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Limits to Green Revolution in Rice in Africa

The Case of Ghana

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ABSTRACT

The Ghana National Rice Development Strategy in 2009 was developed to double rice production by 2018 with a 10 percent annual increase and to reduce overreliance on imports and help achieve national food security, increased income, and reduced poverty. Data show that rice production has been increasing at 8 percent annually since 2009, but most of this (6 percent) comes from land area expansion, and only 2 percent comes from productivity improvements. National average rice yield remains at 2.2 tons per hectare (tons/ha) compared to the potential achievable yields of 6-8 tons/ha based on on-farm trials. This paper examines closely the constraints in productivity improvements and evaluates available rice technologies looking at the heterogeneity of irrigated and rainfed ecologies in 10 regions in Ghana.

Employing yield response models, profitability analysis, and adoption models, results show various practices contribute to yield improvements in irrigated and rainfed systems including chemical fertilizer use, use of certified seed of improved varieties, transplanting, bunding, leveling, use of a sawah system, seed priming, and row planting. Evidence also shows that extension services on rice production are limited and that intensifying extension services can contribute to increases in rice yield. While some technologies can contribute to increasing yields, marginal increases in yield from these technologies in rainfed systems are not high enough to match the productivity growth achieved during the Green Revolution in Asia. Expansion of irrigated areas will be necessary to boost rice productivity and production in Ghana.

Fertilizer subsidies seem to have reduced costs and increased production in the short run, but the government of Ghana has to find ways to reduce its major production costs to be competitive in the future. Main factors to encourage fertilizer use intensity and adoption of other productivity-enhancing technologies are the degree of commercialization and improving market access, reducing milling and marketing costs for local production to be competitive with imported rice, and reducing costs and improving accessibility of power tillers—for plowing and bunding—and hired labor, which comprise 40–56 percent of the overall production costs.

Keywords: productivity, profitability, technology adoption, fertilizer subsidy, rice, Green Revolution, Africa south of the Sahara

JEL Codes: Q12, Q16, Q18, C36

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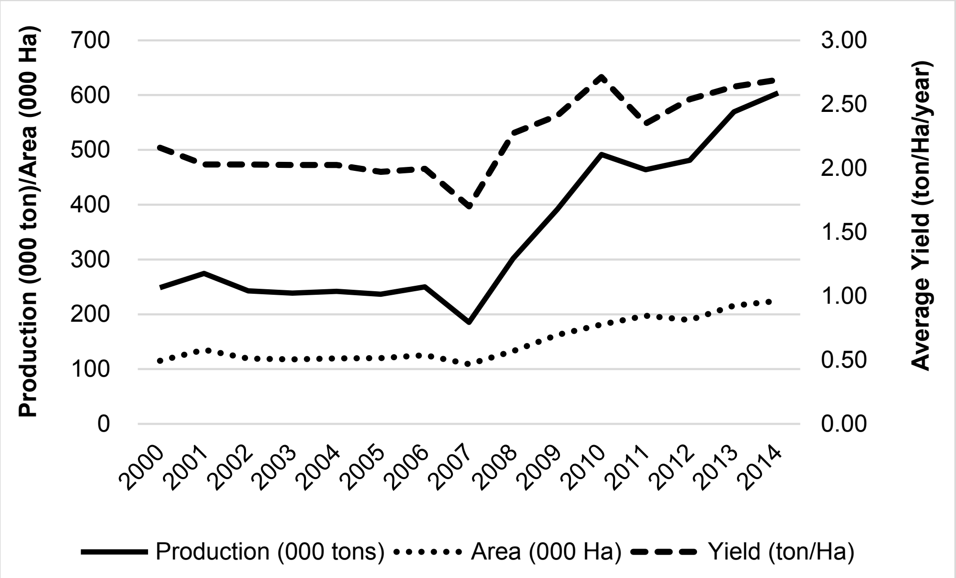
1. INTRODUCTION

Rice is playing a key role in providing food security for low-income households of rural and urban populations not just in Asia but also in Africa south of the Sahara (SSA). Due to the rapid population growth and urbanization on the continent, the consumption of rice has been increasing far more rapidly than domestic rice production, thereby necessitating an increase in the net importation of rice (Balasubramanian et al. 2007). In West Africa, for example, rice increased from the fourth most consumed cereal in 1990 to the first in 2014, followed by corn, millet, and sorghum in the region (USDA 2015). Annual rice consumption also increased in the region very quickly by an average of 6 percent per year between 2008 and 2012 against a rate of 2 percent for the period 2000–2007 (USDA 2014). Rice is also a major income-generation activity for many farming households; in Ghana, for example, rice-producing households sell 70 percent of their total rice harvest on average (Ragasa et al. 2013). Realizing the role of rice as food security and highly commercial crop, the Coalition for African Rice Development was launched with the aim of doubling rice production in SSA within 10 years. Several countries have subsequently developed ambitious National Rice Development Strategies and implemented important policy measures to stimulate domestic production (Seck et al. 2013). But growth in rice production and productivity remain slow, and reliance on rice imports continues at 40 percent of total rice consumption to cover for the continuous rise in rice consumption (AfricaRice 2011). This is particularly the case in Ghana, despite political attention and policies initiated, including 40.0 percent tariff and taxes on imported rice (Ragasa et al. 2014). While substantial investments in national rice production have been made, local production is still not able to keep up with growing demand for rice in Ghana. Although local production of milled rice recently has grown by 7 percent annually, from 242,000 tons in 2004 to 604,000 tons in 2014, most of this growth in production has come from area expansion (5 percent), with the remaining 2 percent coming from productivity improvements (Figure 1.1). Despite these efforts, Ghana imported 640,000 tons of rice in 2013, representing 53 percent of rice consumption, and 414,000 tons in 2014, representing 40 percent of rice consumption.

Figure 1.1 Production, area cultivated, and yield of rice in Ghana, 2000–2014



Source: Raw data from the Statistics, Research and Information Directorate of the Ministry of Food and Agriculture (SRID, MOFA) (2000-2014).
Note: Ha = hectare.

This paper discusses in detail the case of Ghana. Compared to most countries in SSA, political and economic conditions in Ghana are more favorable and stable and therefore can showcase the potential of rice-sector development in Africa and whether it can lead to a rice Green Revolution. Ghana has a middle-income status and is among the few countries that achieved the Millennium Development Goals of reducing poverty and hunger. The profitability of rice production at both private and social prices in Ghana is quite established (Ragasa et al. 2014; Akramov and Malek 2012; Winter-Nelson and Aggrey-Fynn 2008) in all rice systems they studied. But to further stimulate local production in the face of concerns about importation costs, foreign exchange imbalances, and protection from price shocks, Ghana is among those with the highest protection on rice (up to 40 percent tariff and taxes). On average, production of aromatic rice yields gross margins that are twice those of nonaromatic rice, while irrigated rice gives three times the margins of rainfed rice (Ragasa et al. 2014). Rice production in the Kpong irrigation area yields gross margins that are twice those of irrigated rice in the north and is considered to be driving a rural transformation in that part of Ghana (Takeshima et al. 2013). This highlights the heterogeneity of conditions across Ghana.

Using Ghana as a case study, this paper contributes to the literature on several fronts. First, it contributes to understanding the puzzle of high returns to technology on average at the same time as low adoption and explores the heterogeneity of rice-producing households and locations. It looks at available technologies, including those transferred and adopted from the Asian context, to determine where and when they are productive and profitable and what explains their adoption. We explore a unique dataset covering both north and south and both irrigated and rainfed rice ecologies in Ghana. Most studies on rice in Ghana cover the Northern region (see Owusu Coffie et al. 2016; deGraft-Johnson et al. 2014; Dogbe et al. 2014; Faltermeier and Abdulai 2009; Yiridoe, Langyintuo, and Dogbe 2006), given the historical importance of that region, but geographical distribution has shifted in recent years, with the Volta region contributing the highest production, accounting for 31 percent of national rice production in 2014, surpassing the Northern region, accounting for 27 percent. With the Upper East region, which accounts for 18 percent of national production, these three regions account for more than 77 percent of national rice production. We compare northern (mainly Northern and Upper East) and southern (mainly Volta) parts of Ghana and irrigated and nonirrigated rice ecologies in this paper.

Second, this paper contributes to understanding whether weak extension or dissemination of improved technologies is really the major constraint in rice productivity growth in SSA more generally. This has been highlighted by several studies (see Kijima, Ito, and Otsuka 2012 on Uganda; deGraft-Johnson et al. 2016 on northern Ghana; Nakano, Kajisa, and Otsuka 2016 on Tanzania). Third, this paper analyzes in detail the effect of fertilizer on productivity and the effect of fertilizer subsidies on rice profitability. This will help determine whether fertilizer subsidies contribute to enhancing technology adoption and change the economics of rice production. Fourth, this paper analyzes rainfed production vis-à-vis irrigated systems and contributes to the debate about whether it is possible to have high yields without irrigation or whether irrigation is a necessary requirement for a rice Green Revolution in Africa, using the case of Ghana.

The remainder of this paper is organized as follows. Section 2 discusses the empirical model and data. We present the results in Section 3, starting with a descriptive analysis of the extent of technology adoption, followed by the results of the production model, profitability analysis, and adoption models. Section 4 concludes with implications of results for policies on raising agricultural productivity in Ghana's rice system and similar rice production systems in other countries.

2. DATA AND METHODS

Production Function

To examine the rice yield response to inputs and technologies (fertilizer, improved seed, and other improved technologies) in Ghana, we estimated a production function of the following form:

$$Y = f[V, X,\ Z], \tag{1}$$

where Y is the quantity of the crop produced per unit area;[1] V is the vector of inputs including land characteristics, seed, fertilizer, labor, and water used by the farmer on a particular plot; X is a vector of farmer characteristics and management practices; and Z is the vector of household- and location-level characteristics.

For the quantity of fertilizer used, we used a quadratic functional form to estimate the yield model represented in equation 1. Despite some criticism regarding the quadratic or higher-order polynomial functional form (Grimm, Paris, and Williams 1987), we adopt this functional form because it permits 0 inputs and concavity in the yield response curves, a process that is more consistent with most biological relationships (Sheahan, Black, and Jayne 2013; Xu et al. 2009; Burke 2012; Traxler and Byerlee 1993; Kouka, Jolly, and Henao 1995).[2] We estimate the following model:

$$Y = \beta_0 + \beta_i F + \beta_i'\, F^2 + \alpha_k S + \delta_m L + \vartheta_j R + X_1 \emptyset_1 + X_2 \emptyset_2 + \varepsilon, \tag{2}$$

where Y is the measure of productivity, which in our case is kilograms of rice produced per hectare; F represents the fertilizer nutrients; S represents the seed variables (improved variety, certified and uncertified seed, and seed rate); L is a vector of land quality variables; and R represents variables to capture water availability. These variables are discussed in more detail below.

F is the quantity of nitrogen from the fertilizer used, which we derive from the chemical composition of the fertilizers available on the market and converted into their equivalent chemical components. In Ghana, the Ministry of Food and Agriculture (MoFA) recommends that farmers growing rice should at minimum use two 50-kg bags of nitrogen, phosphorus, potassium (NPK) 15-15-15 at planting or few days after planting and two bags of sulfate of ammonia for rice four to six weeks after planting per acre. This is equivalent to 240 kg of NPK and 240 kg of sulfate of ammonia per hectare. NPK 15-15-15 is a fertilizer that has an equal proportion of nitrogen, phosphorus, and potassium (15 percent for each nutrient) while sulfate of ammonia has 21 percent nitrogen and 24 percent sulphur. According to the Food and Agriculture Organization of the United Nations (2005), potassium is not limited in Ghana, but nitrogen and phosphorus are, so our focus would be on these two nutrients. Since

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[1] A common measure of productivity used in the literature is the value of yield per hectare of various crops (see Owens, Hoddinott, and Kinsey 2003; Peterman et al. 2011) to capture intercropped systems. Intercropped maize plots have artificially low maize yield compared to monocropped maize plots, and this is the reason the value of production of all crops planted in the plot is often used. However, this method captures variations of both output prices (often at the district level or regional level) and yield. It is not able to isolate the changes in yield and includes village-level or regional-level factors depending on the aggregation of the output price used. In this paper, we separate intercropped versus monocropped plots in comparing and describing the differences in productivity. In the yield response models, we control for intercropping using a dummy variable and seeding rate during planting. By using these control variables, we are able to isolate the variations on yield on maize, which is the interest of this paper, at the same time addressing the possible artificially low productivity for intercropped plots.

