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Mineral Fertiliser Adoption and Land Productivity: Implications for Securing Stable Rice Production in Northern Ghana

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Abstract: The promotion of farm innovations, such as mineral fertiliser, is one of the strategies for attaining the Sustainable Development Goals (SDGs) of zero hunger and poverty alleviation in developing countries. However, the adoption of mineral fertilisers has been low in Africa, particularly in Ghana. The present study not only analyses the impact of mineral fertiliser on the land productivity of rice farmers in northern Ghana but also determines factors that are associated with the adoption of mineral fertilisers using a primary dataset from 470 rice farmers. The study employs endogenous switching regression and propensity score matching approaches in the empirical analysis. The result shows that the adoption of mineral fertiliser tends to significantly increase the land productivity of rice farmers by improving soil fertility and making nutrients readily available to rice crops. The empirical finding further indicates that the adoption of mineral fertiliser is positively influenced by land area, seed, improved rice variety and row planting whereas farmers' location and market distance exert negative effects on mineral fertiliser adoption. To maximise the land productivity of farmers, it is imperative for agricultural policy interventions to promote mineral fertiliser application by targeting key policy variables such as getting fertiliser input market outlets closer to farmers.

Keywords: Ghana; mineral fertiliser; rice sector development; land productivity; rice farming; endogenous switching regression

1. Introduction

Achieving the sustainable development goals (SDGs) of zero hunger and poverty alleviation has become a policy priority for most governments in developing countries, notably those in Africa. However, land degradation in the form of soil erosion and nutrient depletion is increasingly prevalent in Sub-Saharan Africa (SSA), particularly in Ghana, thereby hampering the attainment of the aforementioned SDGs. In developing countries, it is estimated that about 60% of the cultivated soils are associated with nutrient deficiencies and toxicities, which cause biotic plant stress [1–3]. These issues, together with abiotic stress such as high temperature and drought, tend to contribute to low agricultural productivity in these countries. The abovementioned situations pose a great threat to the livelihoods of many people in rural communities in sub-Saharan Africa, where more than half of the population depends on subsistence agriculture.

One of the crops that has attracted the attention of governments, stakeholders and non-governmental agencies is rice. Rice is the second most important food staple after maize in Ghana. The consumption of rice keeps on rising due to population growth, urbanisation and consumer eating habits. Over the years, the local rice production has been unable to consistently meet domestic demand. This compels the country to rely hugely on importation to meet the ever-increasing

demand. For example, Ghana can only supply less than 40% of its domestic rice demand despite favourable agro-ecological conditions for rice cultivation [4]. The importation of rice is estimated to cost over \$600 million annually [5]. Unfortunately, the productivity of rice farms in Ghana has been low.

It is therefore argued that one of the innovative ways to enhance rice yields is through land improvement measures such as the use of mineral fertilisers. Mineral fertiliser is shown to improve crop productivity in Africa, including in Ghana [1–3]. Mineral fertiliser such as Nitrogen-Phosphorous-Potassium fertilisers (NPK) readily supply adequate nutrients like nitrogen, phosphorous and potassium. These plant nutrients tend to alleviate abiotic and biotic stresses in plants. It is revealed that nitrogen and phosphorus deficiencies reduce the hydraulic conductivity of the root cortical cells. Nitrogen is an important macronutrient, which plays a critical role in temperature stress tolerance [3]. Nitrogen is also involved in the utilisation of absorbed light energy and photosynthetic carbon metabolism [6]. Waraich et al. [3] indicated that an excess of unused light energy could occur in nitrogen-deficient leaves, which tends to cause a high risk of photo-oxidative damage. Specifically, in rice plants under high light intensity, nitrogen deficiency results in enhanced lipid peroxidation [6]. Kato et al. [7] confirmed that plants grown under high light intensity with adequate nitrogen had a greater tolerance for photo-oxidative damage and higher photosynthesis capacity than those grown under similar light intensity but with insufficient nitrogen supply. Potassium plays an essential role in the survival of plants under environmental stress conditions. It is required for many physiological processes such as photosynthesis, translocation of photosynthates into sink organs, maintenance of turgidity and activation of enzymes under stress conditions [3,6,7]. Existing studies have shown that potassium deficiency is associated with a reduction in photosynthetic CO₂ fixation and impairment in the partitioning and utilisation of photosynthates [6,7]. These demonstrate that mineral fertilisers are necessary for increased yields by supplying nutrients to improve abiotic and biotic stress tolerance in crops. However, evidence suggests that the adoption of mineral fertilisers is low in Africa, especially in the rice sector of Ghana.

The research questions guiding this study are: *RQ1: What accounts for the low adoption of mineral fertiliser in Ghana? RQ2: What is the impact of mineral fertiliser adoption on rice yields?* The main objective of this research is to analyse the factors that influence the adoption of mineral fertiliser among rice farmers and to quantify the impact of mineral fertiliser adoption on rice yields in Ghana.

