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Inefficiency of rice production in Kilombero-Tanzania from stochastic profit frontier model: Farming household as a unit of analysis

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Abstract

Rice grain is substantially touching livelihoods of majority in the world since half of the world's human population rely on the grain for food. Tanzania as a country has been trying to produce rice tremendously in an effort to make livelihoods of its people, making the country in first ranking for East African region in rice production. However, such a good position of the country in rice production has not been reflected in the profit that farming households accrue. This study surveyed 100 farming households in Kilombero district as a showcase to understand why there has been such economic inefficiencies. This research paper used Stochastic Profit Frontier Model (SPFM) to test the hypothesis that socioeconomic aspects do not explain profit inefficiencies of farming households. Results from SPFM showed that farming households in the study area experience economic inefficiency of 24.1% which has been caused by their state of not being technically and allocatively efficient. Further, labor cost was found leading determinant of economic efficiency among other factors. Inefficiencies in profit were eventually found being attributable to socioeconomics specifically irrigation technology used, participation to off-farm economic activities and access to support services like extension and credit facilities. Finally, findings suggest that labor sharing cooperative society could be formed in the study area for labor expense minimization and the conduction of technical trainings to farmers is generally vital to make them producing efficiently especially from economic sense.

Key words: *Farming household; gross margin; Kilombero; stochastic frontier*

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Introduction

Rice is one of the essential grains consumed by majority. Globally, about half of the world's population rely on the grain for food consumption (Msafiri, 2021; Erenstein, 2022). Besides being a staple food, rice along its value chain employment opportunities are created and the grain has been exchanged for income generation. It is pronounced that more than 500 million metric tonnes of milled rice were produced worldwide in the cropping year of 2021 (Shahbandeh, 2023). The Report by Shahbandeh (2023) and DGCIS (2024) stated that India and China are the major world's rice exporting and consuming countries respectively. These facts generally show the rice grain is substantially touching the livelihood of many in the world.

Tanzania in particular, the country produces about 2.2 million milled tons of rice(URT, 2019). it is ranked second position after Madagascar in both production and consumption of rice grain (Kadigi *et al*., 2020; Msafiri, 2021). More important is that Tanzania is leading in East African region in production and consumption of the grain(URT, 2019). Such promising position of Tanzania in the region's rice production and consumption might be attributed to the country's land arability and conducive climatic patterns (Diedhiou *et al*., 2021). The status of Tanzania in rice production in addition has been streamlined by sectoral strategies from the ministry of agriculture. For instance the phase II of NRDS by URT (2019) points out that there has been an extended cultivation area for rice under irrigation and rain-fed. This in turn makes rice production in both seasons secured.

A good position of the country in production and consumption of rice has not fully been reflected in the profitability that rice growers accrue in the farming. Tanzania's rice sub-sector is largely featured by gaps in yield, undesirable quality and improper systems of marketing, leading to poor productivity. According to SAGCOT (2019) Tanzania's rice productivity remains low at 2.5 milled tons compared to the potential of 6.5 milled tons per hectare. The gap between the potential and actual productivity tells that farmers in major rice producing areas like Mbeya and Morogoro are still not efficient in production (Ndabila, 2018). Besides low productivity, rice markets are showing market failures in terms of unstable prices at an expense of increased operational and transactional costs (Kulyakwave *et al*., 2020; Rugumamu, 2014). The situation is even more exacerbated by the fact that these farmers are just smallholders with very little or no influence on the prevailing prices, eventually jeopardizing their profit efficiencies (Nkwabi, 2021). In this regard, when the aforementioned situation is resolved especially closing the yield gap and sorting of marketing systems, there is still potential to accrue more profit by the farmers countrywide (Busindi *et al*., 2014; Kulyakwave *et al*., 2020). It is worth noting Tanzanian rice farmers are not efficient in making profit to capitalize potentials at their disposal (Harding *et al*., 2017).