[2] The production theory is moot on a specific functional form for crop yield response, so we rely on past studies to choose the most appropriate functional form. Grimm, Paris, and Williams (1987) provide some guidance about what to consider when choosing the function form, while Burke (2012) discusses the pros and cons of some of the popular functional forms used in literature. He argues that some functional forms, for example, the von Liebig models, linear and plateau, von Liebig quadratic, and plateau response models, are best suited for experimental field data than farmer survey data (see Berck and Helfand 1990). The main disadvantage of these models is that they assume that the limiting factor is known or, if not known, would be the same for all observations. This assumption is less likely to hold for survey data because of the heterogeneity among farmers' fields (Berck and Helfand 1990; Berck, Stohs, and Geoghegan 2000).

the nutrients are applied as fertilizer mixtures, there is high collinearity ($\rho = .75$) between nitrogen and phosphorus, so we dropped phosphorus and assumed that nitrogen was a proxy for overall fertilizer use.[3]

S represents seed varieties, seed type, and the rate of application per hectare. We defined two seed-related classifications used in the yield response model: (1) improved versus traditional varieties and (2) certified new seed (of improved varieties), recycled or uncertified seeds (of improved varieties) versus seeds of traditional varieties. The main difference between the first and second classifications is the breakdown of improved varieties in the second one into certified and uncertified seeds of improved varieties. This will suggest whether the yield response (or lack of) can be attributable to the functioning of the seed certification system or varietal research.

L represents land quality variables. Marenya and Barrett (2009a) and Matsumoto and Yamano (2010) demonstrated that the profitability of adoption of improved technology can differ significantly by soil quality even for plots in roughly similar agroecological conditions. Unfortunately, we do not possess plot-level data to adequately account for the difference in land quality. Instead, we proxy the land quality by using a soil quality variable captured from farmers' perceptions of the soil fertility of their plots before fertilization. Farmers were asked, "Before you had applied inorganic or organic fertilizer, kindly rate the inherent soil fertility of this plot [scale from 1 (*not fertile*) to 5 (*very fertile*)]." Given that farmers have unique knowledge, experience, and experimentation on their plots, their perceptions or ratings of soil fertility can be a good indicator of soil quality. Also, we included a dummy variable for whether the farmer applied organic manure (green or animal manure) as a proxy for organic matter content and the general community soil characteristics that have been collected by the Soil Research Institute of the Council for Scientific and Industrial Research (CSIR/SRI) in Ghana.

The following soil types are used in Ghana: (1) Vertisols, Gleysols, Fluvisols, and Cambisols, which are wetland soil, more associated with occasional flooding, and important for rice cultivation because they can hold water for some time; (2) Vertisols, Plinthosols, and Planosols, which are clayish soils; (3) Acrisols, which are more leached and slightly more acidic but can still be suitable for upland rice cultivation; (4) Lixisols, which are highly weathered soils with some clay movement and can be suitable for upland rice cultivation; and (5) Leptosols and Arenosols, which are gravelly, stony, or highly permeable soil types that are not suitable for rice production. We use the last soil classification as the control, and we hypothesize that coefficients of the other soil classifications are significantly higher than this control. Unfortunately, we could not include pH level because there was little variation in the average pH-level data received from CSIR/SRI.

R represents rainfall recorded from the closest meteorological station in the surveyed communities. In rainfed agricultural systems such as in Ghana, farmers determine the level of input use according to the variability of level of rainfall and drought risk, so we computed a variable rainfall stress that we defined as the number of periods with less than 20 millimeters total rainfall during the crop-growing season. To control for regional differences, we initially included three agroecological dummy variables with the Forest zone as the reference. In the models estimated, agroecological zones in the south (Forest, Transitional, and Coastal zones) did not differ in the adoption models and yield response model; therefore we grouped them as south and used only one dummy for location (that is, north).

The vector of X_1 included farm management practices that are promoted in Ghana, including bunding, leveling, using a sawah system, using a tillage method, crop rotating, intercropping, row planting, and seed priming. Evidence in the literature suggests that yield within ecology within a country varies considerably (Saito et al. 2013) due to various types of practices including extent of irrigation,

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[3] Unfortunately, our dataset can address a few of the complexities and is not able to show effects and yield response of interactions of water and nitrogen (N), weeds and N, soil health and N, N and phosphorus (P), and other nutrients. We cannot do the interaction between the nutrients (N, P, and potassium [K]) as the fertilizer available is a compound and comes as a package; therefore, we cannot artificially break them. Doing so will be an ad hoc process with limited actual application. We also tried the other interactions, such as with soil types and with weedicides, but due to high collinearity, we had to drop them; otherwise estimates would have not been valid. Socioeconomic and household survey data analysis would need to be complemented with experiment trials or biophysical studies to get more information as to the correct combination of N, P, K, and other nutrients to maximize maize yields.

organic and mineral fertilizer use, timing of fertilizer application, timeliness of production and harvesting, weed control, and soil-fertility management including bunding and herbicide application (Becker and Johnson 1999, 2001a, 2001b; Haefele et al. 2000; Haefele et al. 2001; Wopereis et al. 1999; Nhamo et al. 2014).

In addition to these inputs and technologies, the production function is conditioned on the farm physical environment, family labor time allocated to labor and leisure, and a full income constraint. In a smallholder environment with widespread market imperfections, such as the rural areas in Ghana, utility maximization may differ from profit maximization. In this environment characterized by market failures, market prices do not reflect the full opportunity cost of various goods, particularly inputs and services such as agricultural knowledge and fertilizer. Hence, the variables included in X_2 should cover a broad set of socioeconomic variables that also capture individual market access conditions and risk preferences. Table 2.1 summarizes the descriptive statistics of the variables used in this study.

Table 2.1 Descriptive statistics of the variables used in this study

	Lowland rainfed ($N = 405$)				**Irrigated ($N = 162$)**			
Variable	***Mean***	***SD***	**Min**	**Max**	***Mean***	***SD***	**Min**	**Max**
Yield (kg/ha)	1660.14	1241.72	118.61	8539.95	3886.13	3049.47	237.22	13750.48
Nitrogen (kg/ha)	36.85	40.62	0.00	266.87	82.80	46.23	0.00	333.59
Improved variety[a]	0.53	0.50	0.00	1.00	0.99	0.08	0.00	1.00
Perceived soil fertility[a]								
Not fertile	0.23	0.48	0.00	1.00	0.43	0.46	0.00	1.00
Moderately fertile	0.36	0.48	0.00	1.00	0.30	0.46	0.00	1.00
Very fertile	0.40	0.49	0.00	1.00	0.27	0.45	0.00	1.00
Soil type[a]								
Most fertile soil type[b]	0.15	0.36	0.00	1.00	0.45	0.50	0.00	1.00
Clayish soil[c]	0.22	0.42	0.00	1.00	0.13	0.34	0.00	1.00
Lixisols	0.31	0.46	0.00	1.00	0.22	0.42	0.00	1.00
Acrisols	0.20	0.40	0.00	1.00	0.13	0.34	0.00	1.00
Stony soil[d]	0.09	0.29	0.00	1.00	0.07	0.25	0.00	1.00
Stress period (<20 mm)	2.77	2.30	0.00	8.00	5.00	3.00	0.00	8.00
Plot size (ha)	1.15	1.43	0.10	20.23	0.72	0.46	0.12	4.05
Management practices								
Seeding rate (kg/ha)	95.03	55.59	10.00	250.00	99.06	50.34	10.00	250.00
Animal manure[a]	0.05	0.22	0.00	1.00	0.10	0.30	0.00	1.00
Bunding[a]	0.27	0.45	0.00	1.00	0.86	0.34	0.00	1.00
Seed priming[a]	0.22	0.42	0.00	1.00	0.61	0.49	0.00	1.00
Row planting[a]	0.16	0.36	0.00	1.00	0.15	0.36	0.00	1.00
Continuous cultivation[a]	0.77	0.42	0.00	1.00	0.85	0.36	0.00	1.00
Herbicide[a]	0.74	0.44	0.00	1.00	0.83	0.37	0.00	1.00
Total family labor (person-days/ha)	129.35	131.95	0.00	672.65	96.31	119.84	0.00	622.76
Total hired labor (person-days/ha)	48.89	73.97	0.00	500.00	101.07	112.53	0.00	647.42

Table 2.1 Continued

	Lowland rainfed (*N* = 405)				Irrigated (*N* = 162)			
Variable	***Mean***	***SD***	**Min**	**Max**	***Mean***	***SD***	**Min**	**Max**
Other controls								
Membership in FBO [a]	0.48	0.50	0.00	1.00	0.50	0.50	0.00	1.00
Received extension contact[a]	0.23	0.42	0.00	1.00	0.40	0.49	0.00	1.00
Female[a]	0.20	0.40	0.00	1.00	0.23	0.43	0.00	1.00
Age	41.69	11.82	19.00	78.00	42.69	12.25	20.00	76.00
North[a]	0.61	0.49	0.00	1.00	0.49	0.50	0.00	1.00
Total landholdings (ha)	3.91	4.95	0.20	53.42	2.21	2.41	0.20	21.85
Education level								
No education[a]	0.57	0.35	0.00	1.00	0.41	0.41	0.00	1.00
Primary education[a]	0.14	0.35	0.00	1.00	0.22	0.41	0.00	1.00
Secondary or higher[a]	0.29	0.45	0.00	1.00	0.37	0.48	0.00	1.00

Source: CRI/SARI/IFPRI survey November 2012–February 2013.

Note: FBO = farmer-based organizations; ha = hectare; kg = kilogram; Min = minimum; Max = maximum; mm = millimeters; SD = standard deviation. [a.] Binary values—therefore, the proportion is derived by multiplying each by 100. [b.] Includes Luvisol, Fluvisols, Cambisol, and Gleysols. [c.]Includes Vertisols, Planasols, and Plinthosols. [d.] Includes Leptosols and Arenosols.

Profitability and Risk Associated with Technologies

We assess the profitability of fertilizer (with or without improvement seed in various locations) in two ways using the estimates from the yield response model described above: (1) via the estimation of value-cost ratio (VCRs) and (2) via plotting the value marginal physical product (VMPP) and fertilizer prices and fertilizer use to determine how far or near is the actual use intensity to this optimal rate. The point at which VMPP and fertilizer price (P_F) intersect (VMPP = P_F) gives us the economically “optimal” fertilizer use for farmers to maximize profit given price levels and rice yield–fertilizer response rates, similar to the approach by Sheahan, Black, and Jayne (2013). A similar approach is computing for the VCR multiplying the marginal products of fertilizer from the yield response model by the output/input price ratio as shown below:

$$VCR = \frac{P_F}{P_Y} * \frac{\partial Y}{\partial F} = \frac{P_F}{P_Y} * MPP, \tag{3}$$

where P_F is the fertilizer price, P_Y is the price of rice, and MPP is the marginal physical product of fertilizer obtained from equation 2. We compute two VCRs using market and subsidized fertilizer prices reported by the sample farmers. We used both the selling price of rice (the usual metric for calculating the marginal and average value product of output, see Sheahan, Black, and Jayne 2013) as reported by the sample farmers and the buying price of rice using the district-averaged purchasing price, which is a better measure of the opportunity cost of growing rice for many net-buying households (see Jayne 1994). Results and interpretations of the profitability of fertilizer remain the same.

A VCR of greater than 1 indicates that risk-neutral farmers’ income would go up with an increase in the rate of fertilizer application. So a risk-neutral farmer would choose to use fertilizer or apply more fertilizer if the VCR is greater than or equal to 1. Nevertheless, this assumption is not realistic in a country like Ghana where most farmers are thought to be risk averse due to the risks associated with the rainfed agricultural system. We adopt a VCR greater than or equal to 1.5 (following Jayne and Rashid 2013) to reflect the added risk premium intended to accommodate risks and uncertainty faced by the farmers as well as to adjust for unobservable costs associated with fertilizer use. Moreover, we compared the results and implications using a more restrictive criterion, a VCR greater than or equal to 2, as recommended by Crawford and Kelly (2002).

Another important factor is risk, and we attempted to incorporate it into our analysis. We included a standard measure of risk aversion in our questionnaire and dataset. The particular question is,

> Imagine that you could choose one of the following bags of maize seeds. Each bag contains maize seeds that will produce different harvest of maize the following year depending on the weather. Which seed would you choose? [using visual aids] 1 = Seeds which can produce stable 10 bags per acre regardless of the weather; 2 = Seeds which can produce 7 bags per acre (during bad weather) or 20 bags per acre (during good weather); 3 = Seeds which can produce 4 bags per acre (during bad weather) or 30 bags per acre (during good weather); and 4 = Seeds which can produce 0 bags per acre (during bad weather) or 40 bags per acre (during good weather).

We included this variable in the yield response and adoption models (with different variants, like using four scales, and using only two scales, summing one and two and then three and four together). However, this risk indicator did not show as significant in our productivity and adoption models, and thus we did not explore this further. Nevertheless, we controlled for rainfall levels and variability to account for rainfall and climate-related risks.

Determinants of Adoption of Fertilizer, Improved Variety, and Other Technologies

The decision to use a particular technology is usually modeled as a binary decision via probit or logit; thus a farmer uses or does not use technology. However, farmers are more likely to make input use decisions jointly, so we use the multivariate probit model, which allows us to jointly estimate several correlated binary outcomes. In our case, we believe that the decision to use fertilizer, improved variety, and certified seed as well as other management practices are correlated so the multivariate probit model would be appropriate for jointly predicting these choices.