The present study is relevant for a number of reasons. First, smallholder farmers grow rice as a cash crop across the country. Rice provides employment opportunities for many people in the agricultural supply chain, especially smallholder farmers, processors, traders among other actors. Therefore, research studies focusing on improving yields of the farmers to enhance standard of living in SSA is timely and appropriate. Second, huge expenditure on the importation of rice tends to drain the foreign reserve of Ghana. The development of the rice sector by exploring an innovative way of improving the rice yields of farmers with the use of mineral fertilisers is therefore relevant.

Moreover, the economic potential of the rice sector in Ghana and Africa as a whole has attracted the attention of policy makers and the scientific community to deliberate on measures that could promote the land productivity of rice farmers. Most of the debates have centred on the adoption of improved production technologies such as improved rice varieties, fertiliser and water conservation technologies. The factors that influence the adoption of these technologies have been widely documented. A recent study described in Donkor et al. [8] has established a significant positive relationship between the adoption of mineral fertiliser and agricultural extension services in the Northern region of Ghana. Wiredu et al. [9] found engagement in off-farm activities and the use of improved seeds minimised the likelihood of adopting mineral fertiliser whereas the expectation of high yield, labour-land ratio and subsidy tended to positively influence rice farmers to apply mineral fertilisers in the Northern region of Ghana. Studies on fertiliser adoption conclude that the price of fertiliser, relatively low income, low output, small farm size and lack of access to credit are factors responsible for the low and slow adoption of mineral fertilisers in Africa and other developing countries [10–12]. As argued by

Williamson [13], the price elasticity of fertiliser demand in developing countries tends to be less but farmers' response to the rise in fertiliser price is becoming more sensitive in recent years, implying that higher fertiliser prices tend to discourage its application among smallholder farmers.

Some studies have analysed the impacts of farm innovations on rice yields, especially in the context of the rice sector in Ghana. A recent study revealed that an increasing number of farm innovations tend to raise the rice yields of producers in Ghana [14]. However, the study did not advance the analysis to evaluate the effects of individual innovations such as mineral fertiliser, improved seed and row planting on rice yields. Analysing the yield gap between male and female rice farmers in Ghana, Owusu et al. [15] asserted that females were equally technically efficient as males when equipped with adequate farm inputs and support services. Another study investigated the impact of row planting technology on the rice yield of farmers in northern Ghana and concluded that row planting tended to increase rice yields by reducing competition for water, nutrients and sunlight among the crops; enhancing the application of agrochemicals and mechanical harvesting [16]. This is consistent with the evidence from Faltermeier and Abdulai [17], which showed that adopters of the dibbling technology had a higher output than non-adopters and combining the dibbling technology with intensified weeding tended to exert significant positive effects on rice output and net returns. It is apparent from these empirical studies that less emphasis has been placed singularly on the effect of mineral fertiliser on the farm yields of farmers. Therefore, limited literature exists on the effect of mineral fertiliser application on rice yields. The present study contributes to narrowing this knowledge gap by applying econometric techniques, notably the endogenous switching regression and propensity score matching approaches, to evaluate the impact of mineral fertiliser adoption on the rice yields of rice farmers in northern Ghana.

2. Theoretical Framework

The present study derives its theoretical foundation from the production theory, which establishes a physical relationship between farm output and inputs. The production process involves the transformation of different factor inputs into an output using a given technology [18]. In the agricultural economic literature, land productivity has been measured as the quantity of farm output generated from a unit area of land. In the extant empirical literature, land productivity analysis is performed using econometric models such as the stochastic frontier approach, data envelopment analysis, linear regression, endogenous switching regression and propensity score matching [8,15–19]. The stochastic frontier and data envelopment analysis are mostly applied to estimate productive efficiency, whereas linear regression, endogenous switching regression and propensity score matching are used to estimate the effect of variable of interest on land productivity. For our study, the key focus is to analyse the effect of mineral fertiliser adoption on land productivity. Hence, the endogenous switching regression and propensity score matching approaches are applied in the empirical analysis. These methods are discussed later in this section.

In this study, land productivity is operationalised as rice output harvested from a hectare of land, which is also the same as rice yield. Rice yield of farmers is examined with a generalised production function written as:

$$Rice_i = f(X_{1i}, X_{2i}, \dots, X_{JN}, Fert_i; \tau_i) \quad i = 1, 2, \dots, N \quad (1)$$

