FOOD SECURITY RESEARCH PROJECT

FACTORS INFLUENCING THE PROFITABILITY OF FERTILIZER USE ON MAIZE IN ZAMBIA

BY

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EXECUTIVE SUMMARY

Fertilizer use remains very low in most of Africa despite widespread agreement that much higher use rates are required for sustained agricultural productivity growth. This study estimates maize yield response functions in agro-ecological Zone IIA, a relatively high-potential zone of Zambia, to determine the profitability of fertilizer use under a range of small farm conditions found within this zone.

The theoretical framework used in this study incorporates agronomic principles of the crop growth process. The model distinguishes different roles of inputs and non-input factors in crop production. We estimate the effects of conventional production inputs as well as household characteristics and government programs on maize yield for households in the dominant acrisols soil type.

Results indicate that even within this particular soil type within Zone IIA, the maize-fertilizer response rate in the two specific years varied widely across households. The main factors explaining the variability in maize-fertilizer response rates were the rate of application, the timeliness of fertilizer availability, the use of animal draught power during land preparation, and whether the household incurred the death of an adult member in the past three years. These modifying factors, as well as variations in input and output prices due to proximity to roads and markets, substantially affected the profitability of fertilizer use on maize. Fertilizer use on maize tended to be unprofitable at full commercial fertilizer prices for farmers who received fertilizer late and who were located in relatively remote areas.

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ACRONYMS

A	Paverage products
ADULT	Number of adults (above age 14)
AGE	Age of household head
AP	average products
AVCR	average value cost ratio
BSLPCT	Percent of basal fertilizer over total fertilizer application
CDFA	Chipata District Farmers Association,
CSA	Census Supervisory Areas
CSPR	Civil Society for Poverty Reduction
DRTPW	used animal or mechanical draught power in land preparation
EDUC	Years of schooling of household head
EXTNSN	received extension service
FEMHD	female household head
FSP	Fertilizer Support Programme
GRZ	Government of the Republic of Zambia
GVCHNL	acquired fertilizer from government channel
HYBD	used hybrid seed
MAZR	Maize planting area (hectare)
M-C	Mundlak–Chamberlain approach
MLE	maximum likelihood estimation
MP	marginal products
MRTLT	adult mortality within past three years
MVCR	marginal value-cost ratio
N	Nitrogen application (kg/hectare)
ONTM	basal fertilizer available on time
PHS	Post Harvest Survey
PRSP	Poverty Reduction Strategy Paper
PSID	Panel Study on Income Dynamics
RAIN	Rainfall (mm)
SEA	Standard Enumeration Areas
SRI	System of Rice Intensification
YIELD	Maize yield (kg/hectare)

1. INTRODUCTION

Fertilizer use remains very low in most of Africa despite widespread agreement that much higher use rates will be required for sustained agricultural productivity growth. Many studies have examined the causes of continued low use of modern inputs in Sub-Saharan African countries (World Bank 2008; Moser and Barrett 2006; Crawford et al. 2003). While weak input, credit, and output markets, poor soils, and high production risks have often been identified as the main reasons for low uptake of fertilizer among African farmers, there is a relative dearth of insight about why fertilizer use remains low even in relatively high-potential and accessible areas where fertilizer use is believed to be profitable.

Agricultural production in Zambia is largely rainfed and is based on small-scale family farming systems. Over 80% of smallholder farmers nationwide own less than 5 hectares of land. Zambian government agricultural policy has for the past several decades focused on fertilizer subsidies and targeted credit programs to stimulate small farmers' agricultural productivity, enhance food security and ultimately reduce poverty. Improving maize productivity has been a major goal of the government policy. Over 70% of the 900,000 small-scale farmers grow maize as their major staple crop and they are responsible for 65% of the maize production in the country. Maize is the single greatest source of cash income from the sale of agricultural products (Zulu, Jayne, and Beaver. 2007).

In 2002, the Zambian Government launched programs and policies under the framework of its Poverty Reduction Strategy Paper (PRSP) which, in the agricultural sector, includes: the Fertilizer Support Programme (FSP) out-grower schemes, land and infrastructure development, technology development, agriculture extension, and maize marketing in support of small-scale farmers (GRZ 2004; World Bank 2002a, 2002b).

Despite government's efforts over the past several decades, overall fertilizer consumption has expanded slowly and mean maize yields remain at the level of 1.2 to 1.8 tons per hectare over the past decade. Maize yields vary greatly among households, but 75% of households obtain between 0.7 and 2.5 tons per hectare. Several recent assessments of the implementation and effectiveness of the FSP conclude that FSP has had little impact in terms of increasing maize production and enhancing household incomes and livelihoods (CSPR 2005; CDFA 2008; Agricultural Consultative Forum 2009). Several factors were identified as responsible for reducing the effectiveness of the FSP including late delivery of inputs to farmers, mismanagement by those in charge of distributing inputs, diversion of program inputs, low output prices, poor crop marketing arrangements, and poor transport facilities. These studies underscore the need, among other things, for a better understanding of the factors affecting maize yield response to fertilizer, including the timeliness of fertilizer application, and the profitability of fertilizer use under small farm conditions, so as to inform policy process aimed at achieving sustainable increase in maize productivity and smallholder incomes.