Modeling Both Fertilizer Use and Intensity

To analyze the factors associated with fertilizer use and intensity or application rate, we fitted Cragg's double-hurdle model to gain efficiency due to the corner solution associated with fertilizer use intensity (Burke 2009, 2012). We assume that the farmer's decision to use fertilizer or not use fertilizer comes first, followed by the decision about how much to use. The structure of the double-hurdle model used in this paper is as follows:

$$FertU_i^* = \delta X_i' + \varepsilon_i' \qquad \varepsilon_i' \sim N(0, \sigma^2) \quad , \tag{3}$$

where $FertU_i = 1$ if $FertU_i^* > 0$, otherwise $FertU_i = 0$, and

$$FertQ_i^* = \vartheta X_i'' + \mu_i' \qquad \mu_i' \sim N(0, \sigma^2) \quad , \tag{4}$$

where $\mathrm{FertQ_i} = FertQ_i^*$ if $FertQ_i^* > 0$ and $\mathrm{FertU_i} = 1$, otherwise $\mathrm{FertQ_i} = 0$.

The subscript i refers to the ith farmer, $FertU_i$ is the observable discrete decision to use fertilizer or not, and $FertU_i^*$ is the latent (unobservable) variable of $FertU_i$. $FertQ_i^*$ is an unobserved, latent variable for fertilizer quantity used while $FertQ_i$ is the observed quantity used. X_i' and X_i'' are vectors of explanatory variables assumed to be exogenous in the fertilizer use and fertilizer intensity equations, and ϑ and ∂ are parameters to be estimated imposing the conditional independence for the latent variable's distribution. Thus, conditional on X, there is no correlation between the disturbances from the fertilizer use (ε_i') and fertilizer intensity (μ_i') equations.

Identification Strategy and Other Econometric Considerations

The estimation of equation 2 is faced with a number of problems, which a lot of studies in the literature chose to ignore but could lead to biased yield response estimates. First, farm inputs such as fertilizer and seed are unlikely to be random because farmers can control input use. Input decisions are unlikely to be independent of land quality, so input demand is partly determined by crop yield and is hence endogenous.[4] Ignoring this will result in our estimates' being biased because of the simultaneity bias and omitted variable problem. To deal with this issue we estimate our model using instrumental variable (IV) regression and the control function (CF) approach. IV regression is used when the model has endogenous variables, as in the case of fertilizer and seed use, and is often used to address important threats to internal validity such as omitted variable bias from a variable that is correlated with the regressors but is unobserved, so it cannot be included in the regression. In IV regression, the critical step is finding valid instruments, or variables that can indirectly, not directly, affect the dependent variable through the regressors. There are several formal tests to ascertain the validity of the instruments.

A Wu-Hausman *F* test statistic was conducted to test whether improved seed use and fertilizer intensity are, in fact, exogenous or endogenous. We were able to reject the null hypotheses that they are exogenous (*p* values were less than .01). This means that the endogeneity among these regressors would have deleterious effects on ordinary least squares estimates.

Instruments used are indicators of access (distance to input source, distance to market, and distance to plot and their square terms), affordability (average price paid for NPK 15-15-15 fertilizer and average price paid for certified seed at the village level), incentive to adopt (degree of commercialization measured in terms of the past year's percentage of rice harvest sold), and proportion of fertilizer and certified seed users in the community. Distance to input sources and markets directly affect fertilizer and improved seed use but do not directly affect productivity. Similarly, distance from home to plot mirrors the amount of monitoring needed and would discourage adoption of fertilizer and improved seed use but would not directly discourage productivity. Prices of seed and fertilizer affect fertilizer and improved seed use directly but do not directly affect productivity. The past year's proportion of harvest sold can promote an expectation of the degree of salability and commercialization that provides the incentive to use fertilizers and improved seed but does not directly affect productivity. Last, the proportion of adopters in the community can be used as a proxy for the peer effect in technology adoption (Table 2.2 reports coefficients). The minimum condition for these instruments to be valid is that they are sufficiently correlated with the endogenous variables (Verbeek 2004, 148). This can be tested by estimating the first-stage regression of each endogenous variable on the instruments used and performing an F statistic test (Verbeek 2004, 145). Stock and Watson (2003), also cited in Verbeek (2004, 148), suggest that a minimum F statistics of 10 is sufficient for validity. The F statistic test results (F statistic = 23.1) confirm that the instruments used are strongly correlated with the endogenous variables instrumented. We also test the validity of these instruments using a simple falsification test following Di Falco, Veronesi, and Yesuf (2011) and Shiferaw et al. (2014). Results show that the instruments considered are jointly statistically significant in the fertilizer and improved seed models but not in the productivity models, suggesting that the instruments are valid.

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[4] Burke (2012) calls this structural endogeneity because the yield function is part of the structural model from which input demand is derived.

Table 2.2 Multivariate probit model for certified seed, fertilizer, seed priming and row planting, and probit model for extension service access

Explanatory variable	New certified seed (= 1)	Fertilizer (= 1)	Seed priming (= 1)	Row planting (= 1)	Extension advice (= 1)
Market and plot access					
Distance to agroshop (km)	–0.003 ***	0.003	–0.005 ***	–0.003 ***	–0.001
	(–3.01)	(1.59)	(–5.21)	(–2.80)	(–0.72)
Distance to plot (km)	0.001 **	0.001	0.001 **	–0.001	0.000
	(2.22)	(1.44)	(2.50)	(–1.47)	(–0.71)
Distance to extension officer (km)	–0.004 **	0.002	–0.005 **	–0.002	–0.082 ***
	(–2.81)	(1.48)	(–3.21)	(–0.80)	(–3.72)
Affordability					
Certified seed price (GHc/kg)	–0.056 ***	–0.036 ***	0.015	–0.083 ***	
	(–4.59)	(–3.36)	(1.20)	(–5.59)	
Fertilizer price (GHc/kg)	0.160 ***	0.026	0.030	0.206 ***	
	(3.30)	(0.37)	(0.52)	(3.97)	
Lagged percentage of harvest sold (%)	0.001	0.001 **	–0.001 *	0.000	0.002 *
	(1.14)	(2.30)	(–1.93)	(–0.47)	(1.72)
Lagged proportion of income from crop sales (%)	0.000	0.000	0.000	0.001	0.000
	(0.48)	(–0.55)	(0.59)	(1.46)	(0.00)
Total landholding size (ha)	–0.002	–0.005	–0.005	–0.009	0.008 *
	(–0.42)	(–1.40)	(–0.85)	(–1.61)	(1.88)
Plot size (ha)	0.017	–0.063 ***	–0.016	–0.053 *	–0.011
	(1.30)	(–3.62)	(–0.68)	(–1.95)	(–0.60)
If plot is owned	0.021	–0.004	–0.076 **	–0.062 *	0.021
	(0.65)	(–0.10)	(–2.06)	(–1.74)	(0.45)
If plot is owned, with written land title	–0.013	0.176 *	0.141 **	0.290 ***	–0.169 **
	(–0.20)	(1.63)	(2.08)	(4.23)	(–2.38)
Soil type (control = not fertile)					
Soil perceived moderately fertile (= 1)	–0.100 ***	–0.083 **	–0.025	–0.023	0.090 *
	(–2.87)	(–1.98)	(–0.65)	(–0.65)	(1.71)
Soil perceived very fertile (= 1)	–0.020	–0.158 ***	0.002	–0.042	0.101 **
	(–0.63)	(–3.95)	(0.04)	(–1.15)	(1.97)
Labor availability					
Total family labor (person-days/ha)	0.000	0.000	0.000	0.000	
	(0.24)	(–1.61)	(0.57)	(0.14)	
Total hired labor (person-days/ha)	0.000 *	0.000	0.000	0.000	
	(–1.74)	(–0.28)	(–0.12)	(–0.82)	
Access to information					
Member of farmer-based organization or co-op (= 1)	0.044	0.016	0.002	–0.018	0.178 ***
	(1.58)	(0.52)	(0.07)	(–0.60)	(4.51)
Received extension advice (= 1)	0.123 ***	0.019	0.133 ***	0.045	
	(4.49)	(0.50)	(4.10)	(1.34)	

Table 2.2 Continued

Explanatory variable	New certified seed (= 1)		Fertilizer (= 1)		Seed priming (= 1)		Row planting (= 1)		Extension advice (= 1)	
Farmer and household characteristics										
Primary (= 1)[a]	0.012		0.081	*	0.055		0.018		0.209	***
	(0.30)		(1.76)		(1.34)		(0.44)		(3.49)	
Secondary or above (= 1)[a]	0.082	***	0.029		0.124	***	0.101	***	0.145	***
	(2.72)		(0.76)		(3.71)		(3.02)		(3.01)	
Female (= 1)	0.034		0.063		0.071	*	0.057		–0.174	***
	(0.96)		(1.47)		(1.87)		(1.59)		(–3.70)	
Age	0.000		0.001		–0.001		–0.001		0.003	*
	(0.31)		(0.61)		(–0.91)		(–0.96)		(1.64)	
Household size	–0.004		0.000		0.000		0.000		0.001	
	(–1.64)		(–0.23)		(0.11)				(0.33)	
Location-specific factors										
6-year rainfall coefficient of variation	–0.004	**	0.001		–0.009	***	0.000		–0.008	***
	(–2.15)		(0.48)		(–4.42)				(–2.97)	
Northern Ghana (= 1)	0.032		0.101	**	–0.370	***	0.071		–0.216	***
	(0.64)		(2.06)		(–7.06)		(1.51)		(–3.40)	
Irrigated (= 1)	0.064	*	0.120	*	0.222	***	–0.191	***	0.226	***
	(1.81)		(1.81)		(5.53)		(–4.67)		(4.49)	
Adoption in the village (peer effect)										
% of fertilizer users	0.144	***								
	(5.11)									
% of certified seed users			0.135	***						
			(4.22)							
% of seed primers					0.139	*				
					(2.41)					
% of row planters							0.141	*		
							(2.19)			
% of extension service receivers									0.134	***
									(5.49)	
Number of observations	601								601	
Log likelihood	–794.007								–291.937	
Chi-square	727.48								124.51	
Probability > chi-square	.000								.000	
Pseudo *R*-squared									.18	

Source: Crops Research Institute/Savannah Agricultural Research Institute/International Food Policy Research Institute survey (November 2012–February 2013).

Note: ha = hectare; kg = kilogram; km = kilometer. [a] The control used is no formal education. *$p < .10$. **$p < .05$. ***$p < .01$.

A similar approach to IV is the CF method, which entails taking the residuals from a reduced form model of the endogenous inputs (fertilizer and improved seed) and including them as a covariate in the structural model of productivity (equation 4). The significance of the coefficient on the residual both tests and controls for possible endogeneity, or correlation between the inputs and the error term. We derived the generalized residual from a first-stage probit model for improved seed use using the following formula (Imbens and Wooldridge 2007; Wooldridge 2008):

$$gr_{i2} = y_{i2}\lambda(\boldsymbol{Z_i\beta_2}) - (1 - y_{i2})\lambda(-\boldsymbol{Z_i\beta_2}) \tag{5}$$

where gr_{i2} is the generalized residual, y_{i2} represents the use of improved seed, and $\lambda(.)$ is the inverse mill ratio, expressed as the ratio of the standard normal density function and the cumulative standard normal distribution.

We derived the generalized residuals from the first-stage double-hurdle for quantity of fertilizer used using the following formula (Greene 1997, 972):

$$e_i = \left(\frac{1}{\sigma^2}\right)\left[z_i(y_i - \boldsymbol{\beta' X_i}) + (1 - z_i)\sigma\left(\frac{\phi_i}{1-\Phi_i}\right)\right] \tag{6}$$

where $\sigma$and $\boldsymbol{\beta}$are estimates from the double-hurdle model, z_i= 1 if quantity of fertilizer > 0, and z_i= 0 if they are 0; y_i is the quantity of fertilizer; ϕ_i indicates the standard normal density function; and Φ_i is the cumulative standard normal distribution.

Due to various models involved in estimating the first-stage input choice models (probit model for modern variety and certified seed, censored regression for fertilizer use and intensity, and continuous variables regression for yield), we modeled both input choice models and the yield model with a multistage and multi-equation conditional mixed process that allows mixing of these models in multi-equation systems (see Roodman 2009).

The second problem is more difficult to deal with because we do not have panel data to control for the unobserved heterogeneity caused by omitted variables such as plot level land quality variables and even farmers' abilities and skills. For example, Marenya and Barrett (2009b) and Matsumoto and Yamano (2010) show that soil carbon content had an effect on demand for fertilizer and omitting such a key variable would result in biased yield response estimates. Unlike a few recent rigorous studies that used panel data, we are not able to adequately deal with the unobserved heterogeneity problem because we possess only cross-sectional data (see Burke 2012; Matsumoto and Yamano 2010). Nevertheless, this remains a problem for most studies using survey data instead of agronomic experiments. To minimize the problem, we included some variables as proxies of soil quality, including the farmers' perception of soil quality before fertilizer application, average community-level soil type, fallow history, and contemporary use of organic manure and other soil fertility management practices.

