

# Moving in the right direction? The role of price subsidies in fertilizer use and maize productivity in Ghana

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**Abstract** Despite major maize programs in the last two decades and costly investments in a price subsidy program in Ghana, maize productivity remains very low. Utilizing cross-sectional data on 645 maize plots in Ghana, this paper provides empirical evidence on the responsiveness of maize yield to fertilizer application, profitability of fertilizer use, and how the economics of fertilizer use have changed with the subsidy program. There was a statistically significant maize yield response to increased fertilizer application (i.e. 1-kg of nitrogen leads to a yield increase of 22–26 kg per hectare), higher than those estimated in other countries in Africa. Value-cost ratio shows that maize production with fertilizer is profitable both at market and subsidized prices in different locations and with different farming practices, even after incorporating risk into the estimation and analysis. However, despite subsidized prices and profitable fertilizer use, the actual application rate (at 44 kg/ha of nitrogen on average) is much lower than research institute's and government recommendation and far off the computed economically "optimal" levels (at 225 kg/ha of nitrogen; where the fertilizer price intersects the value of marginal physical product derived from the yield response model). Results suggest that fertilizer prices do not seem to be the binding constraint in greater fertilizer application and productivity

increases in maize; other factors appear to be major bottlenecks to greater fertilizer application and productivity increases including accessibility to modern varieties, mechanization, and hired labor. This result shows the limits to fertilizer subsidy as the focus strategy and suggests a more integrated and holistic approach to encourage greater fertilizer application, productivity and income among maize farmers in Ghana.

**Keywords** Yield response · Profitability · Productivity · Fertilizer subsidy · Fertilizer intensity · Ghana

**JEL classifications** Q12 · Q16 · Q18 · C36

## Introduction

Development experts have emphasized the crucial importance of increasing agricultural productivity in sub-Saharan Africa (SSA) in achieving economic transformation, food security and the Millennium Development Goals (MDGs) (Timmer 1988; World Bank 2007). The productivity in maize, being the most important staple crop and covering 20% of calorie intake and 13% of total cultivated land in SSA, is key to these goals. However, maize yields in SSA remains the lowest in the world, averaging only 0.5 to 2.5 tons per hectare, compared to the global average of 6–7 tons per hectare. Two widely recognized reasons for the persistent low yields in rainfed areas in SSA are soil nutrient depletion and use of low-yielding varieties. Therefore, the two most common instruments for increasing maize productivity, used by governments and development partners, are research and development (R&D) and fertilizer subsidy to promote fertilizer use. There have been mixed results in terms of the effectiveness and impact of these instruments given the limited assessment studies.

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Much of the literature on R&D show significantly positive effects on productivity, poverty reduction, and food security of investments in R&D. However, it remains a puzzle as to why actual productivity levels remain low despite the availability of various modern varieties and claims of high rates of returns to investments in R&D (e.g. Alene et al. 2009). The use of fertilizer subsidy is not much more positive. A recent special issue in *Agricultural Economics* on fertilizer subsidies suggests mixed results on the effects of these subsidies on productivity, income and food security, although there is a general consensus that program costs often outweigh the benefits (Jayne and Rashid 2013). The mainly cited success story of Malawi fertilizer subsidy, which has influenced the resurgence of fertilizer policy in many SSA countries has also been questioned (Jayne and Rashid 2013). Modeling conducted by Folberth et al. (2013) suggests that simply increasing application rate of inorganic fertilizer to 50 kg of Nitrogen (N) and 18 kg of Phosphorus (P) per hectare would double the maize yields in SSA. However, Jayne and Rashid (2013) have also cautioned on declining maize-fertilizer response rate observed in many SSA countries due to continuous nutrient mining and soil degradation.

Aggregate fertilizer use trends in SSA show an annual growth of 9% over the 1960s and 1970s, stagnant until the early 2000s (Minot and Benson 2009), and an apparent growth since the reintroduction of fertilizer subsidy in 2008. Despite the reintroduction of the subsidy program, many African farmers still use much less fertilizer than is economically optimal (Sheahan et al. 2013; Duflo et al. 2008). While country level statistics show great variability in fertilizer use trends within SSA, the average fertilizer rate in SSA is estimated to be 15 kg/ha in 2013,<sup>1</sup> which is low compared with an average of 106 kg/ha in other developing countries. Despite promising experimental trial results of the yield response to fertilizer (see Duflo et al. 2008) and expensive subsidy programs to boost fertilizer demand, it remains a puzzle to many economists and researchers why the adoption rate of fertilizer remains low. Several studies have provided different explanations to this puzzle including low returns to many farmers despite high average returns when heterogeneity of farmers is considered (Suri 2007), fixed cost of acquiring fertilizer and complementary input such as hybrid seed (Suri 2007), risk factors (Hardaker et al. 2004; Pannell et al. 2000; Kingwell 2011; Monjardino et al. 2013), credit constraints (Duflo et al. 2007), and learning and information barriers (Duflo et al. 2007). Duflo et al. (2008) also highlight that returns to fertilizer use are often high in experimental trials but returns are often much lower in actual farmers' fields

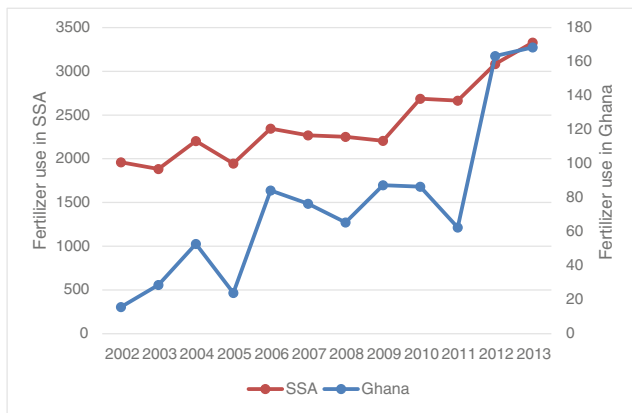
where conditions are less ideal and farmers are constrained. Suri (2007) also emphasizes that while average returns to fertilizer may seem high, one can still observe many farmers who experience low returns to fertilizer in communities with high heterogeneity. Similarly, Sheahan et al. (2013) highlight that the profitability of fertilizer use changes by location and by year. These various hypotheses and many different explanations highlight the context-specificity of yield response to increased fertilizer application, the economics of fertilizer use in particular, and the economics of maize production in general. This paper aims to contribute to the literature by presenting the context of maize and fertilizer in Ghana.

Ghana has just earned its middle-income status and continues to be widely regarded as an African success story due to its impressive achievements in accelerating growth and reducing poverty and hunger in line with the MDGs. Major investments were made in maize, Ghana's most important food crop, for many decades, including the Ghana Grains Development Project (1979–1997) and Food Crops Development Project (2000–8), both focusing on strengthening research and technology diffusion; and Ghana was the pilot country for the mass technology transfer and extension program of Sasakawa Global 2000. These efforts have often been cited as success stories of long-term capacity strengthening and agricultural development in Africa (World Bank 2007). However, the productivity of maize, is persistently among the lowest in the world (at 1.7 tons/ha), despite these major efforts and huge investments. Attainable yield potential of maize in Ghana is estimated to be around 4–6 tons/ha based on on-farm trials, indicating a large yield gap and unexploited potential of the maize sector (Ragasa et al. 2013a).

In 2008, the government of Ghana (GoG) reintroduced the subsidy program to lower the cost of fertilizer for smallholder farmers in Ghana and stimulate an increase in fertilizer use on staple crops, including maize, to raise yields and overall food production. While the reintroduction of fertilizer subsidy in Ghana started in 2008, it was not until 2012 that there was a jump in fertilizer use, while the whole of SSA saw a sharp increase in fertilizer use starting in 2010 (see Fig. 1). Ariga et al. (2006) classified Ghana among the group of countries in Africa with a high growth rate of fertilizer use of at least 30% but an average intensity of fertilizer use below 25 kg/ha over the 1990–2003 period, which is among the lowest. Government expenditure devoted to the fertilizer subsidy program has more than tripled from \$10 million in 2008 to \$35 million in 2011 (Benin et al. 2011) with an announced subsidy cost of \$60 million in 2012 (MoFA 2012). This trend is likely to continue as the fertilizer subsidy program has become one of the preferred policies of the government in trying to stimulate increased fertilizer use and raise crop productivity to

<sup>1</sup> Source: FAO (Food and Agriculture Organization of the United Nations). <http://faostat3.fao.org/download/R/RF/E>. Accessed October 13, 2015.

Note: Data refer to the 31 countries for which data exist in the new FAO fertilizer data series over the 2002–2013 period.



Source: FAO (Food and Agriculture Organization of the United Nations) <http://faostat3.fao.org/download/R/RF/E>. Accessed October 13, 2015.

**Fig. 1** Fertilizers consumption in Sub-Saharan Africa (1000 metric tons of nutrients) Source: FAO (Food and Agriculture Organization of the United Nations). <http://faostat3.fao.org/download/R/RF/E>. Accessed October 13, 2015

deal with the country's declining cereal production, food price hikes, and high rural poverty rates. In addition, the GoG through the Ministry of Food and Agriculture (MoFA) has established a National Food Buffer Stock Company (NAFCO) which is mandated to buy crops from farmers at economic prices (based on costs of production).

From these strategies, it is clear that the government is trying to address two of the factors (cost of fertilizer and output price) that affect profitability of fertilizer use on major staples, including maize. However, the most elusive factor is the yield response to fertilizer use, which is also a function of many variables including other complementary inputs such as seed variety, herbicide and pesticide use, farm management, land quality and unpredictable weather conditions and their interactions. The low fertilizer use and intensity could be the reason why yields have remained low but this remains an empirical question. While there is evidence that the subsidy program has encouraged greater adoption of fertilizer, at least for maize and rice farmers (see Ragasa et al. 2013a, 2013b), there remains a research and policy question as to whether fertilizer contributes to increased productivity and other questions as to whether the subsidy has changed the incentives for and profitability of fertilizer use.

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 discussion on yield response to fertilizer application; profitability and economically "optimal" levels of fertilizer application; and determinants of fertilizer and modern variety adoption. Section 4 concludes with implication of results for policies on raising agricultural productivity in Ghana's maize system and similar maize production systems in other countries.