Equation (1) can be expressed explicitly as:

$$Rice_i = X_i' \beta + Fert_i' \gamma + \tau_i \quad (2)$$

where $Rice_i$ is the quantity of rice of output produced per ha; X_{1i}, \dots, X_{JN} indicate a set of intensive factor inputs, namely labour, seed and pesticides used for production; f describes the physical relationship between the output and the factor inputs. β and γ represent parameters to be estimated. τ_i is the error term. $Fert_i$ denotes the application of mineral fertiliser which is captured as a variable, 1 represents application of mineral fertiliser and 0 otherwise. Equation (2) can be estimated with the ordinary least

squares approach. However, the variable mineral fertiliser is likely to be endogenous, which implies that some factors tend to influence mineral fertiliser adoption. Without addressing this potential endogeneity issue, the estimates generated from the ordinary least squares (OLS) estimation become biased which may result in misleading conclusions and faulty policy implications. Some approaches are suggested to correct such endogeneity problem, including the propensity score matching (PSM), difference in difference and the endogenous switching regression (ESR). The difference in difference approach is appropriate for panel data sets. However, our dataset is cross-sectional; therefore, the PSM and ESR are suitable. PSM can account for observable factors but unable to address unobservable factors that affect the adoption process and the outcome variable [17]. Therefore, we employ the ESR in the present study, which is capable of addressing both observable and unobservable factors, while we use the PSM as a robust check.

2.1. Endogenous Switching Regression

According to the theory of innovation [20], the technology adoption decision processes in the context of this study are outlined as follows. First, the farmer gathers information regarding the innovation (knowledge). The farmer develops either a favourable or an unfavourable attitude towards the innovation (persuasion) based on the knowledge acquired. Afterwards, the farmer decides to adopt or not adopt the innovation (decision and implementation) and lastly, the farmer decides whether to continue or discontinue the use of the innovation based on the perceived and observed benefits (confirmation). Based on this conceptualisation, we theorise that rice farmers, being rational, decide to apply mineral fertiliser by evaluating the marginal utility of adoption and that of non-adoption. There is a higher propensity for rice farmers to apply mineral fertiliser if the marginal utility from adoption (U_1) exceeds that of non-adoption (U_0), thus, $U_1 - U_0 > 0$ or $U_1 > U_0$. The adoption process can be modelled as:

$$Fert_i^* = \mathbf{X}_i\Psi + e_i \tag{3}$$

$$Fert_i = \begin{cases} 1, & \text{if } Fert_i^* = \mathbf{X}_i\Psi + e_i > 0 \\ 0, & \text{if } Fert_i^* = \mathbf{X}_i\Psi + e_i \leq 0 \end{cases} \tag{4}$$

Following Lokshin and Sajaia [21], the theoretical models for the two regimes (adopters and non-adopters) with the selection equation are presented as in Equations (5) and (6):

$$Rice_{i1} = \mathbf{X}_{i1}\beta_1 + \tau_{i1} \quad \text{if } Fert = 1 \tag{5}$$

$$Rice_{i0} = \mathbf{X}_{i1}\beta_0 + \tau_{i0} \quad \text{if } Fert = 0 \tag{6}$$

where \mathbf{X}_i is a vector of socioeconomic, institutional and technological characteristics related to the farmer. β_1 and β_0 are vectors of parameters, τ_1 and τ_0 are error terms and τ_1 , τ_0 and e_i are assumed to have a trivariate normal distribution with mean zero and non-singular covariance matrix which is specified as:

$$\text{cov}(\tau_1, \tau_0, e_i) = \begin{bmatrix} \sigma_e^2 & \sigma_{\tau_1 e} & \sigma_{\tau_0 e} \\ \sigma_{e\tau_1} & \sigma_{\tau_1}^2 & \cdot \\ \sigma_{e\tau_0} & \cdot & \sigma_{\tau_0}^2 \end{bmatrix} \tag{7}$$

where σ_e^2 is a variance of e_i , $\sigma_{e\tau_1}$ is the covariance of e_i and τ_1 , $\sigma_{e\tau_0}$ is the covariance of e_i and τ_0 , $\sigma_{\tau_1}^2$ is the variance of τ_1 and $\sigma_{\tau_0}^2$ is the variance of τ_0 . Both $Rice_{i1}$ and $Rice_{i0}$ are not observed simultaneously. The covariance between τ_1 and τ_0 is not defined and no information is available for the covariance [22]. Equations (4)–(6) should be estimated in a way that accounts for the correlation between the error terms.

Using the ordinary least squares or the maximum likelihood estimation approach may yield inconsistent and biased estimates. A two-stage procedure can be used to estimate the parameters in Equations (4)–(6). The procedure involves estimating the probabilities of adopting mineral fertiliser using the maximum likelihood estimation approach [22]. The estimated probabilities (\hat{Fert}_i) are used to

estimate selectivity terms that account for the endogeneity of mineral fertiliser adoption. The selectivity terms denoted by γ_0 and γ_1 are expressed as:

$$\gamma_1 = \phi(\hat{Fert}_i) / \Phi(\hat{Fert}_i) \tag{8}$$

$$\gamma_0 = -\phi(\hat{Fert}_i) / [1 - \Phi(\hat{Fert}_i)] \tag{9}$$

ϕ and Φ denote the probability density and cumulative distribution function of the standard normal distribution, respectively. The selectivity terms are included in Equations (5) and (6) as explanatory variables in addition to \mathbf{X}_i . The modified equations are specified as:

$$Rice_{i1} = \mathbf{X}_{i1}\beta_1 + \gamma_1\omega_1 + \tau_{i1} \text{ if } Fert = 1 \tag{10}$$

$$Rice_{i0} = \mathbf{X}_{i0}\beta_0 + \gamma_0\omega_0 + \tau_{i0} \text{ if } Fert = 0 \tag{11}$$

