly in the foreign exchange earnings. Rice is the third largest crop in terms of area sown, after wheat and cotton, and is cultivated on over 2.5 million hectares in 2005. Its importance in the national economy needs no emphasis as it accounts for 6.1 percent of the total value added in agriculture and about 1.3 percent to GDP (Government of Pakistan, 2005-06).

Pakistan has two major rice-producing provinces, namely Punjab and Sindh. Both provinces account for more than 88 percent of total rice production. Punjab due to its agro-climatic and soil conditions is producing 100 percent of Basmati rice in the country. Important rice producing districts in Punjab are Gujranwala, Sheikhupura, Sialkot, Okara, Hafizabad, Mandi Bahaudin Din and Jhang accounting for more than 70 percent of Basmati rice production in the country.

Several recent studies on the technical and economic efficiencies of crop production, particularly for wheat and rice, have pointed out the existence of a 'yield gap'. This 'gap' refers to the difference in productivity on 'best practice' and on other farms operating with comparable resource endowments under similar circumstances (Kebede, 2001; Wadud, 1999; Villano, 2005). The difference between actual and technically feasible output for most crops implies great potential for increasing food and agriculture production through improvements in productivity, even without further advancement in technology and employment of additional resources (land, labour and water etc.). It is generally believed that resources in the agricultural sector, especially in under-developing countries, are being utilized inefficiently. Farmers are mainly concerned with profitability of farming business which directly or indirectly depends on resource use efficiency. However, little work has been done along these lines in the rice sector of Pakistan and present study is attempting to fill this gap.

Rice production can be increased either by increasing the area under rice production or by improving the efficiency of existing resources allocated to rice production. If rice farmers are already technically efficient, then increase in productivity requires new inputs and technology to shift the production frontier upward. However, if significant opportunities exist to increase productivity through more efficient use of existing resources and inputs with current technology, a stronger case can be made for institutional investment in input delivery, infrastructure, extension system, farm management services, and farmers' skills in order to promote technical efficiency of resource use at the farm level (Ali and Chaudhury, 1990). Hence, like in other crops it is important to investigate technical efficiency and its determinants in rice production.

The present study is attempting to establish a relationship between resource endowments and technical efficiency in rice production in Pakistani environment. It is expected to lead the policy manager to decide where future resources should be allocated to improve rice productivity. The key objective of present study is to estimate technical inefficiency of rice farmers that could contribute in explaining

the yield gap and to determine the role of institutes in improving technical efficiency and rice productivity.

The scheme of the paper is as follows. Section II delineates the analytical model, explains the data collection procedure and discusses the empirical model. Section III presents empirical results and discusses their implications. Last section derives conclusion based on empirical findings.

II. METHODOLOGY AND DATA COLLECTION PROCEDURE

ANALYTICAL FRAMEWORK

Mainly there are three sources of variation in output namely, fluctuations in inputs, technical inefficiency and random shocks. The contribution of inputs can be captured through a production function specification. The variation in output due to technical inefficiency and random shocks can be decomposed through stochastic production frontier approach (parametric approach). The existence of inefficiency in production leads to inefficient use of scarce resources. Technical efficiency (TE) can be estimated by employing different approaches and these includes stochastic production frontier and data envelopment analysis (DEA), also called the non-parametric approach. The advantages and disadvantages of each approach have been discussed by Coelli (1996) and Coelli and Perelman (1999). However, DEA approach works under the assumption of no random shocks in the data set. Farmers always operate under uncertainty and therefore, present study employs a stochastic production frontier approach introduced by Aigner *et al.* (1977); and Meeusen and Broeck (1977). Following their specification, the stochastic production frontier can be written as,

$$y_i = F(x_i, \beta)e^{\varepsilon} \quad i = 1, 2, ..., N \tag{1}$$

where, y_i is the output of rice for the ith farm, x_i is a vector of k inputs (or cost of inputs), β is a vector of k unknown parameters, ε_i is an error term. The stochastic production frontier is also called 'composed error' model, because it postulates that the error term ε_i is decomposed into two components: a stochastic random error component (random shocks) and a technical inefficiency component as follows:

$$\varepsilon_i = v_i - u_i \tag{2}$$

where v_i is a symmetrical two sided normally distributed random error that captures the stochastic effects outside the farmer's control (*e.g.* weather, natural disaster, and luck), measurement errors, and other statistical noise. It is assumed to be independently and identically distributed $N(0, \sigma_v^2)$. Thus, v_i allows the production frontier to vary across farms, or over time for the same farm and therefore, the production frontier is stochastic. The term u_i, is a one sided ($u_i \geq 0$) efficiency component that captures the technical inefficiency of the ith farmer. This

one sided error term can follow different distributions such as, truncated-normal, half-normal, exponential, and gamma (Stevenson, 1980; Aigner *et al.*, 1977; Green, 2000, 1990; Meeusen and Broeck, 1977). In this paper it is assumed u_i follows a half normal distribution $N\left(0, \sigma_\mu^2\right)$ as typically done in the applied stochastic frontier literature. The truncation-normal distribution is a generalization of the half-normal distribution. It is obtained by the truncation at zero of the normal distribution with mean μ, and variance, σ_μ^2. If μ is pre-assigned to be zero, then the distribution is half-normal. Only two types of distributions are considered in FRONTIER 4.1, *i.e.* half-normal and truncated-normal distributions.[1] The two error components (v and u) are also assumed to be independent of each other. The variance parameters of the model are parameterized as:

$$\sigma_5^2 = \sigma_v^2 + \sigma_u^2; \quad \gamma = \frac{\sigma_u^2}{\sigma_5^2} \quad \text{and} \quad 0 \le \gamma \le 1 \tag{3}$$

The parameter γ must lie between 0 and 1. The maximum likelihood estimation of equation (1) provides consistent estimators for β, γ, and σ_s^2 parameters. Where, σ_s^2 explains the total variation in the dependent variable due to technical inefficiency (σ_u^2) and random shocks (σ_v^2) together. Hence, equations (1) and (2) provide estimates for v_i and u_i after replacing ε_i, σ_s^2 and γ by their estimates.

The function determining the technical inefficiency effect is defined in its general form as a linear function of socio economic and management factors:

$$U_i = F\left(Z_i\right) \tag{4}$$

The more detail about dependent and independent variables is given in empirical model.

DATA COLLECTION PROCEDURE

Analysis is carried out by using primary data on input-output quantities and prices from 200 farm households' belongings to two Tehsils, Sheikhupura and Ferozewala from Sheikhupura district of Punjab. The data is collected from 10 villages from these tehsils by the extension department of the Punjab Government. Twenty farmers from each village are randomly selected. A well structured and field pre-tested comprehensive interviewing schedule is used for the collection of detailed information on various aspects of rice for the year 2005.

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[1]On the basis of generalized likelihood ratio test, half-normal distribution is selected for the present study.

EMPIRICAL MODEL

Technical Efficiency can be defined as the ability of a decision-making unit (*e.g.* a farm) to produce maximum output given a set of inputs and technology. The empirical specification of stochastic frontier production function is given as below:

$$\ln y_i = \ln \beta_0 + \sum_{j=1}^{6} \beta_j \ln x_{ij} + \sum_{m=1}^{3} \beta_m D_{im} + \varepsilon_i, \quad i = 1, 2, \ldots, N \qquad (5)$$

Where, '*i*' stands for i^{th} farm and '*j*' stands for j^{th} input. However, 'D' represents the dummy variables and β_0, β_j and β_m denotes intercept, coefficients of different variables and dummy variables, respectively. 'y_i' represents output of rice for the ith farm, x_{ij} is a vector of k inputs (or cost of input) and the detail of independent variables is summarized as follows:

X_{i1} = Area planted for rice

X_{i2} = Plowing hours/farm

X_{i3} = Irrigation hours/farm

X_{i4} = Labour hours/farm[2]

X_{i5} = Plant protection cost or pesticide cost (Rs/farm)

X_{i6} = NPK, Nutrients/farm

D_{i1} = Dummy for planking, if practiced then 1, otherwise 0

D_{i2} = Dummy for puddling, if practiced then 1, otherwise 0

D_{i3} = Dummy for seed dressing, if practiced then 1, otherwise 0

β_j is a vector of k unknown parameters, ε_i is an error term.