Data Source

This paper draws on data from a survey of 576 rice farmers in 23 districts in 10 regions in Ghana implemented from November 2012 to February 2013 by the Crops Research Institute (CRI), Savannah Agricultural Research Institute (SARI), and International Food Policy Research Institute. The districts surveyed are shown in Figure 2.1.

Figure 2.1 Map of districts surveyed in four agroecological zones in Ghana

Source: List of sample districts are from CRI/SARI/IFPRI November 2012–February 2013 survey (2013).
Note: The administrative boundaries are based on information from http://www.gadm.org/country.

The survey used a three-stage, clustered, and randomized sampling procedure. First, a proportional probability sampling of districts was done, giving more weight to those with higher rice production, and the final list of sample districts was done in a randomized procedure. That was followed by a random selection of enumeration areas (EAs) in each of the sample districts using the same classifications and boundaries as the census and the Ghana Living Standards Survey. And finally, a random selection of farmers was made in each of the sample EAs.

Twenty-three districts were selected from a list of rice-producing districts (districts with more than 1,000 ha of rice production). The sampling frame represents 98 percent of total hectares planted with rice in Ghana during 2009–2011. A proportional probability sampling was used to select the sample districts (that is, districts with a larger production area of rice were given a higher probability of being selected). The selected districts represent 65 percent of total rice production area (and 69 percent of total rice production in tons) in Ghana during 2009–2011.

The method of sampling within each rice-producing district was not straightforward given that rice production is still not common in most villages, even in rice-producing districts, and there is no census or national dataset that provides information about where the rice-producing communities and rice farmers are in the country. In each sample district, communities and farmers were selected based on three rice ecologies: irrigated, lowland rainfed, and upland rainfed systems. Within irrigated areas, six major irrigation schemes were selected, representing 92 percent of the total hectares of developed area for irrigated crop cultivation (mainly rice). For each of the six irrigation schemes, 21 farmers were selected at random. Given that there were no available data on lowland and upland rice production per district, three EAs were randomly selected in each sample district, from which the sample lowland and upland rice farmers were selected. An additional three EAs were selected to serve as replacement EAs in case the first three turned out to be non-rice-producing EAs. In each selected EA, seven farmers were randomly selected from a compiled list of all rice farmers in the sample EAs. To be included in the list, a farmer had to manage and make decisions regarding a rice plot with a minimum size of 0.5 acre (0.2 ha) during the major season of 2012. The list was arranged by upland and lowland systems and by gender (that is, upland and lowland rainfed systems and gender were used for implied stratification in the sampling process). The total sample was 576 rice farmers, with 80 percent male and 20 percent female. A quarter of the sample rice farmers reported cultivating and managing two rice plots; therefore, the dataset includes 601 rice plots that were used for analysis. About 6 percent of the sample farmers were in upland rice ecologies, 67 percent in lowland rainfed rice ecologies, and 27 percent in irrigated rice ecologies.

The average rice plot size in the sample is 1.04 ha (Table 2.3). About 20 percent of the rice farmers in the sample were female, and, except in the Forest and Transitional zones, the majority of the sample rice farmers were natives in the community (not settlers from other locations). The average age was 40 years and the average number of years of education was five. Most of the rice farmers in the sample had primary educations, and the next largest groups were those with no formal education and those with secondary educations.

Table 2.3 Characteristics of sample rice farmers

	Agroecological zone				
Characteristics	Forest	Transitional	Northern Savannah	Coastal Savannah	All zones
Number sample farmers	63	80	336	97	576
Plot size (ha)[a]	104	0.8	1.1	0.9	1.0
% of rice sold[a]	85	76	59	90	70
Female (%)	15	37	13	34	20
Married (%)	90	90	88	86	88
Native (%)	37	47	98	83	82
Age, average	41	44	40	45	42
Years education, average	6	8	3	7	5
Household size, average	9	7	16	8	13
Crop income*	88	85	85	76	84
Total farm land (hectare), average	5.1	2.0	4.0	1.4	3.5

Source: CRI/SARI/IFPRI November 2012–February 2013 survey (2013).

Note: *Percent of total income. [a]. Averages; other columns (except column 2) are the proportion of total farmers in each zone.

The number of crop plantings in a year is dictated by irrigation or rainfall availability in the agroecological area. The majority of farmers in rainfed areas (upland and lowland) plant during the major season only, with the exception of a few farmers growing for two seasons in the Forest area, with or without pump irrigation. Most farmers plant at least two seasons of rice in irrigated areas.

There were a few plots under block farming, which is a government project that provides inputs via credit scheme, or other special project by nongovernmental organizations or donors in 2012 (irrigation projects are not included). Only 6 percent of rice area was under block farming in the 2012 major season. For irrigated rice ecology, 22 percent of rice area was under block farming. In lowland rainfed systems, only 2 percent of rice hectares were under block farming, inland rice development projects, or other projects. For upland, 4 percent of total hectares were under a special project (block farming).

3. RESULTS

This section presents a descriptive analysis of the status of technology adoption, followed by the results of the production models, profitability analysis, and adoption models.

Descriptive Analysis

Fertilizer Use

Inorganic fertilizer was applied by 77 percent of farmers (Table 3.1). Almost all farmers in irrigated rice areas used inorganic fertilizer, while there was a much lower adoption rate in lowland and upland rainfed areas (68 percent and 82 percent of rice area, respectively). For rice plots with fertilizer, the amount of nitrogen applied was 64 kilogram/ha on average, and about 30 kilogram/ha each of phosphorus and potassium. The application rate recommended by CSIR and MOFA are 95 kilogram/ha of nitrogen for rice plots, and therefore, the average rate of application falls short of the recommendation. The fertilizer subsidy program may have been instrumental in encouraging greater use of fertilizer, but 23 percent of rice farmers were still using fertilizer, and for those using fertilizer the application rates were lower than the recommended rate. Application rates on plots in rainfed lowland and upland areas were much lower than the recommended rates and much lower than the rates applied to irrigated plots.

Table 3.1 Distribution of rice farmers by fertilizer use and their application intensity, in percentages

Variable	All	Irrigated	Lowland rainfed	Upland rainfed
Inorganic fertilizer (% of farmers)	77	99	68	82
For plots with fertilizer (kg/ha)				
N	64	84	54	43
K	30	43	25	19
P	31	43	25	19
For plots with fertilizer (% of farmers)				
NPK 15-15-15 (N 15%, P 15%, K 15%)	90	99	87	71
Sulfate of ammonia (N 21%, S 24%)	77	84	75	61
Urea (N 46%)	12	17	10	4
Sulfan (N 24%, NH4 4%, NO3 12%, S 6%)	1	1	0	7
Actyva (N 23%, P 10%, K 5%, S 3%, Mg 2%, Zn 0.3%)	3	1	3	14

Source: CRI/SARI/IFPRI November 2012–February 2013 survey (2013).

Notes: B = boron; K = potassium; kg/ha = kilograms per hectare; Mg = magnesium; N = nitrogen; NH4= ammonium; NO3 = nitrate; P = phosphorus; S = sulfur; Zn = zinc.

The most commonly used type of fertilizer was NPK 15-15-15 (applied to 90 percent of plots with fertilizer). Sulfate of ammonia was more commonly used for the second application (77 percent) compared with urea (12 percent). These three fertilizer types are covered in the subsidy program.

Improved Varieties and Certified Seeds

Sixty-five percent of rice farmers planted improved varieties during the major season of 2012 (99 percent in irrigated areas; 53 percent in lowland rainfed areas; and 44 percent in upland areas)[5] (Table 3.2). However, only 17 percent of rice farmers planted with improved varieties from certified sources (registered seed dealers, certified seed growers, MOFA projects, or researchers/breeders), while 83 percent planted with seed sourced from recycled seeds, other farmers, or the grain market. Farmers recycle their improved varieties for four years on average.

Table 3.2 Distribution of sample farmers by variety and seed use (in percentages of farmers)

Variable	All	Irrigated	Lowland rainfed	Upland rainfed
Improved variety	65	99	53	44
Improved variety (new seed or up to 5 years of recycling)	56	88	45	41
Improved variety (new seed or up to 4 years of recycling)	53	83	42	35
Improved variety (new seed or up to 3 years of recycling)	45	71	36	35
Improved variety (new seed or up to 2 years of recycling)	36	59	27	29
Improved variety (new seed or up to 1 year of recycling)	28	46	21	24
New certified seed	17	34	11	12
Average number of years of seed recycling (number of years)	*4.3*	*2.6*	*5.1*	*3.1*
Popular varieties grown				
Jasmine 85/Gbewaa/Lapez (2009)[a]	30	52	23	24
Togo Marshall[b]	12	20	10	0
Mandii[c]	11	1	15	16
Jet 3[b]	5	10	4	3
Digang/Aberikukugu[a]	3	0	3	14
Aromatic Short[b]	2	6	1	0

Source: CRI/SARI/IFPRI November 2012–February 2013 survey (2013).

Notes: [a] Officially released and registered improved varieties. [b] Not officially released—they are most likely improved, but CRI and SARI are not sure exactly where they came from at the time of writing this report. CRI and SARI are in the process of testing them through research. [c] Considered the local variety—it originally came from Sierra Leone and was introduced by MOFA in Ghana in the 1970s.

The most commonly planted variety was Jasmine 85, an aromatic improved variety, which was grown by 30 percent of farmers during the 2012 major season. The second most commonly planted variety was Togo Marshall, which is also an aromatic improved variety. The third most common is Mandii, which is considered the local variety, was originally from Sierra Leone, and was introduced by MOFA in the 1970s. It is suitable for low-input systems, can withstand long flood periods, and can compete well with weeds according to CRI/SARI breeders. The other popular varieties are Jet 3 and Digang—modern varieties but nonaromatic—and Aromatic Short, which is an aromatic modern variety.

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[5] This Crops Research Institute/Savannah Agricultural Research Institute/International Food Policy Research Institute survey and the official certified seed production data from MOFA seem consistent overall, although there seems to be greater adoption of GR 18 (Afife) and TOX 3107 (Bumbaz) based on the 11-year production of certified seed, while in this 2012 survey we saw very little adoption of these two varieties and more adoption of Aromatic short, Jet 3, and Togo Marshall. This may be because production of the former two varieties stopped in 2010 while production of the latter three varieties started in 2011, and these seem to be the ones planted in rice plots in 2012.

Other Management Practices

The most important management practices being promoted by CRI and SARI in Ghana are (1) application of herbicide before planting, pre-emergence and postemergence; (2) plowing and harrowing; (3) seed priming; (4) row planting and plant density; (5) nets for protecting rice grains from birds; and (6) the sawah system, which is a technology package used in lowland areas involving bunding, puddling, and leveling to achieve better water control and nutrient management.

There was strikingly high use of herbicide in rice plots, with 84 percent of rice area treated with herbicide across all rice ecologies (Table 3.3). Fifty-eight percent of rice area was treated with herbicide before planting, and 69 percent of the area was treated with herbicide after planting.

Table 3.3 Distribution of rice area by management practices during major season 2012, in percentages

Practice	Total	Irrigated	Lowland rainfed	Upland rainfed
Herbicide use				
Herbicide use either before or after planting	84	88	82	89
Herbicide use only before planting	58	70	55	55
Herbicide use only after planting	69	73	66	79
Herbicide use both before and after planting	43	55	39	45
Other management practices				
Plowing	69	81	56	91
Leveling	33	71	26	0
Bunding	37	89	27	0
Puddling	15	68	3	0
Sawah	15	68	3	0
Transplanting	20	55	12	0
Broadcasting	50	45	53	22
Row planting	13	20	10	25
Plant density (kg/ha)	96	99	95	92
Seed priming	25	62	18	5
Nets to keep birds away	4	5	4	0
Nets to keep birds away (for those reporting birds as a problem)	6	7	6	0

Source: CRI/SARI/IFPRI November 2012–February 2013 survey (2013).
Note: kg/ha = kilograms per hectare.

In terms of land preparation, 61 percent of rice area was plowed using a tractor or power tiller, and 8 percent was plowed using animal traction, mainly in the Northern Savannah zone. The large majority of plots in irrigated areas and upland areas were plowed, while only 56 percent in lowland rainfed areas were plowed. A third of rice area was leveled and bunded, and only 15 percent was puddled. About 15 percent of rice area was under sawah (bunded, leveled, puddled, and irrigated). In terms of planting preparations, a quarter of rice area was planted with primed or soaked seed for better germination and yield. CSIR and MOFA also recommend treating the seed with recommended pesticide right before planting (CRI and MOFA 2005). Only 1 percent reported treating seed right before planting. Only 1 percent of rice farmers reported treating seed for storage with chemicals.

In terms of planting practices, only 20 percent of rice area was transplanted, while half of rice area was still planted through broadcasting and 30 percent through dibbling or drilling. Only 13 percent of rice area was planted in rows or lines, despite much promotion of row planting since the 1990s. Last, Table 3.3 shows that using nets to keep birds away is not popular, with only 4 percent of rice area netted in the major season. About 73 percent of the farmers reported that birds were a major problem before harvest, but it seems that using nets has not become popular yet.

