

NERICA Adoption and Impacts on performance of Rice Producing Households in Ghana: Implications for Research and Development

ABSTRACT

In an effort to enhance agricultural development in Ghana, rice producers have witnessed myriads of improved agricultural technology development and dissemination. Notably among them is the Multi-national NERICA Rice Dissemination Project (MNRDP). However the empirical evidence linking these technologies to productivity indicators is limited. This paper uses cross sectional data which were collected from 200 smallholder rice producers from major rice growing districts in Ghana, to examine whether adoption of NERICA rice varieties have impacted on technical efficiency. Taking into account the endogeneity of technology adoption and assuming that impact is heterogeneous across the population, we use propensity score matching approach to estimate average treatment effect (ATE) on technical efficiency. Our analyses reveal an adoption rate of 68 per cent among sample rice farmers. The data further suggest an average technical efficiency of 69.1 per cent. In addition, adoption of NERICA rice varieties has been found to have a positive and significant impact on technical efficiency of rice producing households in the country. Besides NERICA adoption, other factors that significantly influenced technical efficiency include; education, household size, gender and non-farm income. The result also highlights a positive influence of institutions such as NGOs and extension services on technical efficiency. The findings suggest that access to improved varieties is an essential factor to consider in promoting interventions aimed at improving technical efficiency of smallholder rice producers. Further, continuous provision of training through the establishing and strengthening linkages between farmers and these institutions is recommended to enhance the smooth transformation of adoption efforts into efficient rice production among smallholder rice farmers in Ghana.

Keywords: *Impact, adoption, NERICA varieties, technical efficiency, average treatment effect (ATE), Ghana.*

ABBREVIATIONS

ARI: Africa Rice Initiative, **ATE:** Average Treatment Effect, **CSIR:** Council for Scientific and Industrial Research, **DEA:** Data Envelopment Analyses, **FBO:** Farmer Based Organizations, **NERICA:** New Rice for Africa, **MNRDP:** NERICA Rice Dissemination Project, **NGO:** Non-governmental Organizations, **TE:** Technical efficiency

1. INTRODUCTION

Rice is one of the world's most important foods and is the main source of nutrition for more than half of the world population [46]. In Africa, rice has increasingly become a popular food as it is tasty and quick to cook. Its importance it competes effectively with traditional coarse grains and roots and tuber crops. Besides being an important food staple for both rural and

29 urban communities across Ghana, it is the most important cash crop in the communities in
30 which it is produced [6].

31 In Ghana, domestic demand for rice has not been adequately met by growth in local
32 production. To meet this gap, the country currently imports about 70per cent of domestic rice
33 requirement accounting for about USD 600 million per annum [24]. Apparently, rice is a key
34 economic commodity in Ghana. It is one of the crops that have a high potential to improve
35 self-sufficiency hence have received reasonable attention by policy makers in the country
36 lately.

37 Against this background, there have been myriads of development interventions aimed at
38 promoting local rice production and consumption including the Multi-national NERICA Rice
39 Dissemination Project (MNRDP). With the support from of the Government of Ghana the
40 project promoted the New Rice for Africa (NERICA) varieties together with complementary
41 agronomic technologies under the Africa Rice Initiative (ARI), throughout Africa.

42 Amidst declining land holdings in sub-Saharan Africa, productivity gains has been projected
43 to come from investment in technologies that lead to higher levels of output given the current
44 size of land while ensuring environmental sustainability [30, 37]. In view of this, strategies
45 towards improving productivity and efficiency must include, among others, accelerated
46 adoption of improved crop varieties, increased restoration of soil nutrients through the use of
47 organic and inorganic fertilizers and adoption of improved soil and water conservation
48 technologies in order to reduce erosion and improve soil moisture content [37].

49 However, in view of the challenges and costs of improving soil nutrients through
50 conservation technologies as well as the use of soil organic and inorganic fertilizers,
51 adoption of improved varieties have been a one of the key ways through which increased in
52 productivity and efficiency among small scale farmers in Ghana can be achieved.

53 Literatures on the positive impacts of agricultural development interventions on the
54 livelihoods of farm households in Ghana have been documented. These interventions have
55 promoted improved technologies including high yielding crop varieties as well as best-bet
56 agronomic practices. The impacts of these interventions have been channelled through the
57 adoption decision making processes. These adoption decision processes have been
58 analysed extensively with various forms of binary choice and censored regression models [1,
59 3, 4, 18, 23]. Least squares estimates have also revealed significantly higher efficiency and
60 productivity among farmers who adopt and use improved agricultural technologies [36; 45].

61 In most of these studies however, the status of sampled respondents in terms of their
62 participation in the intervention is assumed to be random which in reality is not the case.
63 Parameter estimates from such approach are characterised by selection and endogeneity
64 biases [21, 26, 28]. In addition, there is scanty evidence on the impact of adoption of
65 NERICA rice varieties on efficiency and productivity of rice producing households.