Education and age (proxy for experience) are important variables that help to improve the managerial ability of the farmer and both are expected to contribute positive role in the improvement of technical efficiency. It supports the hypothesis that education and experience are basically inputs that are useful for dealing with rapid change in farming system. Therefore, both have included in technical inefficiency effect model. The impact of farm size is ambiguous on inefficiency. The large planting area is likely to have negative effects on inefficiency because larger the planting area, the greater likely is the opportunity to apply modern technologies such as tractors and irrigation. Therefore, farmers with large planting area could be more efficient or less inefficient. Another group of researchers is

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[2]Labour hours include labour for transplanting, weeding, fertilization and spraying pesticide while labour for plowing and irrigation is not included because separate variable exists for these operations. Moreover, labour for harvesting is also not included because harvesting labour is not affecting the output.

arguing that small farmers could be more efficient in utilizing limited available resources for their survival because of economic pressure.

In order to get higher output farmers try to decrease the distance between plants during the transplanting of rice. However, if they have known the mechanics of rice plant and process of nutrients uptake then they would have follow the recommendations of extension department to maintain a standard distance of 9 inches between plants. The accurate distance could play a significant role to improve technical efficiency and that is why we attempted to study the impact of distance between plants on technical inefficiency. As it is assumed that tractor plow deeper than bullocks and therefore, could have positive affect on plant growth. In order to address this hypothesis we study the impact of tractor use on technical inefficiency.

Technical inefficiency (U_i) could be estimated by subtracting technical efficiency from one. The function determining the technical inefficiency effect is defined in general form as a linear function of socio economic and management factors as discussed below:

$$U_i = \delta_0 + \sum_{j=1}^{5} \delta_j Z_{ji} \tag{6}$$

Where, δ_j is the coefficient of explanatory variables and

Z_{1i} = Age of the household head (years), *i.e.* farm decision maker

Z_{2i} = Education, *i.e.* No of schooling of the farmer (years)

Z_{3i} = Farm size (acre)

Z_{4i} = Plant to plant distance

Z_{5i} = Dummy for tractor, *i.e.* if tractor owned then $Z_{5i} = 1$, otherwise 0

Various software packages exist to estimate Maximum Likelihood Estimates (MLE) parameters of the stochastic production function described in equation (5). We employed Frontier 4.1 developed by Coelli (1994). However, it should be noted here that technical efficiency model and inefficiency effect model is not estimated step by step as discussed above rather study employed Frontier 4.1 software which can estimate the coefficient of production function and inefficiency effect model altogether.[3]

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[3]Frontier 4.1 under the option of inefficiency model allows to estimate the Maximum Likelihood Estimates (MLE) of the production function and inefficiency effect model in one step as proposed by Wang and Schmidt (2002).

TABLE 1

Summary Statistics for Different Variables of Rice Farmers in Pakistan, Punjab

Variables	Mean Value	Unit
Age	49	Year
Education	8	Year
Yield/Acre	35	Maund
Farm Size	21	Acre
Area	15	Acre
Plowing	5	No
Fertilizer (NPK)	94	Kg
Plant Protection Cost	459	Rs
Irrigation	30	Hour
Labour	184	Hour
Plants	66021	No/acre
Plant to Plant Distance	10	Inches

The average age of the farm decision maker is observed to be 49 years of old (Table 1), indicating that majority of the old people are involved in farming activities. Average year of schooling of farmer's family member is eight years. It is presumed to be low because of limited available facility of schooling in the vicinity. Mean farm size is 21 acres. The average fertilizer (NPK) rate is 94 kg per acre which is lower than the recommended level of 114 kg of NPK. However, proper combination of N, P, and K (as recommended) is not being followed by the farmers. Average number of plants grown per acre is 66021. Farmers have access to both canal and own tube well water and average hours of irrigation is 27 hours/acre. The average rice yield is 35 mounds [4] per acre with a range of 15 to 60 mounds per acre. High variation in yield could be due to difference in number of plants, planting time, soil quality, different level of input use and random shocks etc. This huge gap of 25 mounds per acre between average and highest farm yield is suggesting that there are constraints on the farmer's side which create hurdles for increasing rice yield from a given set of technology and resources.