Rice Yield Function

Several yield response models were estimated based on the type of seed and variety variables included, interactions with irrigation, and whether pooled or disaggregated data for lowland rainfed and irrigated areas are used in the estimation. The full sample was estimated first, and then separate models were tested for lowland rainfed and irrigated areas. Table 3.4 shows the highlights of the results.[6] First we show the results of the ordinary least squares models, then the adjusted results using the IV approach. Estimates using the CF approach are similar to those of the IV. Therefore, only one of the models is presented in Table 3.4. Moreover, various management practices are highly correlated with each other: seed priming, transplanting, bunding, leveling, and using the sawah system. Due to multicollinearity, each of these is used one at a time and not simultaneously in the models. Estimates are similar, and therefore only one variant of the models (using seed priming) is presented here.

Table 3.4 Rice yield response model estimates

Explanatory variable	Full Sample		Lowland rainfed		Irrigated	
	OLS	IV	OLS	IV	OLS	IV
Nitrogen (kg/ha)	10.768***	26.553***	9.967***	25.867***	16.591***	48.430***
	(2.259)	(6.431)	(2.060)	(5.094)	(5.221)	(18.726)
Nitrogen squared	–0.025	–0.074**	0.014	–0.042	–0.036	–0.012
	(0.018)	(0.034)	(0.018)	(0.029)	(0.037)	(0.034)
Modern variety (= 1)	–444.275**	–2443.090***	–331.427**	–1599.979***		1211.680*[a]
	(177.836)	(154.158)	(139.190)	(185.999)		(707.650)
Modern variety × Number of Years of seed recycling	–15.290	–10.239	13.174	8.243	–48.761	–246.509
	(17.492)	(14.979)	(13.744)	(12.621)	(56.756)	(164.634)
Irrigated plot (= 1)	1469.346***	983.990***				
	(223.257)	(201.579)				
Nitrogen × Irrigated	9.011**	14.209				
	(3.832)	(9.335)				
Soil type (control = not fertile)						
Soil perceived moderately fertile (= 1)	165.896	89.841	4.685	48.406	–526.855	44.367
	(159.230)	(184.097)	(139.355)	(158.938)	(473.692)	(675.537)
Soil perceived very fertile	466.819***	371.057*	181.813	262.659	338.093	724.693
	(162.446)	(193.062)	(143.022)	(168.324)	(522.240)	(631.542)

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[6] The rest of the results are available upon request from the authors.

Table 3.4 Continued

Explanatory variable	Full Sample		Lowland rainfed		Irrigated	
	OLS	IV	OLS	IV	OLS	IV
Soil type (reference: less suitable soil types [Leptosols and Arenosols])						
More suitable soil types (Cambisols, Fluvisols, Luvisols, and Gleysols)	93.100	–330.978	–96.773	–257.236		
	(282.822)	(329.096)	(268.540)	(303.257)		
Clayish (Vertisols, Planasols, and Plinthosols)	1245.486***	862.686**	401.680	650.791**		
	(304.005)	(366.512)	(268.309)	(307.529)		
Lixisols	723.101**	449.618	248.588	492.156		
	(287.646)	(339.934)	(264.657)	(304.797)		
Acrisols	699.768**	991.013***	498.453**	776.158***		
	(283.326)	(323.087)	(243.171)	(281.186)		
Plot size (ha)	–28.193	16.925	–65.168*	–4.485	212.594	626.834
	(52.744)	(65.412)	(39.394)	(48.737)	(392.027)	(559.890)
Seed used per ha (kg/ha)	5.555***	3.150*	2.625**	1.476	4.331	11.667
	(1.457)	(1.717)	(1.268)	(1.467)	(11.617)	(15.900)
Seed used squared	–0.003	–0.000	–0.008	–0.000	0.045	–0.012
	(0.015)	(0.018)	(0.013)	(0.015)	(0.047)	(0.067)
Stress periods (<20 millimeter decads)	–11.948	32.587	12.307	2.128		
	(34.799)	(41.061)	(30.544)	(36.377)		
Applied manure (= 1)	47.384	69.753	–92.551	–86.169		
	(270.930)	(307.849)	(251.475)	(284.702)		
Seed priming (= 1)	640.502***	1011.479***	335.014*	462.870**	–33.412	–336.013
	(179.640)	(207.811)	(194.350)	(220.752)	(394.899)	(568.117)
Row planting (= 1)	877.172***	553.895**	110.110	51.116	3731.198***	3180.492***
	(178.308)	(233.280)	(158.231)	(193.137)	(781.572)	(1084.243)
Continuously cultivated in last 11 years (= 1)	–116.136	–196.464	103.136	33.420	–975.742*	–818.055
	(156.289)	(177.654)	(132.552)	(150.728)	(547.718)	(752.091)
Applied herbicide (= 1)	61.563	31.553	88.379	–63.851		
	(184.675)	(236.747)	(147.239)	(188.644)		
Member of FOB or co-op (= 1)	–99.871	–13.106	39.860	48.831		
	(133.213)	(152.310)	(113.182)	(128.296)		
Received extension advice (= 1)	206.699	396.332**	304.996**	391.111**	464.436	541.924
	(151.319)	(172.849)	(137.932)	(156.465)	(377.637)	(510.954)

Table 3.4 Continued

Explanatory variable	Full Sample		Lowland rainfed		Irrigated	
	OLS	IV	OLS	IV	OLS	IV
Highest education (control = no education)						
Primary (= 1)	–24.229	–14.441	–144.488	–188.580	–190.581	–201.109
	(180.479)	(205.610)	(159.809)	(181.109)	(452.789)	(612.936)
Secondary or above (= 1)	156.251	210.988	75.171	97.084	–25.576	–479.349
	(159.471)	(182.589)	(139.389)	(159.256)	(425.840)	(601.729)
Female (= 1)	–165.514	–90.569	–353.424**	–341.119**	–259.827	297.575
	(169.024)	(193.230)	(147.415)	(167.536)	(446.190)	(639.191)
Age	17.112***	18.858***	3.267	6.473		
	(5.835)	(6.681)	(4.980)	(5.662)		
Age squared	–1.034***	–0.957**	–0.576*	–0.809**		
	(0.348)	(0.406)	(0.314)	(0.365)		
Total family labor[b]	0.076	–0.265	–0.063	–0.103		
	(0.533)	(0.606)	(0.433)	(0.492)		
Total hired labor[b]	–0.221	–0.001	–0.889	–0.655		
	(0.787)	(0.918)	(0.781)	(0.903)		
Northern Ghana (= 1)	–1384.839***	–1346.005***	–825.290***	–1427.395***		
	(233.349)	(262.145)	(217.845)	(254.061)		
Kpong irrigation scheme (= 1)					668.764	–1877.616
					(802.929)	(1456.456)
Constant	1984.733***	3353.176***	1855.626***	2911.095***	3100.285***	3397.996**
	(425.410)	(515.541)	(359.270)	(424.512)	(1123.325)	(1605.516)
Observations	601	601	405	405	162	162
Log likelihood	–5209.960	–14271.519	–3361.559	–7546.216	–1458.448	–2624.559

Source: CRI/SARI/IFPRI November 2012–February 2013 survey (2013).

Notes: FBO = farmer-based organization; ha = hectare; IV = instrumental variable; kg = kilograms; OLS = ordinary least squares. Standard errors are in parentheses. $^{*}p < .10$. $^{**}p < .05$. $^{***}p < .01$. [a] Since almost all farmers in irrigated areas planted modern varieties, the variable used here was modern variety on new seed or recycled up to 2 years, which is the recommendation of Crops Research Institute/Savannah Agricultural Research Institute. [b] person-days/ha.

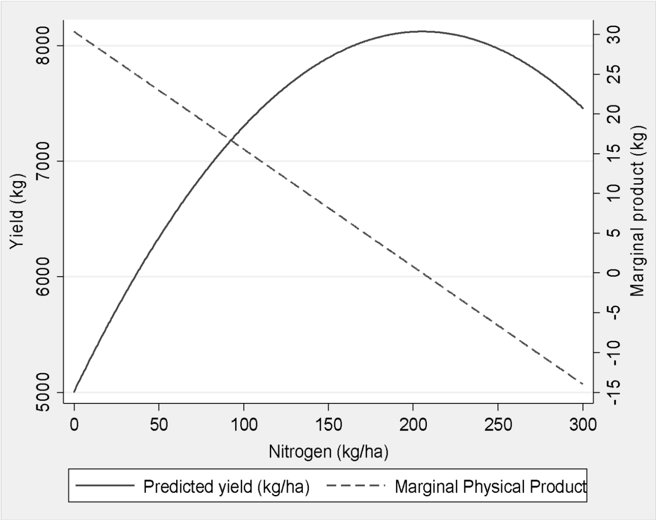
Significant factors explaining variations in yield include nitrogen; improved varieties; different management practices including seeding rate, seed priming (which is highly correlated with transplanting, bunding, leveling, and the sawah system), row planting, and access to extension advice; and controls including gender, age, location, and soil types.

Nitrogen

Nitrogen is highly significant in explaining differences in yield across rice plots. An additional 1 kg of nitrogen applied to rice plots leads to 27 kg more yield. The yield response to fertilizer decreases slightly for every additional kilogram of nitrogen. The interaction term between nitrogen and irrigation is positive although not statistically significant. It shows that yield response in irrigated areas is slightly higher than in lowland rainfed areas.

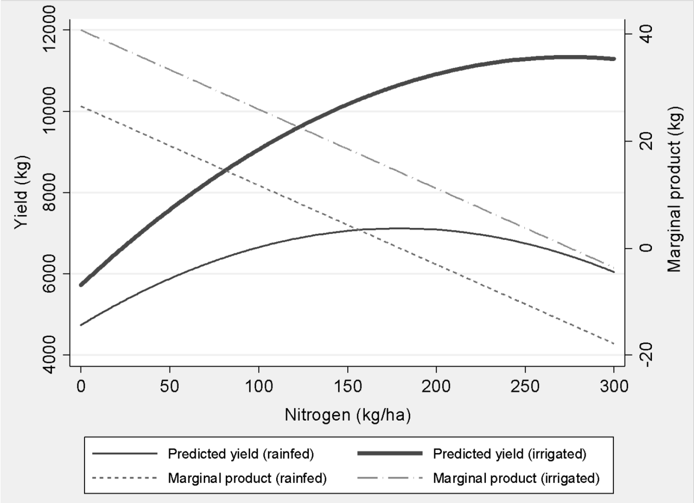
An additional 1 kg of nitrogen applied to rice plots leads to about 26 kg (without irrigation) and 40 kg (with irrigation) more yield. Using pooled data, the yield response rate to fertilizer application is decreasing, and it peaks at 205 kg/ha of nitrogen (Figure 3.1), when the yield started to decline for every additional kilogram of nitrogen. For lowland rainfed areas, yield response rate to fertilizer application is also decreasing, and it peaks at 180 kg/ha of nitrogen (Figure 3.2), when the yield started to decline for every additional kilogram of nitrogen. For irrigated areas, it peaks at 270 kg/ha of nitrogen (Figure 3.2). The current recommendation of MoFA/CSIR (90 kg/ha/ of nitrogen) is about half of this estimated optimal level for rainfed areas or a third of the estimated optimal level for irrigated areas, suggesting that there is still ample room for increased intensity.

Figure 3.1 Rice yield response to nitrogen application and marginal physical product, full sample



Source: CRI/SARI/IFPRI November 2012–February 2013 survey (2013).
Notes: ha = hectare; kg = kilograms.

Figure 3.2 Rice yield response to nitrogen application and marginal physical product, irrigated and lowland rainfed areas



Source: CRI/SARI/IFPRI November 2012–February 2013 survey (2013).
Notes: ha = hectare; kg = kilograms.

Improved Seed

The use of improved varieties has a negative effect on yields. Plots planted with seeds of improved varieties have a lower yield of 2,443 kg than those planted with traditional varieties, holding other factors constant. This is similar in the separate models on lowland rainfed areas, where improved varieties have lower yield of 1,600 kg than traditional varieties (almost all irrigated plots were planted with improved varieties, so there is comparison). This is counterintuitive as one would expect higher yield from improved varieties. This suggests that improved varieties do not have a yield advantage over local varieties although most of the popular improved varieties (such as Jasmine 85 and Togo Marshall) have other advantages such as aromatic and long grains that consumers demand, especially in urban areas. Local aromatic rice sells at a 30–40 percent premium over local nonaromatic rice (100–120 cedi per 50-kg bag for non-aromatic rice versus 130-170 cedi per 50-kg bag of aromatic rice).

This finding supports a breeding program that focuses on combining different desirable traits such as high yield, aromatic and long grain, and drought and disease resistance into a variety, for example, through the application of more advanced breeding like biotechnology.

