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Performance Gap between Best-bet System of Rice Intensification and Farmers' Practices in Zamfara State, Nigeria: An Additive-Multiplicative Translog Stochastic Frontier Profit Function

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ABSTRACT
Inadequate information about the performance of a technology can hinder its uptake. The aim of this paper was to provide a thorough examination of the performance gap between the best bet system of rice intensification (BB-SRI) and farmers' practices (FP) in Zamfara State, Nigeria. Using a multi-stage sampling technique, a sample of 300 rice farmers were selected from the Bakolori Irrigation Scheme, Zamfara State, among which 40 farmers (13%) used the BB-SRI while the remaining 260 farmers (87%) used FP. The data were analyzed using descriptive statistics, farm budget technique, additive-multiplicative stochastic frontier translog profit function and propensity score matching (PSM) estimator. The findings revealed that yield increased from 5,285 kg/ha with FP to 12,735 kg/ha with BB-SRI, an increase of 141%. Rice production was profitable under both FP and BB-SRI with return on investment (ROI) increasing from 2.64 using FP to 6.66 under BB-SRI, an increase of 152%. There was evidence of profit inefficiency in rice farming since the profit could still be raised by 7% and 21% using FP and BB-SRI, respectively. The yield, ROI and profit efficiency gaps between the BB-SRI and FP ranged from 7,452 kg/ha to 7,510 kg/ha, 4.02 to 4.05, and from 0.08 to 0.09, respectively. We recommend therefore that important investments and training in SRI should be considered as a top priority for the transformation and sustainability of the rice sector in order to ensure its successful promotion, uptake and diffusion across other rice producing States in Nigeria.

Keywords:
Efficiency,
Intensification,
Irrigation,
Matching,
Profit.

INTRODUCTION

Rice (*Oryza Sativa*), which is one of the most important crops in Nigeria in terms of provision of calorie intake and income, is cultivated in the country under five major rice production systems – Rainfed upland, rainfed lowland, irrigated, deep water/floating, mangrove swamp – with the lowland irrigated system being the most productive with an estimated potential yield varying between 6 to 10 tonnes/ha (Ezedinma, 2008; Kamai *et al.*, 2020). But the supply and demand gap continue to be a serious concern for the government over several years despite continuous investments and promotions of local rice farming (Udemezue, 2018; Kamai *et al.*, 2020). An important limitation to these farming systems is that the bulk of the production is cultivated mainly by inefficient small-scale farmers whose capital and capacity to overcome the effects of climate change such as drought, flood, degrading soil quality, pest and diseases are quite inadequate. Although, a number of improved rice varieties have been released in recent years to minimize the effect of the poor environmental conditions in which farmers find themselves, the actual yield still falls far below its potential which itself is lower than the potential yield in other developing countries like China, India and Indonesia. In other developing countries especially in Asia and South America, in contrast, small-scale farmers have taken advantages of other methods of rice production such as the system of rice intensification (SRI) not only to close the gap between the demand and supply, but also to offer themselves the opportunity to shift their production frontiers in order to generate marketable surplus for improved income and to become more efficient.

A common characteristic of the irrigated system of rice production based on conventional practices is its high cost of production (Selvaraju, 2013). Although, this may not be less true with respect to SRI especially for farmers with very limited experience in the application of SRI principles, the benefits of SRI are diverse such as environmental (reduced green house gas emission), economic (increased yield and profit), and social (Anthofer, 2004; Thiyagarajan, 2004; Xiaoyun *et al.*, 2005; Sato, 2006; Gathorne-Hardy *et al.,* 2016; Zaman *et al.*, 2017). It is remarkable to note that the promotion of SRI in Africa as a whole and in Nigeria in particular still remains limited despite showcasing promising results in Asia most especially. Several reasons have been proposed as to why SRI has not experienced rapid dissemination and adoption worldwide. One of these is the controversy surrounding its actual benefits, which could be due to the fact that SRI is not viewed as a technology where fixed set of practices are predefined, necessitating intensive training by experts (Mati, 2010; Selvaraju, 2013; Barrett *et al.*, 2021). This may equally point out the fact that more empirical evidence is required to provide a strong basis to justify investments in SRI. One of the strategies to achieve such objective is by providing evidence on performance gap between the existing rice farming system and SRI. Moreover, of critical importance is the issue of improving farmers' resource management of their productive inputs. The current literature seems to agree that SRI farms are more technically efficient than conventional farms. However, technical efficiency does not provide an estimate of the overall performance of a firm, which is critical in this context where there are questions regarding the cost implications of SRI. Moreover, incomplete information concerning the availability and profitability of a technology can hinder its adoption (De Janvry *et al.,* 2017). There is therefore a need to consider broader measures of performance such as profit efficiency which captures not only farmers' cost minimization behaviour but also their output and revenue maximization behaviours.

It is against this background and drawing from the SRI's promotional study carried out in 2020 in Zamfara State, North-west, Nigeria, that this paper proposed to achieve three specific objectives: (1) to estimate the profitability of the BB-SRI and FP; (2) determine the profit efficiency of users of the BB-SRI and FP; (3) to assess the performance gap between the BB-SRI and FP.

MATERIALS AND METHODS

Description of the Study Area

The study was carried out in Bakolori Irrigation Scheme (BIS) which is located in Zamfara State and particularly in three of its fourteen Local Government Areas (LGAs) namely Talata Mafara, Maradun, and Bakura. The Bakolori dam whose water is used to supply the project site, had a water storage capacity of 450 million cubic meters at the time its construction was completed in 1979, but is currently estimated to be 351,010,027 cubic meters as at 2013 (Sa'adu *et al.,* 2017). It presently supplies water to 7,039 ha (31%) by gravity and 15,961 ha (69%) through sprinklers, which makes up the total land area of 23,000 ha covered by the project. The major occupation in the State in general and in the project site in particular is farming which is carried out by resource-poor farmers, but other important occupations include craft, trading, hunting, and nomadic pastoralism (Saddiq, 2012). Aside rice, other crops mainly produced in BIS include millet, sorghum, groundnut, maize, cassava, sweet potatoes, pepper and tomatoes.