III. RESULTS AND DISCUSSION

In order to select the type of production function that fits best to our data set we tested the null hypothesis H_0: $\beta_{jk} = 0$, *i.e.* the coefficient of square and interaction terms in translog production function are zero. After testing the hypothesis whether Cobb-Douglas production function is an adequate representation of the data, given

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[4] 1 mound = 40 kg

the specifications of the translog model we can finally choose the best production function that fits best to our data set. Both functions are estimated but in order to maintain the length of the paper within limits, results are reported only for Cobb-Douglas production function. The values of the log likelihood function for Cobb-Douglas and translog production functions are 115.34 and 140.1, respectively. By employing the log-likelihood ratio test (LR = –2*(117.6-140.1) = 45), we estimated the value of Log Likelihood Ratio (LR) equal to 45. This value is compared with the upper five percent point for the χ^2_{14} distribution, which is 23.68. Thus the null hypothesis that Cobb-Douglas frontier production function adequately represents the data is accepted, given the specifications of the translog frontier.

TABLE 2

OLS and Maximum Likelihood Estimates of the Cobb Douglas
Stochastic Frontier Function

Production Coefficient	OLS Coefficients	MLE Coefficients
Intercept	2.66*** (9.20)	2.98*** (11.55)
ln (Area)	0.80*** (8.98)	0.86*** (10.84)
ln (Plowing hours)	–0.09*** (–2.18)	–0.06** (–1.53)
ln (Irrigation Hours)	0.31*** (6.15)	0.19*** (4.11)
ln (Labour Hours)	0.03^{ns} (1.09)	0.04** (1.52)
ln (Plant Protection cost)	–0.01^{ns} (–0.38)	0.02^{ns} (0.82)
ln (Fertilizer, NPK)	–0.05** (–1.56)	–0.06*** (–2.02)
Dummy for Planking	0.09*** (2.64)	0.06*** (1.94)
Dummy for Seed Dressing	0.14*** (4.79)	0.12*** (4.69)
Dummy for location	–0.10*** (–3.80)	–0.10*** (–4.30)
σ^2	0.02	0.06*** (3.01)
γ		0.83*** (10.24)
Log Likelihood function	102.27	117.63
Inefficiency Effect Model		
Intercept		0.61** (1.49)
Age of the Respondent		0.01*** (1.89)
Education		–0.02*** (–2.11)
Farm Size		0.003*** (2.34)
Plant to Plant Distance		–0.13** (–1.58)
Dummy for Tractor		–0.32*** (–2.14)

NOTE: Values in brackets represent t-ratio.

*** = Highly significant at 1% level, ** = Significant at 5% level, ns = Non significant

The results of Ordinary Least Squares (OLS) and Maximum Likelihood Estimates (MLE) for Cobb-Douglas production function are reported in Table 2 which can be used to test the null hypothesis H_0: $\gamma = 0$, *i.e.* no technical efficiency exists in rice production. It should be noted that the values of log-likelihood function for the full stochastic frontier model and the OLS fit are calculated to be 117.58 and 102.27, respectively and reported in Table 2. This implies that the generalized likelihood-ratio statistic for testing the absence of technical inefficiency effect from the frontier is calculated to be LR = $-2*(102.27–117.58) = 30.62$ which is estimated by the Frontier 4.1 and reported as the "LR" test of the one sided error. The degrees of freedom for this test are calculated as $q + 1$, where q is the number of parameters, other than γ specified to be zero in H_0, thus in our case $q = 9$. The value of "LR" test is significant because it exceeds from the tabulated value taken from Kodde and Palm (1986). The log likelihood ratio test indicates that inefficiency exists in the data set and therefore, null hypothesis of no technical inefficiency in rice production is rejected.