To further investigate the negative relationship of improved variety use and yields, we unpacked improved variety use into variety names, degree of seed recycling, or purchase of new certified seeds (Table 3.5). First, we use dummies for the top three popular varieties (Jasmine 85, Togo Marshall, and Jet 3) and other improved varieties in the models and use local varieties as the control. We also added the number of years of seed recycling. The Jet 3 variety (nonaromatic) has significantly higher yields than the rest of the varieties, while Togo Marshall (aromatic) has a significantly lower yield than local varieties (Table 3.5). Jasmine 85 (aromatic), the most popular variety, has no significant difference in yield compared with local varieties. The number of years of seed recycling is negative and statistically significant in relation to yield. One additional year of seed recycling corresponds to a 34 kg reduction in yield (or 19 kg for the rainfed lowland system).

Table 3.5 Various models using different variety and seed-related variables

Variable	Model 1	Model 2	Model 3	Model 4
Full sample				
Years of seed recycling	–33.99*			
	(19.90)			
Variety type (control = local)				
Jasmine 85	–8.14			
	(199.35)			
Togo Marshall	–700.85**			
	(274.35)			
Jet 3	971.33***			
	(327.78)			
Other modern	–259.69			
	(201.37)			
Seed type (control = local)				
New certified seed		564.26**		
		(232.49)		
Recycled seed of modern variety		–2188.78***		
		(279.49)		
New or recycled once			–209.63	
			(193.38)	
Other recycled seed of modern variety			–1935.76***	
			(310.09)	
New or recycled at most twice				–356.25*
				(182.76)
Other recycled seed of modern variety				–1845.60***
				(310.19)

Table 3.5 Continued

Variable	Model 1	Model 2	Model 3	Model 4
Lowland rainfed				
Years of seed recycling	–19.15*			
	(11.44)			
Variety type (control = local)				
Jasmine 85	–91.88			
	(165.21)			
Togo Marshall	–60.34			
	(235.27)			
Jet 3	622.34**			
	(315.16)			
Other modern	–127.86			
	(165.88)			
Seed type (control = local)				
New certified seed		830.73**		
		(344.97)		
Recycled seed of modern variety		–335.27***		
		(123.97)		
New or recycled once			–3.28	
			(550.50)	
Other recycled seed of modern variety			–274.10**	
			(135.54)	
New or recycled at most twice				–1680.88***
				(260.11)
Other recycled seed of modern variety				–290.36**
				(138.42)
Irrigated areas				
Years of seed recycling	128.12			
	(168.10)			
Variety type (control = other seed)[a]				
Jasmine 85	702.83*			
	(425.68)			
Togo Marshall	–1836.55**			
	(755.40)			
Jet 3	1725.16**			
	(686.20)			
Seed type (control = other seed)[a]				
New certified seed		489.65		
		(921.59)		
New or recycled once			1045.30	
			(1097.97)	
New or recycled at most twice				1211.68*
				(707.65)

Source: CRI/SARI/IFPRI November 2012–February 2013 survey (2013).
Note: Standard errors are in parentheses. [a] The control variable used is local seed. *$p < .10$. **$p < .05$. ***$p < .01$.

Second, improved varieties were divided into newly purchased certified and uncertified seeds (and using local varieties as control). Results show that newly purchased certified seeds have a significantly higher yield than local seeds while recycled seeds of improved varieties have a significantly lower yield than local seed. Newly acquired certified seeds have a 564-kg higher yield compared to local seeds. Third, improved varieties were divided into a group of newly purchased certified seeds and those recycled only once and another group of other recycled seeds of improved variety (and using local varieties as control). Results show that newly purchased certified seeds or those recycled only once have no significant difference compared with local seeds; other recycled seeds of improved varieties have a significantly lower yield than local seed. Fourth, we tried a different grouping—a group of newly purchased certified and those recycled up to two years and another group of other recycled seeds of improved variety (and using local varieties as control). Results show that both these groups have a significantly lower yield than local seed. This shows that the yield advantage of certified seeds disappears once they are recycled.

Rice is a self-pollinating crop, and seeds of improved varieties can be replanted many times as long as seeds are selected properly from harvest and are not mixed with other varieties during planting, harvesting, and storage. However, key informants' interviews suggest that improper harvesting of rice is common in Ghana and that much grain of old varieties stays in the ground during harvest and gets mixed with new seeds planted, suggesting that seed recycling may be quite an issue in terms of losing the yield advantage of improved varieties quickly. This finding is consistent with Kijima, Otsuka, and Sserunkuuma (2011), who show that a major reason for the weak impact of NERICA (New Rice for Africa) rice in Uganda is the use of farmer saved seeds and highlighting the importance of improving the seed distribution system and strengthening the dissemination and extension of proper seed production.

Seeding Rate

The quantity of seed planted is a significant (although weak) determinant of yield in the pooled data. However, the significance disappears in the disaggregated models. We also tried differentiating between transplanted and broadcasted seeds, but the seeding rate remained significant (although weak) in both of these planting methods in the pooled data but not in the disaggregated models.

Row Planting

Plots planted in rows have a significantly higher yield than those not planted in rows. Plots planted in rows have 550 hg higher yields than those not planted in rows using pooled data. This may also be related to easier application of fertilizer and easier weeding if rice is planted in rows; therefore, we see a large difference between rice planted in rows and that planted randomly. Disaggregated models reveal that row planting matters only in irrigated areas and not in lowland rainfed areas. Plots planted in rows have 3.1 tons more yield than those not planted in rows in irrigated areas, although we should use caution when discussing the magnitude of this effect due to the small sample size in the models for irrigated areas.

Seed Priming

Seed priming is statistically significant in affecting yield. Seeds that were primed first before planting yield higher by 1 ton compared to those not primed using the pooled data. Disaggregating between rainfed and irrigated areas, seed priming seems to matter only in rainfed areas. Primed seeds have 462 kg more yield than those not primed. There is no significant difference in irrigated areas in most models. Similarly, transplanting, bunding, leveling, and using the sawah system are other technologies that seem to be associated with higher yields in rainfed lowlands.

Extension

Extension service or the provision of agricultural advice to farmers is statistically significant in affecting yields, although it seems to matter only in lowland rainfed areas. This is expected as the majority in these areas have no extension, and the results show just that yield can be improved by improving the delivery of extension services on rice in rainfed areas. Farmers receiving extension advice have a 396-kg higher yield than those without extension advice. It did not seem to matter in irrigated areas as most of the irrigation schemes have in-house extension agents from the Ghana Irrigation Authority. Other models were also estimated with extension services receipt as endogenous to productivity since more productive farmers may be more likely to get or search for information and advice. IVs used included proportion of farmers in the community receiving extension services and distance to extension officer (Table 2.2). The results remain the same—a significant effect of extension on productivity in lowland rainfed areas.

Gender

There seems to be no gender difference in yield using the pooled data. However, there is some difference when we disaggregate rainfed areas. Female farmers seem to have lower yields in rainfed areas than male farmers after controlling for input use, location, and other factors. There seems to be no difference in yield between female and male farmers in irrigated areas.

Age

Age appeared to be significant in the pooled data but not in the disaggregated models for rainfed and irrigated areas.

Spatial Differences

After controlling for all the factors that are hypothesized to influence rice yield response, we find that there are spatial variations between the Northern Savannah zone and the southern zones when it comes to productivity of rice. Plots in the north have 1.3 tons lower yield than those in the south. This may be due to the difference in humidity and plot-specific soil fertility and types between north and south Ghana (Food and Agriculture Organization of the United Nations 2005; Kombiok, Buah, and Sogbedji 2012), which we were not able to control for in the model estimations. We were able to control for rainfall data, periods of stress or too little or too much rain, village-level soil type, and perception of farmers about their plot fertility. In irrigated areas, there is highly significantly lower yield in the north; however, we removed the dummy variable north in the data as all of the variables become insignificant and the models become unstable. Instead, we added a dummy variable for the Kpong irrigation scheme, which has systematically higher yields than the other irrigation schemes. However, our results show that yields in the Kpong irrigation scheme are not statically different from other irrigation schemes after controlling for other factors in our regression models.

Profitability and Risk Associated with Technologies

The coefficients in the above yield response models are used to estimate the profitability of fertilizer use (with or without improved seed in various locations) through VCR. Table 3.6 suggests that in general at the current yield response rates, it is profitable to use fertilizer on rice across the sample on average with subsidy. Even if we assume the VCR is greater than 2 (which is necessary in very high-risk environments and is a benchmark suggested by Crawford and Kelly 2002), the results suggest that fertilizer is still profitable, on average, with subsidy. Profitability is highest when fertilizer is combined with certified seed in irrigated areas, where yield response is maximized given these three practices. The case with the market price of fertilizer is different, in which only with certified seed or irrigated area in the south can nitrogen have a VCR greater than 2. This shows that in most cases, rice will not be profitable given market prices of fertilizer and that the subsidy seems to have helped in making rice production profitable. This is somewhat consistent with Akramov and Malek's (2012) analysis, showing that rice farming is not profitable for the observed average farm both in private and social prices if family labor is included. Profitability is lowest in rainfed areas, especially with uncertified seeds, and in irrigated areas in the northern part of Ghana.

Table 3.6 Value-cost ratios using subsidized and market fertilizer prices

	Scenario	Marginal physical product (A)	At subsidized fertilizer prices: Value-cost ratio[a] (B)	At market fertilizer prices: Value-cost ratio[a] (C)
1	Nitrogen (whole sample)	15.57	2.75	1.39
2	Nitrogen in irrigated areas	18.46	3.26	1.65
3	Nitrogen in lowland rainfed areas	14.51	2.56	1.30
4	Nitrogen and certified seeds	24.90	4.40	2.23
5	Nitrogen and local seeds	13.62	2.41	1.22
6	Nitrogen and certified seed in irrigated areas	35.23	6.22	3.16
7	Nitrogen and certified seed in rainfed areas	21.09	3.73	1.89
8	Nitrogen in the north	13.68	2.42	1.23
9	Nitrogen in the south	18.21	3.22	1.63
10	Nitrogen in irrigated areas in the north	12.07	2.13	1.08
11	Nitrogen in irrigated areas in the south	27.36	4.83	2.45
12	Nitrogen in rainfed areas in the north	14.27	2.52	1.28
13	Nitrogen in rainfed areas in the south	14.83	2.62	1.33

Source: Authors' calculations, based on CRI/SARI/IFPRI November 2012–February 2013 survey (2013).

Notes: The prices used are based on the averages from the survey data: average market price for a 100-kg bag of rice paddy = 72 GHc (or 0.72 cedi/ kg). Subsidized nitrogen, phosphorus, potassium (NPK) 15-15-15 price = 39 GHc; subsidized sulfate of ammonia price = 35 GHc; average market NPK 15-15-15 price = 76 GHc; average market sulfate of ammonia price = 70 GHc. Price of 1 kg of nitrogen: using the Ghana Ministry of Food and Agriculture fertilizer recommendation of two bags of NPK 15-15-15 and two bags of sulfate of ammonia per acre, thus a 1:1 ratio, and the fact that NPK 15-15-15 contains 15% nitrogen and sulfate of ammonia contains 21% nitrogen, the price of 1 kg of nitrogen is given by 100 / 36 × (NPK 15-15-15 price per kg + sulfate of ammonia price per kilogram). Therefore, the average subsidized price of 1 kg of NPK 15-15-15 and sulfate of ammonia used is 0.74 cedi/kg (or 4.11 cedi/kg of Nitrogen); and the average market price of 1 kg of NPK 15-15-15 and sulfate of ammonia used is 1.46 cedi/kg (or 8.11 cedi/kg of Nitrogen).[a.] Value-cost ratio = rice paddy price per kilogram / fertilizer price per kilogram.

A few farm budgets were compiled to further analyze profitability of rice production, with or without subsidy, using informal interviews with farmers and average farmer calculations from the CRI/SARI/International Food Policy Research Institute survey (Table 3.7). As shown in Table 3.7, different farmers adopt different inputs and management practices and therefore have different production costs, have different yields, and face different output prices. Even with these few farm budgets, rice production can be profitable or not; net profits can range from –408 to 2,156 cedi/ha with subsidy and from –680 to 1,938 cedi/ha without subsidy. From the CRI/SARI/International Food Policy Research Institute survey, an average farmer can get a profit of 596 cedi/ha with fertilizer subsidy and 264 cedi/ha without fertilizer subsidy in irrigated areas. The profits in lowland rainfed areas are slightly lower. But if family labor is accounted for, profits become negative with or without subsidy in both irrigated and rainfed areas, consistent with Akramov and Malek (2012).