## Methods

### Study area

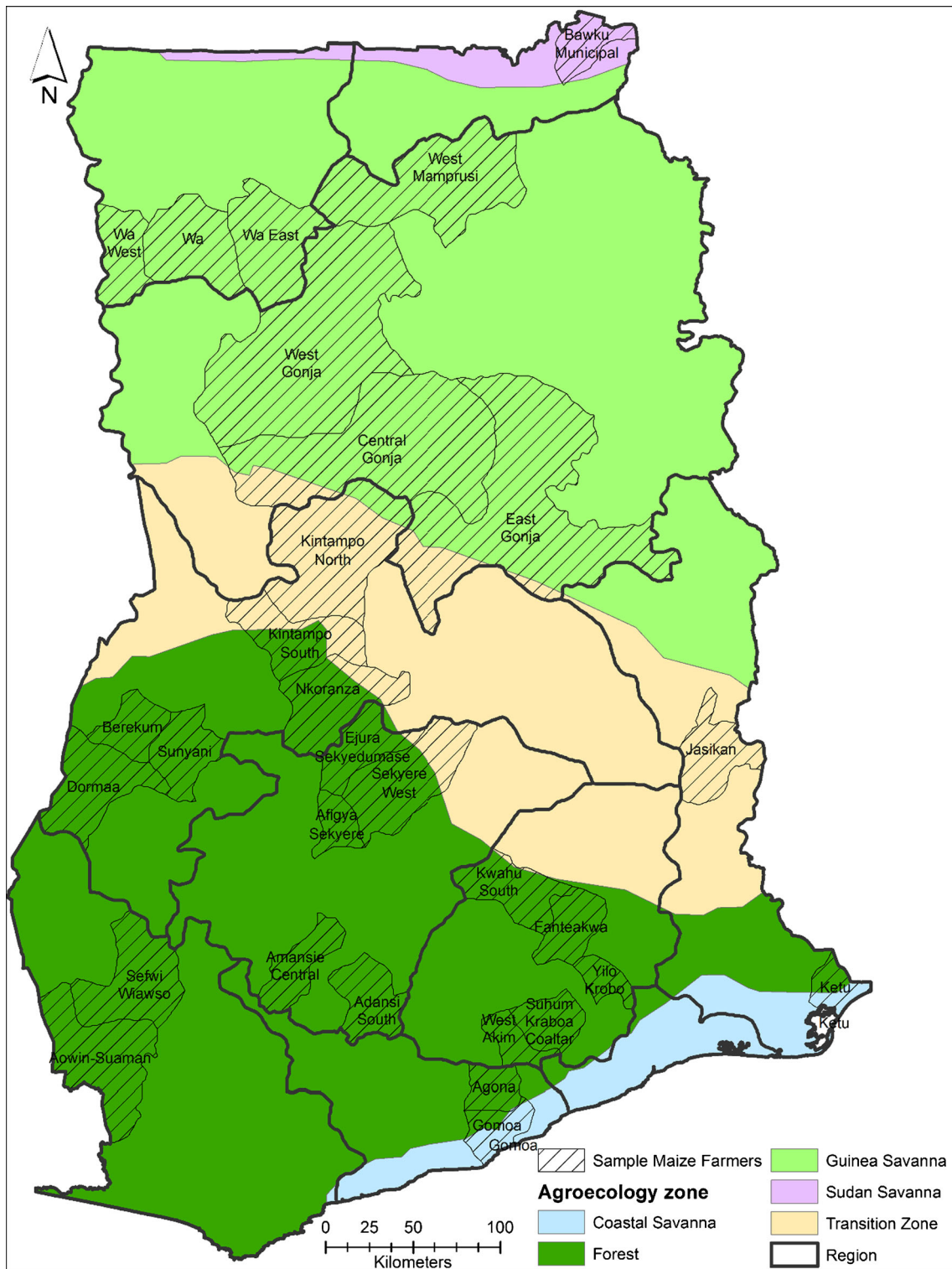
Ghana is part of western Africa, surrounded by Cote d'Ivoire, Burkina Faso, and the Gulf of Guinea. It has a tropical climate with distinct wet and dry seasons. The annual mean temperature is generally above 24°C, but annual rainfall varies considerably across the country with the lowest in the coastal savannah and the highest in the rainforests of the southeastern parts of the country. There are five major agroecological zones in the country, and this study covers all of them (Fig. 2).

The coastal savannah zone includes a narrow belt of savannah that runs along the coast, widening toward the east of the country. Farmers in this zone grow maize and cassava, often intercropped, as their principal staples. Annual rainfall, which is bimodally distributed, totals only 800 mm, so most maize is planted following the onset of the major rains that begin in March or April. Soils are generally light in texture and low in fertility, so productivity is low.

The forest zone is immediately inland from the coastal savannah. Most of Ghana's forest is semi-deciduous, with a small proportion of high rain forest remaining. This zone accounts for 43% of agricultural GDP, attributed mainly to cocoa production, occupying about 1.6 million hectares, which is equivalent to the total cereal area of the country (Olesen et al. 2013). Maize in this zone is grown in scattered plots, usually intercropped with cassava, plantain, or cocoyam as part of a bush fallow system. Although some maize is consumed in the forest zone, it is not a leading food staple and much of the crop is sold. Major staples are cassava, plantain and taro. Annual rainfall in the forest zone averages about 1500 mm (1400–1900 mm); maize is planted both in the major rainy season (beginning in March) and in the minor rainy season (beginning in September).

The transition zone is north of the forest zone. The exact boundary between the two zones is subject to dispute, which is not surprising considering that the boundary area is characterized by a constantly changing patchwork of savannah and forest plots. What is certain, however, is that the transition zone is an important region for commercial grain production and is considered as the corn belt of Ghana. Much of the transition zone has deep, friable soils, and the relatively sparse tree cover allows for more continuous cultivation (and greater use of mechanized equipment). The soils are fairly fertile and support a wide variety of crops such as maize, yams, cassava and to some extent plantain. Rainfall is bimodally distributed and averages about 1300 mm per year. Maize in the transition zone is planted in both the major and minor seasons, usually as a monocrop or in association with yam or cassava.

The Guinea Savannah zone occupies most of the northern part of the country and covers about 57% of the land area in Ghana (Olesen et al. 2013). Annual rainfall totals about



**Fig. 2** Sample districts surveyed in this study. Source: List of sample districts are from CRI/SARI/IFPRI survey (November 2012–February 2013). The administrative boundaries are based on <http://www.gadm.org/country>

1100 mm (950–1300 mm), falling in a single rainy season beginning in April or May. Sorghum and millet are historically the dominant cereals in this zone, but maize has started to gain

more prominence in recent years. The soils are generally poor with better soils in the floodplains and along river banks. Rice is the most important cash crop in the zone and is produced in



the valley bottoms. Some fields are prepared by tractor, but most are prepared by hand. Maize is grown in permanently cultivated fields located close to homesteads, as well as in more distant plots under shifting cultivation. Cotton, another important cash crop, is more important to small-scale farmers. Livestock production is an important activity in the zone with over 70% of the country's population of cattle, sheep and goats (Olesen et al. 2013).

The Sudan Savannah zone is northeast of the Guinea Savannah zone. This zone receives less rainfall 952 mm (550–1000 mm) than the latter, but shares many similarities in terms of staple crops and practices with the latter, explaining why both zones are often lumped together as one zone in many reports. What is interesting with this zone is that maize production is increasing quite fast. Maize is historically not a major crop in this zone (mostly Upper East region), and even not included in the earlier 1997 survey by Morris et al. (1998) due to minimal maize production at that time, but maize production in the Upper East region jumped, starting in 2008 and accounted for 6% of national maize production by 2014.

### Farmer survey and data sampling

This paper utilizes cross-sectional data from a survey of 630 maize farmers in 30 districts in 9 out of 10 administrative regions<sup>2</sup> and all 5 agroecological zones in Ghana implemented in November 2012 to February 2013 by the Crops Research Institute (CRI), Savannah Agricultural Research Institute (SARI) and the International Food Policy Research Institute (IFPRI). The sample districts surveyed in this study is presented in Fig. 2. The survey used three-stage, clustered, and randomized sampling procedure. First, a proportional probability sampling of districts was done, giving more weight to those with higher maize production. The districts were selected based on the list of maize-producing districts (districts with more than 3000 ha of maize production, 2009–11 average). The sampling frame represents 92% of total hectares planted with maize in Ghana during 2009–11. Selected districts represent 40% of the total maize production area (and 39% of the total production in tons or 37% of total area) in Ghana in 2009–11. For each sample district, three EAs were randomly selected, and seven farmers were randomly selected from the sample villages based on a list of maize farmers arranged by gender and plot size (that is, gender and plot size were used for implied stratification in the sampling process). We define a maize farmer as one who managed and decided on a maize plot during the major season of 2012 (with a minimum area of 0.5 acres, or 0.2 ha). The total sample was 630 maize farmers,

of which 78% were male and 22% were female. Fifteen farmers reported cultivating and managing two maize plots, and therefore, the dataset includes 645 maize plots that were used for analysis. More details about the data can be found in Ragasa et al. (2013a, 2013b). The farmer survey was complemented by a series of key informants' interviews held in Accra, Kumasi, Tamale and Volta, conducted from August to December 2012.

### Yield response models

There are two major methods for measuring and analyzing yield response to fertilizer: using field experiments (in a controlled, small-area researcher-managed plots) and using surveys relying on observational data (in a large sample of farmer-managed plots). There are advantages and disadvantages to each. Field experiments can control for many variables, and can vary across weather conditions and space; while observational data cannot control effectively for unobserved farmer and location attributes that may jointly affect fertilizer use and output. On the other hand field experiments are done in a very controlled manner and are often small-scale; while surveys allow analysis on socioeconomic factors and differences across farmer types. Harou et al. (2014) were able to analyze a unique dataset from Malawi. This consisted of a large-scale, repeated, nationwide experimental, plot-level dataset which was merged with detailed soil and weather data. This allowed the generation of flexible econometric estimates of the marginal physical returns to fertilizer use. But such a dataset is not readily available in most countries, including Ghana. Also, even with this innovative study, the authors acknowledge that while assignment of fertilizer applications was randomized, it was managed by non-randomly selected local farmers and therefore was not representative of some types of farmers.

A third method of analyzing yield response, which is rapidly growing and utilized, is crop simulation or modeling. These simulation models include Agricultural Production Systems Simulator (APSIM), Decision Support System for Agro technology Transfer (DSSAT), CERES, EPIC, ALAMANC, CROPSYST, WOFOST and ADEL, among others. There are many crop simulation modelling tools that are available that measure yield fertilizer response mainly using biophysical and meteorological data. Rauff and Bello (2015) provide a recent review of some of these models. For example, APSIM was used to simulate maize farming processes in response to temperature and rainfall, soil management practice, and the fertilizers N and P for a typical sandy soil of the Kamphenga area (Keating et al. 2003); it was also used to simulate soil and crop processes in highly

<sup>2</sup> Excluding Greater Accra, which has minimal maize production, accounting for 0.37% of national maize production.

constrained, low yielding maize/legume systems in Malawi (Kamanga et al. 2013; Robertson et al., 2000, 2005) and in similar environments in Zimbabwe (Ncube et al. 2009; Shamudzarira and Robertson 2002). DSSAT software, which requires data sets of crop growth and management, daily weather data and soil data, was used to forecast rice yields in Sri Lanka (Dias et al. 2016) and the yield response of maize to fertilizer in SSA (Guo et al. 2009). These models are powerful and are applied in a broad range of decision making, including farming systems, design for production or resource management objectives, assessment of the value of seasonal climate forecasting, analysis of supply chain issues in agribusiness activities, and guides to research and education activity (Keating et al. 2003). Moreover, these models can reduce substantially the time and cost of traditional field experimentation necessary for adequate evaluation of new cultivars and new management systems. However, these tools are also criticized for their limited method of validation and the large amount of site-specific data they require are often not available (Rauff and Bello 2015). At times, these models are not able to give accurate projections because of inadequate understanding of natural processes and relationships and because a large set of hypotheses is being tested simultaneously, as compared to traditional field experiments (Rauff and Bello 2015). Given the focus on biophysical processes, these crop models are also often best accompanied by economic models based on observed data and incorporating socio-economic indicators (Keating et al. 2003; Whitbread et al. 2010). In this paper, we use biophysical data in the form of rainfall levels and variability and soil characteristics along with market potential and socioeconomic characteristics of households and communities and modeled these using statistical methods.

Using observational data from 645 maize plots nationwide to examine maize yield response to fertilizer in Ghana, we estimated a production function of the form

$$Y = f[V, X, Z] \quad (1)$$

where  $Y$  is the quantity of the crop produced per unit area;  $V$  is the vector of inputs including land, 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 as in eq. 2 below to estimate the yield model represented in eq. 1. Despite some criticism regarding the quadratic or higher order polynomial functional form (see Grimm et al. 1987), we adopted this functional form because it permits zero inputs and concavity in the yield response curves, a process that is more consistent with most biological

relationships (Xu et al. 2009; Burke 2012; Traxler and Byerlee 1993; Kouka et al. 1995).<sup>3</sup> We estimated the following model:

$$Y = \beta_0 + \beta_i F + \beta'_i F^2 + \alpha_k S + \delta_m L + \vartheta_j R + X\varnothing + \varepsilon \quad (2)$$

where  $Y$  is the measure of productivity which, in our case, is kilograms of maize produced per hectare,<sup>4</sup>  $F$  represents the fertilizer nutrients,  $S$  represents the seed variables (modern 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, that we derive from the chemical composition of the fertilizers available on the market and converted into their equivalent chemical components. In Ghana, MoFA recommends that farmers growing maize should, at the minimum, use two 50-kg bag of NPK 15:15:15 at planting or few days after planting and two bags (50 kg) of sulphate of ammonia for maize four to six weeks after planting per acre.<sup>5</sup> This is equivalent to 240 kg of NPK and 240 kg of sulphate of ammonia per hectare. NPK 15:15:15 is a fertilizer that has an equal proportion of N, P and K (15% for each nutrient) while sulphate of ammonia has 21% nitrogen and 24% sulphur.<sup>6</sup> According to FAO (2005), K is not limiting in Ghana but N and P are, so our focus would be

<sup>3</sup> The production theory is moot on a specific functional form for crop yield response, so we relied on past studies to choose the most appropriate functional form. Grimm et al. (1987) provide some guidance as to what to consider when choosing the function form whilst Burke (2012) discusses the pros and cons of some of the popular functional forms used in the literature. He argues that some functional forms, for example, the von Liebig models, linear and plateau, von Liebig quadratic and plateau response models, are better suited to experimental field data than to 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, it 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 et al. 2000).