66 Approaches to minimize the bias associated with selection and endogeneity biases are
67 deeply rooted in the concept of counterfactual outcome framework. These methodologies
68 produce consistent estimates of the effect of an intervention/adoption on a randomly
69 selected population, also known as average treatment effect (ATE). This approach has
70 been employed to estimate the actual and potential impacts of the interventions [7, 20, 21,
71 22, 38].

72 The measurement of efficiency draws on the seminal works of Farrell [25] who suggested
73 the efficiency of a firm consisting of two main components as technical efficiency and

allocative efficiency. Technical efficiency is a measure of the ability of a firm to obtain maximum output from a set of inputs given the best available technology. Efficiency scores are performance measures or indicators used in evaluating production units including farm households. There are two main approaches for estimating efficiency, parametric and nonparametric [8, 17, 39, 47]. The parametric can broadly be classified into two categories, namely, deterministic frontier models and stochastic frontier models. The most common nonparametric method is data envelopment analyses (DEA).

The parametric method of estimation involves econometric modelling of production frontiers. This has been widely applied in the literature [8, 16, 43, 13]. This approach accounts for measurement error in both the output and the stochastic element of production, thereby decomposing the effect of noise from the inefficiency effect. In addition, it allows conventional statistical tests to be carried out. However it is unable to measure efficiency of multi-output cases [8, 9, 17]. The nonparametric DEA does not require a functional form to specify the relationship between the inputs and outputs, and also it has the ability to accommodate multiple-input and multiple-output technologies [9; 17].

This paper employed the counterfactual outcome framework and estimated the impact of adoption of the NERICA varieties on technical efficiency of rice farmers in Ghana. It aims at quantifying the impact of adoption of NERICA varieties developed and disseminated to rice farmers on technical efficiency of smallholder farmers in Ghana. In addition, we explore whether establishing and strengthening institutional linkages among farmers to improve technical efficiency of smallholder farmers.

The remaining sections of this paper are presented as follows. We present description of the methodology and the study area. It includes a brief overview of the MNRDP in Ghana, data collection methods and the empirical framework. The next two sections present the results of analysis of the empirical findings and the implications of the result. We end with some concluding remarks and policy recommendations.

2. METHODOLOGY

2.1 The NERICA Rice Dissemination Project in Ghana

The Multi-national NERICA Rice Dissemination Project (MNRDP) was one of the numerous development interventions that received huge support from the Government of Ghana [35]. The MNRDP was part of an overall initiative to promote the New Rice for Africa (NERICA) varieties together with complementary agronomic technologies throughout Africa, the Africa Rice Initiative (ARI). The project was intended to ultimately contribute to poverty reduction and food security among rice producers in the country. The NERICA rice varieties combine their high yielding potential, disease resistance and early maturity traits together with a new potential for upland rice cultivation in Ghana [2].

In Ghana the project was implemented in 3 pilot rice producing districts namely, Ejura-Sekyeredomase and Hohoe in southern Ghana and Tolon-Kumbungu in northern Ghana. Ejura-Sekyeredomase is located on latitude 070 23' 00.00" N and longitude 010 22' 00.00" W. Hohoe is located on latitude 070 08' 56.54" N and longitude 000 28' 28.56" E. Tolon-Kumbungu is located on latitude 090 25' 51.41" and 010 03' 52.56" W.

The project included 3 main components, namely, technology transfer, production support and capacity building. Under technology transfer was participatory evaluation, adaptation and selection of appropriate technology mix. The identified technology mixes were designed to meet the needs of the respective agro-ecological of the targeted districts [35].

121 Production support was in the form of rice production infrastructure such as roads and
122 postharvest facilities, human resource development and inputs and seed supply. While
123 roads and postharvest facilities were to ensure effective market participation, the latter were
124 expected to improved farm level performance. The production and distribution of certified
125 seeds of the NERICA varieties among beneficiary farmers was very crucial for the success
126 of the project. The creating access to NERICA seeds the project in facilitated the adoption of
127 the NERICA varieties. The component on capacity building focused on market integration. It
128 involved sensitization and training of key stakeholders to facilitate the process of market
129 integration.

130 After 5 years of selection, promotions and capacity building, the MNRDP ended in 2010 [35].
131 The success of the MNRDP like all agricultural technology dissemination interventions can
132 be measured by the observed changes in adoption decisions which are further translated
133 into improved farm level performance and the overall wellbeing of beneficiaries [45]. For the
134 MNRDP, adoption of the NERICA rice varieties was assured through the facilitation of
135 access to the seeds. Adoption of the NERICA rice varieties was in turn expected to impact
136 positively on efficiency and productivity among targeted rice producing households in the
137 country.