Profit efficiency in rice production can be easily understood, when the major rice producing areas are studded into district level. In this consideration, Kilombero district presents a compelling area where the issue of profit inefficiency among rice farmers can be looked on. The district contributes to 9% of all rice produced in Tanzania (Musamba *et al*., 2019). However the accessed studies conducted in Kilombero district showed that farmers are below 50% efficient in rice production (Mwanitu, 2015; Isinika *et al*., 2021). This calls for more investigations to estimate current inefficiency in rice production, factors for the inefficiency and strategies that would be adopted to increase efficiency of producing rice among farmers in Kilombero district. The study used farming household as a unit of analysis to estimate the extent at which farmers are currently profit efficient and thus testing the hypothesis that socioeconomic aspects do not explain the level of profit inefficiency among farming households which grow rice in Kilombero.

Theoretical Perspective

This study from microeconomic point of view is led by the theory of economic efficiency. Basically, there are three types of efficiency that economic unit like farming household or a firm may aim to achieve. There is technical efficiency (1), allocative efficiency (2) and economic (profit/production) efficiency (3). Technical efficiency entails an ability of economic unit (farming household) to produce maximal output by the given level of

inputs. The economic unit in this case, farming household, is said to be technically inefficient if it fails to produce maximal output from a given number of inputs. And for the case technically efficient economic unit, it must operate along production frontier (attaining maximum output by the number of inputs given). Moreover, allocative or price efficiency means an economic unit is capable of producing to apply inputs or resources in optimal magnitudes given the respective prices and the available technology. Finally, an economic unit qualifies to be economic/profit efficient if it is both technically and allocatively efficient. In other words, profit efficiency combines technical and allocative efficiency. In this regard, not all technically efficient economic units are profit efficient, they must be allocative efficient as well to achieve profit efficiency.

From the theoretical proposition, profit efficiency of an economic unit is achieved when farming household is able to attain the highest probable profit provided the prevailing prices and fixed number of inputs of the farming household, if this condition is satisfied the farming household is pronounced to operate on the profit frontier, otherwise it is the profit inefficiency. Furthermore, in explaining the concept of profit efficiency in analytical perspective, Battesse and Coelli (1995) came up with an extended expression of stochastic production frontier model that improved the earlier stochastic frontier. The improvement comes from the expression of inefficiency effects as a linear function with independent variables reflected from farming household specific characteristics.