<sup>4</sup> A common measure of productivity used in the literature is the value of yield per hectare of various crops (see Owens et al. 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 why 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 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 controlled for intercropping using a dummy variable and seeding rate during planting. By using these control variables, we were able to isolate the variations in yield of maize, which is the interest of this paper, at the same time addressing the possible artificially low productivity for intercropped plots.

<sup>5</sup> The recommended is for plots that have been continuously cultivated for at least five years. NPK20–20–0 can also be used as starter fertilizer (with the same intensity as NPK 15–15–15) and urea as side dressing (half the intensity of sulphate of ammonia).

<sup>6</sup> Higher intensity of nitrogen is needed for faster plant growth, while sulfur is recommended to increase organic matters in the soil, especially in the absence of green and animal manure, as well as to aid in micronutrient uptake and efficiency from the starter fertilizer.

on these two nutrients. Since the nutrients are applied as fertilizer mixtures, there is high collinearity ( $\rho = .75$ ) between N and P so we dropped P and assumed that N was a proxy for overall fertilizer use.

*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) modern versus traditional varieties; and (2) certified new seed (of modern varieties), recycled or uncertified seeds (of modern varieties) versus seeds of traditional varieties. The main difference between the first and second classifications is the breakdown of modern varieties in the second one into certified and uncertified seeds of modern 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. Also, we controlled for the seeding rate or quantity of seed planted in a plot.

*L* represents the land quality variable. We proxied land quality by using soil quality variable captured from farmers' perception on the soil fertility of their plot before fertilization as we do not possess plot level data to adequately account for the difference in land quality. Marenya and Barrett (2009b) and Matsumoto and Yamano (2010) demonstrated that the profitability of adoption of improved technology can differ significantly according to soil quality even for plots in roughly similar agro-ecological conditions. To address this question, 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 perception or rating on soil fertility can be a good indicator of soil quality. Moreover, we used fallow system or cultivation history at plot-level as another indicator of soil quality. In addition, we considered the inclusion of two community level general soil characteristics that have been collected by the Soil Research Institute in Ghana; average soil pH and soil type. Soil pH is important and has been shown to limit the availability of Phosphorous (Burke 2012) and is likely to be a problem in high rainfall areas. Unfortunately, there was little variation in the average pH level data received from the Soil Research Institute of the Council for Scientific and Industrial Research (CSIR) for the communities in the sample so we dropped the variable.

*R* represents rainfall level and variability. We used rainfall data recorded from the closest meteorological station in the surveyed communities to compute three rainfall variables to capture water availability during the crop growing season. In particular, we computed the average rainfall received during the crop growing season (June through August) and the rainfall variance during that period. In rainfed agricultural systems, such as in Ghana, farmers determine the level of input use according to the variability of rainfall and drought risk so we computed a variable rainfall stress, which we defined as

the number of periods (10-day period) with less than 20 mm 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 (i.e., north).

The vector of *X* included factors recommended in the economic production literature as those that affect crop production levels. We grouped these factors into farmer and household characteristics (age, gender, years of schooling of farmer and marital status of the farmer, total land controlled by the household, household commercialization index (HCI)<sup>7</sup> and the ratio of hired labor to total labor days used on the maize plot) and farm management practices (such as tillage method, crop rotation, intercropping, and row planting). We controlled for location, particularly differentiating North and South, given the heterogeneity of farmers and farming systems across these areas and incorporating the main conclusion of Suri (2007) and Sheahan et al. (2013). We also controlled for agroecological zones and districts in some models. Table 1 summarizes the descriptive statistics of the variables used in this study.

Four different yield response models were estimated based on the type of seed and variety variables included in the estimation: (1) Model A, included modern variety as one of the explanatory variables; (2) Model B has an interaction term of modern variety and quantity of fertilizer application added to Model A allowing us to examine the differential impacts on yield of fertilizer intensity between modern varieties and traditional varieties; (3) Model C, instead of including a single variable capturing modern variety as in Model A, we split the variable into two binary variables, (a) farmers using newly purchased and certified seed of a modern variety, and (b) recycled or uncertified seed of modern variety, with seed of traditional variety as the reference group; and (4) Model D includes the interactions terms for the two binary seed variables introduced in Model C.

The results control for the potentially artificially lower yield due to intercropping by including a dummy variable for intercropping and seeding rate. Seed and variety variables along with fertilizer application are also modeled as endogenous inputs, but since there are only a few hybrid seed growers in our sample, we could not model hybrid seed adoption. In order not to distort the yield level of modern varieties, farmers growing hybrid seeds were excluded in our yield response model.

<sup>7</sup> This is defined as the proportion of maize harvest that is sold in the market. We used the average of the past 2 years as a proxy of the market orientation of farmers to avoid issues of simultaneity and endogeneity in the adoption models.

**Table 1** Descriptive statistics of the variables used in this study

| Variable   | Mean    | Standard deviation | Minimum | Maximum |
|--|---------|--------------------|---------|---------|
| Yield (kg/ha)                                    | 1214.57 | 851.63             | 71.66   | 5189.21 |
| Nitrogen (kg/ha)                                 | 21.88   | 33.80              | 0.00    | 312.59  |
| Phosphorus (kg/ha)                               | 9.64    | 14.19              | 0.00    | 74.13   |
| Modern seed variety*                             | 0.62    | 0.49               | 0.00    | 1.00    |
| Certified seed*                                  | 0.22    | 0.42               | 0.00    | 1.00    |
| Quantity of seed planted (kg/ha)                 | 20.17   | 11.49              | 5.00    | 50.00   |
| Rainfall (mm)                                    | 627.95  | 146.38             | 271.10  | 872.20  |
| Stress periods (<20 mm)                          | 3.63    | 1.56               | 0.00    | 8.00    |
| 6-year rainfall coefficient of variation         | 23.03   | 6.75               | 12.17   | 40.99   |
| Acrisols*  | 0.37    | 0.48               | 0.00    | 1.00    |
| Clay Soils (excluding acrisols)*                 | 0.40    | 0.49               | 0.00    | 1.00    |
| Sandy soils*                                     | 0.08    | 0.27               | 0.00    | 1.00    |
| Plot size (ha)                                   | 1.55    | 1.52               | 0.20    | 12.14   |
| Zero tillage*                                    | 0.09    | 0.28               | 0.00    | 1.00    |
| Plowing with a tractor*                          | 0.24    | 0.43               | 0.00    | 1.00    |
| Hand hoeing*                                     | 0.07    | 0.26               | 0.00    | 1.00    |
| Used herbicide*                                  | 0.55    | 0.50               | 0.00    | 1.00    |
| Used crop or animal manure*                      | 0.16    | 0.37               | 0.00    | 1.00    |
| Intercropping*                                   | 0.41    | 0.49               | 0.00    | 1.00    |
| Row planted maize*                               | 0.60    | 0.49               | 0.00    | 1.00    |
| Gender of farmer (1 = female)*                   | 0.21    | 0.41               | 0.00    | 1.00    |
| Age of farmer                                    | 44.54   | 11.88              | 19.00   | 85.00   |
| Years of education of farmer*                    | 6.58    | 4.91               | 0.00    | 20.00   |
| Primary school*/ <sup>a</sup>                    | 0.19    | 0.39               | 0.00    | 1.00    |
| Secondary school or above*/ <sup>a</sup>         | 0.50    | 0.50               | 0.00    | 1.00    |
| Family/communal labor (person-days per ha)       | 48.30   | 58.45              | 0.00    | 512.74  |
| Hired labor (person-days per ha)                 | 34.96   | 45.90              | 0.00    | 311.64  |
| Distance to agro-shop (km)                       | 4.40    | 5.46               | 0.00    | 25.00   |
| Distance to plot (km)                            | 25.78   | 21.75              | 0.63    | 150.00  |
| Certified seed price (GHc/kg)                    | 3.14    | 2.05               | 0.90    | 9.00    |
| Proportion of harvest sold (%)/ <sup>c</sup>     | 70.91   | 26.47              | 0.00    | 100.00  |
| Member of a FBO*                                 | 0.26    | 0.44               | 0.00    | 1.00    |
| Received crop extension advice*                  | 0.26    | 0.44               | 0.00    | 1.00    |
| Soil perceived moderately fertile*/ <sup>b</sup> | 0.25    | 0.44               | 0.00    | 1.00    |
| Soil perceived very fertile*/ <sup>b</sup>       | 0.59    | 0.49               | 0.00    | 1.00    |
| Marital status (1 = married)*                    | 0.89    | 0.32               | 0.00    | 1.00    |
| Southern Ghana                                   |         |                    |         |         |
| Forest zone*                                     | 0.47    | 0.50               | 0.00    | 1.00    |
| Transitional zone*                               | 0.24    | 0.42               | 0.00    | 1.00    |
| Coastal Savannah zone*                           | 0.08    | 0.27               | 0.00    | 1.00    |
| Northern Savannah zone*                          | 0.21    | 0.41               | 0.00    | 1.00    |

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

CV coefficient of variation, *kg/ha* kilogram per hectare, *mm* millimeters, *FBO* farmer-based organization, *km* kilometer, *GHc/kg* Ghana cedi per kilogram

\* Binary variables

<sup>a</sup> Reference group is no formal education

<sup>b</sup> Reference group is soil perceived to be not fertile;

<sup>c</sup> HCI is defined as the households' crop commercialization index computed as ratio of value of total crop sales divided by the value of crop production



### Profitability and riskiness of fertilizer use

Farmers are faced with the challenge of risks, among them are crop yield and price of inputs and outputs risks induced by rainfall and soil variability, as well as market volatility (Hardaker et al. 2004; Pannell et al. 2000; Kingwell 2011). Farmers choose from a range of N rates and timing of application according to their attitude to risk and their expected net returns in each season type. Monjardino et al. (2013) quantified the variability in net revenue from sale of crop produced, less the fixed and variable costs, including the rate of N applied at sowing and in-season, to assess the effects of rainfall and soil variability on economic net returns from dryland agriculture. This study used a combination of crop simulation, probability theory, profit function and finance techniques, which was not possible for the present study given our available data.

Instead, we assessed the profitability of fertilizer in two ways using the estimates from the yield response model in section 2.3 above, (1) via the estimation of value cost ratios (VCR), 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 the farmers to maximize profit given price levels and maize yield-fertilizer response rates, similar to the approach by Sheahan et al. (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:

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

where  $P_F$  is the fertilizer price and  $P_Y$  is the price of maize and MPP is the marginal physical product of fertilizer obtained from eq. 2. This can be interpreted as the ratio of the value of the increased output to cost of fertilizer. We computed two VCRs using market and subsidized fertilizer prices reported by the sample farmers. We used both the selling price of maize (the usual metric for calculating the marginal and average value product of output, see Sheahan et al. 2013) as reported by the sample farmers, and the buying price of maize using district-averaged purchasing price, which is a better measure of the opportunity cost of growing maize 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 equal to 1 or greater. Nevertheless, this assumption is not realistic in a

country like Ghana where most of farmers are thought to be risk averse due to the risks associated with rainfed agricultural system. We adopted VCR equal to or greater than 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 also compared the results and implications using a more restrictive criterion, VCR equal to or greater than 2, as recommended by Crawford and Kelly (2002).