Sampling Procedure and Sample Size

The TRIMING-SRI project was implemented in two phases. The first phase was concerned with the testing of SRI practices conducted in 2018 and 2019 while the second phase involved the promotional research which was carried in 2020. But the focus of this study was on the promotional research of 2020. Using a multi-stage sampling technique, SRI and Non-SRI rice farmers were selected for this study. In the first stage, seven (7) sectors or intakes where the project was carried out were purposively selected. In the second stage all the 40 main farmers who participated in the promotion of the BB-SRI were selected (Table 1). In the third stage, based on the sample frame and using a proportional random sampling technique, a total of 260 farmers under FP were equally selected, thereby making a total of 300 rice farmers for the study.

Table 1: Sampling frame and sample size of rice farmers in BIS based on the promotion of SRI carried out in 2020

Sector	S. Frame	Prop.	Sample size		
			SRI	Non-SRI	Total
E-Down	1,295	0.08	3	20	23
E-Left	1,645	0.1	4	25	29
M-Rice B	1,750	0.1	4	27	31
N-Rice	3,500	0.21	8	54	62
G-Rice B	2,730	0.16	6	42	48
Intake C	3,325	0.2	8	51	59
F-Right	2,660	0.16	6	41	47
Total	16,905	1	40	260	300

Source: Bakolori Irrigation Scheme (2020)

The BB-SRI

For the identification of the BB-SRI most suitable for the ecology in BIS, a testing research investigation was carried out between 2018 and 2019 in BIS by the SRI component of the Transforming Irrigation Management in Nigeria (TRIMING-SRI) project. The intention of the two-year testing research was basically for the purpose of establishing robust results given that climate has become quite unpredictable in recent years in Northern Nigeria. During this phase, different sets of SRI recommended practices were tested namely, age of seedlings at transplanting treatments, spacing patterns, irrigation regimes and fertilizer trials (Table 2). Using the yield, net farm income (NFI), and ROI as performance indicators, the best combinatorial practice which we referred to as the BB-SRI comprised of 11 days old seedling (DOS), 25 cm × 25 cm, AWD and "Full compost". The "Full NPK" had a higher profitability than the Full Compost as a fertilizer trial. However, Due to ethical and economic reasons, organic manure along with urea in form of supper granules was applied instead of the "Full NPK". Specifically, farmers were unwilling to use full organic fertilizer alone on their rice plots. Consequently, to encourage the uptake of SRI practices in the study area, the decision of using organic manure along with urea was proposed to farmers which yielded positive responses. Moreover, the choice of adding urea was proven reasonable because of the high possibility of nitrogen leaching and denitrification in the rice fields.

Table 2: SRI and non-SRI practices tested in BIS in 2018 and 2019

S/N	Treatment	SRI	non-SRI
1	Seedlings' age at transplanting	9 days old, 11 days old, 13 days old and 14 days old.	16 days old, 18 days old and FP
2	Spacing patterns	25 cm × 25 cm, 30 cm × 30 cm and 35 cm × 35 cm	20x20 cm and FP (Random close spacing of less than 20 cm x 20 cm)
3	Irrigation regimes	Alternate wetting and drying (AWD)	Continuous flooding
4	Fertilizer trials	Full Org, 1/2NPK & 1/2Org, 3/4NPK & Full Org and Full NPK.	FP (NPK =119 kg/ha and Urea =89 kg/ha) and control trial (No fertilizer)

Source: Transforming Irrigation Management in Nigeria (TRIMING, 2020)

This study used primary data which were collected using pre-tested structured questionnaires by trained extension agents. The main managers of rice plots in the study area were interviewed and detailed data on input and output with their respective market prices were collected. Data on cost and returns were equally collected from the scientists that supervised the SRI plots in order to crosscheck the data provided by farmers.

Analytical Framework

Farm Budget Models

Following Bandumula *et al.* (2017) and Zaman *et al.* (2017), the farm budget model was used to estimate the profitability of the BB-SRI and FP. The indicator of profitability considered here is the return on investment (ROI) from using the BB-SRI. The farm budget model was computed as:

$$NR = TR - TC \quad (1)$$

where NR = Net returns; TR = Total revenue; TC = Total cost of production while the ROI was estimated as:

$$R\hat{O}I = \left(\frac{TR}{TC}\right) - 1 \quad (2)$$

There is production loss or profit if $ROI < 0$ or $ROI > 0$. On the other hand, there is neither profit nor loss if $ROI = 0$.

Additive-multiplicative Translog Stochastic Frontier Profit Function

Production and cost functions can be viewed as restricted profit functions (Varian, 1992) and are therefore inadequate to provide a complete explanation of the overall efficiency of a firm. Let us assume that rice farmers attempt to maximize their profit according to the following maximization programme:

$$\max_{Y,X} \quad PY - W^{'}X$$
$$s.t. \quad Y = f(X)e^{-u} \quad (3)$$

where P = Output price; $Y \geq 0$ is a scalar output; W = Vector of variable inputs' prices; $X = (x_1, \cdots, x_N)$ = Vector of variable inputs; $f(\bullet)$ = Deterministic kernel of a stochastic production frontier which represents the relationship between inputs and output; e =Exponential operator; $u \geq 0$ is the output-oriented technical inefficiency (OO-TI) term. We assumed here that quasi-fixed inputs are negligible given that farmers are small-scale producers. The first-order conditions (FOCs) are given as:

$$Pf_j(X)e^{-u} = W_j$$
$$f_j(X)e^{-u} = \frac{W_j}{Pe^{-u}} \quad (4)$$

where $j = 1, \cdots, J$; $f_j(\bullet) =$ Partial derivative of $f(X)$ with respect to input *j*. Drawing from Kumbhakar *et al*. (2014), the derived profit function can be expressed as:

$$\pi(W, Pe^{-u}) = Pe^{-u} f(X(\bullet)) - w^{'} X(\bullet) \quad (5)$$

where $f(X(\bullet)) =$ Output supply function and $X(\bullet) = x(W, Pe^{-u}) =$ Input demand function. The actual and maximum profit function can be expressed following equation (5), respectively, as:

$$\pi^a = \pi(W, Pe^{-u}) = Pe^{-u} f(X(\bullet)) - w^{'} X(\bullet) \quad (6)$$

$$\pi^m = \pi(W, P) = Pf(X(\bullet)) - w^{'} X(\bullet) \quad (7)$$

According to equation (7), the maximum (frontier) profit is simply the actual profit without inefficiency. In other words, given the homogeneity property of a profit function, that is $Pe^{-u} \leq P$ and $\pi(W, Pe^{-u}) \leq \pi(W, P)$, the actual profit can be defined as a function of the frontier profit and a deviation function as:

$$\pi^a = \pi(W, Pe^{-u}) = \pi(W, P) \times g(W, P, u)$$

$$or$$

$$ln\, \pi^a = ln\, \pi\, (W, Pe^{-u}) = ln\, \pi\, (W, P) + ln\, g\, (W, P, u) \quad (8)$$

where the deviation function $g(W, P, u) = \frac{\pi(W, Pe^{-u})}{\pi(W, P)}$ can be viewed as the profit efficiency level which is expected to be between 0 and 1; $ln =$ Natural logarithm operator. By considering a normalized version of equation (8) and supposing that $f(X)$ takes a translog form and is homogenous of degree 1, the profit function can be specified as (Kumbhakar *et al.*, 2014):

$$ln\left(\frac{\pi_i^a}{P}\right) \equiv \beta_0 + \beta_1\, ln\left(\frac{w_1}{P}\right) + \sum_j \beta_j\, ln\left(\frac{w_j}{P}\right) + \frac{1}{2}\sum_j \sum_k \beta_j\, ln(\widetilde{w}_j)\, ln(\widetilde{w}_k) - \tilde{u} \quad (9)$$

where $\beta_1 = \frac{-r}{(1-r)} - \sum_j \beta_j$; $ln(\widetilde{w}_j) = ln\left(\frac{w_j}{P}\right) - ln\left(\frac{w_1}{P}\right)$;$\tilde{u} = u[1 - \sum_j \beta_j] j, k = 1, .., J$; $r =$ Return to scale; $\tilde{u} =$ Difference between the log of maximum profit and actual profit. The implication is that $\tilde{u} \times 100$ measures the percentage by which profit is forgone due to technical inefficiency. In order to assess the profit differential effect between two distinct groups, equation (6) can be reformulated as (Gujarati, 2004):

$$ln\left(\frac{\pi_i^a}{P}\right) \equiv \beta_0 + \beta_1\, ln\left(\frac{w_1}{P}\right) + \sum_j \beta_j\, ln\left(\frac{w_j}{P}\right)$$

$$+\frac{1}{2}\sum_j \sum_k \beta_j\, ln\left(\frac{w_j}{P}\right) ln\left(\frac{w_k}{P}\right) + \beta_A A + \sum_j \beta_{Aj} A\, ln\left(\frac{w_j}{P}\right) - \tilde{u} \quad (10)$$

Equation (10) can be viewed as an additive-multiplicative translog stochastic frontier profit function (AM-TSFPP). To account for negative profit, the method suggested by Bos and Koetter (2011) was adopted. It consists of creating an extra regressor called the negative profit indicator (NPI) which takes the value of 1 if the profit is positive and the absolute value of the profit if otherwise. On the other hand, the dependent variable profit takes the value of 1 when the profit is negative and its actual value if it is positive. The advantage of the method is that the entire sample is used which reduces potential bias that could arise due to missing data while ensuring that the parameters' estimates obtained are stable (Bos *et al.*, 2011). Thus, in this study the AM-TSFP model for rice production was estimated as:

$$ln\left(\frac{\tilde{\pi}_i}{P}\right) \equiv \beta_0 + \beta_1\, ln\left(\frac{w_{1i}}{P}\right) + \sum_{j=2}^{6} \beta_j\, ln\left(\frac{w_{ji}}{P}\right) + \beta_{SRI} SRI_i$$

$$+\frac{1}{2}\sum_{j=1}^{6} \sum_{k=1}^{6} \beta_j\, ln(\widetilde{w}_{ji})\, ln(\widetilde{w}_{ki}) + \sum_{j=1}^{6} \beta_{SRIj} SRI\, ln\left(\frac{w_{ji}}{P}\right) + \beta_{NPI} NPI + v_i - u_i \quad (11)$$

where $\pi_i = TR_i - TC_i =$ Actual profit realized (₦); $TR_i =$ Total Revenue (₦); $TC_i =$ Total Cost incurred (₦); $P_i =$ Market price of rice paddy (₦/kg); $w_{1i} =$ Price of seed (₦/kg); $w_{2i} =$ Price of inorganic fertilizer (₦/kg); $w_{3i} =$ Price of organic fertilizer (₦/kg); $w_{4i} =$ Price of agrochemicals (₦/L); $w_{5i} =$ Price of labour (₦/man-day); $w_{6i} =$ Price of transport (₦/kg); $SRI_i =$Use of BB-SRI (1 = Yes; 0 = No); $v_i =$ Independently and identically distributed error term assumed to be normally distributed with zero mean and a constant variance $(v_i \sim N(0, \sigma_v^2))$; $u_i =$ Independently and identically distributed one-sided error term (technical inefficiency) assumed to be half-normally distributed with zero mean and a constant variance $(u_i \sim N^+(0, \sigma_u^2))$. The profit efficiency was derived as (Kumbhakar *et al.*, 2014):

$$\pi_{eff_i} = e^{-\tilde{u}_i} = \frac{\pi_i^a}{\pi\left(\frac{w_{1i}}{P_i}\right)}, \quad \tilde{u}_i \geq 0 \quad (12)$$