Extension messages in Zambia have been based on one nationally recommended application rate of 200 kilograms of basal fertilizer (Compound D, 10-20-10 NPK) and 200 kilograms of top dressing fertilizer (Urea, 46-0-0) per hectare of maize. This one-size-fits-all recommendation ignores heterogeneity in small farm conditions and differing market conditions. As fertilizer remains an expensive input in Sub-Saharan Africa, efforts to raise the profitability and effective demand for fertilizer will depend on helping farmers to use the input efficiently, which in turn depends on management practices, use of fertilizer-responsive seeds, and taking into consideration how agroecological and market conditions affect appropriate application rates.

This study examines maize yield response to a range of farm inputs, determines the profitability of fertilizer use by small-scale farmers, and identifies the potential to increase maize productivity and profitability of fertilizer use through public policy tools. The analysis focuses on a relatively high-potential area of Zambia well suited to maize production. An accurate understanding of these issues can be achieved through appropriate specification and estimation of crop production models.

Crop response research has featured various models, in particular, flexible functional forms such as the quadratic and translog, which achieve second-order approximations to arbitrary functions. However, recent crop production studies (see, e.g., Chambers and Lichtenberg 1994; Guan et al. 2005; Guan et al. 2006) suggest that the approximation-based models suffer theoretical drawbacks because these models treat inputs symmetrically and implicitly assume different inputs affect crop yield in the same way. To address this issue, asymmetric models have been proposed. In this study we further generalize the asymmetric models proposed in the literature in order to better capture the underlying data generating process in crop responses. The model provides a more robust tool for analyzing crop yield responses.

The article is organized as follows. We describe the yield response modeling framework in section 2. Section 3 describes the data and empirical model. The estimation method is presented in the fourth section, followed by a discussion of the findings in Section 5. We conclude with a summary and implications for policies to promote the profitability of fertilizer use by smallholder farmers in Zambia.

2. MODELING FRAMEWORK

Recent studies of crop production functions have recognized the relevance of specific agronomic processes in yield determination (e.g., Lichtenberg and Zilberman 1986; Chambers and Lichtenberg 1994, 1996). Guan et al. (2006) proposed a conceptual framework that dichotomized inputs used in crop production into growth inputs and facilitating inputs based on agronomic perspectives that different factors influence yield differently.[1] Growth inputs are defined as those that are directly involved in biological process of crop growth and thus essential for crop growth such as seed type, nutrients, and water. Growth inputs determine attainable yield level in a given biophysical environment, assuming no yield-reducing factors for maximum yield such as weeds, diseases, and pests. These factors cause actual farm yield to be lower than the attainable yield. Facilitating inputs are defined as those that are not directly involved in the basic biological process, but can help create or alter growth conditions under which growth inputs take effect. Guan et al. (2006) included labor, capital, and pesticides in this category. A general crop production model is written as:

(1) $$y = G(\boldsymbol{x}) \cdot S(\boldsymbol{z})$$

where y is crop yield, x is a vector of growth inputs, and z is a vector of facilitating inputs. Growth inputs and facilitating inputs affect crop output through different mechanisms indicated by crop growth function $G(\cdot)$ and scaling function $S(\cdot)$. Crop-growth function $G(\cdot)$ determines the attainable yield level given the biophysical environment. The scaling function $S(\cdot)$ is defined in the interval [0, 1]. When $S(\cdot)$ reaches 1, i.e., when the growth conditions are optimal for a given level of growth inputs x, crop output y attains its maximum value G(x). Actual yield is lower than the attainable yield and scaled down by the factor $S(\cdot)$ under non-optimal growth conditions.

In this study we define a concept of *yield scaling factors* to generalize the concept of facilitating inputs. The yield scaling factors include not only physical inputs (i.e. facilitating inputs) but also non-input factors that directly affect the efficiency of the crop production process and therefore the actual crop yield. The non-input factors, in conjunction with physical inputs, affect *S(z)*. By accommodating non-input factors, we can obtain more accurate estimates of crop responses to agronomic inputs use, especially crop response to fertilizer that is of particular interest in our study. We further propose to use a quadratic functional form in empirical model specification of crop response to growth inputs, *G(.)*. This specification imposes concavity on the yield response which is consistent with most observable biological relationships. The Mundlak–Chamberlain approach is used in estimation to control for unobserved heterogeneity such as time-constant farmer ability and soil variation and its correlation with observables.

[1] In the agronomic literature, three distinct yield levels are described: potential, attainable, and actual. These levels are determined by different growth conditions: (1) growth defining, (2) growth limiting, and (3) growth reducing factors. Growth defining factors such as weather and species characteristics determine the potential yield, assuming there are no growth limiting and reducing factors. Attainable yield is lower than the potential yield due to growth limiting factors such as water and nutrients. Yield gap between actual yield and attainable yield is caused by the growth reducing factors such as weeds, pests, and diseases. Potential yield is typically not achieved due to growth limiting and growth reducing factors; also, it may not be economically viable to attempt to achieve potential yield (Rabbinge 1993; Van Ittersum and Rabbinge 1997; Van de Ven et al. 2003).