### Decision analysis relative to adoption of crop varieties and fertilization patterns

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 ( $T$ ). However, farmers are more likely to make input use decisions jointly, so we used 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, modern variety and certified seed are correlated so a multivariate probit model would be appropriate for jointly predicting these choices. The estimated multivariate probit models are defined as follows:

$$T_1 = 1 \text{ if } T_1^* > 0 \text{ and } 0 \text{ otherwise} \tag{4}$$

$$T_2 = 1 \text{ if } T_2^* > 0 \text{ and } 0 \text{ otherwise} \tag{5}$$

$$T_3 = 1 \text{ if } T_3^* > 0 \text{ and } 0 \text{ otherwise} \tag{6}$$

$$\text{with } \begin{matrix} T_1^* = X_1\beta_1 + \varepsilon_1 \\ T_2^* = X_2\beta_2 + \varepsilon_2 \\ T_3^* = X_3\beta_3 + \varepsilon_3 \end{matrix} \text{ and } \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \end{bmatrix} | X \sim N \left( \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & \rho_{12} & \rho_{13} \\ & 1 & \rho_{23} \\ & & 1 \end{bmatrix} \right)$$

where  $T_1$  is fertilizer use,  $T_2$  denotes modern seed variety and  $T_3$  is the use of newly purchased certified seed and the betas ( $\beta$ 's) are to be estimated via estimating the trivariate probit model.  $X$  is a vector of variables that are hypothesized to influence the farmer’s decision to use technology ( $T$ ). In  $X$ , we include a set of variables to capture the personal attributes of the farmer (sex, age, level of education and marital status); farming systems and resource characteristics (size of plot cultivated, crop management practices, household/farmer endowments and household size); institutional and infrastructural factors (market access variables, access to extension advice, membership in farmer-based organizations or cooperatives and market prices of the technology); and lastly the environmental factors which in our case included the regional dummy variable.

In order to jointly analyse the factors associated with fertilizer use and intensity or application rate, we fitted the Cragg’s double-hurdle model to gain efficiency due to the corner solution associated with fertilizer use intensity (Burke 2012;

Burke 2009). We assume that the farmer's decision to use fertilizer or not use fertilizer comes first, followed by the decision on how much to use. The structure of the double-hurdle model used in this paper is as follows:

$$\text{Fert}U_i^* = \delta X_i' + \varepsilon_i' \quad \varepsilon_i' \sim N(0, \sigma^2) \quad (7)$$

where  $\text{Fert}U_i = 1$  if  $\text{Fert}U_i^* > 0$ , otherwise  $\text{Fert}U_i = 0$ , and

$$\text{Fert}Q_i^* = \vartheta X_i' + \mu_i' \quad \mu_i' \sim N(0, \sigma^2) \quad (8)$$

where  $\text{Fert}Q_i = \text{Fert}Q_i^*$  if  $\text{Fert}Q_i^* > 0$  and  $\text{Fert}U_i = 1$ , otherwise  $\text{Fert}Q_i = 0$ ,

The subscript  $i$  refers to the  $i$ th farmer,  $\text{Fert}U_i$  is the observable discrete decision to use fertilizer or not, while  $\text{Fert}U_i^*$  is the latent (unobservable) variable of  $\text{Fert}U_i$ .  $\text{Fert}Q_i^*$  is an unobserved, latent variable for fertilizer quantity used while  $\text{Fert}Q_i$  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  $\vartheta$  and  $\delta$  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 ( $\varepsilon_i'$ ) and fertilizer intensity ( $\mu_i'$ ) equations.

### Econometric considerations

The estimation of eq. 2 is faced with a number of problems, which many studies in the literature choose to ignore but could lead to yield response estimates that are biased. 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 hence endogenous.<sup>8</sup> Ignoring this will result in our estimates being biased because of the simultaneity bias and omitted variable problem. To deal with this issue we estimated our model using Instrumental Variable (IV) regression. 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 exogenous or endogenous. We were able to reject the null

<sup>8</sup> Burke (2012) calls this structural endogeneity because the yield function is part of the structural model from which input demand is derived.

hypotheses that they are exogenous ( $p$ -values were less than 0.01). This means that the endogeneity among these regressors would have deleterious effects on ordinary least square 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 fertilizer and average price paid for certified seed at village level), and incentive to adopt (degree of commercialization measured in terms of the past year's percentage of maize harvest sold). Distance to input sources and markets directly affect fertilizer and improved seed use but 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 but not directly productivity. Prices of seed and fertilizer affect fertilizer and improved seed use directly but productivity not directly. Lastly, 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. 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 perform 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-statistics = 11.12) confirm that the instruments used are strongly correlated with the endogenous variables instrumented. We also tested the validity of these instruments using a simple falsification test following Di Falco et al. (2011) and Shiferaw et al. (2014). The instruments considered were jointly statistically significant in the fertilizer and improved seed models but not in the productivity models, suggesting that the instruments are valid.

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 modelled both input choice models and yield model with a multi-stage and multi-equation conditional mixed process (cmp) 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 land quality variables and even farmers' ability and skills. For example, Marenya and Barrett (2009a) and Matsumoto and Yamano (2010) showed 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 were not able to

adequately deal with the unobserved heterogeneity problem because we only possessed 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.

## Results

### Yield response

The yield response model results are presented in Table 2.

**Nitrogen** Nitrogen is significant in explaining differences in yield across maize plots. One kilogram of additional fertilizer resulted in 22–26 kg of additional yield per hectare on average. This is consistent with earlier estimates in Ghana and in other countries in sub-Saharan Africa in the 1990s (Yanggen et al. 1998). For example, Heisey and Mwangi (1996) reported maize response to nitrogen for Ghana to be between 0 and 35 kg for every additional kilogram of nitrogen nutrients, bearing in mind the diminishing returns with excessive application. However, the figure for Ghana is higher than recent estimates compiled by Jayne and Rashid (2013), which ranged from 8 kg/ha in Malawi to 23 kg/ha additional yield per kilogram of Nitrogen in Uganda. This may be due to a more recent reintroduction of fertilizer and a more recent jump in fertilizer adoption and application rates in Ghana as compared to the other countries surveyed by Jayne and Rashid (2013). Before the recent surveys conducted (see Ragasa et al. 2013a), Ghana was cited as a country that was among the lowest in fertilizer application in SSA (FAO, 2005); therefore declining maize-fertilizer response rates may not have been serious in Ghana as compared to other countries.

The yield response rate to fertilizer application peaks at 251 kg/ha of nitrogen after which it starts to decline for every additional kilogram of nitrogen (Fig. 3). The current recommendation of MoFA/CSIR (90 kg/ha of N) is about third of this threshold suggesting that there is still ample room for yield increases in response to increased N.

**Modern seed varieties** The use of modern varieties also explains differences in yield. Plots planted with seeds of a modern seed variety have more than half a ton per hectare extra yield (572 kg) than those planted with traditional varieties (Model A). However, we obtained counterintuitive negative result when modern varieties and nitrogen use were interacted (Model B).

**Certified seed** Both the coefficients on new purchased certified seed of modern varieties and other recycled uncertified seed of modern varieties were positive and statistically significant and therefore their yields were higher than seed of traditional varieties (Model C). This is consistent with results of Models A and B that modern varieties (certified and uncertified seed) have higher yield than traditional varieties. The yield response difference between newly-purchased certified seed and uncertified seed (both of modern variety) is very small (2.4 kg per hectare), suggesting that there is no yield difference between certified and uncertified seed of modern varieties. This may be a reflection on the quality of certified seed available at retail shops and other sources and the credibility of the certification system.

Similar to results in Model B, the interaction between uncertified seed of modern varieties and quantity of nitrogen used is negative and statistically significant, suggesting that the yield response rate to fertilizer decreases faster with uncertified seeds of modern varieties compared with traditional varieties and with certified seeds. The yield response rates to fertilizer are the same with certified seeds and seeds of traditional varieties for any level of fertilizer application. These results are similar to the results in Models A and B that on average, significantly higher yields are obtained with higher levels of nitrogen (until the peak), combined with a modern variety. As more nitrogen is applied, the yield advantage of uncertified seed of a modern variety over traditional a variety diminishes, but the yield advantage of certified seeds over seeds of traditional varieties stays the same for any level of fertilizer application.

**Row planting** A priori one would expect that the use of row planting will have a positive impact on maize yield but our results show that there is a significant yield differences between farmers planting in rows and those not and the coefficient on this variable is negative and statistically significant. Thus, farmers whose plots were row planted get 178 kg per hectare less than those who do not. At first this is surprising because planting in rows is a cheap technology that, if combined with other crop management practices, may have a positive effect on yield as articulated by the CSIR and the MoFA. However, according to key informants, row planting alone does not guarantee higher yields, but what matters is the correct plant density and spacing and number of seeds per hill depending on the results of germination tests (personal communication, Dr. Robert Tripp).

**Hired labor** The coefficient on the total family labor household per hectare is positive and statistically significant, but not hired labor. A search of literature in Ghana on why we find such a result yielded only one study by Akramov and Malek (2012), which showed a positive correlation between productivity and use of family labor; thus they found that more profit-

efficient farmers had higher yields for maize, rice and soybean and they used more family labor than hired labor. Also, Chapoto et al. (2013) in a qualitative study of farm commercialization in Ghana found that medium and large-scale farmers, because of their market-oriented production system, relied heavily on hired labor but preferred to directly supervise or had their family members comingled with the hired labor to supervise farming activities considered to be critical for achieving high production levels, such as planting and fertilizer application. So our results seem to suggest that there may be very high monitoring costs of hired labor but as farm size increases the principal-agent problem cannot be avoided as the farmers have to rely more on hired labor.

**Herbicide use** The only other inputs that were significant and exhibiting expected sign were the use of green or animal manure and herbicide use. Farmers using herbicides for weed control before or after planting obtained on average 178 kg (range 155 kg to 198 kg) more maize per hectare compared to those farmers using other methods including manual weeding (Table 2, Model A). These results are consistent with the descriptive findings where we find a significantly higher average yield of plots where herbicide was used compared to those without herbicide use. The results support CSIR and MoFA's efforts to persuade farmers to use herbicides before planting.<sup>9</sup>

**Animal manure** Plots, where animal manure was supplied, had 387–417 kg more output per hectare compared to those without manure. Despite a seemingly impressive positive impact of manure on yield, *ceteris paribus*, it is important to note that there is very limited adoption of this practice in Ghana. Despite the continued promotion of manure use by CSIR and MoFA, animal manure was applied to only 3% of the maize area in our sample. Even though farmers indicated their willingness to use animal manure, sufficient supply would never be available to meet the demand, hence the focus on inorganic fertilizers (Ragasa et al. 2013a).

**Spatial differences** After controlling for all the factors that are hypothesized to influence maize yield response, we found that there was spatial variation between the Northern Savannah zone and southern zones in productivity of maize. Plots in the north have 874- to 977-kg per hectare lower yield than those in the south. This may be due to differences in soil fertility and rainfall patterns between north and south Ghana (FAO, 2005; Kombiok et al. 2012), with poor soils and erratic rainfall patterns in the north, hence the lower yields. By looking at the interaction term, the yield response rate to

intensity of fertilizer use does not seem to be different between plots in the north and in the south. This means that whether the plot is in the north or south, the yield response rate to 1-kg of additional nitrogen is 22 kg per hectare.

### Profitability and optimal levels of fertilizer use

The coefficients in the above yield response models were used to estimate the profitability of fertilizer use through value cost ratios (VCR) calculated as VMPP multiplied by the ratio of maize price per kg and fertilizer price per kg. The economically "optimal" fertilizer use is given by the value of marginal physical product (VMPP) being equal to fertilizer price ( $P_f$ ), similar to Sheahan et al. (2013).

Table 3 suggests that on average at the current yield response rates, it is profitable to use fertilizer on maize across the sample with or without subsidy under the rule of  $VCR > 1.5$  (adopted from Jayne and Rashid 2013). Even if we assume  $VCR > 2$  (which is necessary in very high risk environments; and a suggested benchmark by Crawford and Kelly 2002, and also used by Sheahan et al. 2013), the results suggest that fertilizer use is still highly profitable for both North and South. VCRs computed for Ghana are much higher than those estimated in other countries (ranging from 0.3–1.2 in Zambia to 3.7 in eastern lowland in Kenya) (Jayne and Rashid 2013). This is partly due to higher maize-fertilizer response rates in Ghana, and may also indicate a relatively less serious nutrient mining and slower rate decline in maize-yield response rates over time in Ghana compared to other African countries. More importantly, the higher VCR in Ghana is largely due to the lower relative price of nitrogen to price of maize grain compared to other SSA countries even at unsubsidized prices of fertilizer (Table 4).