138 **2.2 Data and sampling technique**

139 The basic information for the analysis was obtained from primary data collected with the aid
140 of objective oriented structured questionnaire. The data described rice producer and
141 production characteristics and access to information. The study was conducted within the
142 project districts in Ghana. A total of 200 rice producing households, 10 per community were
143 systematically selected and interviewed. The selection of the households followed a two-
144 stage systematic random sampling procedure. In the first stage, communities were randomly
145 selected from a list of rice producing communities in the project districts. The second stage
146 involved the selection of farm households from a list of households from the selected
147 communities.

148

149 **2.3 Empirical framework and estimation technique**

150 In this paper, we follow a two-stage impact estimation method. First stage, we use the
151 stochastic frontier estimation analysis to generate technical efficiency scores following
152 Battese and Coelli [10]. Second, the estimated technical efficiency scores are regressed on
153 NERICA adoption alongside other socio-economic, institutional and farm level covariates,
154 which are hypothesised to affect technical efficiency. To accounts for endogeneity in the
155 choice of variety and selection bias, we adopt the propensity score matching approach [5,
156 12, 19, 33] to estimate the impact of adoption on technical efficiency.

157

158 **2.3.1 Estimating technical efficiency**

159 This study applies the parametric approach because the rice producing environment is
160 largely influenced by external factors. This approach specifies some functional form to
161 represent the relationship between output and inputs. A preferred functional form has the
162 properties identified by Coelli et al [17]. Both the A Cobb-Douglas and the transcendental
163 logarithmic (translog) function developed by Christensen et al. [15] satisfies these properties
164 and are widely used in econometric estimation. Both functional forms were considered

165 represent the rice production model. However, a hypothesis test result suggests that
166 translog functional form is not an adequate representation of the data given the assumptions
167 of the translog stochastic frontier model and was therefore not employed in our analyses.

168

169 Following Battese and Coelli [10], Cobb-Douglas production function can be specified as
170 follows:

$$171 \quad \ln Y_i = \beta_0 + \sum_{j=1}^5 \beta_j \ln X_{ji} + V_i - U_i \quad (1)$$

172 , $i=1,2,3,\dots,N$

173 Where the subscript i indicate the i -th farmer in the sample:

174 Y represents the quantity of rice harvested for the sampled farmer (in kilograms)

175 X_1 is the total area of land (in hectares) planted to rice;

176 X_2 is the total labour (in man days) used in rice cultivation;

177 X_3 is the quantity of seeds(in kilograms) used in rice cultivation;

178 X_4 is the quantity of herbicides (in kilograms)used in rice cultivation;

179 X_5 is the quantity of fertilizers (in kilograms) used in rice cultivation;

180 The V_i^s are the random errors, assumed to be independent and identically distributed as
181 $N(0, \sigma^2)$

182 The U_i^s are the non-negative technical inefficiency effects assumed to be independently
183 distributed among themselves and between the V_i^s , such that U_i^s is defined by the
184 truncation of the $N(\mu_i, \sigma^2)$ distribution, where μ_i is defined by a set of other explanatory
185 variables that are hypothesized to influence technical efficiency. The magnitude of the effect
186 of these factors will then be explored when analyzing the determinants of technical
187 efficiency.

188 The variables included in the technical efficiency model are area, labour, seeds, fertilizer and
189 herbicide. These variables are major inputs used in rice cultivation in Ghana and have been
190 widely applied in several previous studies on technical efficiency [9, 11, 41, 42, 43].

191 The technical efficiency of the i -th farmer is defined by

$$192 \quad TE_i = e^{-U_i} \quad (2)$$

193 Where λ is the inefficiency effects component of the model.

194 The parameters of the stochastic frontier production function model, defined by equation (1)
195 are estimated by the maximum-likelihood method using the program, FRONTIER 4.1 [16].

196 Tests of several null hypotheses for the parameters in the frontier production function are
197 performed using the generalized likelihood-ratio test statistic defined by

$$198 \quad \lambda = -2\{\ln[L(H_0)/L(H_1)]\} \quad (3)$$

199 where $L(H_0)$ and $L(H_1)$ denote the values of the likelihood function under the null (H_0)
200 and alternative (H_1) hypotheses, respectively. If the null hypothesis is true, the test statistic
201 has approximately a chi-squared or a mixed chi-squared distribution with degrees of freedom
202 equal to the difference between the numbers of the parameters involved in the alternative
203 and null hypotheses. If the inefficiency effects are absent from the model, as specified by the
204 null hypothesis, $H_0 : \delta_0 = \delta_{01} = \delta_{02} = \delta_1 = \dots = \delta_6 = \gamma = 0$, where $\gamma = \sigma^2 / \sigma_s^2$ and
205 $\sigma_s^2 = \sigma_v^2 + \sigma^2$, then λ is approximately distributed according to a mixed chi-squared
206 distribution with at least 10 degrees of freedom. In this case, critical values for the
207 generalized likelihood ratio test are obtained from Table 1 of Kodde and Palm [32].
208