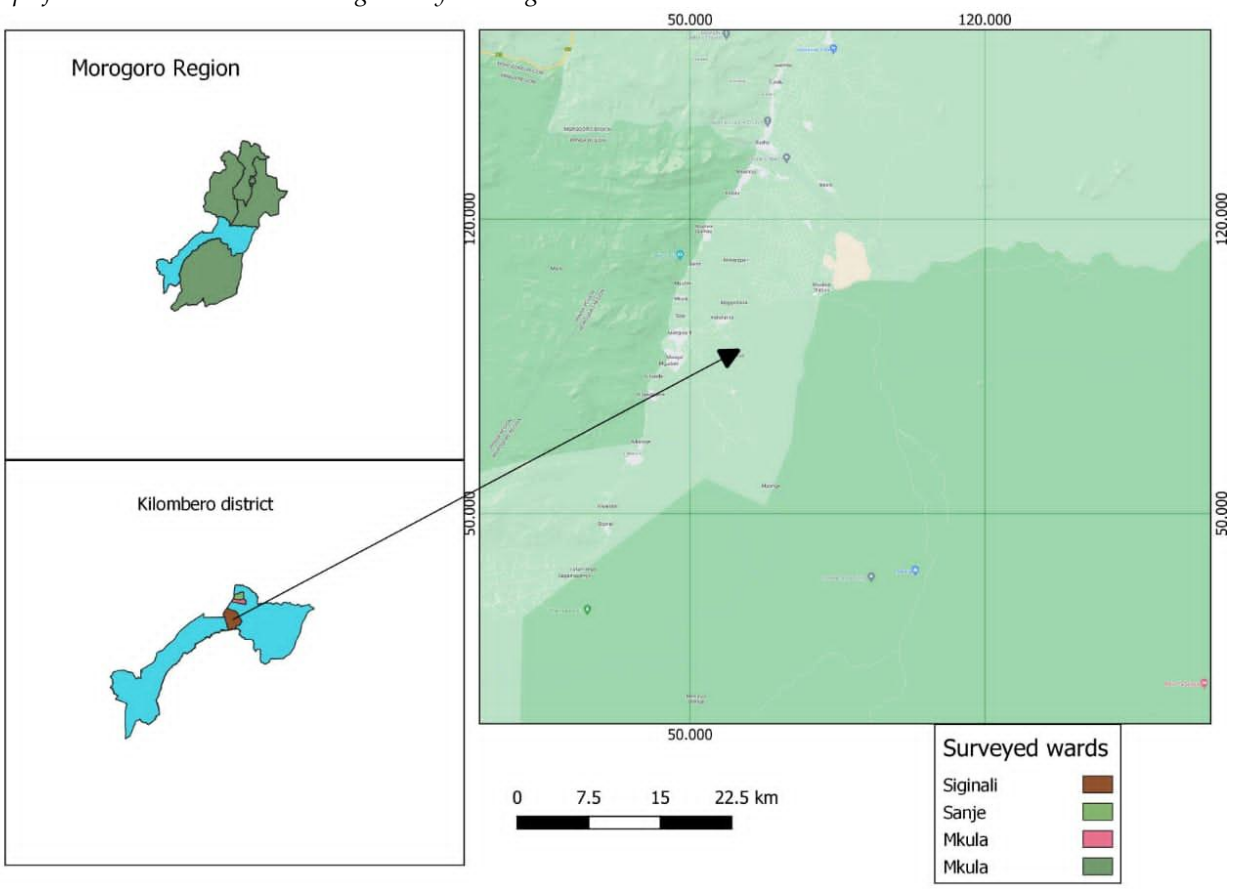
Materials and methods

Study location

This study was conducted in Kilombero District which administratively is found in Morogoro region located in the Mid-Eastern portion of mainland Tanzania. As established above, Morogoro represents major rice producing regions in Tanzania. Kilombero district is leading district in Morogoro region for rice farming and following this fact, data for this study was collected in Kilombero District. The district headquarters are in Ifakara town which is located 410 km away from Dar es Salaam. Geographically, the district headquarter is situated in Ifakara town. Geographically the district is bordered with Mufindi district in the Northern part, Kilosa, Mvomero and Morogoro Districts to the East, Songea and Ulanga Districts to the South-East. The district has human population of 582 960 based on 2022 national census (URT, 2022). The sub-basin has about 400 000 hectares of arable land of which rice production occupies more than 90% of the land (Wilson *et al*., 2017).

Figure 1

Map of Kilombero Districts showing surveyed villages



According to Mosha *et al.* (2016) and Alavaisha *et al.* (2021), Kilombero district has good infrastructures for SRI irrigation as there are major schemes like Msolwa Ujamaa, Mkula and Njage irrigation schemes with lined main canals that supply irrigation water to farm through small, secondary and tertiary canals. Existence of these main, secondary and tertiary canals in these schemes enables farmers in the schemes to easily do alternate wetting and drying which are key practices to adherence of SRI irrigation principles.

Sampling procedures

This study employed multi-stage sampling technique. In first stage, data for this study were collected from four villages purposefully selected from three wards. These included (1) Sululu village which found in Signal ward; (2) Mkula village which found in Mkula ward; (3) Sanje village which found in Sanje ward; and (4) Msolwa Ujamaa Village which is found in Sanje ward. The villages and the respective wards were purposefully selected basing on the existence of irrigation schemes assuring sustainability rice production in both seasons of cropping year. In fact, all available irrigation schemes in Kilombero District are based in the selected study locations.