Despite this profitability, only 45% of farmers used fertilizer on their maize plots during major season of 2012, five years after the reintroduction of fertilizer subsidy. This figure is more than twice the finding of Morris et al. (1998) (21%) and much higher than the finding of Quinones and Diao (2011) (25%) using the Ghana Living Standards Survey 5 (GLSS5) implemented in 2005 and 2006. This suggests that the fertilizer subsidy program may have encouraged more farmers to use fertilizer in their maize plots. However, application rate or intensity of use was at 44 kg/ha of N and 24 kg/ha of P, which are about half of the MoFA and CSIR recommendation of 90 kg/ha of N and 38 kg/ha of P (for continuously cropped plots, most common in the sample). Even after providing the about 40–50% fertilizer subsidy, the fertilizer application rates are still much lower than those recommended. Even in the Northern Savannah zone, which is reported to have less fertile soils than the southern zones (FAO 2005; Kombiok et al. 2012), the application rate was at 56 kg/ha of N and 29 kg/ha of P, still much lower than the recommendation.

<sup>9</sup> The general rule is to have maize plots free from weeds especially during the first 30 days of planting. CSIR and MoFA recommend the use of herbicide before planting and after planting. Glyphosate (e.g., Roundup or Roundup turbo) is a systemic herbicide and is recommended for treatment of actively growing weeds two weeks before planting (Ragasa et al. 2013a).



**Table 2** Maize production function regression estimates

|   | Yield (Kg/ha)           |                         |                         |                         |
|---|-------------------------|-------------------------|-------------------------|-------------------------|
|   | Model A                 | Model B                 | Model C                 | Model D                 |
| Nitrogen(Kg/ha)   | 22.066***<br>(3.637)    | 26.510***<br>(4.721)    | 22.175***<br>(3.635)    | 26.062***<br>(4.799)    |
| Nitrogen squared  | -0.044***<br>(0.012)    | -0.042***<br>(0.013)    | -0.045***<br>(0.012)    | -0.040**<br>(0.013)     |
| <i>Seed type (reference: traditional variety)</i>         |                         |                         |                         |                         |
| Modern variety (=1)                                       | 572.946***<br>(147.667) | 570.400***<br>(154.869) | -                       | -                       |
| Newly-purchased certified seed of modern variety (=1)     | -                       | -                       | 573.690**<br>(175.991)  | 528.294**<br>(184.323)  |
| Recycled or uncertified seed of modern variety (=1)       | -                       | -                       | 571.336***<br>(149.070) | 588.169***<br>(156.094) |
| <i>Interaction terms</i>                                  |                         |                         |                         |                         |
| Nitrogen*Modern variety                                   | -                       | -4.977*<br>(2.880)      | -                       | -                       |
| Nitrogen*Newly-purchased certified seed of modern variety | -                       | -                       | -                       | -2.840<br>(3.834)       |
| Nitrogen*Recycled or uncertified seed of modern variety   | -                       | -                       | -                       | -5.642*<br>(2.948)      |
| Nitrogen*North  | -                       | 1.345<br>(2.647)        | -                       | 1.933<br>(2.669)        |
| <i>Soil type (reference: fertile organic soils)</i>       |                         |                         |                         |                         |
| Acrisols  | 258.377<br>(356.364)    | 241.163<br>(358.751)    | -64.415<br>(327.889)    | -23.993<br>(335.816)    |
| Clay soils  | -80.671<br>(117.545)    | -96.426<br>(117.636)    | -102.125<br>(110.265)   | -109.458<br>(111.980)   |
| Sandy soils   | 61.263<br>(80.585)      | 68.135<br>(80.697)      | 94.090<br>(75.751)      | 97.831<br>(76.488)      |
| Plot size (ha)  | -29.194<br>(24.357)     | -29.871<br>(24.356)     | -32.932<br>(24.329)     | -32.638<br>(24.313)     |
| Seed used per ha (kg/ha)                                  | 4.719<br>(3.297)        | 4.062<br>(3.321)        | 3.206<br>(3.126)        | 2.682<br>(3.178)        |
| Stress periods (<20 mm decads)                            | -23.548<br>(30.677)     | -24.835<br>(30.780)     | -41.370<br>(29.068)     | -41.840<br>(29.500)     |
| Applied manure (=1)                                       | 417.448**<br>(190.275)  | 397.670**<br>(190.018)  | 401.051**<br>(190.344)  | 386.708**<br>(189.825)  |
| <i>Crop management practices</i>                          |                         |                         |                         |                         |
| Crop intercropped (=1)                                    | -165.739**<br>(77.437)  | -162.184**<br>(77.896)  | -170.036**<br>(77.247)  | -164.479**<br>(77.522)  |
| Applied herbicide (=1)                                    | 178.245**<br>(90.446)   | 155.590*<br>(91.255)    | 193.865**<br>(90.918)   | 165.801*<br>(91.852)    |
| Plowed (=1)   | 97.690<br>(141.366)     | 62.367<br>(141.690)     | 102.889<br>(140.759)    | 75.980<br>(141.452)     |
| Plot tilled by hoe (=1)                                   | 177.606<br>(153.320)    | 165.215<br>(156.451)    | 204.376<br>(155.000)    | 173.081<br>(158.784)    |
| Plot burn before planting (=1)                            | -112.663<br>(91.540)    | -112.778<br>(91.254)    | -116.495<br>(91.716)    | -111.959<br>(91.410)    |
| Row planted (=1)  | -176.284**<br>(86.838)  | -179.054**<br>(86.878)  | -172.577**<br>(86.665)  | -172.862**<br>(86.458)  |

Table 2 (continued)

|   | Yield (Kg/ha)            |                          |                          |                          |
|---|--------------------------|--------------------------|--------------------------|--------------------------|
|   | Model A                  | Model B                  | Model C                  | Model D                  |
| Continuously cultivated in last 11 years (=1)       | -93.223<br>(78.120)      | -89.190<br>(77.983)      | -105.804<br>(78.461)     | -100.431<br>(78.297)     |
| <i>Access to information</i>                        |                          |                          |                          |                          |
| Member of FBO or Coop (=1)                          | 77.268<br>(79.151)       | 83.629<br>(78.985)       | 67.013<br>(79.244)       | 73.211<br>(79.058)       |
| Received extension advice (=1)                      | 99.450<br>(83.302)       | 107.368<br>(83.246)      | 103.388<br>(83.697)      | 105.382<br>(83.777)      |
| <i>Farmer characteristics and household factors</i> |                          |                          |                          |                          |
| Primary (=1) /1                                     | -15.930<br>(105.401)     | -15.464<br>(105.783)     | -19.629<br>(105.502)     | -23.336<br>(105.793)     |
| Secondary or above (=1)                             | -23.652<br>(88.664)      | -16.308<br>(88.526)      | -32.134<br>(89.372)      | -25.846<br>(89.243)      |
| Female (=1)   | 33.977<br>(88.418)       | 27.427<br>(88.261)       | 30.093<br>(88.445)       | 22.122<br>(88.145)       |
| Age   | 2.771<br>(3.030)         | 3.012<br>(3.026)         | 2.215<br>(3.013)         | 2.511<br>(3.006)         |
| Family/communal labor (person-days per ha)          | 1.190*<br>(0.658)        | 1.115*<br>(0.659)        | 1.347**<br>(0.661)       | 1.280*<br>(0.665)        |
| Hired labor (person-days per ha)                    | -0.395<br>(0.816)        | -0.334<br>(0.816)        | -0.405<br>(0.816)        | -0.298<br>(0.815)        |
| Northern Ghana (=1)                                 | -873.701***<br>(164.217) | -937.858***<br>(196.947) | -901.655***<br>(164.393) | -977.011***<br>(196.876) |
| Constant  | 552.957*<br>(294.693)    | 566.543*<br>(298.527)    | 671.995**<br>(282.128)   | 676.181**<br>(285.541)   |
| Observations  | 614                      | 614                      | 614                      | 614                      |
| Log lik.  | -6726.412                | -6724.868                | -6734.408                | -6732.286                |
| Chi-squared   | 607.206                  | 610.294                  | 591.213                  | 595.458                  |

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

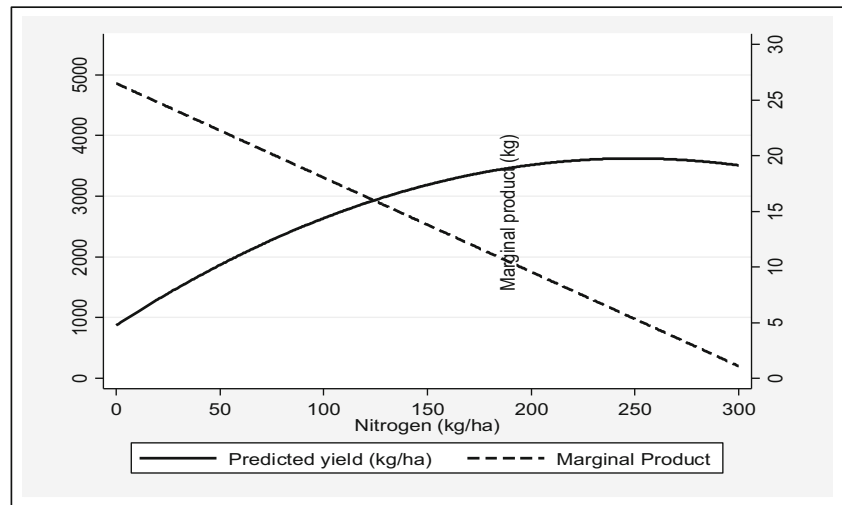
Standard errors in parentheses, \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ . /1 reference group is no education. *ha* hectare, *kg* kilogram

We calculated for the economically “optimal” fertilizer use (i.e., where the value of marginal physical product (VMPP) is equal to fertilizer price ( $P_f$ )), similar to the method used by Sheahan et al. (2013). Optimal N computed was 190 kg/ha using market prices and 256 kg/ha using subsidized prices in the North and 130 kg/ha using market prices and 190 kg/ha using subsidized prices in the South. These economically “optimal” N values calculated for Ghana are much higher than those calculated by Sheahan et al. (2013) for Kenya, which was roughly an average of 40.6 kg/ha assuming MVCR = 1 for risk neutral farmers and 10.2 kg/ha for risk-averse farmers. It is also higher than other estimates largely due to the lower relative price of fertilizer to price of maize in Ghana compared to other countries even at unsubsidized prices (Table 4).

Results for Ghana show that the actual application rates (44 kg/ha of N) is far off from the “optimal” N (Fig. 4). In the north, the optimal level is about 256 kg/ha of N with

subsidized price of fertilizer, compared to 56 kg/ha of N average actual application rate, implying a shortage of 200 kg/ha of N to maximize profits (Fig. 5). In the south, the optimal level is about 190 kg/ha of N with subsidized price of fertilizer, compared to 40 kg/ha of N average actual application rate, implying a shortage of 150 kg/ha of N to maximize profits (Fig. 6). These results suggest the scope to increase fertilizer application rates in both south and north, given the yield response and profitability. Even though 87% of farmers in the north are applying fertilizer and the application rate is much higher in the north than in the south, farmers in the north are also much farther off the optimal level and therefore much greater efforts are needed to intensify fertilizer application in the north. Results also suggest that fertilizer prices seem to be not the binding constraint in greater fertilizer application and productivity increases in maize. Other factors appear to be major bottlenecks to greater fertilizer application and

**Fig. 3** Maize yield response to nitrogen application and marginal physical product. Source: CRI/SARI/IFPRI survey (November 2012–February 2013)



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

productivity increases and these are explored in the subsequent sections where determinants of fertilizer and modern variety adoption are modeled.