209 **2.3.2 Estimating the impact and determinants of technical efficiency**

210 The determinants of technical efficiency were estimated by regressing the technical
211 efficiency scores on NERICA adoption together with other socio economic covariates such
212 as age, gender, education, household size, non-farm income, farm level covariates such as
213 fertilizer and herbicide use as well as other institutional covariates like access to roads,
214 distance to market, access to agricultural development projects, access to FBOs, access to
215 NGOs, and access to extension services using ordinary least squares regression procedure.

216 The OLS regression model is explicitly expressed as:

$$217 \quad TE_{Si} = \alpha_0 + \alpha_a A + \sum_{k=1}^5 \alpha_{Hk} H_{ki} + \sum_{k=1}^2 \alpha_{Gk} G_{ki} + \sum_{k=1}^6 \alpha_{Ek} E_{ki} + e_i \quad (4)$$

218 where $\alpha_a, \alpha_{Hk}, \alpha_{Gk}$ and α_{Ek} are parameters of the A, H, G and E variables, respectively;

219 A denote NERICA adoption, H_1 denotes the age of the household head; H_2 denotes the
220 gender of the household head; H_3 denotes the number of years of formal education of the
221 household head; H_4 denotes the size of the household and H_5 denotes the non-farm
222 income of the household head; G_1 represents the use of fertilizer in rice production and G_2
223 is the use of herbicide in rice production; E_1 is represents access to roads; E_2 is the
224 distance to market; E_3 denotes access to extension services; E_4 denotes access to

225 agricultural development projects; E_5 denotes access to FBOs; E_6 denotes access to
226 NGOs; and e_i is the random error term in the model.

227 In estimating the impact of NERICA adoption on technical efficiency, we expect the adoption
228 of NERICA varieties to result in two potential outcomes for any farmer selected at random.
229 Assuming that the potential outcome for adopting NERICA varieties is y_1 and that for not
230 adopting is y_0 , then the average treatment Effect which represents the expected population
231 impact of adoption can be derived as follows:

$$232 \quad TE_i = y_{i,1} - y_{i,0} \quad (5)$$

$$233 \quad ATE = E(y_1 - y_0) \quad (6)$$

234 where TE_i denotes 'treatment effect' and represents the effect of adoption on farmer i , $y_{i,1}$
235 the potential impact for adopters, and $y_{i,0}$ as the potential impact for non-adopters of
236 NERICA varieties.
237

238 In reality, an outcome and its counterfactual cannot be observed and so $y_1 - y_0$ is undefined
239 for farmer i . Since adoption is a necessary condition for impact, then $y_0 = 0$ for a randomly
240 sampled farmer. This implies that the impact on farmer i is $y_{i,1}$ and the average adoption
241 impact $ATE = E(y_i)$. This in reality underestimates the true population impact because y_1
242 is observed only for adopting, a situation that may result in the problem of selection bias. If
243 $N_A = 1$ denotes adoption and $N_A = 0$, denotes non-adoption, the average impact on the
244 adopting sub-population or ATE on the treated (ATE1) can be obtained as a conditional
245 expected value. In the same way, the average expected impact on the non-adopters or ATE
246 on the untreated (ATE0) can also be derived. These are given as follows:
247

$$248 \quad ATE1 = E(Y_1 | N_A = 1) \quad (7)$$

$$249 \quad ATE0 = E(Y_1 | N_A = 0) \quad (8)$$

250

251 Where Y_1 = the outcome variable (technical efficiency)

252

253 Two broad approaches have been used in the quest to deal with selection bias associated
254 with the noncompliance or endogenous treatment variable [29]. One of the approaches is
255 based on the assumption of conditional independence [21], which postulates the existence
256 of a set of observed covariates k , which, when controlled for, renders the treatment status
257 independent of the two potential outcomes y_1 and y_0 . The ATE parameter estimates under
258 the conditional independence assumptions can be obtained by either pure parametric
259 regression or two-stage procedure. In the pure parametric regression-based method, the
260 covariates are further assumed to interact with the treatment status variable to account for
261 heterogeneous responses. With the two-stage estimation procedure, the conditional
262 probability of treatment or the propensity score, $\pi(N_A = 1 | X) \equiv \pi(x)$, is estimated in the

first stage. In the second stage, the ATE parameters are estimated by either parametric regression-based methods or nonparametric methods [20]. In this study, we adopt the parametric regression-based propensity score method to estimate the impact model.