In words, profit efficiency is the ratio of actual profit to maximum profit with value lying between 0 and 1. If $\pi_i^a \geq 0$, the actual percentage of profit loss due to technical inefficiency can be estimated as $(1 - e^{-\tilde{u}_i}) \times 100$. In addition to σ_v^2 and σ_u^2, the parameters in (11) were estimated by maximizing the following log-likelihood function (Greene & Hensher, 2010):

$$L_i = -\, ln\left(\frac{1}{2}\right) - \frac{1}{2} ln(\sigma_v^2 + \sigma_u^2) + ln\, \phi\left(\frac{\varepsilon_i}{\sqrt{\sigma_v^2 + \sigma_u^2}}\right) + ln\, \Phi\left(\frac{\mu_{*i}}{\sigma_*}\right) \quad (13)$$

where $\mu_{*i} = \frac{-\sigma_u^2 \varepsilon_i}{\sigma_v^2 + \sigma_u^2}$ and $\sigma_* = \frac{\sigma_v^2 \sigma_u^2}{\sigma_v^2 + \sigma_u^2}$.

Propensity Score Matching

The main challenge in impact evaluation using observational data is to estimate the counterfactual of the treated group based on the control group's characteristics. This is the goal in impact evaluation using Propensity Score Matching (PSM) when the conditional independence assumption (CIA) is retained. Although, it is virtually impossible to observe observations that are similar in all respect (economic, genetic, personal, etc.), even when a single identifying factor such as the Propensity Score (PS) is being used in place of the observations' various characteristics as the matching rule. Other important challenges exist in the literature when it comes to the selection of the most appropriate PSM methods or algorithm. Five basic and common PSM algorithms are often considered in empirical study of impact evaluation of technology adoption namely nearest neighbour matching, caliper matching, Radius matching, Stratification matching and the Kernel matching (Cochran *et al.*, 1973; Rubin, 2001; Caliendo and Kopeinig, 2008), Egwuma *et al.*, 2021). In order to find the counterfactual of the adopters of SRI in this study, the PS (probability to use the BB-SRI) was first estimated using the following PS model (Egwuma *et al.*, 2021):

$$PS_i = p(A_i = 1|X) = \Lambda(X'\alpha) \qquad (14)$$

where PS_i =propensity score function; $\Lambda(\bullet)$ = Logistic cumulative density function (CDF); A_i =dummy variable taking 1 if a used the BB-SRI and 0 if otherwise; α = Vector of parameters indicating the effect of changes in X on the probability to participate in CP; X =Vector of explanatory variables. The selection of the explanatory variables in $X$was informed by previous studies on market participation generally. Note that the vector of regressors X in equation (14) is not necessarily the determinants of SRI adoption since the aim in estimating equation (14) was to find the counterfactual of the adopters. The vector X is given as: x_{1i} =Age of household head (in years), x_{2i} =Total land under rice cultivation (ha); x_{3i} =Distance from house to rice plots (km), x_{4i} =E-Left (1 = Yes; 0 = Otherwise), x_{5i} =M-Rice B (1 = Yes; 0 = Otherwise), x_{6i} =N-Rice (1 = Yes; 0 = Otherwise), x_{7i} =G-Rice B (1 = Yes; 0 = Otherwise); x_{8i} =Intake C (1 = Yes; 0 = Otherwise), x_{9i} =F-Right (1 = Yes; 0 = Otherwise). The parameters in (14) were estimated by maximizing the following log-likelihood function:

$$ln(\beta|X, y) = \sum_{i=1}^{n}(1 - A_i)\, ln\left[1 - \Lambda\left(\beta'X\right)\right] + A_i\, ln\, \Lambda\left(\beta'X\right) \qquad (15)$$

Assuming that the PS model achieved adequate balance, the three estimators of the profitability gap were computed as:

$$\hat{\pi}_{\text{Gap}}^{\text{BB-SRI}} = \frac{1}{n_1}\left\{\sum_{i\in\{A_i=1\}}\left[y_{1i} - \left(\sum_{i\in\{A_i=0\}} w(i,j)y_{0i}\right)\right]\right\} \qquad (16)$$

$$\hat{\pi}_{\text{Gap}}^{\text{FP}} = \frac{1}{n_0}\left\{\sum_{i\in\{A_i\{\}\}}^{\Sigma}\left[\left(\sum_{i\in\{A_i\{\}\}}^{\Sigma} w(i,j)y_{1i}\,()_{0i}\right)[\,]\right]\right\} \qquad (17)$$

$$\hat{\pi}_{\text{Gap}}^{\text{pooled}} = \left[\frac{n_1}{n} \times \hat{\pi}_{\text{Gap}}^{\text{BB-SRI}}\right] - \left[\frac{n_0}{n} \times \hat{\pi}_{\text{Gap}}^{\text{FP}}\right] \qquad (18)$$

where $\hat{\pi}_{\text{Gap}}^{\text{BB-SRI}}$ =Profitability gap between BB-SRI and FP for the adopters (Average Treatment Effect on Treated); $\hat{\pi}_{\text{Gap}}^{\text{FP}}$ =Profitability gap between BB-SRI and FP for the non-adopters (Average Treatment Effect on Treated); $\hat{\pi}_{\text{Gap}}^{\text{pooled}}$ =Profitability gap between BB-SRI and FP for the pooled farmers (Average Treatment Effect on Treated); n_1 = Number of adopters; n_0 = Number of nonadopters; $n = n_1 + n_0$; y_{1i} = Outcome of the SRI adopters after matching (Yield, ROI and profit efficiency), y_{0i} = Outcome of non-adopters after matching, *w(.)* = weight function; ∑ = Sum operator.