3. DATA AND EMPIRICAL MODEL

3.1. Data

Household-level data used in this study are from three surveys, the 1999/2000 Post Harvest Survey (PHS), the linked First Supplemental Survey to the 1999/2000 PHS, and the Second Supplemental Survey to the 1999/2000 PHS. All three surveys were conducted by the government Central Statistical Office. A panel data set for two agricultural seasons, 1999/2000 and 2002/2003, is available from these surveys. PHS is a nationally representative survey using a stratified three-stage sampling design. Census Supervisory Areas (CSA) were first selected within each district, next Standard Enumeration Areas (SEA) were sampled from each selected CSA, and in the last stage a sample of households were randomly selected from a listing of households within each sample SEA. The SEA is the most disaggregated geographic unit in the data, which typically includes 2-4 villages of several hundred households. Agro-ecological zone and soil type information is available at the SEA level. Our study area is the primary maize surplus production region, Zone IIA (medium rainfall area) with dominant soil type acrisols or ferrolsols. The parts of Zone IIA with these soil types are considered to be relatively well suited to maize production and responsive to fertilizer application. Households were also separated into two equal groups according to their distance to the nearest district town. We differentiate between these relatively accessible and remote areas in the assessment of fertilizer use profitability. The panel data set consists of 707 farmers in two periods, producing a total of 1,414 observations. The variables used in the analysis are defined in Table 1 and their panel data summary statistics are presented in Table 2.

Table 1. Variable Definitions

Variable	Description
YIELD	Maize yield (kg/hectare)
N	Nitrogen application (kg/hectare)
BSLPCT	Percent of basal fertilizer over total fertilizer
RAIN	Rainfall (mm)
HYBD	1=used hybrid seed
ONTM	1=basal fertilizer available on time
DRTPW	1=used animal or mechanical draught power in land
MZAR	Maize planting area (hectare)
EXTNSN	1=received extension service
GVCHNL	1=acquired fertilizer from government channel
ADULT	Number of adults (above age 14) per hectare of maize
AGE	Age of household head
EDUC	Years of schooling of household head
FEMHD	1=female household head
MRTLT	1=adult mortality within past three years
YEAR	1=2002 season

Table 2. Summary Statistics for Variables Used in the Analysis

	full sample (n=707)				used fertilizer both years (n=203)				Did not use fertilizer either wave (n=315)				Used fertilizer at least one year (n=392)	
		Source of variation (StDev)				Source of variation (StDev)				Source of variation (StDev)				StDev
Variable	Mean	Overall	Between	Within	Mean	Overall	Between	Within	Mean	Overall	Between	Within	Mean	Overall
Yield (kg/ha)	1,779	1,140	874	732	2,198	1,252	980	780	1,573	1,021	759	685	2,082	1,235
Maize area (ha)	1.40	1.50	1.25	0.84	2.04	2.09	1.74	1.16	1.07	0.89	0.71	0.54	1.22	1.90
Nitrogen (kgs/ha)	25.1	42.6	34.7	24.6	62.7	47.8	36.3	31.1					59.0	47.6
Basal-top dress ratio	0.21	0.27	0.23	0.15	0.49	0.17	0.13	0.11					0.49	0.19
Basal on time [0,1]					0.70	0.46	0.33	0.32					0.68	0.47
Fertilizer from gov't channel [0,1]					0.38	0.49	0.36	0.33					0.35	0.48
Use hybrid [0,1]	0.24	0.43	0.35	0.24	0.45	0.50	0.41	0.29	0.10	0.30	0.23	0.19	0.41	0.49
Use power [0,1]	0.50	0.50	0.43	0.26	0.67	0.47	0.41	0.24	0.38	0.48	0.40	0.27	0.63	0.48
Female head of household [0,1]	0.18	0.38	0.35	0.15	0.11	0.31	0.28	0.13	0.22	0.41	0.39	0.14	0.14	0.35
Age (years)	46.0	15.1	13.8	6.0	45.9	13.7	12.8	4.8	45.3	15.9	14.4	6.7	46.1	14.2
Education (years)	4.7	3.9	3.7	1.3	5.7	4.1	3.9	1.3	3.9	3.6	3.4	1.2	5.4	4.0
Adults over 14	3.7	3.0	2.2	2.0	3.6	2.7	2.0	1.8	3.8	3.1	2.2	2.1	3.5	2.6
Mortality	0.11	0.23	0.23	0.00	0.12	0.24	0.24	0.00	0.11	0.23	0.23	0.00	0.11	0.23
Extension advice [0,1]	0.41	0.492	0.34	0.35	0.45	0.50	0.33	0.38	0.36	0.48	0.34	0.34	0.45	0.50
Rain (mm)	936	177	96	149	912	196	91	173	955	159	98	126	914	187

Notes: “overall”= standard deviation over the pooled sample; “between”=standard deviation across time-averaged household sample (sample size is half that of overall sample); “within”=standard deviation within households from their variable means.

The output specified is maize yield in kilograms (kg) per hectare. Growth inputs consist of fertilizer, seed type, and rainfall. We include nitrogen (the most important nutrient in maize growth) application rate[2] in kg per hectare, as well as the percentage of basal fertilizer in total kilograms fertilizer usage.[3] Seed is specified as a dummy variable indicating whether purchased hybrid seed was used. Rainfall is district-level seasonal rainfall in millimeters. Yield scaling factors modeled as (0,1) variables include whether animal draught power was used during land preparation, whether fertilizer was available at the time of planting, whether fertilizer was acquired from the government fertilizer subsidy program, and whether the household received maize advice from the national extension service. Other factors entering the scaling function include maize planted area, characteristics of household head (age, gender, and education), number of adults above age fourteen, and whether the household incurred the death of a prime-aged adult between the first and second surveys. A year dummy was included to account for unobserved differences across the two years.