**Factors affecting adoption of crop varieties and fertilizer application patterns**

Despite higher productivity and profitability of fertilizer and modern variety adoption, actual application rates are only 18% of the estimated economically “optimal” application rates and only 61% of farmers plant modern varieties (and

only 2% of farmers plant hybrid seed varieties). The analysis of the factors associated with the adoption of fertilizer and modern varieties based on the joint estimation models of modern varieties, certified seed, and fertilizer as well as the use and intensity of fertilizer are presented in Tables 5 and 6.

*Modern crop varieties*

Factors affecting the adoption of modern varieties are accessibility of modern seed, degree of commercialization, seed price, labor availability and access to extension services, after

**Table 3** Value cost ratios using subsidized and market fertilizer prices

| Scenario <sup>a</sup>                     | Marginal physical product <sup>b</sup> | At subsidized fertilizer prices: value cost ratio <sup>c</sup> | At market fertilizer prices: value cost ratio <sup>c</sup> |
|---|--|--|--|
|   | (A)                                    | (B)  | (C)  |
| 1 Whole sample                            | 24.78                                  | 4.92   | 3.64   |
| 2 Nitrogen in Northern Savannah (North)   | 17.78                                  | 3.53   | 2.61   |
| 3 Nitrogen in Southern Ghana (South)      | 20.87                                  | 4.14   | 3.07   |
| 4 Nitrogen & modern variety in North      | 18.78                                  | 3.73   | 2.76   |
| 5 Nitrogen & traditional variety in North | 23.76                                  | 4.72   | 3.49   |
| 6 Nitrogen & modern variety in South      | 20.39                                  | 4.05   | 3.00   |
| 7 Nitrogen & traditional variety in South | 20.39                                  | 5.04   | 3.73   |

Authors’ calculations based on CRI/SARI/IFPRI survey (November 2012–February 2013)

<sup>a</sup> These different scenarios are for the full sample or subsets of the sample, showing the heterogeneity of marginal products and value cost ratios

<sup>b</sup> This is the change in maize productivity (in kg/ha) per additional 1 kg per ha of Nitrogen (this is the average of the coefficient of Nitrogen in Table 2)

<sup>c</sup> These are ratios, computed using the formula in eq. 3 (section 2.4). The assumptions in terms of prices used to compute these VCRs are as follows:

i) The output prices used are based on the averages from the survey data (CRI/SARI/IFPRI 2012–2013): Average market price for 100-kg bag of maize harvest (shelled) = 81.63 GHc

ii) Subsidized NPK 15:15:15 price =39 GHc; subsidized sulphate of ammonia price =35GHc; average market NPK 15:15:15 price =76 GHc, and average market sulphate of ammonia price =70 GHc

iii) Price of 1 kg of Nitrogen: using the MoFA fertilizer recommendation rate of 2 NPK 15:15:15 and 2 sulphate of ammonium per acre, thus 1:1 ratio and the fact that with NPK15:15:15 contains 15% N and sulphate of ammonium having 21% N, the price of 1 kg of nitrogen is given by-  $100/36 \times (\text{NPK } 15:15:15 \text{ price per kg} + \text{sulphate of ammonium price per kg})$

**Table 4** Review of literature on yield response rate to fertilizer, value cost ratio, and optimal fertilize rates

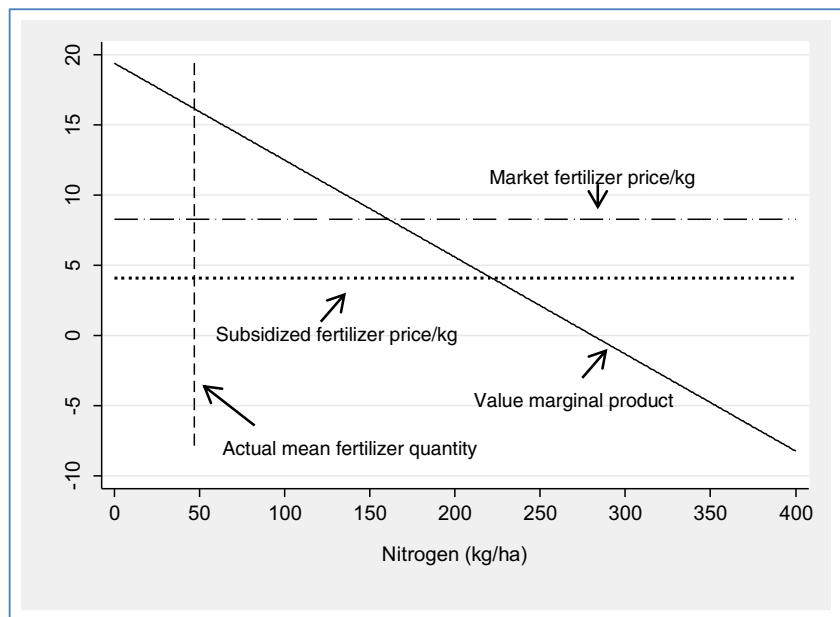
| Author(s)                   | Country                                    | Observed rates   | Response rate (marginal product)           | N-maize price ratio                     | VCR  | Economically “optimal” N rates   |
|-----------------------------|--|--|--|---|--|--|
| This paper                  | Ghana                                      | 44 kg of N   | 18–25 kg/ha                                | 9.5 (market price);<br>5.3 (subsidized) | 2.6–5.0  | 225 kg of N (at subsidized prices) -<br>190 kg/ha (at market prices) and<br>256 kg/ha (at subsidized prices) in<br>the North; 130 kg/ha (market<br>prices) and 190 kg/ha (subsidized<br>prices) in the South |
| Jayne and Rashid (2013)     | review of various<br>SSA countries         | 2.4 kg of N (Uganda)<br>to 95 (Western and<br>Central Kenya) | 8–26 kg/ha                                 |   | from 0.6–1.6 (Malawi)<br>and 0.3–1.2 (Zambia)<br>to 3.7 (eastern lowlands<br>in Kenya) |  |
| Matsumoto and Yamano (2011) | Kenya                                      |  | 21–25 kg/ha                                | 16.0                                    | 1.05–1.24  | with HYV seeds, optimal or<br>under-application based on survey<br>year; with local/recycled seeds,<br>optimal to slightly over-application<br>of the nitrogen   |
| Sheahan (2011)              | Uganda                                     |  | 11–20 kg/ha                                | 37.5                                    | 0.75–1.05  | Relative price is too high for fertilizer<br>use to be profitable  |
| Cuvaca et al. (2015)        | Kenya, various<br>regions                  | 16–67 kg of N  | 16–21 kg/ha (ranges<br>from 5 to 48 kg/ha) | 8–15 (various price<br>scenarios)       | 1.3–2.35 (aggregate);<br>3.6–6.3 (Eastern<br>lowlands)                                 | 70 kg of N aggregate (range of 0–105<br>kg of N across locations)  |
| Sime and Aune (2014)        | Lesotho                                    |  | 50 kg/ha                                   |   | 1.4–9.8  | 73–150 kg of N   |
| Chapoto et al. (2015)       | Ethiopia (Central<br>Rift Valley)          |  | 9 kg/ha                                    |   |  | 110 kg of N  |
| Koussoubé and Nauges (2015) | Ghana (Northern<br>region)<br>Burkina Faso |  | 19 kg/ha (ranges<br>from 8 to 28 kg/ha)    | 12.77                                   | 1.4 (0.57–1.99)  | 65–119 kg of N   |

Compiled from various sources

N nitrogen, VCR value cost ratio, kg kilogram, ha hectare, SSA sub-Saharan Africa



**Fig. 4** Full sample: Relationship of value of marginal product and fertilizer prices. Source: CRI/SARI/IFPRI survey (November 2012–February 2013)



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

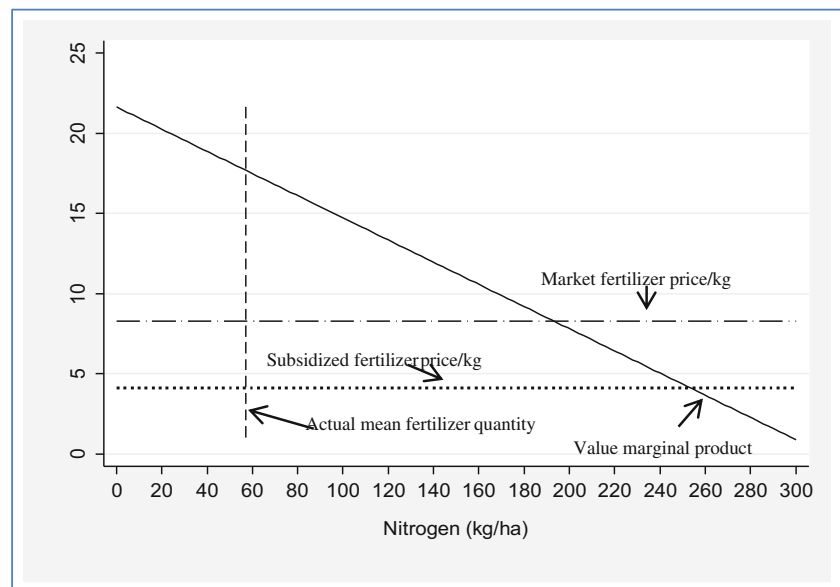
controlling for location and soil types (Table 5). Where these factors are favourable and farmers are located close to agroinput shops and markets, they are more likely to adopt modern varieties.

*Fertilizer use and intensity*

Factors affecting fertilizer use are degree of commercialization, certified seed price, complementary land preparation practices (particularly row planting and plowing), hired labor,

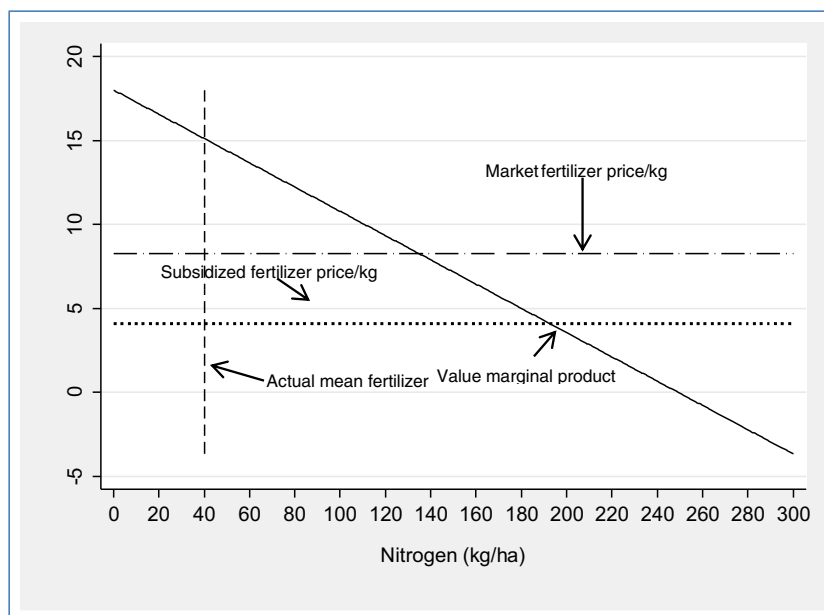
geographical location, and age (Table 6). Farmers who expect to sell more of their harvest are more likely to apply fertilizer. Greater use of fertilizers by farmers and villages is encouraged by lower price of certified seed, a complementary input to fertilizer. Farmers who plow and plant in rows are more likely to use fertilizer than those who do not as are those with a greater proportion of hired labor to total labor. In the north, farmers are more likely to apply fertilizer than regions in the south. And younger farmers are more likely to apply fertilizer than older farmers.

**Fig. 5** Northern Savannah zone: Relationship of value of marginal product and fertilizer prices. Source: CRI/SARI/IFPRI survey (November 2012–February 2013)



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

**Fig. 6** Southern Ghana:  
Relationship of value of marginal  
product and fertilizer prices.  
Source: CRI/SARI/IFPRI survey  
(November 2012–February 2013)



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

The same factors affect fertilizer adoption and application rate, except age. While younger farmers are more likely to apply fertilizer, the amount of fertilizer applied by farmer-adopters does not vary by age.

## Discussion and policy implications

While we have showed above the results of the yield response models, profitability analysis, and adoption models, we further discuss in this section the main findings, especially the surprising ones.