In second sampling step, since there was no precise data for population of farming households in Kilombero District as admitted in personal communication with head of agriculture department of the district. In addition, Mhoja *et al.* (2021) targeted same population for their study but they reported similar concern existing in the district. Therefore, that sample size of 100 rice producing households was considered enough for this study following the suggestion by McClanahan *et al.* (2005), that in absence of precise study population (like what happened in

this study), the sample size of 80-120 respondents could be drawn to represent study population. Moreover, Sululu, Mkula, Msolwa Ujamaa and Sanje were respectively represented by 24, 25, 22 and 29 randomly selected rice producing households to make the sum of 100 rice farming households.

Data Collection.

Primary data were collected by face-to-face household survey using structured household questionnaires. The study collected data on demographic and socio-economic characteristics of rice farming households, food security (quantity of rice consumed), income sources, labor days spent on rice production, quantitative information on production inputs used, rice harvest and prices of rice in different markets. Moreover, data on demographic and socio-economic characteristics of rice farming households, food security (rice), income sources, labor days spent on rice production, quantitative information on production inputs used, rice harvest were collected from farming households. Adding on that, prices of rice and inputs in farmers nearby markets were also collected.

Data analysis

Profit accrued by farming households must prior be computed to analyze their economic efficiency. Farm budgeting was applied to calculate Gross Margin (proxy of profit). The expression of Gross Margin (GM) is given in equation 1 hereunder as also applied by Mluge (2023) in his profit efficiency analysis for chicken keepers in Dar es Salaam, Tanzania.

$$\pi = \sum Py * Y - \sum Px * X \quad [1]$$

π denotes gross margin accrued by farming household, meanwhile first part in the right hand of the equation 1 is the summation of products of unit price and quantity of rice (total revenue), second part in the right hand of the equation 1 is the product of unit price and quantity of variable inputs used in rice farming by respective household (Total variable cost).

Then for the sake of analyzing the factors that predict profit efficiency of the farming household, the present study adopted stochastic cobb-douglas profit frontier model as was put forward by Battese and Coelli (1995) who included the components of inefficiency effect in the model .The profit efficiency model is explicitly given in the equation 2 below.

$$\ln \pi_i = \beta_0 + \beta_1 \ln C_{1i} + \beta_2 \ln C_{2i} + \beta_3 \ln C_{3i} + \beta_4 \ln C_{4i} + \beta_5 \ln F_{1i} + (V_i - U_i) \quad [2]$$

Where; π_i = normalized profit for i^{th} farming household for i=1,2,3…….100 measured in TZS, C_1 = Charge of labor normalized by rice price (Py), C_2=Cost incurred in pesticides application normalized by the price of output rice(Py), C_3=Cost incurred for fertilizer application standardized by the price of output price (Py) , C_4=Cost of seed normalized by the price of output rice (Py), F_1=The quantity of fixed input i.e. number of acres under rice, V= Two sided random error, U=One sided random error, ln=Natural logarithm, β_0 =The constant or intercept of the model and β_j= The coefficients estimated for j^{th} variable such that j=1,2,3, 4, 5.

Hereunder the model for economic inefficiency or profit loss is specified in the equation 3.

$$U = \delta_0 + \sum_{i=1}^{7} \delta_i L_i + \epsilon_i \quad [3]$$

Where: L_i are the variables predicting economic inefficiency of the farming household; i_1= Farming household's years spent in education, i_2= Farming household's head farming experience, i_3=Participation to off-farm economic activities, i_4= Borrowing i_5=Extension visits i_6=group membership, i_7=seed variety, δ_i =Coefficients estimated for i^{th} variable predicting economic inefficiency such that i=1,2…7 and ϵ = error term.

Then, the evaluation of profit efficiency level further allowed the computation of profit loss attributable to economic inefficiency using the following expression in the equation [4]

$$L = \pi_{max}(1 - PE) \quad [4]$$

Where L stands for profit loss attributable to economic inefficiency, π_{max} symbolizes the maximum profit of individual farming household calculated by dividing the acreage actual profit by efficiency score and PE represents the economic efficiency estimated.

Results

Summary statistics of the variables used in stochastic profit frontier model.