3.2. Empirical Model

Under the general framework (1), we specify functional forms for the crop-growth function $G(\cdot)$ and the scaling function $S(\cdot)$ in our empirical application of maize production in Zambia. A quadratic model for the crop-growth function $G(\cdot)$ is specified as:

$$(2)\quad \begin{aligned} G_{it} = {} & \alpha_1 N_{it} + \alpha_2 BSLPCT_{it} + \alpha_3 RAIN_{it} + \alpha_4 HYBD_{it} + \alpha_{11} N_{it}^2 + \alpha_{12} N_{it} \times BSLPCT_{it} + \\ & \alpha_{13} N_{it} \times RAIN_{it} + \alpha_{14} N_{it} \times HYBD_{it} + \alpha_{22} BSLPCT_{it}^2 + \alpha_{23} BSLPCT_{it} \times RAIN_{it} + \\ & \alpha_{24} BSLPCT_{it} \times HYBD_{it} + \alpha_{33} RAIN_{it}^2 + \alpha_{34} RAIN_{it} \times HYBD_{it} \end{aligned}$$

where *N*, *BSLPCT*, *RAIN*, *HYBD* are growth inputs defined in Table 1, and α_1 - α_{34} are parameters to be estimated.

In specifying the scaling function $S(\cdot)$, we extend the traditional production inputs used in the literature to include whether fertilizer is available on time, household characteristics, and government programs. We use an exponential form that does not impose monotonicity on the input-output relationship (Guan et al. 2006):

$$(3)\quad \begin{aligned} S_{it} = \exp[-(& \beta_0 + \beta_1 ONTM_{it} + \beta_2 DRTPW_{it} + \beta_3 MZAR + \beta_4 EXTNSN_{it} + \beta_5 GVCHNL_{it} + \\ & \beta_6 ADULT_{it} + \beta_7 AGE + \beta_8 EDUC + \beta_9 FEMHD + \beta_{10} MRTLT_{it} + \beta_{11} YEAR_t)^2] \end{aligned}$$

where *ONTM*, *DRTPW*, *MZAR, EXTNSN*, *GVCHNL*, *ADULT*, *AGE, EDUC, FEMHD, MRTLT*, and *YEAR* are defined in Table 1, and $\beta_0 - \beta_{11}$ are parameters to be estimated.

With the two functions specified above, the overall maize production function is written as the following nonlinear form:

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[2] It is calculated based on the amount of basal fertilizer and top dressing fertilizer used per hectare and the nutrient components in these fertilizers. 100kg of Compound D basal fertilizer contains 10kg nitrogen (*N*), while 100kg of urea top dressing contains 46kg *N*.

[3] Extension messages recommend applying basal and top dressing at a 1:1 ratio.

$$(4)\quad YIELD_{it} = (\alpha_1 N_{it} + \alpha_2 BSLPCT_{it} + \alpha_3 RAIN_{it} + \alpha_4 HYBD_{it} + \alpha_{11} N_{it}^2 + \alpha_{12} N_{it} \times BSLPCT_{it} + \alpha_{13} N_{it} \times RAIN_{it} + \alpha_{14} N_{it} \times HYBD_{it} + \alpha_{22} BSLPCT_{it}^2 + \alpha_{23} BSLPCT_{it} \times RAIN_{it} + \alpha_{24} BSLPCT_{it} \times HYBD_{it} + \alpha_{33} RAIN_{it}^2 + \alpha_{34} RAIN_{it} \times HYBD_{it}) \exp[-(\beta_0 + \beta_1 ONTM_{it} + \beta_2 DRTPW_{it} + \beta_3 MZAR + \beta_4 EXTNSN_{it} + \beta_5 GVCHNL_{it} + \beta_6 ADULT_{it} + \beta_7 AGE + \beta_8 EDUC + \beta_9 FEMHD + \beta_{10} MRTLT_{it} + \beta_{11} YEAR_t)^2] + f_i + u_{it}$$

where *YIELD* is maize yield in kilogram per hectare, f_i is unobserved household heterogeneity, and u_{it} is random error assumed to be normally distributed. Taking the expectation of $YIELD_{it}$ in equation (4) conditional on inputs and yield scaling factors (denoted as X_i) and taking partial derivative with respect to N_{it}, we get

$$(5)\quad \partial[E(YIELD_{it} \mid X_i)] / \partial N_{it} = (\alpha_1 + 2\alpha_{11} N_{it} + \alpha_{12} BSLPCT_{it} + \alpha_{13} RAIN_{it} + \alpha_{14} HYBD_{it}) \exp[-(\beta_0 + \beta_1 ONTM_{it} + \beta_2 DRTPW_{it} + \beta_3 MZAR + \beta_4 EXTNSN_{it} + \beta_5 GVCHNL_{it} + \beta_6 ADULT_{it} + \beta_7 AGE + \beta_8 EDUC + \beta_9 FEMHD + \beta_{10} MRTLT_{it} + \beta_{11} YEAR_t)^2]$$

It gives the partial effect of N_{it} on the expected $YIELD_{it}$, which is also the marginal product of N_{it}, i.e., the change in expected $YIELD_{it}$ as a result of adding an additional unit of N_{it}, ceteris paribus. As reflected in equation (5), marginal product of nitrogen depends on the nitrogen level as well as the levels of all the other explanatory variables. Partial effects of other continuous variables can be derived similarly by taking the partial derivative of expected $YIELD_{it}$ in equation (4) with respect to that variable. Partial effect of a dummy variable is the difference between the expected yields when the dummy variable changes from 0 to 1.