The parameters in Equations (10) and (11) are computed using the OLS estimator. The two-stage procedure generates consistent coefficients but the standard errors are inconsistent because they produce heteroskedastic residuals of the error terms [22]. To obtain homoscedastic residual terms, the full information maximum likelihood estimation (FIMLE) method is more suitable [22]. The adoption and outcome equations are estimated simultaneously with the FIMLE. The log likelihood function of the FIML estimator is written as:

$$\ln L = \sum_i (Fert_i \theta_i [\ln\{\ln \beta(\gamma_{1i})\} + \ln\{\Omega(\tau_{1i}/\sigma_1)/\sigma_1\}] + (1 - Fert_i) \theta_i [\ln\{1 - \Psi(\gamma_{0i})\} + \ln\{\Omega(\tau_{0i}/\sigma_0)/\sigma_0\}]) \tag{12}$$

where $\Psi(\cdot)$ is a cumulative normal distribution function, $\Omega(\cdot)$ indicates a normal density distribution function, θ_i is an optional weight for observation i and λ_{ij} are defined as:

$$\gamma_{ij} = \frac{(\mathbf{X}_i \Psi + \rho_j \tau_{ij} / \sigma_j)}{\sqrt{1 - \rho_j^2}} \quad j = 0, 1 \tag{13}$$

where $\rho_1 = \sigma_{\tau_1 e}^2 / \sigma_e \sigma_1$ is the correlation term between e_i and τ_1 and $\rho_0 = \sigma_{\tau_0 e}^2 / \sigma_e \sigma_0$ is the correlation term between e_i and τ_0 . To ensure that ρ_1 and ρ_0 are bounded between -1 and 1 and that the estimated σ_1 and σ_0 are always positive, the FIMLE directly estimates $\ln \sigma_1$, $\ln \sigma_0$ and $\text{atanh} \rho_j$ [22]. $\text{atanh} \rho_j$ is further computed as:

$$\text{atanh} \rho_j = \frac{1}{2} \ln \left(\frac{1 + \rho_j}{1 - \rho_j} \right) \quad j = 0, 1 \tag{14}$$

Once the parameters of the models are estimated, the impact of mineral fertiliser adoption, as denoted by average treatment effect on the treated (ATT) can be computed as:

$$\begin{aligned} ATT_{ESR} &= E(Rice_{i1} | Fert_i = 1, X_{i1}) - E(Rice_{i1} | Fert_i = 0, X_{i1}) \\ &= \sigma_1 \rho_1 \Phi(\mathbf{X}_i \Psi) / \Omega(\mathbf{X}_i \psi) - \sigma_1 \rho_1 \Phi(\mathbf{X}_i \Psi) / \{1 - \Omega(\mathbf{X}_i \Psi)\} \end{aligned} \tag{15}$$

The standard t -test is employed to determine if the difference is statistically different from zero. Note that PSM is used as a robust check to complement ESR.

2.2. Propensity Score-Matching Approach (PSM)

Propensity score matching explains the pairing of treatment and control units with similar values on the propensity score and possibly other covariates while removing all the unmatched units [23–27]. Using PSM approach to compute ATT involves two main steps. First, the propensity scores are computed using a binary choice model, in the present study, a probit model. This is expressed as:

$$p(X_i) = \Pr[Fert_i = 1|X_i] = E[Fert_i|X_i]; p(X_i) = \Omega\{g(X_i)\} \quad (16)$$

where $\Omega\{\cdot\}$ can be a normal cumulative distribution and X is a vector of pre-treatment characteristics. The PSM assumes selection on observables only, based on the Conditional Independence Assumption (CIA), that the potential outcome is independent of the technology choice conditional on covariates.

Second, the ATT can be calculated after estimating the propensity scores as:

$$ATT = E\{\Pi_1 - \Pi_0|Fert = 1\} \quad (17)$$

$$ATT = E[E\{\Pi_1 - \Pi_0|Fert = 1, p(X)\}] \quad (18)$$

$$ATT = E[E\{\Pi_1|Fert = 1, p(X)\} - E\{\Pi_0|Fert = 0, p(X)\}|Fert = 1] \quad (19)$$

In this study, we use matching methods, notably nearest neighbour matching (NNM), kernel-based matching (KBM) and radius matching methods, which have been extensively applied in empirical studies.