Table 3.7 Different farm budgets on the profitability of rice production, in Ghanaian cedis per hectare

	Average farmer in irrigated areas[a]		Average farmer in owland rainfed areas		Tamale (rainfed)[b]		Upper East (irrigated)[b]		Upper East (rainfed)[b]		Ashanti (irrigated)[b]	
Cost item	**With subsidy**	**Without subsidy**	**With subsidy**	**Without subsidy**	**With subsidy**	**Without subsidy**	**With subsidy**	**Without subsidy**	**With subsidy**	**Without subsidy**	**With subsidy**	**Without subsidy**
Tractor for land preparation	150	150	150	150	62	62	247	247	90	90	300	300
Fertilizer	341	673	152	300	119	237	272	544	222	445	218	436
Other chemicals	66	66	66	66	49	49	47	47	49	49	75	75
Hired labor	707	707	343	343	178	178	1,045	1,045	300	300	1,501	1,501
Transport from plot to house	40	40	40	40	37	37	59	59	37	37	50	50
Other materials and cost	200	200	100	100	20	20	171	171	57	57	770	770
Transport from house to market, market taxes, milling costs (if applicable)	60	60	60	60	50	50	50	50	30	30	330	330
Total cost	**1,564**	**1,896**	**911**	**1,059**	**515**	**633**	**1,891**	**2,163**	**786**	**1,008**	**3,244**	**3,462**
Cedi per bag	72	72	72	72	60	60	50	50	40	40	90	90
Number of bags	30	30	17	17	19	19	30	30	20	20	60	60
Total revenue	**2,160**	**2,160**	**1,224**	**1,224**	**1,140**	**1,140**	**1,483**	**1,483**	**791**	**791**	**5,400**	**5,400**
Profit	**596**	**264**	**313**	**165**	**625**	**507**	**–408**	**–680**	**5**	**–217**	**2,156**	**1,938**
Family and communal labor	903	903	672	672								
Net profit (including family labor)	**–307**	**–639**	**–359**	**–507**								

Source: [a] Authors' calculations, based on CRI/SARI/IFPRI November 2012–February 2013 survey (2013). [b] Based on informal interviews of selected farmers.

An interesting finding is that in some cases, such as our sample farmer in the lowland rainfed area in the Upper East region, fertilizer subsidy can matter in getting positive or negative profits. Fertilizer subsidies may help to increase productivity and production in the short run, but the government of Ghana has to find ways to reduce its production costs to be competitive in the future.

A study conducted by the Natural Resources Institute (2013) reveals much higher production, milling, and marketing costs in Ghana compared to another importer of rice in West Africa, Senegal, and a major exporter of rice, Thailand. For example, production costs were estimated to be $283 /ton[7] of paddy rice in the Northern region and $316 in the Volta region in Ghana, compared to only $194to $216/ha in Senegal and $159 to $220 in Thailand. Much of the differential in production costs is the cost of mechanization and hired labor for land preparation, crop establishment, crop care, and harvesting. Cost of milling in Ghana was estimated to be $98 to $296/ton of milled rice, compared to only $63 in Senegal and $67 to $73 in Thailand. The subsidized fertilizer price in Ghana (estimated by Natural Resources Institute 2013to be around $133/ha in the north) is much lower than fertilizer prices in Senegal ($208/ha) and Thailand ($250). But the market price of fertilizer is Ghana is about twice the subsidized one ($266), which makes it much higher than Senegal's price and slightly higher than Thailand's. Fertilizer subsidies may help in reducing some of the production costs in Ghana, but the bulk of the high cost differential, including high mechanization, hired labor, milling, and marketing costs, is untouched and remains the major bottleneck for improved competitiveness of Ghana rice in the future. Rashid et al. (2013) highlighted that the Asian Green Revolution involved a package approach of input promotion involving investments in agricultural research and development, irrigation, promotion of domestic fertilizer, and investments in rural roads, instead of focusing mostly on seed and chemical fertilizer and not on fertilizer subsidy.

Using the results from the yield response model and data on prices of fertilizer and rice grain output, optimal levels of fertilizer application were computed. Going back to the theory of profit maximization and assuming that markets are perfect, optimal fertilizer use is given by VMPP equal to fertilizer price (P_f). Comparing the point at which these are equal to the actual fertilizer application rates in Ghana provides us with the opportunity to check how far or near fertilizer use in the country is from the optimal fertilizer use and understand possible constraints if there are huge gaps. Results show that the actual application rate (49 kg/ha of nitrogen) is far off from the optimal level of 205 kg/ha of nitrogen before yield starts to decrease using the full sample (Figure 3.3). The level to maximize profits given subsidized fertilizer prices is 165 kg/ha of nitrogen, which is far off from the actual application rate (Figure 3.3).

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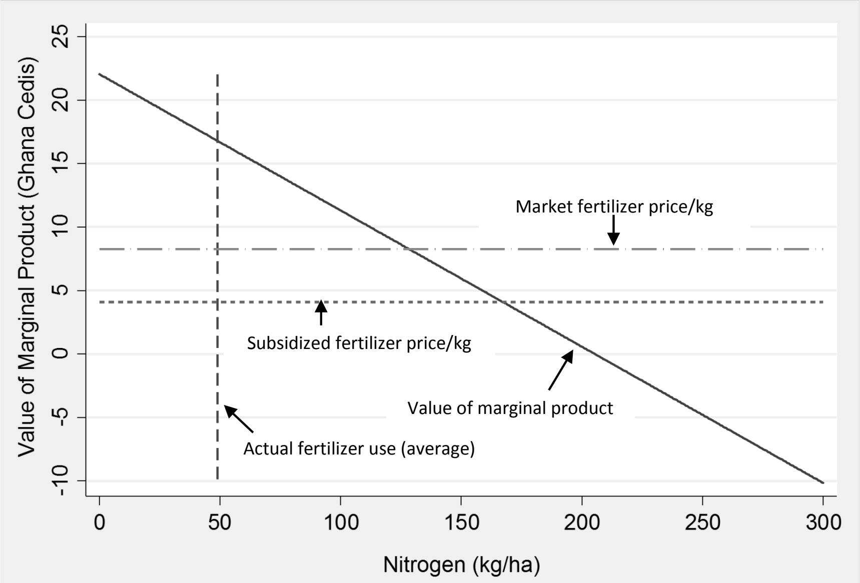
[7] All $ are in US dollars.

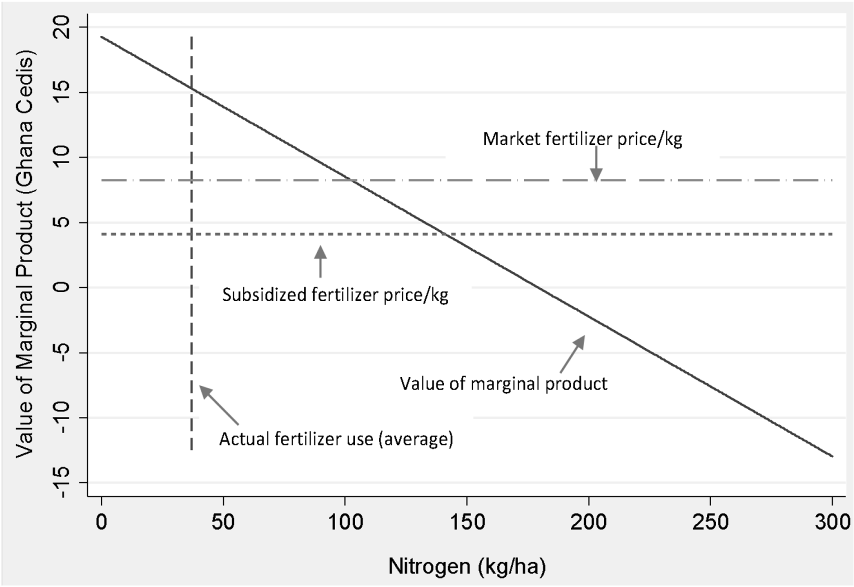
Figure 3.3 Value of marginal product and fertilizer prices, full sample



Source: CRI/SARI/IFPRI November 2012–February 2013 survey (2013).
Notes: ha = hectare; kg = kilogram.

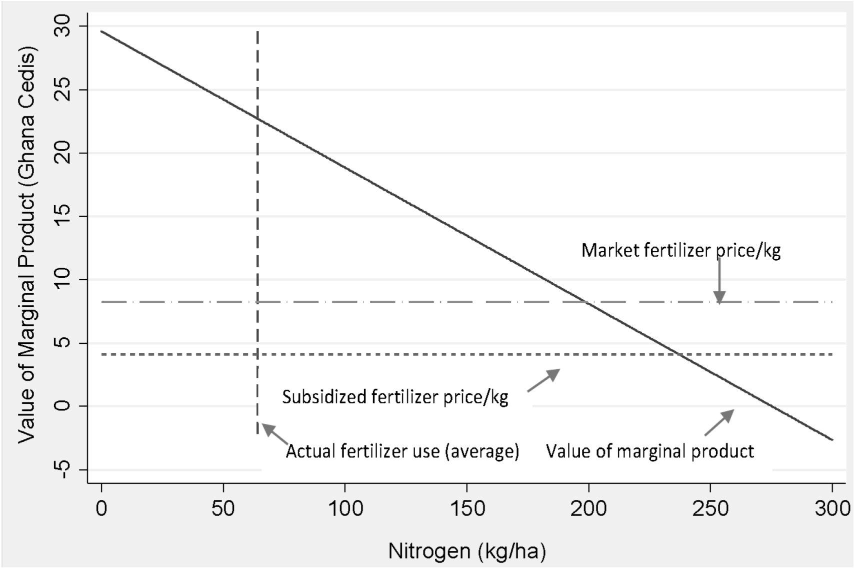
In lowland rainfed areas, the optimal level is about 145kg/ha of nitrogen at the subsidized price of fertilizer, compared to the average actual application rate of 37 kg/ha of nitrogen, implying a shortage of 108 kg/ha of nitrogen to maximize profits (Figure 3.4). In irrigated areas, the optimal level is about 240 kg/ha of nitrogen at the subsidized price of fertilizer, compared to the average actual application rate of 83 kg/ha of nitrogen, implying a shortage of about 160 kg/ha of nitrogen to maximize profits (Figure 3.5). These results suggest the scope to increase fertilizer application rates in both irrigated and rainfed areas, given the yield response and profitability. Even though 99 percent of farmers in irrigated areas apply fertilizer, the rates could be increased, and the gap between actual and optimal levels is wider for irrigated areas. In irrigated areas, the rate of application in the north (59 kg/ha of nitrogen) is much lower than in the south (106 kg/ha of nitrogen). Similarly for lowland areas, the rate of application in the north (30 kg/ha of nitrogen) is much lower than in the south (47 kg/ha of nitrogen). Therefore, farmers in the north are much further off the optimal level, and therefore much greater efforts are needed in intensifying fertilizer application in the north.

Figure 3.4 Value of marginal product and fertilizer prices, lowland rainfed areas



Source: CRI/SARI/IFPRI November 2012–February 2013 survey (2013).
Note: kg/ha = kilograms per hectare.

Figure 3.5 Value of marginal product and fertilizer prices, irrigated areas



Source: CRI/SARI/IFPRI November 2012–February 2013 survey (2013).
Note: kg/ha = kilograms per hectare.

Results also suggest that fertilizer prices seem not to be the binding constraint in greater fertilizer application and productivity increases in rice and that other factors appear to be major bottlenecks to greater fertilizer application and productivity increases. These factors are explored in the subsequent sections, where determinants of fertilizer and improved seed adoption and complementary management practices (seed priming and row planting) are modeled.

Factors Affecting Fertilizer and Improved Variety Adoption

Despite higher productivity and profitability of fertilizer and improved seeds adoption and while 77.0 percent of farmers apply fertilizer (99.0 percent in irrigated areas), actual application rates are half of the MoFA and CSIR recommendations and only a quarter of the estimated optimal application rates based on yield response models. While 64.0 percent plant improved varieties and have a positive yield response to certified seeds, only 17.0 percent of farmers used certified seeds. This section examines the factors associated with the adoption of fertilizer and certified seeds and two improved management practices (seed priming and row planting) that are related to higher yields based on the joint estimation models of these four inputs/practices based on simultaneous adoption decision among farmers (Table 2.2). Adoption models for transplanting, bunding, leveling, and using the sawah system are similar to that of seed priming, and thus only that of seed priming is presented in Table 2.2. The use and intensity of fertilizer were estimated jointly by a double-hurdle model, and the model variables are similar for the first tier (fertilizer use equation) and second tier (fertilizer intensity equation) (Table 3.8). Since extension services access is highly significant in the productivity model, we included an estimation in Table 2.2 of the factors that explain the likelihood of getting access to extension services.