4. ESTIMATION METHOD

Unobserved household heterogeneity such as land quality, farmer skill and motivation can be controlled for through the use of panel data. We estimate production function in equation (4) using the correlated unobserved effects model (Chamberlain 1984; Mundlak 1978). The Mundlak–Chamberlain (hereafter M-C) approach explicitly accounts for unobserved heterogeneity and its correlation with observables, while yielding a fixed effects-like interpretation.[4]

Due to the incidental parameters problem,[5] we do not treat the unobserved heterogeneity f_i as additional parameters to estimate.

The M-C approach allows for correlation between unobserved heterogeneity f_i and explanatory variables X_{it} by assuming f_i has the form:

(6) $$f_i = \tau + \bar{X}_i \gamma + a_i$$

where $\bar{X}_i$ is a vector of the averages of X_{it} across time periods, τ is constant, γ is a parameter vector, and a_i is i.i.d. and normally distributed, and independent of u_{it} in equation (4). Parameters α_1 - α_{34}, $\beta_0 - \beta_{11}$, τ, and γ are estimated using maximum likelihood estimation method (MLE). Under regularity conditions, MLE is asymptotically unbiased and efficient.

We can determine whether unobserved heterogeneity is correlated with by the joint significance test of γ. If the hypothesis H0: γ=0 is rejected, there is evidence of unobserved heterogeneity that is correlated with , thus parameter estimates of the crop production function will be inconsistent if unobserved heterogeneity fi is ignored in production function estimation. A joint significance test of the time-averaged explanatory variables reject the hypothesis H0: γ=0 in (6), suggesting that unobserved heterogeneity is correlated with the time-averages , and indicating that the correlated unobserved M-C approach is superior to the pooled or random effects estimators.

[4] For linear models, the correlated unobserved effects estimator of coefficients on time-variant regressors are mathematically identical to the fixed effects estimator, which is why we describe them as *fixed-effects like* in the non-linear case.

[5] An incidental parameters problem arises with maximum likelihood estimation of panel data models that treat unobserved effects as additional parameters to estimate, leading to inconsistent estimators when N is large and T is small and fixed (Wooldridge 2002).

5. EMPIRICAL RESULTS

We first examined sample attrition which is necessary because nonrandom attrition can cause the panel sample to be unrepresentative of the population of interest and potentially bias the empirical result. Sample attrition is a common problem in panel survey data. Reasons for sample attrition in developing countries include household migration, dissolution due to head death, household split-off, or refusal to be interviewed (Deaton 1997). Refusal rates are relatively low in developing countries, which may be related to low opportunity cost of time or cultural attitudes (Maluccio 2004). Of the households interviewed in the first survey round, 164 of the 871 are lost from the second round, leading to a balanced panel of 707 households. Potential attrition bias is tested using the methods suggested in the literature (Becketti et al. 1988; Fitzgerald et al. 1998a and 1998b; Maluccio 2004). The sample of households in the first survey round is first divided into two sub-samples: attritors and non-attritors. Univariate comparison indicates that unconditional means of most variables are not significantly different between the two subsamples. A formal test for attrition bias was then performed using the sample for the first period. An attrition indicator along with interaction terms of the attrition indicator and explanatory variables were added in crop production function (4). The terms involving attrition indicator are jointly insignificant, suggesting that estimation of the crop production function based on the non-attriting sample will unlikely have attrition bias problem in our particular sample.

5.1. Production Function Estimation Results

Because of the model's nonlinear functional form, the parameter estimates do not provide an straightforward interpretation of the effects of specific inputs or factors. The partial effects of each variable on maize yields were estimated using the delta method and are presented in Table 3 evaluated at the 50th percentile level for continuous variables for households using fertilizer. The partial effects of nitrogen use, timely availability of fertilizer acquisition from government channel, and use of animal or mechanical draught power in land preparation, had statistically significant yield increasing effects. Use of hybrid seed had a positive impact on yield and was significant at the 10% level, Adult mortality was statistically significant and negatively associated with crop yield. The area planted to maize, age and gender of the household head, and the number of adults in the household were not statistically significant. Farmers receiving advice from extension agents had statistically significantly lower yields.

The impact of timely receipt of fertilizer on yield was large, with a partial effect of 11% of average yield at the median rate of nitrogen fertilization; the impact was virtually the same for both waves. The use of animal draft power in land preparation also had a large effect on yield, with a partial effect of nearly 15% evaluated at the median of nitrogen use. The impact of hybrid seed use is of similar magnitude, 16.5%. The partial effect of a 16% increase in yields on farms acquiring fertilizer from the government channel may be due to information diffusion by involved agencies. Another possible explanation is that the government program targeted subsidies to more productive farmers in relatively high-potential areas within the sampled zone. The negative partial effect on yield of farms receiving advice from extension agents was 2.9%, suggesting some of the recommended agronomic practices may have a counterproductive effect on yield. Waterlogged soils and flooding were frequent problems during the two waves which may help explain the negative impact of rainfall.