2.3. Empirical Strategy

The empirical specification of the selection and outcome equations are given as:

$$Fert_i = \Psi_0 + \sum_{j=1}^6 \Psi_j Finputs + \sum_{j=7}^{11} \Psi_j Hcapital_{ij} + \sum_{j=12}^{14} \Psi_j Institutional_{ij} + e_i \quad (20)$$

$$Rice_{ik} = \beta_{0k} + \sum_{j=1}^5 \beta_{jk} Finputs_{ijk} + \sum_{j=6}^{10} \beta_j Hcapital_{ijk} + \sum_{j=11}^{13} \beta_{jk} Institutional_{ijk} + \tau_{ik} \quad (21)$$

$k = 1(\text{adopters}), 2(\text{non-adopters})$

where $Fert_i$ equals 1 if the farmer applied mineral fertiliser and 0 otherwise. β_0 and Ψ_0 are constant terms; β_{jk} , Ψ_j are the parameters to be estimated; and e_i , τ_k represent the error terms.

$Finputs_{ijk}$ denotes a vector of farm inputs such as labour, seed, rowplanting and pesticides. *Labour* is the quantity of man-days of labour input used per ha. *Seed* is the amount of rice seed planted per ha. *Pesticide* is the cost of pesticide applied per ha. *Rowplanting* denotes 1 if farmer planted rice seeds in rows and 0 otherwise.

$Hcapital_{ij}$ is a set of human capital, which comprises gender, 1 if the farmer is a male and 0 otherwise, age in years, education measured as the number of years of formal schooling, household size representing the number of people in the household and location dummy variable, specifically, Kassena equals 1 if the farmer is located in the Kassena Nankana district and 0 otherwise.

$Institutional_{ijk}$ is a bundle of institutional variables including extension denoting 1 if farmer has access to agricultural extension services and 0 otherwise, credit denoting 1 if the farmer has access to credit and 0 otherwise and market distance measured as the distance to the nearest market centre in kilometres.

Non-linearity is removed from the model by transforming all the continuous variables, including seed, pesticide, labour, market distance, age, household size and land into a natural logarithm. For the purpose of identification, land area is used as an instrument in the mineral fertiliser adoption equation since all the factor inputs are converted into factor intensities while the total output is converted to yield or output per unit of land area.

2.4. Source of Data

The survey dataset was extracted from the Ghana Agricultural Production Survey (GAPS), which was conducted by the Ministry of Food and Agriculture in Ghana in collaboration with the International Food Policy Research Institute (IFPRI) in 2011/2012 cropping season. The GAPS data was obtained

from farming households in the ten regions of Ghana using a structured questionnaire. In the selection of the respondents, GAPS used a multistage sampling technique. In this study, we extracted the dataset related to rice farmers in the Upper East region of Ghana. There are eight districts, namely Bawku Municipal, Bawku West, Bolgatanga Municipal, Bongo, Builsa, Garu-Tempane, Kassena Nankana East and Talensi-Nabdam. However, Kassena Nankana East District and Bawku Municipal are well known for rice production in the Upper East region. In total, 470 respondents, comprising 350 and 120 rice farmers from Kassena Nankana East and Bawku, respectively, were used. The detailed sampling procedure for the GAPS can be retrieved from the IFPRI website. The descriptive statistics of the relevant variables included in the models are presented in Table 1. On average, adopters planted 74.032 kg of rice seed per ha whereas that of non-adopters is 55.918 kg per ha. This shows that adopters plant 18.114 kg per ha more than non-adopters. The mean labour input used by adopters and non-adopters are 109.311 mandays per ha and 80.272 mandays per ha, respectively. The mean difference of labour input between these two groups is 29.039 mandays per ha and it is statistically different from zero at 1%. This descriptive evidence shows that adopters tend to use more labour input than non-adopters. For the application of mineral fertiliser is labour intensive. Table 1 further shows that there are no significant differences between adopters and non-adopters in terms of farm inputs, notably pesticides, use of improved seeds and row planting. Adopters and non-adopters have similar human capital, especially age, gender, household size and education. However, the proportion of adopters in Kassena Nankana is higher than adopters in Bawku Municipal suggesting that Kassena farmers tend to apply more mineral fertilisers in rice production. About 41.8% of the adopters have access to agricultural extension services whereas 31.11% of the non-adopters accessed agricultural extension services. This demonstrates that adopters tend to have more access to agricultural extension services. The means of market distance and access to credit are quite similar for adopters and non-adopters.

Table 1. Summary statistics of the variables included in the models.

Variable	Adopters	Non-Adopters	Mean Difference	t-Value
Yield	1138.864 (958.045)	844.854 (741.951)	294.010 ***	3.733
Farm inputs				
Seed (kg/ha)	74.032 (57.728)	55.918 (43.091)	18.114 ***	3.884
Labour (mandays/ha)	109.311 (70.027)	80.272 (62.542)	29.039 ***	4.682
Pesticide (Gh¢/ha)	3.087 (23.889)	3.351 (14.077)	−0.264	−0.151
Improved seed	0.191 (0.394)	0.111 (0.315)	0.080	0.071
Row planting	0.831 (0.376)	0.721 (0.450)	0.110	0.026
Human capital				
Age	33.176 (16.875)	33.449 (16.631)	−0.273	0.172
Gender	0.486 (0.501)	0.530 (0.500)	−0.044	−0.720
Location dummy (Kassena)	0.833 (0.374)	0.607 (0.491)	0.226 ***	4.190
Household size	5.606 (3.156)	5.285 (2.707)	0.321	1.173
Education	2.776 (4.273)	2.645 (4.276)	0.131	0.798
Institutional variables				
Extension	0.418 (0.494)	0.311 (0.464)	0.107 **	1.860
Market	7.978 (6.461)	7.168 (5.688)	0.810	1.422
Credit	0.038 (0.192)	0.024 (0.155)	0.014	0.520