Given that the unit of analysis of this study is the household, and majoring household head as the one who makes decisions related to his or her household. It was therefore plausible to describe household head to snapshot how the particular household looks like. Table 1 includes descriptive data of the variables related to household specified in the stochastic profit frontier model.

The mean age of the household heads surveyed approximated to 47 and the lowest and highest ages being 21 and 74 respectively, indicating that most household heads are in productive ages. Another important demographic aspect of education showed that household head spent an average of 8.8 years in schooling, implying that most of these household heads surveyed probably did not develop further their academic career after completing primary education. Nevertheless, there was an average of 6 years farming experience in rice production among household heads interviewed, showing that most of them are convincingly experienced farmers. On the other side of production, the average size of land allocated for rice farming approached to 1 hectare (2.25 acres), with 0.5 acre (the lowest) and 10 acres (the highest). On average, labor payment accounted for the highest cost on acreage terms among other expenses in rice production. Farming household in the study setting incurs TZS 247138.2 per acre for paying labor. Equally important, the mean fertilizer cost (TZS 45842.93) was found to be the highest one over other expenses incurred in purchasing of agriculture inputs like pesticide (TZS 13603.81) and seeds (TZS 10869).

Table 1

Summary statistics of the variables used in stochastic profit frontier model.

Variable	Mean	Std. Dev.	Lowest	Highest
Household head age	46.71	13.907	21	74
Years spent in Education	8.845	3.988	0	17
Experience years in rice farming	6.3	4.130449	1	22
Land size	2.255	1.781988	.5	10
Seed cost (acreage)	10869	31102.5	0	300000
Fertilizer cost(acreage)	45842.93	49641.99	0	240000
Pesticide cost (acreage)	13603.81	20118.31	0	120000
Payment for labor (acreage)	247138.2	156064.3	0	666666.7
Actual Profit (GM/acre)	575782.6	655554.4	-184666.7	2960000

More important, farming households earn TZS 575782.6 per acre, with the lowest (loss of TZS 184666.7) and the highest (profit of TZS 2960000), which commonly indicating that most farming households surveyed are operating at profit.

Determinants of economic efficiency in rice production among farming households.

Table 2 presents the outputs of the models specified in the equation 2 (profit efficiency model) and 3 (Profit inefficiency model). The profit efficiency model generally portrays the effect of the cost incurred in variable and fixed inputs on the total profit accrued by farming households in rice production. Results from efficiency model showed maximum likelihood is 129.4 which indicates best selection of the cobb-Douglas model over others. Outputs in Table 2 further shows the predicted gamma value is 0.96 (close to 1) implying that 96% of the disturbance in this stochastic profit model has been caused by the state of farming households in the study setting being economic inefficient.

The estimated coefficients of explanatory variables in Table 2 are simply the elasticities of profit with respect to input costs incurred by farmers. In this context, elasticity of profit entails the ratio of percentage change in profit and percentage change in input cost given other factors are hold constant. As it was prescribed theoretically, negative signs in the coefficients of variables specified in the efficiency model shows inverse relationship between input costs and profit. In this regard, a percentage increase in the costs of inputs like seed, fertilizers, pesticides and labor payment would result to a percentage decrease in the respective farming household's profit level.

As it was expected, under ceteris paribus, a percent increase in the labor payment would cause 0.91% decrease in profit level and this finding was found statistically significant. Equally important, one percent increase in the cost of pesticide would result into fall in profit level by 0.53% holding other factors unchanged. Furthermore, it was found statistically significant that 1% increase in the cost of fertilizer would lead to .20% decline in the production profit of the respective farming household.

Table 2

Determinants of economic efficiency in rice production among farming households.