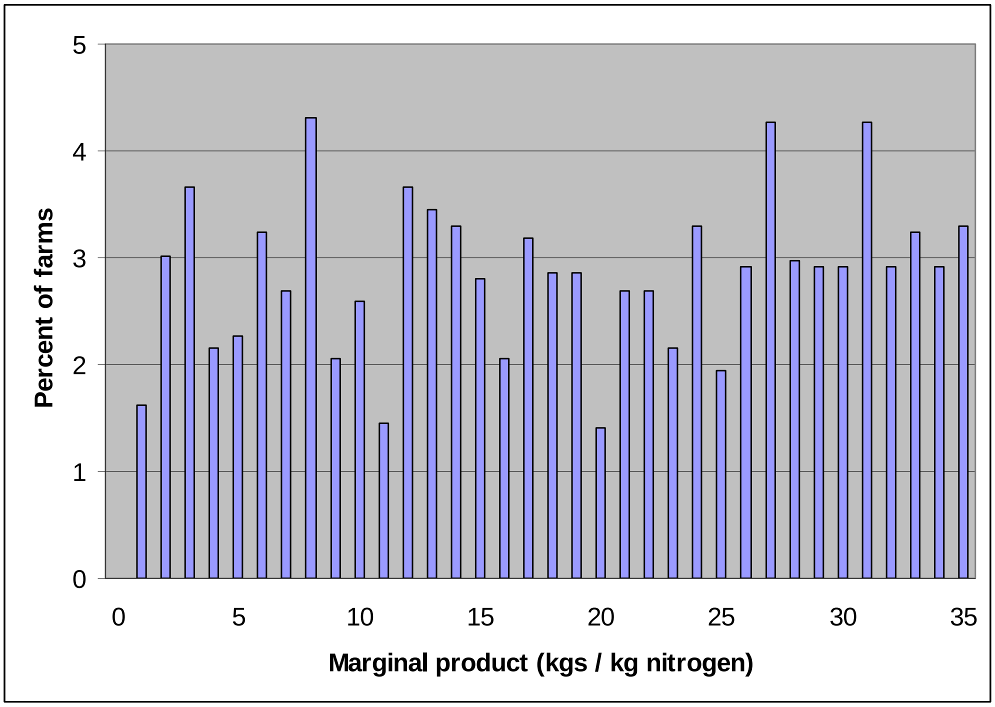
Table 3. Estimates of Partial Effects

Variable		Period 1999/00	Period 2002/03
N	Nitrogen application (kg/hectare)	7.80* (0.002)	11.70* (0.000)
BSLPCT	Percent of basal fertilizer over total fertilizer application	4.61 (0.068)	6.92 (0.062)
RAIN	Rainfall (mm)	-0.51* (0.007)	-0.76* (0.002)
HYBD	1=used hybrid seed	121.38 (0.090)	184.25 (0.084)
ONTM	1=basal fertilizer available on time	201.06* (0.000)	201.96* (0.000)
DRTPW	1=used animal or mechanical draught power in land preparation	267.49* (0.000)	270.34* (0.000)
MZAR	Maize planting area (hectare)	-40.54 (0.308)	-48.17 (0.292)
EXTNSN	1=received extension service	-56.90* (0.001)	-54.06* (0.008)
GVCHNL	1=acquired fertilizer from government channel	122.54 (0.065)	183.28* (0.000)
ADULT	Number of adults (above age 14) per hectare of maize	27.33 (0.280)	32.47 (0.276)
AGE	Age of household head	-0.06 (0.904)	-0.08 (0.904)
EDUC	Years of schooling of household head	1.53 (0.522)	1.81 (0.517)
FEMHD	1=female household head	-8.03 (0.661)	-9.30 (0.657)
MRTLT	1=adult mortality within past three years	-275.65* (0.000)	-268.64* (0.000)

Note: Numbers in parentheses are p-values. * indicates the estimate is significantly different from zero at 5% or higher level. Partial effects are evaluated at *HBRD*, *ONTM*, *DRTPW*, *EXTNSN*, *GVCHNL*, *FEMHD*, *MRTLT* equal to zero, and *N*=45.90, *BSLPCT*=50, *RAIN*=892.6, *MZAR*=1.215, *ADULT*=3, *AGE*=44, *EDUC*=6, the 50 percentiles of households with N>0.

The average (AP) and marginal (MP) products of nitrogen application are of particular interest, because they are major determinants of households' incentives to invest in fertilizer. The AP and MP of nitrogen are influenced by the application rate, the other variables entering the growth input function [G(.)], and scaling function [S(.)]. The estimated values of the scaling function range from near zero to near one within the sample; that is, there is substantial variation in the capacity to realize the productivity of the applied fertilizer amongst the households applying fertilizer. The estimated marginal product of N on maize among farmers using nitrogen in at least one wave varied widely within the relatively high-potential zone in which this study was undertaken. The median estimated marginal product of nitrogen was 15.9 kgs of maize per kg nitrogen, but as shown in Figure 1, it was under 10 kgs maize per kg nitrogen for 25.6% of the sample, between 10 to 20 kgs for 29.9% of the sample, between 20 to 30 kgs for 27.2%, and over 30 kgs maize per kg nitrogen applied for 18.3% of the farms.

Figure 1. Histogram of Estimated Marginal Product of Nitrogen for Farmers Using Fertilizer



The remainder of this section focuses on the main sources of variation in the marginal product of fertilizer application on maize yield. Two of the most important factors were the fertilizer application rate and whether fertilizer was available to farmers on time. Table 4 presents the estimated average and marginal products of N for households applying nitrogen in at least one wave for three rates of application rates and dependent upon whether nitrogen was available in a timely manner (67% of the time for fertilizer received through the government subsidy program and 70% of the time for fertilizer purchased from private suppliers). The rates of application are the 25th percentile for those that used fertilizer in at least one wave (28 kgs N per ha), 50th percentile (46 kgs N per ha), and 75th percentile (69 kgs N per ha). Clearly, the nationwide recommended application rate of 200 kgs Compound D and 200 kgs urea (which amount to approximately 112 kgs of nitrogen) per hectare of maize is well beyond the rates used by the majority of fertilizer users.