*, ** and *** denote 10%, 5% and 1% statistical levels, respectively. The values in parentheses represent standard deviations.

3. Results and Discussion

The results from the estimated selection and outcomes equations are presented in Table 2. The likelihood ratio (LR) chi-square ($\chi^2_{(13)} = 25.170$) from the ESR estimates is statistically significant at the 1% level, suggesting that the vector of explanatory variables examined in the models jointly influence the adoption and its impact on rice yields of adopters and non-adopters. The constant terms for the adoption of mineral fertiliser shows a significant negative effect, which confirms the conception that farmers are resistant to change regarding technology adoption [15]. An important finding from the estimates is the signs and significance of the covariance terms (ρ_1 and ρ_0). The covariance term for the rice yield of adopters is statistically significant at 1%, implying self-selection into the adoption of mineral fertiliser by the rice farmers and that the adoption of mineral fertiliser may not exhibit the same effect on adopters, if they choose to adopt. The negative sign of ρ_1 represents a positive selection bias, implying that farmers with above rice yields are more likely to adopt mineral fertiliser. This result from our study is consistent with studies described in Donkor et al. [16] but inconsistent with that of Faltermeier and Abdulai [17]. The value of the chi-square statistics of 25.12 is statistically different from zero, suggesting that the independence assumption of the selection and outcome equations must be rejected at 1% level and which justifies the appropriateness of using the FIMLE to estimate jointly the parameters of the models.

Table 2. Estimates of the Endogenous Switching Regression model.

Variable	Selection		Yields			
	Coeff	SE	Adopters		Non-Adopters	
			Coeff	SE	Coeff	SE
Constant	3.849 ***	1.274	3.927	0.483	1.993	0.348
Farm inputs						
Lnlabour	0.080	0.121	0.134	0.086	0.053	0.061
Lnseed	1.238 ***	0.287	0.887 ***	0.077	0.581 ***	0.105
Lnpesticide	0.060	0.171	0.006	0.053	0.020	0.034
Lnland	1.538 ***	0.287				
Improved variety	0.375 **	0.174	0.132	0.113	0.197 **	0.098
Rowplanting	0.529 ***	0.173	0.207 *	0.110	0.078	0.077
Human capital						
Gender	0.060	0.131	0.160 *	0.084	-0.042	0.061
Lnage	0.140	0.131	0.095	0.092	0.097	0.068
Education	0.005	0.014	0.009	0.010	0.010	0.007
Kassena	0.860 ***	0.072	0.448 ***	0.097	0.300 ***	0.094
Lnhousehold	-0.005	0.100	0.094	0.069	0.050	0.051
Institutional variables						
Extension	-0.594	0.599	0.406 ***	0.099	0.247 ***	0.077
ResidExten	0.166	0.594				
Credit	0.570	0.348	-0.152	0.238	-0.149	0.203
Lnmarket	-0.133 *	0.071	-0.160 ***	0.051	-0.014	0.036
Diagnostic statistics						
Wald chi-square (13)	165.12 ***					
Log likelihood	-559.291					
Sigma 1	0.706 **	0.047				
Sigma 2	0.505 ***	0.028				
Rho 1	-0.991 ***	0.006				
Rho 2	-0.300	0.233				
LR test of independent equations	$\chi^2(1) = 25.170$ ***					
Observation	470					

*, ** and *** denote 10%, 5% and 1% statistical levels, respectively. Coeff denotes coefficient and SE denotes standard error. ResidExten denotes residual of extension variable.

3.1. Determinants of Mineral Fertiliser Adoption and Rice Yields

3.1.1. Farm Inputs

The coefficients of seed and land show significant positive effects on the adoption of mineral fertiliser. These results imply that, as farmers increase the quantity of seed and expand land area under

cultivation, they tend to apply mineral fertiliser. Similarly, farmers who grow improved rice seeds and plant in rows are more likely to adopt mineral fertiliser. The result in Table 2 also shows the significant positive effects of rice seeds on the yields of both adopters and non-adopters but the magnitude of the impact of seed is higher for adopters than for non-adopters. Row planting exhibits a significant positive effect on rice yield of adopters but is statistically insignificant for non-adopters. This implies that farmers who planted their rice seeds in rows and applied mineral fertiliser tended to generate a higher yield. Row planting is known to minimise competition among crops for nutrients, water and light and thus ensuring efficient utilisation of nutrients supplied by the mineral fertiliser [16,17]. In contrast, the coefficients of improved rice variety, pesticides and labour did not show any significant effect on rice yields of adopters and non-adopters.