The coefficients of different input variables estimated with MLE technique are reported in last column of Table 2. The parameters of Cobb-Douglas production function can be directly illustrated as production elasticities of inputs in the production process. The parameters of sowing area, number of plowing, irrigation hours, labour hours and fertilizer nutrients (NPK) are significant and hence, playing a major role in rice production. The coefficient of sowing area is positive and highly significant according to the priori expectations. The coefficient of plowing hours is negative and significant at 6 percent probability level; indicating that nearly six percent output will decline with increase in one hour of plowing. It is not clear why this coefficient is significant with negative sign. In order to explain it more specific soil related information is required which are missing in our data set. From the results we can conclude that in our case plowing is less important than puddling, and therefore, farmers should concentrate more on puddling rather than plowing. Additional plowing is wasting the resources because it is just adding in total cost but not in revenue.

The coefficient of irrigation hours is positive and highly significant and it is highest after sowing area, implying that output of rice could be increased further by increasing the availability of irrigation water (canal water etc.) in the area. It is consistent with other studies (Ali and Flinn, 1989; Lingard and Jayasuriya, 1983) because rice is water intensive crop and required comparatively more water than other crops. The coefficient of labour hours is also positive and statistically significant at 10 percent level which is again according to the priori expectation.

The coefficient of pesticide cost is positive but insignificant. It might be due to the reason that heavy pest infestation has occurred which is making the spray ineffective. The coefficient of fertilizer is negative and significant and it is clearly indicating that farmers are using improper combination of different nutrients as discussed in above section. However, total amount of fertilizer (NPK) being used is less than the recommended level and, therefore, negative coefficient of NPK cannot

be referred to higher use of fertilizer as usually argued rather coefficient of NPK in our case is negative because of improper combination of NPK.[5] The improper combination of NPK will not only affect the productivity of soil but it could also affect the quality of ground water in the long run (Nyuyen, 1999; Nguyen *et al*., 2000; NFDC, 1998; Sarah and Brad, 1993). Both soil and ground water are important sources of production and therefore, these resources should be sustained for the future generation in order to maintain their welfare level. Therefore, policy should be adapted to preserve our natural resources by maintaining the output level. Hence, the role of the extension department should be strengthened in the study area to guide the farmer so that they can use the different nutrients of fertilizer in a combination recommended by the Ministry of Food, Agriculture and Livestock, Federal Water Management Cell (1997). Another approach to achieve the similar objective is through input price mechanism.

The coefficient of planking dummy is positive and significant at 1 percent probability level, showing that farmers who plank their field have higher output than those who don't. The coefficient of dummy for seed dressing is also positive and highly significant; supporting the hypothesis that if seed is dressed chemically before plantation then probability of getting disease significantly reduced which appears in terms of higher output. The location dummy is included in the production function to capture the resource based differences in two tehsils of Sheikhupura district. The negative sign of tehsil dummy indicates that output would be less in Ferozewala tehsil compare to Sheikhupura tehsil. It means Sheikhupura tehsil has more conducive soil and climatic conditions for rice production compared to Sheikhupura tehsil.

It is observed that MLE for γ is 0.83 and highly significant (Table 2). It is consistent with the theory that true γ-value should be greater than zero. The value of γ-estimate is significantly different from one, indicating that random error is playing significant role to explain the variation in rice production and this is normal especially in case of agriculture where uncertainty is assumed to be a main source of variation. This implies that stochastic frontier model is significantly different from deterministic frontier, which does not include random error. However, it should be noted that 83 percent variation in output is due to technical inefficiency and 17 percent is due to stochastic random error.