Variables	**Coefficient**	**Z-ratio**
Efficiency model		
Seed cost	-0.19	-1.59
Fertilizer cost	-0.20	-2.14*
Pesticide cost	-0.53	-2.79*
Labor cost	-0.91	-3.18**
Land size	0.373	1.58
Intercept	5.855	4.34
Inefficiency model		
Irrigation technology (0=Traditional flooding irrigation technology and 1=SRI irrigation)	-0.829	4.53**

Years spent in education	0.011	1.07
Engagement in Off-farm economic activity (0=Did not engage, 1=Engaged)	-0.239	-2.22*
Experience years in farming	0.027	2.92**
Form of rice sold (0=not threshed, 1=threshed)	0.647	2.70*
Use of extension service	-0.139	1.99*
(0=Received service, 1=Did not receive service)		
Borrowing (0=Did not borrow money for farming, 1=Borrowed money for farming)	-0.830	3.12**
Group membership	-0.128	-1.57
(0=Has no membership, 1=Has membership) s		
Intercept	.247	2.01
Diagnostic statistics		
Sigma-squared (σ^2)	.774	8.22
Gamma(Ɣ)	.962	79.01
LR test for one sided error	129.4	

** and *statistically significant at 0.01 and 0.05 probability levels respectively.
Source: Computer printout of FRONTIER 4.1

Moreover, second part of Table 2 shows output from the profit inefficiency model. These findings were very decisive in testing the study hypothesis. Overall, there was statistical significance of the model comprising of socioeconomic aspects in explaining profit inefficiency. Hence, the study hypothesis was strongly rejected considering the gamma value of 0.96 (close to 1) which was statistically significant at 0.05 probability level. Further, as it was described in theoretical section, positive signs in the variables' coefficients imply increase in profit inefficiency or decrease in profit efficiency while negative signs in other variables coefficient imply decrease in profit inefficiency or increase in profit. As it was expected, irrigation technology applied had significant influence in the profit inefficiency.

Also, engagement in off-farm economic activities (EFOEA) was found statistically substantial in explaining variation in profit inefficiency among farming households. Farming households with household engaging in off-farm economic activities were less economic inefficient over those not engaging at all. The possible reason is that Off-farm economic activities widen income scope of the farming households to cover the arising production costs in rice farming.

Equally important, each increment in years of farming experience by household head would mean decline in economic inefficiency *ceteris paribus*. This finding holds probably because of the value that experience adds in farming activities. Principally, experience capacitates a respective farmer to handle farm level risks which often exposes production into harvest and finally profit loss. Also, the threshed rice was found statistically

significant to have reduced the profit inefficiency. Farmers who sold rice in threshed form were in good position to be efficient economically compared to their counterparts. The reason is that farmers selling threshed rice win price premiums attributable to form value addition.

Indifferent from the expectation, access to support services among the surveyed farming households has substantially predicted economic inefficiency. For instance, it was found that farming households which used extension services were less economically inefficient than those did not. This might be due to the role that extension services play in rice production activities. Farmers are actually told how to address or improve farm managerial irregularities through officers' farm visits as a popular extension method. In addition, farming households that accessed and used credit facility were more economically efficient compared to those did not. The possible reason for the finding is that the borrowed fund was used to cover the farm expenses emanated in an effort to realize desirable harvests and profit.

Distribution of profit efficiencies

Table 3 shows that the lowest profit efficiency score was 7.2% while the highest profit efficiency score was 97.1%. Further from the findings, the mean score of profit efficiency was 74.9%, indicating that the farming households in the studied area experiences 24.1% loss in profit. In other words, the surveyed farming households have a chance of improving their existing production technologies by 24.1%.

Table 3

Distribution of profit efficiencies

Economic efficiency score (%)	Frequency	Percent
Below 50	2	2
50-60	2	2
61-70	27	27
71-80	38	38
81-90	26	26
91-100	5	5
Total	100	100
Lowest	7.2%	
Highest	97.1%	
Mean	74.9%	
Standard deviation	12.2	

Results in Table 3 have also indicated that few (31%) of the farming household scored at least 91% of profit efficiency and the fewest (2%) scored below 50% of profit efficiency. It follows that most farming household have profit efficiency scores ranging from 50% to 80% which based on Saysay (2016) categorized it as the middle class of profit efficiency scores.