3.1.2. Human Capital

Apart from the location variable (Kassena), none of the human capital variables exerts a significant effect on the adoption of mineral fertiliser. The positive significant coefficient of the location variable (Kassena) demonstrates that farmers there are more likely to apply mineral fertiliser compared to rice farmers located in the Bawku District. The ESR estimates indicate a positive significant impact of the location variable (Kassena) on rice yields of both adopters and non-adopters. This implies that both adopters and non-adopters from the Kassena District are more productive in rice production than those in Bawku district. The estimates reveal that rice yields of adopters in Kassena are higher than that of non-adopters. The difference can be attributed to the application of fertiliser besides other important factors like better access to output and input markets, support services including extension services in Kassena than in Bawku. This result agrees with empirical evidence from References [15,17]. The gender variable does not significantly influence the adoption of mineral fertiliser and rice yields of non-adopters but it exerts a positive significant effect on the rice yields of adopters. The results indicate that male adopters tend to have higher yields in rice farming than females. Females are mostly constrained by inadequate economic resources such as financial and land. Females are also involved household chores, which make them allocate limited time to rice farming. These factors may be responsible for the low rice productivity of female farmers [15].

3.1.3. Institutional Variables

All the institutional variables examined in the selection model show significant positive impacts on the adoption of mineral fertiliser. Specifically, access to extension services tends to promote the adoption of mineral fertiliser. Extension agents encourage farmers to apply innovative farm inputs including mineral fertilisers to achieve higher yields. Farmers with access to credit are more likely to apply mineral fertiliser. Mineral fertiliser is a capital-intensive farm innovation and since most these smallholder farmers are credit-constrained, affordable credit is required to enable them to purchase mineral fertiliser. The result further points out that as distance to market centres increases, the farmers tend to apply less mineral fertiliser. When input and output markets are far away from farmers, transaction costs increase. For instance, high transport costs can discourage farmers from purchasing mineral fertiliser.

Access to agricultural extension services shows significant positive effects on the rice yields of adopters and non-adopters. This result implies that farmers with access to extension services are more likely to be productive. Having access to extension services exerts a higher impact on the rice yields of adopters than those of non-adopters. Adopters with access to extension agents receive technical support on efficient combination of fertiliser with other productive inputs. The complementing fertiliser input with other technical support from extension service tends to offer adopters comparative advantage over non-adopters who only obtain technical supports.

The coefficient of market distance has a negative significant effect on rice yield of adopters but no effect on rice yields of non-adopters of mineral fertiliser. As already noted, a long distance to market increases the transaction costs associated with transporting farm inputs, including fertiliser, to the farm. Besides transport cost, long distances may influence the timeliness of fertiliser application leading to inefficiency in application of farm inputs.

3.2. The Impact of Mineral Fertiliser on Rice Yield

Table 3 shows the estimates of the Average Treatment Effect on the Treated (ATT) from the endogenous switching regression (ESR) model. For all estimates in Table 3, the treated group (adopters) have higher yields than the control group (non-adopters). Specifically, the ESR estimates show that adopters harvest 211.34 kg/ha higher than non-adopters. These results show that the adoption of mineral fertilisers tends to increase the yields of rice farmers. The application of mineral fertilisers like NPK supplies the plant with essential nutrients, notably nitrogen, phosphorus and potassium. Nitrogen is an important structural part of chlorophyll required for photosynthesis; phosphorous is needed for energy generation and storage, an essential structural component of nucleic acids; potassium for osmotic regulation and activation of enzymes [2,3].

Table 3. Estimates on Average Treatment Effects on the Treated (ATT).

Method	Treated	Control	ATT	t-Value
Endogenous switching regression	999.158	787.817	211.340 ***	3.61
Propensity Score Matching				
Nearest neighbour matching	1138.863	748.924	389.938 ***	2.87
Radius matching	1138.863	844.854	294.009 ***	3.88

*, ** and *** denote 10%, 5% and 1% statistical levels, respectively.

The Upper East region of Ghana is characterised by high temperatures. Therefore, the application of macronutrients such as potassium could help to modify stomatal function and can assist to activate the physiological and metabolic processes of the rice plant. These processes tend to contribute to preserving high water potential in plant tissues to boost heat stress tolerance [3,6,28,29]. Moreover, evidence in Waraich et al. [3] indicated that the application of nutrients such as nitrogen and potassium are known to minimise toxicity to reactive oxygen species (ROS) by increasing the concentration of antioxidant enzymes in plant cells.