The AP and MP of nitrogen fall as the application rate increases. However, the most striking feature is the impact of the timeliness of fertilizer availability. Comparing cases 1 vs. 2, cases 3 vs. 4, and cases 5 vs. 6 in Table 4 reveals that acquiring fertilizer on time roughly doubles the marginal product of nitrogen. Because over 30% of the households reported that fertilizer was delivered late, these findings indicate that efforts to ensure timely distribution can contribute substantially to the productivity gains achievable from fertilizer use. Interviews of private fertilizer distributors reveal that delays in the distribution of government program fertilizer cause uncertainty for private traders who first assess whether subsidized government fertilizer will be distributed in a certain area of operation before determining where to distribute their fertilizer (Zulu, Jayne, and Beaver. 2007). These dynamics give rise to the late acquisition of fertilizer through both public and private channels.

5.2. Profitability of Fertilizer Use

In the absence of data on full production costs such as labor input, value cost ratios have often been employed to assess the profitability of fertilizer use (Crawford and Kelly 2002). The marginal value-cost ratio (MVCR) divides the value of the marginal product by the price of nitrogen

$$(7)\qquad MVCR = \frac{MPN \times P_{maize}}{P_N}$$

where P_{maize} is the price of maize per kilogram and P_N is the price of nitrogen per kilogram.[6] Similarly, the average value cost ratio (AVCR) measures the average net gain per kg of nitrogen applied. If the response function were known with certainty, the incentive would be to apply nitrogen to the point where the MVCR is 1.0. However, there is clearly substantial uncertainty about the outcome of applying fertilizer as can be seen in Table 4 by comparing the MPN in the first vs. second waves. The marginal products of nitrogen were 2/3 as large in the first wave as in the second. Similarly, the substantial uncertainty associated with whether fertilizer will be available on time exacerbates the problem. Taking both the year and timing of fertilizer availability into account, there is a difference in MPN between the lowest and highest value of 250%. Given these kinds of variations as well as other sources of uncertainty, households would be expected to apply nitrogen at rates below the value where, in a probabilistic sense, the expected MVCR is 1.0.

Prices paid for fertilizer and received for maize vary according to the transport and handling costs they face, and according to the survey data, the more remote group faces roughly 20% lower maize/N price ratios. Overall maize-N price ratios were more favorable in 2002/03 than in 1999/00. Using a nitrogen-maize price ratio of 8.60 in 1999 and 8.06 in 2002 in the accessible areas, the average MVCR across both waves at the 75th percentile application rate is 1.9 if fertilizer is available on time. The ratio drops to 1.0 if fertilizer is not available on time. The comparable values for the median application rate are 2.2 and 1.2. These ratios would fall to 1.6 and 0.96 in the remote areas.

The AVCR captures the average gain per kg of nitrogen used. An AVCR greater than one would imply fertilizer use is profitable if no additional cost is incurred. This is not likely to be the case due to transaction costs and risks associated with fertilizer use. For these reasons, researchers have suggested that an AVCR of 2.0 or greater is generally required for farmers to use fertilizer in appreciable amounts (Crawford and Kelly 2002). Our paper adopts this convention and considers AVCR of at least 2 as an indicator that fertilizer use is likely to be profitable.

We differentiate households into two groups according to their degree of remoteness or accessibility to markets, according to their distance to the nearest district town. The relatively remote group face maize-N price ratios roughly 20% lower than for the relatively accessible group. The majority of farmers in relatively remote areas have MVCRs less than two. During 1999/2000, only 1 case out of 6 cases presented in Table 4 had MVCRs above 2; 2 of the 6 cases have MVCRs above 2.0 in the 2002/2003 season. In the more accessible areas, only 2 of the 6 cases shown in Table 4 had MVCR above 2.0 in 1999/00 while half of the cases had MVCRs above 2.0 in 2002/03. Given current management practices, fertilizer

[6] P_N was calculated using the prices for basal fertilizer and top dressing fertilizer and their nutrient component information. Let x denote the amount of each fertilizer required for 1kg of nitrogen given the 1:1 application ratio of two types of fertilizers, based on the nutrient component information we have $10\%x + 46\%x = 1$. Solving for x yields x=1.79kg, that is, 1kg of nitrogen costs approximately 1.79kg of each type of fertilizer, therefore P_N is 1.79×(basal fertilizer price + top dressing price).

Table 4. Estimates of Marginal and Average Products of Nitrogen and Estimated Value-cost Ratios for Alternative Rates of Nitrogen Application Dependent upon Timeliness of Fertilizer Availability

	25th percentile	50th percentile	75th percentile	Fertilizer available on time		MP of nitrogen (kg/kg N)		AP of nitrogen (kg/Kgs N)		Average Value-Cost Ratio (AP nitrogen*Pmz/Pnitrogen)			
										Remote area		Accessible area	
Case	28 kgs	46 kgs	69 kgs	no	yes	1999	2002	1999	2002	1999	2002	1999	2002
1	x			x		9.2	13.8	10.1	15	1.02	1.66	1.17	1.86
2	x				x	19.2	23.4	20.9	25.5	2.11	2.81	2.43	3.16
3		x		x		8.2	12.2	9.5	14.2	0.90	1.46	1.04	1.65
4		x			x	16.9	20.6	19.7	24.1	1.86	2.47	2.15	2.78
5			x	x		6.9	10.1	8.9	13.2	0.75	1.21	0.87	1.36
6			x		x	14.1	17.2	18.2	22.3	1.55	2.06	1.79	2.32

Note: Average value products over 2.0 signify that fertilizer use on maize is likely to be profitable.

use at the standard recommended rates on maize appears to be profitable only for a minority of smallholder farmers in the relatively remote areas. For farmers in the more accessible areas, fertilizer use tends to be profitable if received and applied on time. If fertilizer is not available on time, even farmers in the more accessible areas of this area of relatively high agronomic suitability for maize production are largely unable to use fertilizer profitably.