First, results in this paper show that there is statistically significant maize yield response to chemical fertilizer application (i.e., 1-kg of Nitrogen leads to 22–26 kg increase in yield on average). This is close to what has been found in earlier studies in Ghana, but much higher than those estimated in other African countries which have recently experienced rapid increases in chemical fertilizer use through their fertilizer subsidy programs (Jayne and Rashid 2013). On the other hand, the maize-fertilizer response rate calculated in this paper is much higher than the estimates by Folberth et al. (2013) modeling for the whole of SSA, suggesting that at 50 kg/ha of N in Ghana and 18 kg/ha of P, with low-yielding varieties and no irrigation, yields will be 3.44 ton/ha. Ghana was already at 44 kg/ha of N, and 23 kg/ha of P in 2012 major season, close to the simulated amount by Folberth et al. (2013), but yields remained at 1.2 ton/season/ha. This indicates that maize-fertilizer response rates are influenced by several complexities and may not be as high as modeled by Folberth et al. (2013).

Unfortunately, our dataset can address only a few of the complexities and are not able to show effects and yield response of interactions of water and Nitrogen (N); weeds and N; soil health and N; N and P and other nutrients. We cannot assess the interaction among the nutrients N, P and K as the fertilizer available was a mixture of compounds containing these elements and came as a package, which could not be broken down into its components. We also tried the other interactions, such as with soil types and with herbicides, 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 obtain better information as to the correct combination of N, P and K and other nutrients in order to maximize yields.

Another very important factor is risk, which we attempted to incorporate into our analysis. Monjardino et al. (2015) highlighted the important role of risk-aversion when assessing N strategies for managing yield gaps and profit maximization. Their results show the value of applying a range of research tools, such as crop growth simulation models in combination with economic-risk measures and risk-aversion theory. In this paper, we included a standard measure of risk aversion in our questionnaire and dataset. The particular question was “Imagine that you could choose one of the following bags of maize seeds. Each bag contains maize seeds that will produce a different harvest of maize the following year depending on the weather. Which seed would you choose? (using visual aids) 1=Seeds which can produce a stable 10 bags per acre regardless of the weather; 2=Seeds which can produce 7 bags per acre with bad weather or 20 bags per acre with good weather; 3=Seeds which can produce 4 bags per acre with

**Table 5** Trivariate probit model for adoption of modern variety, certified new seed and fertilizer

|  | Modern variety (=1)  |                    | New Purchased seed (=1) |                  | Fertilizer use (=1)  |                    |
|--|----------------------|--------------------|-------------------------|------------------|----------------------|--------------------|
|  | Coef.<br>(A)         | Dy/Dx<br>(B)       | Coef.<br>(C)            | Dy/Dx<br>(D)     | Coef.<br>(E)         | Dy/Dx<br>(F)       |
| <i>Market Access</i>                           |                      |                    |                         |                  |                      |                    |
| Distance to Agro-shop (km)                     | -0.043***<br>(-3.79) | -0.014***<br>-3.92 | 0.013<br>(0.82)         | 0.002<br>0.82    | -0.014<br>(-1.15)    | -0.003<br>-1.16    |
| Distance to plot (km)                          | 0.007**<br>(2.86)    | 0.002***<br>2.91   | 0.010**<br>(2.39)       | 0.001**<br>2.41  | 0.000<br>(0.08)      | 0.0001<br>0.08     |
| <i>Affordability</i>                           |                      |                    |                         |                  |                      |                    |
| Lagged HCI                                     | 0.006**<br>(2.21)    | 0.002**<br>2.23    | 0.005<br>(1.10)         | 0.001<br>1.1     | 0.006*<br>(1.88)     | 0.001*<br>1.89     |
| Certified seed price GHc/kg)                   | -0.069**<br>(-2.46)  | -0.022**<br>-2.5   | -0.099*<br>(-1.93)      | -0.014*<br>-1.96 | -0.134***<br>(-3.83) | -0.031***<br>-3.94 |
| Average Fertilizer price (GHc/kg)              | 0.429<br>(0.92)      | 0.14<br>0.92       | -0.574<br>(-0.94)       | -0.081<br>-0.93  | 0.641<br>(1.18)      | 0.149<br>1.18      |
| Plot size (ha)                                 | -0.043<br>(-1.03)    | -0.014<br>-1.03    | -0.147*<br>(-1.92)      | -0.021*<br>-1.92 | 0.006<br>(0.13)      | 0.001<br>0.13      |
| <i>Crop management practices</i>               |                      |                    |                         |                  |                      |                    |
| Applied herbicide (=1)                         | -0.035<br>(-0.23)    | -0.011<br>-0.23    | 0.818**<br>(2.82)       | 0.115***<br>2.8  | 0.125<br>(0.67)      | 0.029<br>0.68      |
| Applied manure (=1)                            | -0.090<br>(-0.30)    | -0.029<br>-0.3     | -0.027<br>(-0.05)       | -0.004<br>-0.05  | -0.169<br>(-0.35)    | -0.039<br>-0.35    |
| Crop intercropped (=1)                         | -0.404***<br>(-3.42) | -0.132***<br>-3.51 | -0.260<br>(-1.44)       | -0.037<br>-1.44  | -0.148<br>(-1.08)    | -0.034<br>-1.08    |
| Soil perceived moderately fertile <sup>a</sup> | 0.388**<br>(2.09)    | 0.126**<br>2.12    | 0.152<br>(0.54)         | 0.022<br>0.54    | -0.493**<br>(-2.15)  | -0.114**<br>-2.17  |
| Soil perceived very fertile <sup>a</sup>       | 0.101<br>(0.59)      | 0.033<br>0.59      | 0.121<br>(0.47)         | 0.017<br>0.47    | -1.062***<br>(-5.07) | -0.246***<br>-5.38 |
| Plowed (=1)                                    | -0.288<br>(-1.43)    | -0.094<br>-1.44    | -0.093<br>(-0.32)       | -0.013<br>-0.32  | 1.269***<br>(5.45)   | 0.294***<br>5.92   |
| Plot tilled by hoe (=1)                        | -0.630**<br>(-2.65)  | -0.205***<br>-2.7  | 0.045<br>(0.11)         | 0.006<br>0.11    | -0.377<br>(-1.30)    | -0.088<br>-1.31    |
| Plot burn before planting (=1)                 | 0.151<br>(1.01)      | 0.049<br>1.01      | -0.028<br>(-0.14)       | -0.004<br>-0.14  | 0.206<br>(1.15)      | 0.048<br>1.16      |
| Row planted (=1)                               | 0.328**<br>(2.72)    | 0.107***<br>2.76   | -0.025<br>(-0.14)       | -0.004<br>-0.14  | 0.855***<br>(6.03)   | 0.198***<br>6.57   |
| Continuously cultivated past 11 years (=1)     | 0.181<br>(1.45)      | 0.059<br>1.46      | 0.091<br>(0.53)         | 0.013<br>0.53    | -0.089<br>(-0.63)    | -0.021<br>-0.63    |
| <i>Access to information</i>                   |                      |                    |                         |                  |                      |                    |
| Member of FBO or Coop (=1)                     | 0.051<br>(0.39)      | 0.016<br>0.39      | 0.318*<br>(1.79)        | 0.045*<br>1.8    | 0.013<br>(0.09)      | 0.003<br>0.09      |
| Received extension advice (=1)                 | 0.236*<br>(1.73)     | 0.077*<br>1.74     | 0.469**<br>(2.69)       | 0.066***<br>2.7  | 0.119<br>(0.76)      | 0.028<br>0.76      |
| <i>Farmer and household factors</i>            |                      |                    |                         |                  |                      |                    |
| Primary (=1) <sup>b</sup>                      | -0.161<br>(-0.94)    | -0.053<br>-0.94    | -0.184<br>(-0.58)       | -0.026<br>-0.58  | -0.316<br>(-1.49)    | -0.073<br>-1.5     |
| Secondary or above (=1) <sup>b</sup>           | 0.099<br>(0.68)      | 0.032<br>0.68      | 0.563**<br>(2.43)       | 0.079**<br>2.44  | -0.140<br>(-0.81)    | -0.033<br>-0.81    |
| Female (=1)                                    | -0.203<br>(-1.42)    | -0.066<br>-1.43    | -0.197<br>(-0.82)       | -0.028<br>-0.82  | -0.045<br>(-0.27)    | -0.011<br>-0.27    |

**Table 5** (continued)

|  | Modern variety (=1) |                  | New Purchased seed (=1) |                 | Fertilizer use (=1) |                  |
|--|---------------------|------------------|-------------------------|-----------------|---------------------|------------------|
| Age  | -0.004<br>(-0.75)   | -0.001<br>-0.75  | 0.004<br>(0.57)         | 0.001<br>0.57   | -0.011*<br>(-1.88)  | -0.003*<br>-1.89 |
| Family/communal labor (person-days per ha) per ha) | -0.002<br>(-1.56)   | -0.001<br>-1.57  | 0.000<br>(0.35)         | 0<br>0.35       | -0.000<br>(-0.26)   | 0.00007<br>-0.26 |
| Hired labor (person-days per ha)                   | 0.005***<br>(3.76)  | 0.002***<br>3.87 | -0.001<br>(-0.47)       | 0<br>-0.47      | 0.003**<br>(2.61)   | 0.001***<br>2.64 |
| 6 year rainfall CV                                 | 0.008<br>(0.95)     | 0.003<br>0.95    | -0.014<br>(-1.07)       | -0.002<br>-1.07 | -0.008<br>(-0.84)   | -0.002<br>-0.84  |
| Northern Ghana (=1)                                | 0.864***<br>(3.89)  | 0.281***<br>4.02 | -0.043<br>(-0.12)       | -0.006<br>-0.12 | 1.521***<br>(4.74)  | 0.353***<br>4.98 |
| Constant   | -0.764<br>(-1.06)   |                  | -2.111**<br>(-2.13)     |                 | -0.344<br>(-0.40)   | 2.080*<br>(1.81) |
| Observations                                       | 625                 |                  |                         |                 |                     |                  |
| Log lik.   | -750.268            |                  |                         |                 |                     |                  |
| Chi-squared  | 505.906             |                  |                         |                 |                     |                  |

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

Z statistic in parentheses for the adoption models

HCI commercialization index, CV coefficient of variation, kg kilogram, ha hectare, km kilometer, FBO farmer-based organizations, Coop cooperative

\*\*\*  $p < 0.01$ \*\*  $p < 0.05$ , \*  $p < 0.1$ . (=1) dummy variables

<sup>a</sup>Reference group is soil perceived to be not fertile

<sup>b</sup>Reference group is no formal education

bad weather or 30 bags per acre with good weather; and 4=Seeds which can produce 0 bags per acre with bad weather or 40 bags per acre with good weather.” We included this variable in the yield response and adoption models (with different variants, such as using 4 scales, and using only 2 scales, summing 1 and 2 and then 3 and 4 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 their variability to account for rainfall and climate-related risks. We also addressed risks faced by the farmers in the calculation of value-cost ratios setting it at greater than 1.5 following Jayne and Rashid (2013) and greater than 2 following Crawford and Kelly (2002). These variables and strategies can be further complemented by more sophisticated profit-risk analyses and modeling as in Monjardino et al. (2015).

Second, results in this paper show that fertilizer use is profitable at both subsidized and market prices for different locations and farming practices. The computed value-cost ratios and economically “optimal” fertilizer rates are much higher in Ghana than those estimated in other countries (ranging from 0.3–1.2 in Zambia to 3.7 in eastern lowland in Kenya for VCR and ranging from 65 to 150 kg of economically “optimal” Nitrogen levels in various SSA countries). This is mainly due to lower relative price of fertilizer to price of maize in Ghana than in the other countries. Based on this analysis, the

conclusion is that more chemical fertilizer use in both North and South will be profitable, even at market prices. A corollary is that subsidy on fertilizer may not play an effective role in changing the economics of fertilizer use and that other factors may be more binding in constraining further fertilizer adoption.