3. RESULTS AND DISCUSSION

This section describes the results of the estimation of the stochastic frontier production for rice. Furthermore, the determinants of technical efficiency as well as the population impact parameters estimated for using OLS and PSM methods are presented and discussed.

3.1 Descriptive statistics and household characteristics

Table 1 presents descriptive statistics of the sample households. Overall, 68 per cent of the farmers have adopted and cultivating the NERICA rice varieties. The average age of the heads of sample was 51 years old with males accounting for about 81 per cent. On the average, more than half of the sampled rice producers had formal education. With an almost equal gender distribution, the typical household includes an average of about 7 members. The data on institutional variables suggest that about 67 per cent of the rice producers have access to extension services. Access to Non-governmental organizations (NGOs) and farmer based organizations (FBOs) accounted for about 15 per cent and 6 per cent, respectively (Table 1). Averagely, the rice producers travelled a distance of 3.87 km to participate in markets (Table 1).

Farm level characteristics reveal that, rice producers planted an average of about 173.74 kilograms of seeds per hectare. For every hectare of rice cultivated, an average of 366.57 kilograms of fertilizer and 44 litres of herbicide were applied per household. The average production of rice was approximately 2934.53 kg per household. The average labour use was approximately 197.25 man-days per hectare. Although rice was the dominant source of household income as well as income from agriculture in general, income from non-farm activities was approximately US\$107 accounting for almost 12 per cent of the total household income (Table 1).

Table 1. Descriptive statistics of the variables in the stochastic frontier production model

Characteristics	Mean	Standard Dev.
Adoption	0.68	
Average Technical efficiency	0.69 ^a	0.14
Household covariates		
Household size (N)	6.75	3.44
Male producers (%)	80.61	
Female producers (%)	19.39	
Age of producer (years)	50.88	12.61

Educated producers (%)	60.62	
Institutional covariates (%)		
Extension	67.01	
NGOs	14.52	
FBOs	5.63	
Infrastructural covariates		
Existence of market (%)	29.9	
Av. distance to market (km)	3.87	4.14
Farm level covariates		
Output (kg)	2934.53	4600.79
Area (ha)	0.86	1.01
Labour (man-days/ha)	197.25	213.73
Seed (kg/ha)	173.74	183.38
Fertilizer (kg/ha)	366.57	1006.55
Herbicides (lit/ha)	44.88	454.26
Agric income (USD)	825.90	2004.75
Nonfarm income (USD)	107.40	305.65

^asignificant at the 1 per cent level

3.2 Empirical results on technical efficiency

The maximum likelihood estimates of the parameters of the Cobb-Douglas stochastic frontier production function are presented in Table 2. The values of the explanatory variables in the Cobb-Douglas stochastic frontier model were mean-corrected by subtracting the means of the variables so that their averages were zero. This approach indicates that the first-order parameters are estimates of output elasticities for the individual inputs at the mean values.

All estimated first-order coefficients in the production function fall between zero and one, except that for fertilizer. The negative estimate contradicts the monotonicity condition that all marginal products are positive at the mean input levels. The results indicate that seed, land, labour, fertilizer and herbicides are essential factors for rice production and the impacts of these variables on the mean rice outputs are significant. However, all these factors had a negative effect on rice output. For the reason that the technical efficiency model was used as a step in the analyses, its estimation comprised of purely production input variables.

Table 2. Maximum-likelihood estimates for parameters of the Cobb-Douglas stochastic frontier production models for rice farmers in Ghana

Variable	Parameter	Coefficient	SE
Constant	β_0	0.419	0.047
Land	β_1	0.015 ^a	0.099
Labour	β_2	0.0095 ^a	0.070
Seeds	β_3	0.039 ^b	0.038
Herbicide	β_4	0.028 ^a	0.083
Fertilizer	β_5	-0.059 ^a	0.075

Gamma	γ	0.367 ^a	0.054
Variance parameters	σ^2	0.797	0.061
Log likelihood function		105.19	

^asignificant at the 1 per cent level, ^bsignificant at the 5 per cent level, ^csignificant at the 10 per cent level

The results further suggest that except fertilizer, all the other variables had a positive significant effect on technical efficiency. This indicates that rice producers are operating below the maximum allowable level of production given the technology available to them. Consequently, increasing the levels of land labour and quantity of seed are likely to increase their level of rice output.

The γ -parameter associated with the variance of the technical inefficiency effects in the stochastic frontiers is estimated to be very high and was highly significant at 1 per cent. This indicates that the technical inefficiency effects are a significant component of the total variability of rice output.