The estimates from the propensity score matching (PSM), which we used as a robust check on our results in the present study, are provided in Table A1 in the Appendix A. The results of the balancing test of the distribution of the covariates in both the treated and control groups are shown in Table A2. The propensity score test indicates a significant reduction in bias after matching and no significant differences in matched adopters and non-adopters for any of the covariates. The nearest neighbour matching (NNM) and the radius matching (RM) algorithms were employed in the estimation of the ATT. The PSM estimates presented in Table 3 show that adopters of mineral fertiliser are able to produce 294.009–389.94 kg/ha of rice output higher than non-adopters. It is evident from Table 3 that the ATT estimates generated from the PSM estimation are higher than the ESR estimate, which may be attributed to the inability of the PSM to account for unobservable factors. The empirical evidence is consistent with the extant studies, which have demonstrated that the application of mineral fertiliser has significantly raised the yields of farmers in Africa [30–32].

4. Concluding Remarks

This study has analysed the impact of the adoption of mineral fertilizer on yields of 470 rice farmers in two districts of the Upper East Region of Ghana. The endogenous switching regression and propensity score matching econometric techniques were employed. The results show that few rice farmers applied mineral fertiliser on their rice farms. Farm inputs such as seed, land, improved

rice variety and row planting had positive effects on the adoption of mineral fertiliser. Location variable—Kassena Nankana was the only human capital that showed a significant positive effect on mineral fertiliser adoption. Market distance negatively influenced the adoption of mineral fertiliser by rice farmers. Different factors, notably farm inputs, human capital and institutional variables, tended to increase the rice yields of adopters and non-adopters.

The empirical results generally show that the adoption of mineral fertiliser tends to increase the yields of rice farmers. Therefore, specific policy recommendations are required to ensure the effective promotion of mineral fertiliser adoption. First, it is important to bring mineral fertilisers closer to farmers by establishing mineral fertiliser input markets at villages. This may reduce the transaction costs associated with the procurement of fertiliser inputs. The proximity will ensure timely application of mineral fertilisers to raise the yields of adopters. In addition, farmers are encouraged to plant their rice seeds in rows and to use improved rice seed varieties. Besides generally promoting the adoption of mineral fertilisers to enhance yields of farmers, specific recommendations are necessary to raise the rice yields of adopters and non-adopters. Agricultural policy should prioritise revamping agricultural extension services by providing adequate supporting facilities such as motorbikes, vehicles, as well as recruiting and training new extension agents. Efficient delivery of agricultural extension services will help to narrow yield gaps between female and male adopters. Lastly, extension officers should emphasise to farmers the impacts of mineral fertilisers on the environment and human health if they are mishandled.

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Appendix A

Table A1. Determinants of the adoption of mineral fertiliser from the propensity score matching (PSM).

Variable	Coefficient	Standard Error	z-Value	p-Value
Lnland	0.536 ***	0.193	2.780	0.006
Lnage	0.027	0.091	0.300	0.766
Gender	0.016	0.158	0.100	0.921
Extension	−0.559	0.887	−0.630	0.529
Kassena	−1.024 ***	0.196	−5.230	0.000
Lnhousehold size	−0.029	0.097	−0.300	0.763
Lnmarket	0.111	0.077	1.430	0.152
Credit	0.755 **	0.330	2.290	0.022
Improved variety	0.481 ***	0.183	2.620	0.009
Rowplanting	0.402 *	0.214	1.880	0.060
Education	0.007	0.014	0.470	0.635
ResidExten	0.193	0.882	0.220	0.827
Constant	−0.274	0.683	−0.400	0.689
Diagnostic statistic				
Wald $\chi^2(12)$	94.75 ***			
Log-likelihood	−268.048			
Observation	470			

*, ** and *** denote 10%, 5% and 1% statistical levels, respectively.

Table A2. Test of selection bias after matching.

Variable	Treated	Control	% Bias	t-Value	p-Value
Lnlabour	4.456	4.386	9.600	0.910	0.362
LnLand	0.164	0.167	−0.500	−0.040	0.969
Lnseed	4.089	4.122	−5.600	−0.480	0.633
Lnpesticide	0.335	0.342	−0.800	−0.080	0.933
Rowplanting	0.831	0.846	−3.800	−0.410	0.685
Extension	0.311	0.322	−2.200	−0.220	0.825
ResidExten	−0.066	−0.061	−1.300	−0.120	0.902
Credit	0.038	0.024	8.000	0.760	0.447
Lnmarket	1.801	1.911	−13.000	−1.300	0.193
Kassena	0.607	0.615	−2.000	−0.170	0.866
Education	2.776	2.471	7.100	0.710	0.477
Lnage	3.402	3.368	7.300	0.690	0.488
Gender	0.486	0.518	−6.400	−0.610	0.541
Lnhousehold	1.554	1.577	−3.800	−0.350	0.730
Improved variety	0.191	0.195	−1.100	−0.100	0.922
Diagnostic statistics	Before matching	After matching			
Pseudo-R ²	0.1601	0.024			
LR of χ^2	77.83 ***	11.990			
P > χ^2	0.000	0.680			
% Mean bias reduction		36.1			

*** denotes 1% statistical level.

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