Discussion

From descriptive statistics, labor payment accounted for the highest cost on acreage terms among other expenses in rice production. This reveals to high labor intensity nature of rice farming. The finding looks different from what Reddy and Mutkuri (2013) found in India that cost for labor in rice farming were relatively declining over other farm expenses attributed to decline in labor intensity of Indian rice farming. Equally

important, the mean fertilizer cost was found to be the highest one over other expenses incurred in acquiring agriculture inputs like pesticide and seeds The observation conforms to conclusion drawn by Chun and Amoranto (2015) that cost incurred in acquiring fertilizers was the leading expense among other agriculture inputs in rice farming in Cambodia, caused by increased importing cost of fertilizers. More important, farming households have positive returns (implying profit), which commonly indicating that most farming households surveyed are operating at profit. This is indifferent from what Mauki *et al*., (2023) communicated in their study that most Tanzanian rice farmers are accruing profit with differing margins.

Furthermore, a percentage increase in the costs of inputs like seed, fertilizers, pesticides and labor payment would result to a percentage decrease in the respective farming household's profit level. Specifically, increase in labor payment had most detrimental effect on profit efficiency holding other factors unchanged. The finding is aligning to contribution made by Bekata and Rembabu (2021) that payment to labor lowers significantly economic efficiency attained in cereal crops among Ethiopian smallholder farmers.

In the case of profit inefficiency, farming households applying SRI irrigation were found to be less economically inefficient compared to those applied traditional flooding irrigation. This is because SRI irrigation is mentioned to be better in productivity and eventually sales. This finding agrees with what Adomako (2020) found in Northern Ghana.

Also, farming households with household head engaging in off-farm economic activities were less economic inefficient over those not engaging at all. The finding supplements to another result by Harmini *et al*. (2022) who found EFOEA reduces technical inefficiency in Indonesia's rice farming implying that EFOEA might not be good in achieving technical efficiency but generally better in achieving economic efficiency.

In addition, support services like extension and credit services were found to lower profit inefficiency among surveyed rice farming households. Sadiq (2021) and Mauki *et al.* (2023) found the same in Nigeria and Tanzania (Mbarali, Mvomero) respectively. In addition, farming households that accessed and used credit facility were more economically efficient compared to those did not. The finding is supported by Duy (2015) and Saysay (2016) who had similar observation in Vietnam and Liberia respectively that credit borrowing positively influenced profit efficiency.

Conclusion

The evaluation of economic efficiency was done by using stochastic profit frontier model. The results show that economic inefficiency exists among farming households in rice production with socioeconomic aspects of farming households determining such inefficiency. It was found farming households in Kilombero have an opportunity of improving their profit efficiency by 24.1% using the existing technologies. The said improvement in profit efficiency as it was put forward in theoretical section could be achieved through recovering both allocative and technical inefficiencies. It was further evidenced that labor cost accounts for major changes in profit efficiency. Further key findings include the use of SRI irrigation, participating to off-farm economic activities and selling threshed rice were positively influencing profit efficiency in rice production. In addition, support services like credit facility and extension services were substantially found to have reduced economic inefficiencies among the surveyed rice farmers.

Recommendations

From these findings, the study proposes that farming households in the study sites could think of forming labor sharing cooperative society in an attempt to minimize labor expenses. The study also recommends more trainings on SRI irrigation superiority and value addition (selling processed rice) being set to make these farming households producing rice profitably.

Further, the study recommends the recruitment and placement of more extension officers to the surveyed sites. This recommendation is of course feasible given the fact that capable graduate extensionists are numerous and not yet found jobs of their profession.

Finally, stakeholders in the supply side of

financial services especially microfinance could initiate financial products like agricultural credit with affordable interest rates in the surveyed wards as the demand for such services is enormous.

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Ethical approval and consent

Authors of this research indubitably declare that all ethics from data collection, analysis and in report writing were adhered to the best of their knowledge.

Conflict of interest

Authors of this research article confidently declare that there is no any conflict of interest pertain to this work.

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