This result is supported by the second hypothesis test in which the null hypothesis, $H_0: \gamma = 0$, where $\gamma = \sigma^2 / (\sigma_v^2 + \sigma^2)$ is the ratio of the variance associated with

inefficiency effects and its sum with the variance of the random errors in the rice production. The results obtained indicate that the null hypothesis of no technical inefficiencies of rice production should be strongly rejected (Table 3). This suggests that the traditional production function is not an adequate representation of the data given the assumptions of the stochastic frontier model.

The first null hypothesis, $H_0: \beta_{ij} = 0$ for all $i \leq j = 1, 2, \dots, 5$, states that the second-order coefficients in the translog production function have zero values and so, if this hypothesis is true, then the Cobb-Douglas production function applies. This null hypothesis is not rejected at 5 per cent level of significance (Table 3), implying that the Cobb-Douglas production function is an adequate representation of the data given the assumptions of the stochastic frontier model.

Table 3. Tests of null hypotheses for parameters in the stochastic frontier production function for rice producers in Ghana

Null hypothesis	λ	Critical Value ^a	Decision
$H_0: \beta_{ij} = 0$ for all $i \leq j = 1, 2, \dots, 7$	15.92	32.1	Do not reject H_0
$H_0: \gamma = 0$	19.21	16.3	Reject H_0

^a Taken from table 1 of Kodde and Palm [32] using 5 per cent level of significance.

3.3 Elasticities and returns to scale

The estimates of the elasticities of output with respect to inputs of production are presented in Table 4. Because the variables of the Cobb-Douglas model were mean-corrected to zero, the first-order coefficients are the estimates of elasticities at the mean input levels. For the Cobb-Douglas model, the elasticities of mean rice output with respect to the different inputs depend on several parameters and values of the inputs. The elasticity of mean rice output with respect to the j -th input variable is defined by the following expression [9]:

$$\frac{\partial \ln E(Y_i)}{\partial \ln X_{ji}} = \{\beta_j + \sum_{k=1}^5 \beta_{jk} \ln X_{ki}\} - C_i \left(\frac{\partial \mu_i}{\partial \ln X_{ji}} \right)$$

(9)

362 where μ_i is the inefficiency in the model; $C_i = 1 - \frac{1}{\sigma} \left\{ \frac{\phi\left(\frac{\mu_i}{\sigma} - \sigma\right)}{\Phi\left(\frac{\mu_i}{\sigma} - \sigma\right)} - \frac{\phi\left(\frac{\mu_i}{\sigma}\right)}{\Phi\left(\frac{\mu_i}{\sigma}\right)} \right\}$; ϕ and Φ

363 represent the density and distribution functions of the standard normal random variable,
364 respectively.

365 The empirical results show that, from the estimates of the Cobb-Douglas production function
366 model, the estimated elasticities of mean rice output with respect to land, labour, seeds,
367 herbicides and fertilizer, at mean input values, were 0.015, 0.0095, 0.039, 0.028 and -0.059,
368 respectively. This indicates that, if land under rice, with the required quantities of labour,
369 seeds, herbicides and fertilizer were to be individually increased by 1 per cent, then the
370 mean production of rice is estimated to increase by 0.015, 0.0095, 0.039 and 0.028 per
371 cent, and decrease by 0.059 per cent respectively. This is because the estimated output
372 elasticity with respect to land, labour seeds and herbicides were found to be positive while
373 that for fertilizer was found to be negative and was all statistically significant.

374 The returns to scale estimates, evaluated at the mean input a value is 0.130 (Table 4). This
375 value is significantly less than one, indicating that rice producers in Ghana are operating
376 under increasing returns to scale.

377
378 **Table 4.** Elasticities of mean rice output with respect to inputs in the stochastic frontier
379 production functions

Input	Estimated output elasticity
Land	0.015(0.099)*
Labour	0.0095(0.070)
seeds	0.039(0.038)
Herbicide	0.028(0.083)
fertilizer	-0.059(0.075)
Returns to scale	0.130 (0.365)

380 *Standard errors are in parenthesis

382 3.4 Technical efficiency indexes

383 Table 5 shows the distribution of the predicted technical efficiencies of the sample rice
384 producers. The mean technical efficiency was estimated to be 0.691, with the maximum of
385 0.937 and the minimum of 0.127. This implies that, on the average, the rice farmers were
386 producing rice about 69 per cent of the potential (stochastic) frontier production levels, given
387 the technology currently being used. Thus, in the short run, there is capacity for increasing
388 technical efficiency in rice production by 31 per cent without necessarily varying the existing
389 input levels.

390
391 In the present study, in general, more than half of the producers had a mean technical
392 efficiency in the range of 0.71–0.99. The remaining proportion of the rice producers had
393 mean technical efficiency ranging from 0.51–0.70. This means that in general, most of the
394 sample rice producers on the average are technically efficient in the allocation and use of
395 inputs.