On the other hand, beneficiaries of the government fertilizer program are more likely to find fertilizer use profitable because they were able to acquire fertilizer at roughly half of the full retail price and this would effectively double the MVCR values.

As a final exercise, we compute the level of nitrogen (N^*) at which the MVCR is equal to 2 for each case. Nitrogen applied at a level lower than N^* has a higher MPN and thereby a higher MVCR for profitable use of fertilizer. The standard extension system recommendation of 4 bags basal plus 4 bags top dressing per hectare of maize contains 116kg of nitrogen per hectare. This N application rate is higher than N^* in all cases for both 1999/00 and 2002/03. The median N^* was found to be in the range of 44 to 71kg of N for cases in which fertilizer was delivered on time. Of course these findings are sensitive to maize/N price ratios observed in the two years of the study. In subsequent years since 2002/03, the maize-to-N price ratio has been more than 10% higher than those observed in 2002/03 in two years, while being more than 10% lower in two years. Hence, the profitability results observed in these two years are likely to remain very close to those prevailing in more recent years. These findings suggest that fertilizer applied on maize can indeed be commercially profitable for farmers in the more accessible areas of Zone IIa as long as the fertilizer is applied on time and application rates are less than the standard 4 by 4 bag recommendation. Recommended application rates are unlikely to be economically viable for farmers in the more remote areas given the more adverse maize-to-fertilizer price ratios observed in these areas in recent years in Zambia. Profitability could, of course, be restored even in the remote areas if farmers were able to use fertilizer more efficiently, i.e., raise the average and marginal product of fertilizer through management improvements and greater use of complementary techniques and inputs.

6. CONCLUSIONS

This paper assesses the profitability of using fertilizer on maize by smallholder farmers in Agro-ecological Zone IIa, a relatively productive area suitable for maize production. Using longitudinal household survey data, we estimate a maize production function using an asymmetric conceptual framework. We generalized the asymmetric framework by categorizing inputs in crop production as growth inputs and yield scaling factors. This framework incorporates agronomic perspectives on the underlying crop growth process and further accommodates the impacts from non-input factors. We control for unobserved heterogeneity using the Mundlak-Chamberlain approach.

The main factors influencing fertilizer use profitability were found to be fertilizer application rates, whether fertilizer was available in a timely manner, whether the household incurred a recent adult death, whether hybrid seed was used, and the maize/fertilizer price ratio facing the household, which is influenced by proximity to roads and markets.

Given current management practices, fertilizer use at the standard recommended rates on maize appears to be profitable for a minority of smallholder farmers in the relatively remote areas on Zone IIa. For farmers in the more accessible areas, fertilizer use tends to be profitable if received and applied on time. If fertilizer is not available on time, even farmers in the more accessible areas of this area of relatively high agronomic suitability for maize production are largely unable to use fertilizer profitably.

Only for beneficiaries of government input programs who purchased fertilizer at a much lower price does fertilizer use appear to be clearly profitable. These findings suggest that many small farmers may lack incentives to purchase commercial fertilizer even for those having the capacity and resources to do so, which may explain why less than 30% of smallholder farmers in Zambia acquire fertilizer commercially.

Strategies to make fertilizer use more profitable for farmers will require raising yield response rates and reducing input and output marketing costs. Our study finds that farmers' ability to acquire fertilizer in a timely manner has a strong positive effect on maize yield response to fertilizer. Subsidized fertilizer under government programs in Zambia has often been distributed late. These programs have also caused uncertainty for private traders who first assess whether subsidized government fertilizer will be circulated in a certain area of operation before determining where to stock fertilizer (Zulu, Jayne, and Beaver. 2007). These dynamics give rise to the late acquisition of fertilizer through both public and private channels. Fertilizer use in any appreciable amount is unlikely to be profitable for a large majority of smallholder farmers until efforts are made to ensure more timely delivery of fertilizer. Moreover, the extension service may consider revising downward their recommended fertilizer application rates taking into consideration relevant factors that will influence profitable use of fertilizer. Lower application rates may be necessary for relatively less efficient farmers to achieve minimum threshold conditions of profitability. However, households in the sample are characterized by great variation in the marginal product of nitrogen even in the same agro-ecological and soil conditions, which most likely reflects differences in management ability, knowledge about appropriate application rates, and whether they are able to acquire fertilizer in a timely manner. Higher fertilizer application rates may become more profitable if there are concomitant improvements in the use of draft power, improved cultivars, timely availability of fertilizer, improved agronomic practices, and investments in physical infrastructure to reduce the costs of acquiring fertilizer and marketing maize.

These findings suggest that improving the efficiency of fertilizer use among smallholder farmers through more effective extension messages and timely fertilizer availability could make fertilizer use profitable even at much higher application rates. We find that if farmers in the bottom half of the distribution ranked by their marginal product of nitrogen were able to achieve the mean marginal product level of 15.9 kgs maize per kg N applied, this itself would raise maize production among the entire sample of fertilizer using households by 15.2%. The findings of this study indicate that efforts to raise the efficiency of fertilizer use by smallholder farmers could make great strides in raising the profitability of, and hence the effective demand for fertilizer in Zambia.

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