In order to investigate the determinants of inefficiency we estimated the technical inefficiency model elaborated in equation (6), where inefficiency is assumed to be dependent variable. We used age of the respondent as an independent variable and its coefficient is positive and statistically significant, implying that if old people are involved in the farm decision making process then it will lead to

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[5]Farmers are using only 21 kg of P while the recommended level is 34 kg per acreage. In addition to that farmers are also using 25 kg of P_2O_5 while the recommended level of P_2O_5 is zero.

higher technical inefficiency. It might be due to the reason that physically they are not very fit to handle the laborious job at their farms. According to our expectations coefficient of education is negative and highly significant, implying that investment on human capital is a powerful tool to improve efficiency in rice producing area. We also try to explore the impact of farm size on farm inefficiency and results indicate as farm size increases inefficiency increases (Table 3). It might be due to the fact that farmers have limited supply of labour especially during the peak time of rice transplantation and moreover rice is labour-intensive crop (this lead to poor management with increase in farm size). Availability of large amount of timely financial resources at large farms could be another constraint; therefore, big farm size is finally resulting in higher technical inefficiency. The negative coefficient of plant to plant distance shows that as distance between plants increases efficiency increases. It might be due to the reason that farmers are facing problem in weed removing process because of small distance between plants or might be distance between two plants is too small that each plant is competing for the limited availability of nutrients in the soil. However, future research needs to focus on optimal plant to plant distance according to each zone. The coefficient of own tractor dummy is also negative and significant, implying that existence of modern technology at their own farms allow them to perform all operations timely and finally this appears in terms of higher technical efficiency. The results of tractor dummy in inefficiency model suggest that investment on tractor will appear in terms of higher farm productivity and profitability. Hence, agencies responsible for credit supply (such as Agriculture Development Bank) should tie up the availability of credit facility with the purchase of tractor because it is positively contributing in the enhancement of agricultural productivity. However, results cannot be generalized for all crops in different regions of the country and therefore, role of farm assets need to be further explored in other crops more intensively in order to develop a consolidated credit policy for agriculture sector of Pakistan.

TABLE 3

Frequency Distribution of Technical Efficiency for Individual Farms

Efficiency interval	Frequency
$0.900 < TE < 1.00$	151
$0.800 < TE < 0.900$	31
$0.700 < TE < 0.800$	12
$0.600 < TE < 0.700$	5
$0.500 < TE < 0.600$	1
Average	0.91
Minimum	0.53
Maximum	0.98

The frequency distribution of technical inefficiency is reported in Table 3. The maximum and minimum values of technical efficiency are 98 and 53 percent, respectively. The mean technical efficiency in rice production is 91 percent and 151 farmers are more than 90 percent technically efficient and 31 farmers are more than 80 percent but less than 90 percent technically efficient. Twelve farmers are less than 80 percent but more than 70 percent technically efficient.

IV. CONCLUSION

Plowing hours and fertilizer have negative and significant impact on output but plant protection cost is insignificant with positive sign. Fertilizer is being used in improper combination which is not only creating the soil degradation problem but also affecting the quality of ground water. Soil and ground water are two important natural resources that need to be protected for sustainable development. The deterioration of ground water has severe implications on soil productivity (Sarah and Brad 1993). The protection of natural resources is the central theme of present policy matrix and therefore, resources allocated for the protection of these natural resources should be increased. The role of the extension department needs to be strengthened in the study area which seems to be very poor in the present situation. Coefficient of irrigation is positive and highly significant, implying that improvement in irrigation facilities could significantly enhance the production of rice in the study area. Therefore, Government should increase the investment on water management related activities to provide better irrigation facilities to the farmers.

The results of inefficiency model suggest that investment on education and mechanization process should be increased. Therefore, private sector should be encouraged to invest on education in the rural areas and Government institutions (such as Banks) could tie up their credit supply policy with the purchase of tractor to improve mechanization. Old farmers are technically inefficient and therefore, young generation needs to be motivated to participate in agricultural related activities because young generation has better ability to adopt modern technology and to make timely decisions.

On an average farmers are 91 percent technically efficient implying that little potential exists that can be explored to improve resource use efficiency in rice production. Therefore, in order to improve rice productivity in the long run, production function needs to be shifted upward with the help of new production technologies. It implies that research institutes should focus for the development of high yielding and more qualitative varieties and this required more investment on research related activities.

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