396
397 **Table 5.** Percentages of technical efficiencies of rice farmers in Ghana within decile ranges

Interval	Percentage
<0.5	7.2
0.51–0.60	13.9

0.61–0.70	24.2
0.71–0.80	35.1
0.81–0.90	19.1
0.91–1.00	0.5
N	194
Mean	0.691
SD	0.139
Maximum	0.937
Minimum	0.127

398

399

400 3.5 Determinants of technical efficiency

401 A summary of the empirical results of the coefficient estimates for the determinants of
 402 technical efficiency is provided in Table 6. The results suggests that significant factors
 403 influencing technical efficiency in rice production include NERICA Adoption, Gender,
 404 Education, Access to road, Household size, NGOs, Extension and the use of Herbicide.
 405 Except for household size which had a negative effect, all the other factors positively
 406 influenced technical efficiency.

407 The positive significant relationships between NERICA adoption and technical efficiency
 408 levels of rice producers suggest that producers who adopted and planted NERICA varieties
 409 tended to have smaller technical inefficiencies in rice production than non-adopters, other
 410 things being equal. The results further indicate that holding other factors constant under
 411 the assumption of homogeneous impact, adoption of the NERICA rice varieties is
 412 associated with a increase of about 11 per cent in technical efficiencies on smallholder rice
 413 farms in the Ghana.

414

415 The positive significant effect of the education variable, which implies educated farmers are
 416 more technically efficient in their rice production. It is therefore an important factor to be
 417 considered in improving rice production in the country. Education augments the capacity of
 418 farmers to obtain and optimize the use of information in relation to production inputs,
 419 consequently improving their use of inputs efficiently [40, 44]. In addition, improvement in
 420 resource use and hence productivity could result from enhanced human capital through
 421 increased access to educational training.

422

423 **Table 6.** Determinants of Technical efficiency of rice producing households in Ghana

Variable	Estimate	Std. error
NERICA Adoption	0.114 ^a	0.0169
Gender	0.042 ^b	0.0176
Age	-0.000527	0.000578
Education	0.00552 ^a	0.00169
Access to road	0.0351 ^b	0.0169
Distance to markets	-0.00151	0.00176
Nonfarm income	0.0000655 ^b	0.0000256
Household size	-0.00631 ^a	0.00209
Agric. Projects	-0.0138	0.0189

FBOs	0.00394	0.0195
NGOs	0.0338 ^c	0.0167
Fertilizer use	0.00821	0.0156
Herbicide use	0.0301 ^c	0.0155
Extension	0.043 ^b	0.0187
Constant	0.555 ^a	0.0414
F-stat.	19.17 ^a	
Adjusted R ²	0.6154	
N	194	

^asignificant at the 1 per cent level, ^bsignificant at the 5 per cent level, ^csignificant at the 10 per cent level

In addition, non-farm income from off farm activities accruing to the household has a positive significant relationship with technical efficiency. This result suggests that the more income obtained by farmers from other non-farm activities, the more technically efficient they become. Similar results were obtained by Villano and Fleming [43] who found that non-farm income enhances farmers' ability to timely acquire the right amount of basic inputs necessary for efficient rice production hence becoming more efficient in their farming operations.

The negative effect of household size on technical efficiency suggests that farmers with small family sizes tend to be more technically efficient than those with larger farm sizes. With larger house sizes, there is the possibility of some of the household members snagging in other non-farm activities hence reducing the attention directed into rice production, this may result in lower technical efficiency. This corroborate by the positive effect of non-farm income on technical efficiency (Table 6). Similar results were obtained by Oduol et al. [37] in the Democratic Republic of Congo. The empirical result further depicts a positive effect of gender on the technical efficiency. This suggests that male farmers were more likely to be technically efficient in rice production than their female counterparts. The largely male dominated rice producers in the country could account for this.

The use of herbicides was positively related with technical efficiency signifying that rice production could be improved by increasing the use of herbicides. This could be as a result of the fact that weeds control in rice production is very essential hence ability to manage and keep them in very low intensity has a significant influence on production. Rice producers in Ghana are generally financially constrained in the acquisition of inputs such as herbicides; promoting access to such inputs therefore has the potential of improving efficient rice production.

Our results also suggest that institutional variables such as the existence of roads used in the transport of both inputs and produce and access to organisations that provide agricultural extension and financial services such as NGOs and access to extension are significant determinants of technical efficiency. The existence of such organisations enhances farmers' access to vital extension, financial and market information which when utilised effectively is likely to improve technical efficiency. This result is further sustained by the high proportion of farmers with access to extension (Table 1). It also signifies the significant role played by NGOs in agriculture in the country since regardless of the low proportion of farmers having access to NGOs, yet its influence on technical efficiency is significant. Positive effects have been found between such institutions and technical efficiency [14, 41, 42]. Development interventions aim at enhancing technical efficiency in

the country could establish and strengthen linkages with these institutions and also between these institutions and farmers.