RESULTS AND DISCUSSION

Profitability of the BB-SRI and FP

The total variable cost (TVC) under the BB-SRI and FP was ₦198,975 and ₦158,580 per hectare, respectively (Table 3). The total fixed cost (TFC) under the BB-SRI and FP, on the other hand, was ₦91,965 and ₦95,390 per hectare, respectively. This shows that the total cost of production reduced from ₦253,970 per hectare with FP to ₦290,940 per hectare with the BB-SRI, an increase of 15%. The increase in total cost was associated with the fact that the cost savings in seed (96%) and mineral fertilizer - Urea (46%%) and NPK (100%) - in particular, were overshadowed by the extra cost incurred in organic fertilizer - manure (143%) – labour (45%), transportation (174%), and empty bags (166%). The cost of seed and mineral fertilizer was basically decreased because the quantity of seed, urea and NPK were reduced by 97, 48 and 100%, respectively. On the other hand, the increase in the cost labour and manure was a reflection of important changes in their consumption. In particular, manure use increased from 2,400 kg per hectare with FP to 5,000 kg per hectare with the BB-SRI, an increase on 108%.

Similarly, the quantity of labour used increased from 150 man-days per hectare with FP to 217 man-days per hectare with the BB-SRI, an increase of 45%. The result is in agreement with the fact that most farmers who participated in the promotional research did not have up to a year of experience in BB-SRI and were therefore less skilled in seed nursery management and transplanting which led to increase in labour use (Anthofer, 2004). This was partly because the demonstration plots were established in different locations with some farmers being newly involved for the study. The contribution of the TVC to the total cost under the BB-SRI (68%) was slightly higher than FP (62%) while the contribution of the TFC to the total cost under the BB-SRI (32%) was barely smaller than that of FP (38%). The relative high influence of labour cost to the total cost, on the other hand, further showed that rice farmers in the study area were smallholder farmers. Several studies have equally found that manual labour still remains one of the most important factors of production in agriculture in Nigeria (Oyewole *et al.*, 2014).

Generally, the significant changes in inputs' use were probably consistent with the principles, benefits and disadvantages of SRI. However, the cost differential may not be attributed entirely to SRI principles given the presence of potential selection bias. Findings regarding the cost differential between SRI and conventional practices are quite mixed. For instance, Durga and Kumar (2013) showed that the total cost of production using SRI was about 17% lower than FP in southern India. The analysis by Takahashi and Barrett (2013) showed that the total cost of production under SRI was raised by 25% in rural Indonesia, although the nonadopters would have experienced a reduction in total cost had they adopted SRI. The average yield estimate for the BB-SRI and FP was 12,735 kg and 5,285 kg per hectare, respectively. This suggests that there was a significant yield gap of about 7,450 kg (141%) per hectare between the BB-SRI and FP. The implication is that the BB-SRI was significantly more productive than FP with great potential to address food insecurity. The finding is consistent with previous findings that demonstrated the positive yield effect of SRI. For instance, Anthofer (2004) and Durga and Kumar (2013) found that there was an evidence of a positive yield gap of 27% and 41% between SRI and conventional method in southern India and Cambodia, respectively. The significant yield gap can partly be attributed to increased number of tillers and increased number of filled grains (TRIMMING-SRI, 2020). Moreover, it should be noted that the influence of environmental factors (level of soil fertility, rainfall, flooding and drought) on yield differential between the BB-SRI and FP was quite limited given that the BB-SRI and FP demonstration plots were established side by side. The net returns under the BB-SRI and FP were about ₦1,937,685 and ₦670,910 per hectare, respectively, indicating that the net income differential was ₦1,266,780. Furthermore, the return on investment (ROI) increased from 2.6 with FP to 6.66 with BB-SRI, an increase of 152%. In other words, for every naira invested, ₦6.70 and ₦2.60 was realized per hectare using BB-SRI and FP, respectively. In order words, the finding suggested that rice production was profitable under both the BB-SRI and FP, although the return per every naira invested using SRI was more than two times higher than FP. This finding is supported by the majority of previous studies that indicated that there was a positive return in rice farming using SRI (Anthofer, 2004; Durga & Kumar, 2013; Bandumula *et al.*, 2017). Moreover, the difference in profit between the BB-SRI and FP was significant at 1% level of probability, which means that the BB-SRI's profit was greater than FP's profit.

Profit efficiency differential between BB-SRI and FP

Table 4 presents the ML estimates of the ordinary least squares (OLS) and half-normal translog stochastic frontier profit functions (TSFPFs) of rice farming. Both models were statistically significant on the basis of the F- and Wald statistic estimates, meaning that all the independent variables jointly and significantly explained the variation in profit (Chikobola, 2016). However, the half-normal translog stochastic frontier profit function was more adequate given the presence of profit inefficiency in the model. Specifically, the estimate of Lambda (the ratio of the standard error of *u* and *v*) was positive and statistically at significant at 1% level of probability (λ =14,44, p<0.01), which implies that there was profit inefficiency in rice farming and that the observed profit was lower than the maximum expected profit. In other words, the estimates of the BB-SRI's and FP's net returns presented earlier can still be improved with the current level of resources available. The interpretation of the profit function was therefore based on the half-normal translog stochastic frontier profit function (TSFPF). The result is in line with a number of previous studies (Galawat & Yabe, 2012; Wongnaa *et al.*, 2019). For instance, Galawat *et al.* (2012) affirmed that technical, allocative and scale inefficiencies affected rice production in Brunei Darussalam.

Translog stochastic frontier functions are easily interpreted using marginal effect or elasticities (Rhaman, 2003; Mailena *et al.*, 2013; Wongnaa *et al.*, 2019). The profit elasticity with respect to the price of seed (β_1 = 0.17, p>0.1) and labour (β_5 = 0.41, p>0.1) were positive and statistically insignificant, which suggests that they were not important determinants of profit. The finding is contrary to expectation (Ani *et al.*, 2013; Wongnaa *et al.*, 2019), but consistent with Mailena *et al.* (2013) who found that the price of seed and labour did not influence profit among rice farmers in Malaysia. The effect of the price of inorganic fertilizer was negative and significant at 1% level of probability (β_2 = -0.75, p<0.01), which means that if the price of inorganic fertilizer increases by 1%, profit will decrease by 0.75%, holding other variables constant.