Table 3.8 Double-hurdle model: Factors explaining fertilizer use and intensity

	Tier 1 (fertilizer adoption)		Tier 2 (fertilizer intensity model)	
	(A)	(B)	(C)	(D)
Explanatory variables	**Coefficient**	**Standard error**	**Log normal**	**Standard error**
Market and plot access				
Distance to agroshop (km)	0.021*	0.011	–0.067	0.155
Distance to plot (km)	0.003	0.002	0.052	0.083
Affordability				
Certified seed price (GHc/kg)	–0.155**	0.056	–7.720**	2.417
Fertilizer price (GHc/kg)	–0.007	0.369	20.830**	9.049
Lagged percentage of harvest sold (%)	0.008**	0.003	0.171	0.119
Lagged proportion of income from crop sales (%)	–0.003	0.004	0.185*	0.099
Total landholding size (ha)	–0.022	0.018	0.009	1.017
Plot size (ha)	–0.274**	0.088	–17.937***	4.807
If plot is owned	0.054	0.179	7.543	6.125
If plot is owned, with written land title	0.645	0.575	–28.738**	12.696
Soil type (control = not fertile)				
Soil perceived moderately fertile (= 1)	–0.374*	0.214	–0.324	5.880
Soil perceived very fertile (= 1)	–0.762***	0.210	1.313	6.167
Crop management practices				
Applied manure (= 1)	–0.144	0.333	3.134	10.244
Bunding (= 1)	0.997***	0.223	10.658*	5.895
Applied herbicide (= 1)	0.472**	0.194	32.831***	7.954
Seed priming (= 1)	0.457*	0.238	11.599*	6.082
Row planting (= 1)	0.953***	0.290	20.900***	6.300
Continuous cultivation (= 1)	–0.008	0.189	–3.549	6.008
Total family labor (person-days/ha)	–0.001*	0.001	0.021	0.023
Total hired labor (person-days/ha)	–0.000	0.001	0.103***	0.026
Access to information				
Member of farmer-based organization or co-op (= 1)	0.099	0.158	7.142	5.089
Received extension advice (= 1)	–0.011	0.192	–10.654*	5.724
Farmer and household characteristics				
Primary (= 1)[a]	0.403*	0.237	–5.363	6.644
Secondary or above (= 1)[a]	–0.003	0.192	–3.212	6.010
Female (= 1)	0.211	0.216	–12.269**	6.113
Age	0.005	0.007	–0.168	0.205
Household size	–0.002	0.010	–0.458	0.364

Table 3.8 Continued

	Tier 1 (fertilizer adoption)		Tier 2 (fertilizer intensity model)	
	(A)	(B)	(C)	(D)
Explanatory variables	Coefficient	Standard error	Log normal	Standard error
Location-specific factors				
6-year rainfall coefficient of variation	0.008	0.013	1.686***	0.347
Northern Ghana (= 1)	0.605**	0.262	4.583	9.680
Irrigated (= 1)	0.563	0.345	13.453**	6.545
Constant	–0.190	0.691	–39.205	23.837
Sigma	—	—	39.588***	1.904
Observations	601			
Log likelihood	–2429.509			
Chi-square	124.854			

Source: CRI/SARI/IFPRI November 2012–February 2013 survey (2013).

Notes: ha = hectare; kg = kilogram; km = kilometer. a. Reference group is no formal education. *$p < .10$. **$p < .05$. ***$p < .01$.

Improved Seed

Factors affecting the use of certified seeds are market access, certified seed prices, access to extension advice, and education level, after controlling for location and soil type (Table 2.2). Farmers who are located closer to agro-input shops and markets are more likely to adopt certified seeds. Farmers' and villages' facing a lower price of certified seed encourages more adoption of certified seed among rice farmers. Farmers who have been visited by extension agents are more likely to adopt certified seed. Similarly, those living nearer an extension officer are more likely to adopt certified seeds. More educated farmers are more likely to use certified seeds. Plots that are located with more rainfall predictability are more likely to be planted with certified seeds. Irrigated plots are more likely to be planted with certified seeds. Certified seed use also seems to be explained by peer effect—a farmer is more likely to use certified seeds in a community with a greater proportion of farmers using certified seeds, holding other things constant. These factors are expected to be statistically significant in explaining the likelihood of certified seed use. There is a similar likelihood of using certified seed in both northern and southern Ghana.

There are also some surprising results. Distance to plot is significant and positive, suggesting that the farther the plot is from the farmer's home, the more likely it is that the farmer will use certified seeds. We expected that farther plots would discourage certified seed use due to higher monitoring costs. The relationship with perceived soil fertility and certified seed use is negative and not as expected. It may be that the perception of soil fertility has to do with the decision whether to use certified seed. It seems that farmers use certified seeds to somehow boost production in farther and not-so-fertile plots while farmers seem to have more confidence with their recycled seeds to get the same production level in their fertile and nearby plots. Fertilizer prices are positively related with certified seed, which means that higher fertilizer prices may provide less cash available to buy certified seed.

Fertilizer Use and Intensity

Factors affecting fertilizer use are degree of commercialization, certified seed price, complementary land preparation practices (particularly manure and herbicide application and bunding), education level, perceived soil fertility of plot, and geographical location (Table 2.2). Farmers who expect to sell more of their harvest are more likely to apply fertilizer. Farmers' and villages' facing a lower price of certified seed, a complementary input to fertilizer, encourages more users of fertilizer. Farmers who apply manure and herbicide are more likely to use fertilizer than those who do not. Farmers in the north are more likely to apply fertilizer than are farmers in regions in the south. Farmers who have primary education are more likely to use fertilizer than farmers with no formal education. Irrigated plots are more likely to be fertilized. Plots that are perceived to be less fertile are more likely to be fertilized, which is expected. If plots are owned, with written land title, farmers are more likely to apply fertilizer. Larger plots are less likely to be fertilized. Fertilizer use also seems to be explained by peer effect—a farmer is more likely to use fertilizer in a community with a greater proportion of farmers using fertilizer, holding other things constant.

Based on the double-hurdle model, the factors that explain the decision to use fertilizer are similar to the multivariate probit model results. However, the factors that explain the intensity of use are quite different (Table 3.8).

Seed Priming

Factors that explain the seed priming decision (and correlated practices such as transplanting, bunding, leveling, and use of sawah) are distance to market, distance to plot, education level, access to extension, gender of farmer, land ownership, complementary management practices, and location (Table 2.2). More educated farmers are more likely to prime seeds before planting. Female farmers are more likely to prime seeds before planting. Farmers with extension services access are more likely to prime seeds before planting than those who do not access extension. Similarly, those living nearer an extension officer are more likely to adopt seed priming. Irrigated plots are more likely to be planted with primed seeds. Plots in northern Ghana are less likely to be planted with primed seeds. Plots with more predictable rain are more likely to be planted with primed seed. Plots that are owned, with written land title, are more likely to be planted with primed seeds. Seed priming also seems to be explained by peer effect—a farmer is more likely to prime seeds in a community with a greater proportion of farmers adopting seed priming, holding other things constant.

Row Planting

Factors that explain the decision to adopt row planting are access to markets, certified seed price, land ownership, education, and irrigation (Table 3.7). Farmers in areas more accessible to markets are more likely to plant in rows. Cheaper certified seeds are related to greater likelihood of row planting, but more expensive fertilizer prices are related to greater likelihood of row planting. Education matters in row planting. Farmers with secondary education are more likely to plant in rows than those without formal education.

Access to Extension

Who has more access to extension services? Factors that explain the likelihood of accessing extension services are access to markets, membership in farmer-based organizations or agri-co-ops, total landholdings, land ownership, education, gender of farmer, age, location, and irrigation. Those who sell more of their harvest (greater commercialization) are more likely to have access to extension visits. Farmers with more total landholdings are more likely to have extension visits. Land ownership also seems to matter, but the sign is not expected: farmers with land owned, with written land titles, are less likely to be visited by extension agents. Farmers with primary or secondary education are more likely to be visited by extension agents. Male or older farmers are more likely to have extension service access than female or young farmers. Farmers who perceive their plots to be fertile and with predictable and stable rainfall throughout the years are more likely to be visited by extension agents. Farmers in the south or in irrigated areas are more likely to be visited by extension agents than those in the north or in rainfed areas. There seems to be a concentration of extension services—a farmer is more likely to receive extension services in a community with a greater proportion of farmers receiving extension services, holding other things constant.

Implications of Adoption Models

There are several implications of these results in encouraging greater fertilizer and certified seed use and adoption of complementary improved management practices, particularly seed priming, transplanting, bunding, leveling, using the sawah system, and row planting, to reach optimal levels and improve productivity among rice farmers in Ghana. To encourage improved seed use, strategies to improve accessibility of seeds of improved varieties, access to extension services, and provision of information about improved varieties and complementary good practices are important. Extension services tend to go more toward male and older farmers located in the irrigated areas or the southern part of Ghana. Efforts have to be made to disseminate information more to female and younger farmers, to those with rainfed plots, and to those in the northern part of Ghana.

To encourage fertilizer use, increased market access, commercialization, and rice processing options would be needed to prevent falling rice grain prices and supply surpluses due to increases in production and productivity from fertilizer use. Part of this will involve addressing high costs in milling, grading, and marketing (compared to Senegal and Thailand) for local rice production to be competitive with imported rice.

Bunding is complementary to fertilizer use, certified seed use, seed priming, and row planting. According to key informants, a major constraint to bunding is lack of or expensive rental of power tillers that are used to plow and bund rice plots. This has implications for the need to ease the constraints in the development and promotion of mechanization in the country.

Certified seed prices are negatively related to certified seed use and fertilizer use and even are reflected in row planting. Efforts to bring down the cost of certified seed seem to be another option for encouraging adoption. Certified seed currently costs about 2.50 cedi/kg (ranging from 0.7 to 6 cedi/kg based on our survey) compared to 0.73 cedi/kg opportunity cost of recycled seed. Compared to other inputs, seed seems to be the first to be cut in the budget in the face of liquidity constraints since farmers have the option of recycling their own seeds from previous years' harvests. Both seed demand and fertilizer demand seem to be responsive to seed prices.

Education level matters in the adoption of these two important inputs and two improved management practices that seem to be related to higher yields. This shows the importance of strengthening access to adult education for farmers and access to better education for their children who will be the future generation of farmers in the country.

4. CONCLUSIONS

This paper illustrates the challenges of achieving a Green Revolution similar to that experienced in Asia, particularly in the rice sector. Using the Ghana case, the evidence presented in the paper shows that despite major programs and investments in the rice sector, and despite several technologies available for use, productivity improvements in rainfed systems and expansion of irrigated rice systems are slow and the needed postharvest and marketing infrastructure remains weak.

Employing yield response models, profitability analysis, and adoption models utilizing cross-sectional data on 576 rice farmers and 601 rice plots in 23 districts in 10 regions in Ghana, results show various practices contribute to yield improvements in irrigated and rainfed systems including chemical fertilizer use, certified seed, transplanting, bunding, leveling, use of the sawah system, and seed priming in rainfed lowland and row planting in irrigated systems. Results show that rice yields are responsive to fertilizer application. One kilogram of nitrogen leads to 27 kg of additional yield (and up to 41 kg in irrigated areas). Yields would be higher if fertilizer use were accompanied by certified seed use, seed priming, transplanting, bunding, and leveling in rainfed lowlands. Certified seeds have higher yields by 830 kg/ha than local or recycled seeds, and one year of recycling lowers yield by 19 kg/ha in rainfed lowland ecologies (average years of rice seed recycling is four to five). The contribution of certified seed to yield improvements seems to be between 100 and 830 kg/ha. Plots with primed seeds (and transplanted, bunded, and leveled) have higher yields by 462 kg/ha in rainfed lowlands. Evidence also shows that extension services for rice production are limited and that intensifying extension services on these productivity-enhancing technologies, as well as environmentally sustainable practices, can contribute to increasing the rice yield over time.

Currently, rice yields in rainfed lowlands average 1.66 tons/ha, which is much lower than the average of irrigated systems (3.9 ton/ha) in Ghana or far from the potential of 5.6 to 9.8 ton/ha in West Africa and attainable yields during the Asian rice Green Revolution. These few productivity-enhancing technologies (new certified seeds, seed priming, and higher quantity of fertilizer use) could give at the most 1 to 2 tons/ha additional yield on average. The technologies that can contribute to increasing yields are few, and marginal increases in yields from these technologies in rainfed systems is not high enough to match the productivity growth achieved during the Green Revolution in Asia. Expansion of irrigated areas will be necessary to boost rice productivity and production in Ghana.

Moreover, no available improved varieties are proving to be productivity enhancing and at the same time to be demanded by farmers due to their aroma and marketability. A modern variety called Jet 3 has a significantly higher yield by almost 1 ton/ha than the other varieties while the more popular varieties that are preferred because of their aromatic traits have no yield advantages over other varieties. Jasmine 85 has no yield advantage over local varieties (although there it has a weak advantage over local varieties in the irrigated areas); Togo Marshall has significantly lower yields by 700 kg/ha than local varieties. This suggests ample room for improvement in rice breeding to combine high-yielding traits with consumer-demanded characteristics such as aromatic and long grain in single varieties. This may contribute to increasing rice productivity and production in other rainfed lowlands and irrigated systems.

Last, fertilizer subsidies seem to have reduced cost and increased production in the short run, but the government of Ghana has to find ways to reduce its major production costs to be competitive in the future. Main factors to encourage fertilizer use intensity and adoption of other productivity-enhancing technologies are the degree of commercialization and improving market access, reducing milling and marketing costs for local production to be competitive with imported rice, and reducing the costs and improving accessibility of power tillers for plowing and bunding and hired labor, which comprise 40–56 percent of the overall production costs.

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