3.6 Impact of NERICA adoption of on technical efficiency

The estimated population impact parameters for both the OLS and PSM are presented in Table 7. The results suggests that adoption of NERICA varieties has had a positive and significant impact on technical efficiency of smallholder rice producers in Ghana. The estimated average impact of adoption NERICA varieties on technical efficiency of sample farmers denoted by the average treatment effect (ATE) was 0.039. Consequently, the impact parameter suggests that adoption of NERICA rice varieties is likely to increase technical efficiency by 3.9 per cent. The population selection bias estimate was not significant indicating that the impact of the adoption on technical efficiency on the entire sample is not significantly different from the impact among sub-sample of adopters. This however coincides with the expectations of all stakeholders in the rice sector including development partners. Similar findings have been reported by Chaovanapoonphol et al., [14] where impact of impact of agricultural loans was found to significantly increase technical efficiency of rice farmers in the Upper North of Thailand. In addition, Mouelhi [34] also found a positive significant impact of adoption of impact of on technical efficiency in the Tunisian manufacturing sector.

Table 7. Estimated population impact parameters

Parameter	PSM		OLS	
	Estimate	SE	Estimate	SE
Average impact on total sample (ATE)	0.049	0.135	0.039 ^b	0.0193
Average impact on adopters (ATE 1)	0.065	0.189	0.039 ^c	0.0232
Average impact on non-adopters (ATE 0)	0.013	0.0435	0.039 ^a	0.0139
Population selection bias	0.016	0.0552	4.6E-10	0.00391
Observed difference in TE	0.035	0.0279	0.032	0.0206
Observed TE of adopters	0.705 ^a	0.0121	0.704 ^a	0.0119
Observed TE of non-adopters	0.669 ^a	0.0252	0.672 ^a	0.0169
N	194			

^asignificant at the 1 per cent level, ^bsignificant at the 5 per cent level, ^csignificant at the 10 per cent level

On the contrary, conflicting findings have been reported by Oduol et al [37] where the impact of adoption of soil and water conservation technologies were found to significantly reduce technical efficiency of small holder farmers in sub-Saharan Africa. Holden et al. [27] and Kassie [31] also found significantly lower returns on plots with improved technologies. For this study, the inability of the treatment variable (adoption) to capture cost of adoption as well as other corresponding packages that comes with it could account for the minimal impact of NERICA on technical efficiency. Consequently, Future projects that seek to ensure access to seeds and other critical inputs should also include strategies to ensure that the cost of adoption of the varieties and that of other corresponding packages that comes with it is well thought-out.

4. CONCLUSION

The aim of this paper was to examine whether the adoption of NERICA rice varieties introduced and disseminated among rice farmers has had an impact on technical efficiency of smallholder rice producers in Ghana. In addition, the paper focused on estimating the technical efficiency and examining its determinants among smallholder rice producers. It also explored the effectiveness of institutional linkages among farmers to improve technical efficiency of smallholder farmers.

We first estimated a Cobb-Douglas stochastic production frontier and used it to generate the technical efficiency scores. The estimated technical efficiency scores were regressed on NERICA adoption besides other socio-economic, institutional and farm level covariates, which are hypothesized to affect technical efficiency and finally to estimate the impact of adoption of NERICA varieties on technical efficiency, propensity score matching and ordinary least squares regression procedure to consistently estimate the average treatment effect.

Our analyses revealed a high adoption rate of 68 per cent among sample farmers. We further found the estimated technical efficiency to range from 12.7 per cent to 93.7 per cent with an average of 69.1 per cent suggesting that rice farmers in Ghana could increase technical efficiency in rice production by 31 per cent without necessarily varying the existing input levels. Our findings further revealed that, adoption of NERICA rice varieties has been found to have a positive and significant impact on technical efficiency of rice producing households in the country, suggesting that the benefits of adoption of the NERICA varieties have been translated into improved technical efficiency. This suggests that access to improved varieties is an essential factor to target among others in the promoting interventions aimed at improving technical efficiency.

The result highlights institutions such as NGOs and extension services to have a positive influence on technical efficiency. This implies that continuous provision of training through the establishing and strengthening linkages between farmers and these institutions is recommended to enhance the smooth transformation of adoption efforts into efficient rice production among smallholder rice farmers in the country.

In this study, the impact of adoption on technical efficiency was examined using cross sectional dataset. A panel dataset could be obtained by conducting a complementary survey that presents the adoption and impact variables over time could allow for a more thorough analysis of the impact of the NERICA on technical efficiency over time. In addition, Future research that seeks to examine the costs associated with adoption and that of other corresponding packages that come with it is therefore essential.

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COMPETING INTERESTS

We declare that no competing interests exists

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