Table 3: Cost and returns estimates of rice production under a package of best bet SRI and farmers' practices

Variables	BB-SRI				FP				Difference			
	Qty	Unit Price (₦/ha)	Value (₦/ha)	Cont (%)	Qty	Unit Price (₦/ha)	Value (₦/ha)	Cont (%)	Qty	Unit Price (₦/ha)	Value (₦/ha)	Cont (%)
Seed (kg/ha)	4	135	540	0.19	132	100	13,332	5.25	-128	34	-12,792***	-5.06
Manure (kg/ha)	5,000	3.5	17,500	6.01	2,400	3	7,200	2.83	2,600	0.5	10,300***	3.18
Urea (kg/ha)	50	200	10,000	3.44	119	157	18,683	7.36	-69	43	-8,683***	-3.92
NPK (kg/ha)	0	0	0	0.00	89	158	14,062	5.54	-89	-158	-14,062***	-5.54
Agrochemicals (L/ha)	3	1,850	5,550	1.91	3.1	1,850	5,735	2.26	-0.10	0	-185	-0.35
Labour (man-day/ha) *	217	550	119,350	41.02	150	550	82,500	32.48	67	0	36,850***	8.54
Empty bags (₦/ha)			23,105	7.94			8,700	3.43			14,404***	4.51
Transport (₦/ha)			22,930	7.88			8,369	3.29			14,561***	4.59
Total variable cost			198,975	68.39			158,582	62.44			40,393***	5.95
Land (₦/ha)			80,570	27.69			83,810	33.00			-3,240***	-5.31
Water charges (₦/ha)			11,390	3.92			11,570	4.56			-181	-0.64
Total fixed cost			91,965	31.61			95,386	37.56			-3,421***	-5.95
Total cost			290,940	100			253,968	100			36,972***	0.00
Yield (kg/ha)	12,735	175	2,228,625		5,285	175	924,875		7,450		1,303,750***	
Gross Margin			2,029,650				766,293				1,263,357***	
Net farm income			1,937,685				670,907				1,266,778***	
Return on investment			6.66				2.64				4.06***	

Source: Survey Data (2020)

Cont=Contribution to total cost; *Labour = cost of nursery management, land preparation, weeding, fertilizer application, bird scaring, harvesting, threshing and bagging; FP=Farmers' Practice.

Table 4: Maximum likelihood estimates of the truncated translog stochastic frontier profit function of rice farming

		OLS		Translog		Profit Elasticity	
Variable	**Parm.**	**Coef.**	**SE**	**Coef.**	**SE**	**Coef.**	**SE**
Constant	β_0	16.98	31.31	17	12.5		
Log w1	β_1	-6.79	6.26	-6.74***	0.98	0.17	0.30
Log w2	β_2	11.42	9.99	11.37**	6.42	-0.75**	0.36
Log w3	β_3	0.23	9.73	0.17	5.72	0.53***	0.20
Log w4	β_4	-9.44	15.14	-9.52***	0.88	-0.8**	0.39
Log w5	β_5	4.53	6.92	4.51	4.93	0.41	0.38
Log w6	β_6	14.01***	3.54	13.58***	1.02	-1.13***	0.25
SRI (1=Yes; 0=No)	β_{SRI}	-0.55	7.01	-0.54	4.65	0.62	0.64
0.5*(Log w1)^2	β_{11}	0.37	2.45	0.34	1.72		
0.5*(Log w2)^2	β_{22}	0.41	4.56	0.4	3		
0.5*(Log w3)^2	β_{33}	0.29	2.01	0.22	1.35		
0.5*(Log w4)^2	β_{44}	5.28	5.40	5.1***	0.89		
0.5*(Log w5)^2	β_{55}	1.02	1.37	0.82	1.16		
0.5*(Log w6)^2	β_{66}	-3.27***	0.52	-2.13***	0.51		
Log w1*Log w2	β_{12}	0.11	1.95	0.04	1.36		
Log w1*Log w3	β_{13}	-0.69	0.86	-0.75	0.53		
Log w1*Log w4	β_{14}	1.93	1.77	1.79*	0.91		
Log w1*Log w5	β_{15}	-0.85	1.55	-0.83	1.17		
Log w1*Log w6	β_{16}	0.95*	0.55	0.64	0.45		
Log w2*Log w3	β_{23}	0.91	1.26	0.95	0.81		
Log w2*Log w4	β_{24}	-3.16	2.78	-3.23*	1.85		
Log w2*Log w5	β_{25}	0.41	1.88	0.39	1.37		
Log w2*Log w6	β_{26}	-1.38	1.16	-0.82*	0.49		
Log w3*Log w4	β_{34}	0.21	1.34	0.03	0.45		
Log w3*Log w5	β_{35}	0.31	1.00	0.34	0.65		
Log w3*Log w6	β_{36}	1.31***	0.41	1.54***	0.18		
Log w4*Log w5	β_{45}	-1.82	2.17	-1.79	1.52		
Log w4*Log w6	β_{46}	-3.43***	1.02	-3.13***	0.34		
Log w5*Log w6	β_{56}	0.34	0.54	0.59	0.49		
SRI*Log w1	β_{SRI1}	0.46	2.47	0.44	1.59		
SRI*Log w2	β_{SRI2}	-0.22	1.58	-0.23	1.08		
SRI*Log w3	β_{SRI3}	-0.26	0.74	-0.27	0.5		
SRI*Log w4	β_{SRI4}	0.47	2.34	0.45	1.58		
SRI*Log w5	β_{SRI5}	-0.3	1.42	-0.31	1		
SRI*Log w6	β_{SRI6}	-0.74	2.58	-0.74	1.68		
NPI	β_{NPI}	-4E-05**	2E-05	-6E-05***	1E-05	-6E-05***	1E-05
F (35, 264)	F	54.56***					
Wald chi2(30)	W			8E+11***			
R-squared	R^2	0.88					
Sigma_u	σ_u			1.82***	0.26		
Sigma_v	σ_v			0.51***	0.12		
Lambda	λ			3.59***	0.36		
Profit Efficiency	π_{eff}			0.50			
Number of obs.	N	300		300			