The actual application rate for fertilizer adopters (at 44 kg/ha of nitrogen on average) is far off the economically “optimal” levels (at 225 kg/ha of nitrogen; where the fertilizer price intersects the value of marginal physical product derived from the yield response model). These results suggest the scope to increase fertilizer application rates in both south and north, given the yield response and profitability. Even though 87% of farmers in the north are applying fertilizer and the application rate is much higher in the north than in the south, farmers in the north are also much farther off the optimal level and therefore much greater efforts are needed to intensify fertilizer application in the north.

Third, results from the different analyses and models suggest that fertilizer prices do not seem to be the binding constraint in greater fertilizer application and productivity increases in maize; other factors appear to be major bottlenecks. Based on the adoption models, these factors include accessibility to modern varieties, mechanization, hired labor and degree of commercialization and market access; and these would need to be improved to help increase fertilizer intensity in both the northern and southern parts of Ghana. To encourage



**Table 6** Double hurdle model: Factors explaining fertilizer use and intensity

|   | Tier 1 (fertilizer use model) |          | Tier 2 (fertilizer intensity model) |             | Average Partial Effect |           |
|---|-------------------------------|----------|-------------------------------------|-------------|------------------------|-----------|
|   | (A)<br>Coef.                  | (B)<br>Z | (C)<br>Log Normal                   | (D)<br>S.E. | (E)<br>Coef.           | (F)<br>SE |
| <i>Market Access</i>                            |                               |          |                                     |             |                        |           |
| Distance to Agro-shop (km)                      | -0.014                        | -1.117   | -2.280*                             | -1.871      | -0.539**               | 0.245     |
| Distance to plot (km)                           | 0.000                         | 0.109    | -0.119                              | -0.467      | -0.019                 | 0.054     |
| <i>Affordability</i>                            |                               |          |                                     |             |                        |           |
| Lagged HCI                                      | 0.006*                        | 1.902    | 0.414                               | 1.502       | 0.130                  | 0.081     |
| Certified seed price (GHc/kg)                   | -0.136***                     | -3.940   | -2.263                              | -0.802      | -1.590***              | 0.191     |
| Average Fertilizer price (GHc/kg)               | 0.648                         | 1.189    | 88.280                              | 1.644       | 21.784                 | 24.500    |
| Plot size (ha)                                  | 0.007                         | 0.152    | -0.022                              | -0.005      | 0.057                  | 1.175     |
| <i>Crop management practices</i>                |                               |          |                                     |             |                        |           |
| Applied herbicide (=1)                          | 0.134                         | 0.724    | 6.518                               | 0.495       | 2.306                  | 3.097     |
| Applied manure (=1)                             | -0.158                        | -0.333   | -23.683                             | -1.044      | -5.087                 | 7.146     |
| Crop intercropped (=1)                          | -0.161                        | -1.173   | -35.795**                           | -2.445      | -7.469**               | 2.848     |
| Soil perceived moderately fertile <sup>/a</sup> | -0.479**                      | -2.086   | 25.346*                             | 1.763       | 0.533                  | 3.661     |
| Soil perceived very fertile <sup>/a</sup>       | -1.052***                     | -5.026   | -2.578                              | -0.183      | -10.321**              | 3.861     |
| Plowed (=1)                                     | 1.275***                      | 5.442    | 29.134                              | 1.610       | 19.555***              | 4.850     |
| Plot tilled by hoe (=1)                         | -0.348                        | -1.210   | 42.924*                             | 1.846       | 5.426                  | 4.972     |
| Plot burn before planting (=1)                  | 0.198                         | 1.106    | 25.832*                             | 1.898       | 6.204*                 | 3.137     |
| Row planted (=1)                                | 0.853***                      | 6.035    | 63.125***                           | 3.504       | 17.192***              | 4.032     |
| Continuously cultivated in last 11 years (=1)   | -0.096                        | -0.680   | -17.256                             | -1.253      | -4.100                 | 2.704     |
| <i>Access to information</i>                    |                               |          |                                     |             |                        |           |
| Member of FBO or Coop (=1)                      | 0.019                         | 0.122    | -19.086                             | -1.591      | 0.295                  | 2.655     |
| Received extension advice (=1)                  | 0.123                         | 0.780    | -9.606                              | -0.752      | -0.706                 | 2.741     |
| <i>Farmer and household factors</i>             |                               |          |                                     |             |                        |           |
| Primary (=1) <sup>/b</sup>                      | -0.330                        | -1.557   | -28.220                             | -1.491      | -7.161                 | 1.896     |
| Secondary or above (=1) <sup>/b</sup>           | -0.159                        | -0.919   | 12.505                              | 0.877       | 0.957                  | 3.035     |
| Female (=1)                                     | -0.056                        | -0.326   | 12.474                              | 0.890       | 1.863                  | 2.992     |
| Age   | -0.011*                       | -1.890   | -0.098                              | -0.186      | -0.112                 | 0.108     |
| Family/communal labor (person-days per ha)      | -0.000                        | -0.329   | 0.010                               | 0.092       | -0.002                 | 0.023     |
| Hired labor (person-days per ha)                | 0.004**                       | 2.648    | 0.394**                             | 3.282       | 0.103***               | 0.027     |
| 6 year rainfall CV                              | -0.009                        | -0.868   | 3.147**                             | 2.898       | 0.504                  | 0.310     |
| Northern Ghana (=1)                             | 1.482***                      | 4.631    | 73.133***                           | 3.573       | 35.246***              | 6.439     |
| Constant  | -0.327                        | -0.379   | -263.420**                          | -2.999      |                        |           |
| Sigma   | -                             | -        | 54.454***                           | 9.953       |                        |           |
| Observations                                    | 625                           |          | 625                                 |             |                        |           |
| Log likelihood                                  | -1642.67                      |          |                                     |             |                        |           |
| Chi-squared                                     | 188.78***                     |          |                                     |             |                        |           |

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

z statistics in column (B) for discrete change of dummy variable from 0 to 1

Standard errors (SE) in columns (D and F)

HCI commercialization index, CV coefficient of variation, kg kilogram, ha hectare, km kilometer, FBO farmer-based organizations, Coop cooperative

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ <sup>/a</sup> Reference group is soil perceived to be not fertile<sup>/b</sup> Reference group is no formal education

fertilizer use and greater intensity of use, complementary land preparation practices (particularly plowing) are important. This has implications for the need to ease the constraints in the development and promotion of mechanization in the country. Access to timely mechanization (power tillers or tractors) was heavily emphasized during the key informant interviews conducted in 2012 as an important constraint in adopting improved technologies and increasing yields. To encourage modern variety use, strategies are needed to improve accessibility of seeds of modern varieties and these should be supported by access to extension services which would provide information on the varieties and complementary good practices. Increased market access, commercialization and maize processing options would also be needed in order to prevent falling prices of maize grain and supply surpluses due to increases in production and productivity from fertilizer use.

Fourth, hired labor (as a proportion of total labor) is significant in explaining modern variety use and both fertilizer adoption and application rates. However, hired labor (in absolute numbers or as a proportion) is insignificant (and has a negative sign) in the yield response models. In contrast the use of family labor is positive and significant in the yield response models. Fertilizer application can be labor intensive and the use of modern varieties is positively linked to greater incentive to use more labor in farm care and in harvesting, given higher yields. Hired labor may be required for use of fertilizer and modern varieties to supplement family labor. However, the results also suggest the need for close monitoring of hired labor, making family labor more desirable. This suggests that availability of family labor may be a constraining factor in being able to monitor hired labor and manage the farm; at the same time availability of hired labor may be a constraining factor in greater intensity of fertilizer use and modern variety adoption. An implication is a greater focus of research should be made on labor-saving technologies to address possible shortage of labor and improve labor productivity. Actions could include addressing constraints to greater mechanization, the production of weed-tolerant and pest-resistant maize varieties, and promotion of herbicide use, accompanied by education on safe handling.

Fifth, while row planting encourages greater adoption and greater application rates of fertilizer, and therefore indirectly influencing yield, row planting had a negative sign in the yield response model, showing a negative direct effect on yield. It is not clear what the net effect is, but this mixed result points to the need for further research on and revisiting of this heavily-promoted agronomic practice. Possible explanations can be offered, based on key informants' interviews. According to these interviews, it is not the planting in line that is important but it is the density of planting, spacing and number of seeds per hole or hill being planted. Therefore, agricultural advice on these rather than focusing on row planting could be further

intensified. Moreover, according to the interviews it is the quality of the seed and its germination that is more important than the method of planting. This implies looking at the quality of the seeds available at retail shops and assessing the certification system to ensure that the nature of the seed planted contributes to increasing maize yields in Ghana.

Sixth, aside from fertilizer, other inputs also have significant effects on yield, namely modern varieties, herbicide, and animal manure. On average, significantly higher yields were obtained with greater application of fertilizer (until the peak of about 251 kg/ha of Nitrogen), and yields were even higher if combined with the use of modern varieties, herbicide, and animal manure. Plots planted with modern varieties have about 570-kg higher yield than those planted with traditional varieties. However, our results did not show significant differences among certified and non-certified or recycled seeds of the same variety, indicating questionable quality of certified seeds available in retail shops and other sources and credibility of the certification system. Plots with animal manure had about 400-kg higher yield and plots with herbicide had about 170-kg higher yield than plots without.

Seventh, our results are consistent with the findings of Vanlauwe et al. (2013) and Giller et al. (2009) on conservation agriculture (CA) literature. They argued that integrating fertilizer and herbicide use into the main principles of conservation agriculture would contribute to the success of its implementation as a way to enhance crop productivity and control soil degradation in SSA. Appropriate amounts and use of fertilizer and herbicide are required to supplement agronomic practices such as minimum tillage, soil surface cover, and diversified crop rotations.

## Conclusion

In this paper, we estimated profitability of fertilizer use with and without subsidy; and modelled farmers' adoption decisions on improved maize technologies, particularly fertilizer and seed technologies. This paper aims to contribute to the literature by using the Ghana maize sector case to (1) provide estimates of the profitability of fertilizer use across heterogeneous farming systems and locations, (2) provide an answer to the puzzle of why fertilizer technology adoption is low despite its high profitability on average, and (3) show the role of fertilizer subsidy in changing the economics of fertilizer use and influencing farmers' adoption decision. Our paper has five main concluding points. First, chemical fertilizer use is profitable in both North and South Ghana and with either traditional or modern varieties or either certified or non-certified seeds, even at market prices. There was less heterogeneity in profitability from fertilizer use than those shown by Suri (2007) and others in other contexts but consistently

high profitability of fertilizer use across different locations and farming practices in the case of the maize sector in Ghana. Second, subsidising fertilizer, however, may not be an effective strategy to promote further fertilizer use as use of fertilizer is profitable even without subsidy and factors other than price constrained its adoption.

Third, the puzzle of low adoption of fertilizer, despite its profitability, seems to be explained by restricted access to complementary inputs such as modern varieties, mechanization, and hired labor. Understanding and finding solutions for improving access to these complementary inputs could help to increase the use of fertilizer in Ghana.

Fourth, in addition to fertilizer, other factors contribute significantly to increasing productivity and should be part of the strategy to boost productivity and agricultural development in Ghana. Modern varieties can contribute to increasing maize yield in addition to fertilizer use, and the development and promotion of available high-yielding varieties should be promoted. However, one has to look at the market for and quality of certified seeds and the system of certification of these seeds to ensure that certification also contributes to enhancing crop yields. In the case of Ghana, animal manure and the use of herbicide to control weeds, which are a major problem for maize in Ghana, should also be part of the agricultural strategy. Availability of labor and associated labor-saving technologies and mechanization are also important parts of the strategy to increase productivity in Ghana.

Last, results show the limits of fertilizer subsidy or promotion of fertilizer use as the main strategies for increasing productivity and suggests a more integrated and holistic approach to encourage greater adoption of improved technologies in order to improve productivity and income among maize farmers. Experience in Ghana may also reflect similar realities in several African countries with long histories of fertilizer subsidy, which have become the central theme of their agricultural productivity and growth strategies. These results suggest the need to explore how the economics of fertilizer application have changed due to subsidy in these countries and identify the binding constraints, other than fertilizer prices, to achieving productivity.

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#### Compliance with ethical standards

**Conflict of interest** The authors declare that they have no competing interests.

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