***<0.01, **<0.05, and *<0.1.

The finding is in line with most previous studies (Mailena *et al.*, 2013) where the price of fertilizer influenced profit negatively. On the other hand, the effect of the price of organic fertilizer was positive and significant (β_3 = 0.53, p<0.01), which was contrary to the a priori expectation. Although the finding is counterintuitive, it could be a reflection of the indirect and elastic relationship between the price of fertilizer and its demand, which would decrease total cost and increase profit ultimately. The profit elasticity with respect to the price of agrochemicals was negative and significant (β_4 = -0.8, p<0.01), which implies that there was an indirect relationship between the price of agrochemicals and profit. By increasing the price of agrochemicals by 1%, profit will decrease by 0.8%, holding other variables constant. The finding aligns with Wongnaa *et al.* (2019) who found that increase in the price of pesticide and herbicide reduced profit among maize farmers in Ghana. There was an indirect relationship between the cost of transport and profit (β_6 = -1.13, p<0.01) such that if the cost of transport increases by 1%, profit will decrease by 1.13%, holding other variables constant. The use of the BB-SRI influenced profit positively but insignificantly (β_{SRI} = 0.16, p>0.1), which indicates that using the BB-SRI did not increase farmers' profit. The finding is contrary to most previous studies (Foltz & Chang, 2002; Khanal & Gillespie, 2011). Although, there are studies that could not find evidence of a significant positive profitability effect of technology adoption, the result here is likely to be biased. One of the obvious reasons is that the BB-SRI use was endogenously determined given that farmers self-selected themselves into the treatment group. Moreover, there is a likelihood that the relationship between the BB-SRI use and farmers' profit is simultaneous (Mazvimavi & Twomlow, 2009). Subsequently in this paper, we attempted to minimize this bias by using the PSM estimator in estimating the profitability gap between the BB-SRI and FP.

Performance gap between the BB-SRI and FP

The use of the BB-SRI was most likely affected by sample selection bias since farmers determined whether or not to participate in the TRIMING-SRI project. Table 6 presents the maximum likelihood estimates of the logit model of the BB-SRI use. However, it is worthwhile to note that the model was not intended to identify the determinants of the BB-SRI use, but was primarily fitted for the purpose of matching users of the BB-SRI with users of FP. The decision to use the BB-SRI was a function of the age of the household head, distance from home to rice plots and the location of the rice farms. The relationship between age and adoption of improved technology can either be positive or negative (Onyeneke, 2017). But in this study, there was a negative and significant effect of age on the BB-SRI use (α_1 = 0.04, p<0.05), meaning that younger farmers were less likely to use the BB-SRI than their counterparts. This could be associated to the experience and knowledge gained over the years. Moreover, older farmers tend to have more access to credit facility due to fact that they usually possess more assets than the younger ones (Ullah *et al.*, 2020; Moahid *et al.*, 2021). The distance from home to rice plots had a negative and significant influence on the BB-SRI use (α_3 = -0.54, p<0.01), meaning that the longer the distance to farm the lower the probability to use the BB-SRI. This is because rice plots far away from home increases the cost of production through increase in transaction costs. The finding is in consonance with Anley *et al.* (2006) who found that subsistence smallholder farmers in Dedo district, Ethiopia who were located far away from their farms were less likely to adopt improved soil conservation measures due to higher transaction costs which were a source of discouragement (Gebremedhin & Swinton, 2003). Finally, the effect of E-left on the BB-SRI use was positive and significant α_3 = 3.31, p<0.01), implying that farmers whose rice plots were in E-left were more likely to use the BB-SRI than their counterparts. Mazvimavi *et al.* (2009) found that agro-ecological location had a strong statistical influence on hand hoe-based conservation farming among vulnerable households in Zimbabwe.

Table 6: Maximum likelihood estimates of the logit regression for the propensity score of the BB-SRI use

Variable	Parm.	Coeff.	SE	*t*-value	Marg. effect
Constant	α_0	-4.07***	1.34	-3.03	0.004
Age of household head	α_1	0.04**	0.02	2.28	0.02
Total land under rice cultivation	α_2	0.24	0.65	0.36	-0.05
Distance from home to rice plots (km)	α_3	-0.54***	0.16	-3.43	0.61
E-left (1 = Yes; 0 = Otherwise)	α_4	3.31***	1.15	2.87	0.16
M-Rice B (1 = Yes; 0 = Otherwise)	α_5	1.29	1.13	1.14	0.10
N-Rice (1 = Yes; 0 = Otherwise)	α_6	0.93	1.10	0.85	0.06
G-Rice B (1 = Yes; 0 = Otherwise)	α_7	0.57	1.14	0.5	0.35
Intake C (1 = Yes; 0 = Otherwise)	α_8	2.15*	1.19	1.8	0.07
F-Right (1 = Yes; 0 = Otherwise)	α_9	0.65	1.17	0.56	
LR chi2(9)		33.25***			
Log likelihood		-101.18			
Pseudo R2		0.15			
Number of observations		300			

***<0.01; **<0.05 and *<0.1

For the purpose of robustness, the profitability gap was estimated using three matching algorithms namely the nearest neighbour matching (NNM), kernel matching (KM) and radius matching (RM) algorithms with 5 neighbours, bandwidths and radiuses, respectively (Table 7). The estimates of ATT, ATU and ATE for yield, ROI and profit efficiency were positive and statistically significant at 1% level of probability in the entire sample, meaning that the performance gap between the BB-SRI and FP was direct and strong. However, there was variability in the magnitude of the impact estimates based on the matching algorithms. Therefore, the yield, ROI and profit efficiency gaps between the BB-SRI and FP among the adopters, in particular, ranged from 7,452 kg/ha to 7,510 kg/ha, 4.02 to 4.05, and from 0.08 to 0.09, respectively. Similarly, had the nonadopters used the BB-SRI, the yield, ROI and profit efficiency gaps between the BB-SRI and FP would have changed from 7,460 kg/ha to 7,486 kg/ha, 4.1 to 4.05, and 0.07, respectively. The performance gap was heterogenous among different age classes as it appeared to increase with farmers' age in general. In other words, the youth were the least impacted, followed by the adults and then the elderly.

CONCLUSION

The cost of production under the BB-SRI was about 13% higher than FP mainly due to labour, although the ROI still increased by about 152%. The difference in ROI was mainly due to the effect of cost savings in seed and fertilizer as well as the huge yield gap recorded (141%). Inorganic and organic fertilizer, agrochemicals, labour and transport were the most important determinants of profit efficiency. Farmers under the BB-SRI were more profit efficient than those under FP. Under BB-SRI, seed and inorganic fertilizer were greatly reduced while other inputs such as organic fertilizer and labour were used in higher intensity. The net return from the BB-SRI was almost twice that of FP with fertilizer, agrochemicals and labour being the most significant factors of production. On average, farmers under both the BB-SRI and FP failed to maximize their profit due to production inefficiency, even though farmers under the BB-SRI were only about 7% below the profit frontier. In an attempt to control for potential selection bias using propensity score matching estimator, it was found that there was a positive and strong performance gap between the BB-SRI and FP not only among the users of the BB-SRI, but also among the non-adopters had they used the BB-SRI, leading to conclude that the BB-SRI was by far more productive and profitable than FP. Despite the controversies still surrounding the relative higher benefits of SRI over the conventional practices, the empirical evidences of this study showed that the BB-SRI can in fact improve the existing production rice level among resource-poor farmers and should therefore be seen as a worthy alternative method. We recommend therefore that important investments and training in SRI should be considered as a top priority to ensure its successful promotion, uptake and diffusion across other rice producing States in Nigeria.

Table 7: propensity score matching estimates of the performance gap between best bet system of rice intensification and farmers' practices

	ATT			ATU			ATE		
Group	**NNM**	**KM**	**RM**	**NNM**	**KM**	**RM**	**NNM**	**KM**	**RM**
Yield (kg/ha)									
Youth	7,448 (192)***	7,409 (185)***	7,422 (156)***	7,394 (158)	7,381 (170)***	7,393 (159)***	7,402 (151)***	7,385 (165)***	7,393 (158)***
Adult	7,569 (121)***	7,572 (122)***	7,550 (117)***	7,550 (141)***	7,487 (125)***	7,523 (122)***	7,552 (138)***	7,497 (113)***	7,526 (124)***
Elderly	7,807 (250)***	7,709 (252)***	7,739 (238)***	7,700 (251)***	7,828 (243)***	7,764 (254)***	7,724 (256)***	7,802 (242)***	7,772 (239)***
All	7,452 (100)***	7,507 (95)***	7,510 (93)***	7,482 (107)***	7,460 (97)***	7,486 (88)***	7,479 (98)***	7,465 (87)***	7,488 (96)***
ROI									
Youth	2.55 (0.22)***	2.54 (0.21)***	2.76 (0.16)***	2.52 (0.19)***	2.55 (0.18)***	2.52 (0.19)***	2.53 (0.19)***	2.55 (0.18)***	2.52 (0.19)***
Adult	4.14 (0.25)***	4.1 (0.25)***	4.12 (0.25)***	4.19 (0.3)***	4.31 (0.29)***	4.24 (0.27)***	4.19 (0.27)***	4.28 (0.28)***	4.23 (0.26)***
Elderly	4 (0.45)***	4.07 (0.45)***	3.91 (0.43)***	3.98 (0.42)***	3.96 (0.61)***	4.01 (0.56)***	3.99 (0.43)***	3.99 (0.56)***	4 (0.52)***
All	4.05 (0.2)***	4.03 (0.2)***	4.02 (0.2)***	4.1 (0.22)***	4.09 (0.24)***	4.05 (0.22)***	4.1 (0.23)***	4.08 (0.23)***	4.05 (0.22)***
PEff									
Youth	0.02 (0.04)	0.02 (0.04)	0.05 (0.02)**	0.03 (0.03)	0.02 (0.04)	0.03 (0.04)	0.02 (0.04)	0.02 (0.04)	0.03 (0.04)
Adult	0.12 (0.02)***	0.09 (0.02)***	0.1 (0.02)***	0.08 (0.02)***	0.08 (0.02)***	0.08 (0.02)***	0.09 (0.02)***	0.08 (0.02)***	0.08 (0.02)***
Elderly	0.14 (0.04)***	0.12 (0.04)***	0.13 (0.04)***	0.12 (0.04)***	0.13 (0.05)***	0.13 (0.04)***	0.13 (0.04)***	0.13 (0.04)***	0.13 (0.04)***
All	0.08 (0.02)***	0.08 (0.02)***	0.09 (0.01)***	0.07 (0.01)***	0.07 (0.01)***	0.07 (0.02)***	0.07 (0.02)***	0.07 (0.01)***	0.08 (0.01)***

NNM = Nearest Neighbor Matching with 12 neighbours; KM= Kernel Matching on the area of on common with replacement and a bandwidth of 0.1; RM = Radius Matching on the area of on common with replacement and a radius of 0.1; ***<0.01, **<0.05 and *<0.1; PEff = Profit Efficiency; ROI = Return on Investment; () Bootstrapped standard errors with 500 replications.

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