# The profitability of inorganic fertilizer use in smallholder maize production in Tanzania: Implications for alternative strategies to improve smallholder maize productivity

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**Abstract:** We use plot-level data from the National Panel Survey to estimate maize-N response rates and the profitability of inorganic fertilizer use. We find that average smallholder maize-N response rates are not even 50% of those from zonal research center trials, implying that there is a considerable gap between actual and potential returns from fertilizer use. Fertilizer use on maize is only marginally profitable for farmers with average response rates, even in higher potential zones. Farmers who fallowed a plot more recently and/or received an extension visit have higher response rates and more profitable fertilizer use, yet fallowing is infrequent and extension does not reach most farmers. These results strongly suggest that regardless of whether NAIVS continues or not, the government must consider complementary strategies (beyond NAIVS) to help increase the profitability of fertilizer use on maize, otherwise, it is doubtful if the gains in farmer use of fertilizer on maize under NAIVS will be sustained when an increasing number of farmers must pay the market price for fertilizer (as NAIVS continues to scale down or stop). We provide a number of strategies that can help improve the profitability of fertilizer use on maize: (i) continuing and completing on-going efforts to update the country's soil maps and recommendations for fertilizer use and integrated soil fertility management practices for maize and other key staple crops; (ii) effective dissemination to smallholders of this new information to enable them to sustainably increase maize productivity through both appropriate fertilizer use improved soil fertility; (iii) improving maize price levels and their predictability; and (iv) reducing fertilizer costs from the port to rural villages.

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**ACRONYMS**

| | |
|---|---|
| AMIS | Agricultural Market Information System |
| AVCR | Average Value Cost Ratio |
| AP | Average Product |
| APP | Average Physical Product |
| ARI | Agricultural Research Institute |
| BMGF | Bill & Melinda Gates Foundation |
| BRN | Big Results Now |
| DAP | Di-Ammonium Phosphate |
| GDP | Gross Domestic Product |
| GISAIA | Guiding Investments in Sustainable Agricultural Intensification in Africa |
| GOT | Government of Tanzania |
| ISFM | Integrated Soil Fertility Management |
| MAFC | Ministry of Agriculture, Food Security, and Cooperatives |
| MIT | Ministry of Industry and Trade |
| MP | Marginal Product |
| MPP | Marginal Physical Product |
| MRP | Minjingu Rock Phosphate |
| MSU | Michigan State University |
| MVCR | Marginal Value Cost Ratio |
| NAIVS | National Agricultural Input Voucher Scheme |
| NBS | National Bureau of Statistics |
| PDB | Presidential Delivery Bureau |
| SUA | Sokoine University of Agriculture |
| TAMASA | Taking Maize Agronomy to Scale in Africa |
| TanSIS | Tanzania Soil Information System |
| TFRA | Tanzania Fertilizer Regulatory Authority |

## 1. INTRODUCTION

While Tanzania has enjoyed strong growth in GDP per capita since 2000, this growth has led to neither substantial reductions in rural poverty nor improvements in household nutritional status. This seeming paradox of economic stagnation amid rapid aggregate growth is also seen in the agricultural sector of Tanzania, as the source of impressive recent growth in agricultural GDP has been concentrated among large-scale producers of rice, wheat, and traditional export crops. As has been recognized by donors and African governments alike in recent years, one of the keys to reducing rural poverty and improving the nutritional status of rural households in Tanzania will be to achieve wide-spread improvements in food crop productivity among smallholder farmers. Prior to the international food price crisis of 2007/08, maize yields in Tanzania remained low, averaging between 800-900 tons/ha nation-wide, despite Tanzania's favorable agro-ecological potential. Subsequently, maize production stagnated during the 2000s and did not keep pace with population growth.

While there are likely to be a range of factors which contribute to low maize yields in Tanzania, an obvious constraint is the fact that as of the Agricultural Census of 2007/08, only 14.3% of smallholder maize producers applied inorganic fertilizer to maize, though this varied considerably by agro-ecological zone from a low of 0.9% in the Lake zone to 21% in the Southern highlands and 24% in the Coastal zone (Mather et al, 2016a). Likewise, use of improved maize seed (either OPVs or hybrids) was also low, as only 23.3% of smallholder maize growers used it in 2007/08 (ibid, 2016a). Although the southern highlands produce much of the country's maize and is a high potential zone, only 17% of maize growers there used improved maize seed in 2007/08. Although some of these growers may have seen demonstration trials of these improved inputs, they had not seen the potential the benefits of fertilizer and improved seed use in maize/rice production, relative to the costs, on their own plots.

In order to address both the short-term challenge of high food insecurity in 2008/09 and the longer-term challenge of improving smallholder demand for and access to inorganic fertilizer and improved seed for maize production, in 2008/09 the GoT, with significant funding from the World Bank, scaled-up an existing pilot targeted voucher scheme that by 2012/13 had provided up to 2.5 million smallholders with access to a limited quantity of inorganic fertilizer and improved maize seed at 50% of the market price (100% subsidy for maize seed) (World Bank, 2014a). The National Agricultural Input Voucher Scheme (NAIVS) was implemented from 2008/09 to 2013/14 and had two main short-term goals: (1) to improve farmer access to inorganic fertilizer for use on maize/rice and improved maize/rice seed; (2) to provide a rapid, sustained and predictable increase in smallholder farmers' effective demand for inorganic fertilizer and improved maize/rice seed so as to promote longer-term investment by the private sector fertilizer and seed supply chains (World Bank, 2009a). A third and long-term goal of NAIVS was that by improving both physical access to fertilizer for smallholders and reducing the financial risk involved for both smallholders and the supply chain suppliers, this would provide a relatively low-risk learning opportunity and experience for all actors in the supply chain for fertilizer and improved seed use in maize and rice production. Ideally, this lower-risk 'experimentation period' would lead to both an increase in smallholder demand for commercially priced fertilizer and improved seed, and an increase in supply chain actor investments in physical infrastructure, human capital, and exchange relationships so as to ‘jump-start’ the development of a spatially wider market-driven agricultural input distribution system.

However, whether or not experimentation with subsidized fertilizer and improved seed in smallholder maize production during the NAIVS period leads to an increase in their demand for market-priced fertilizer for use on maize– and thus contributing to the longer-term goal of sustainable increases in smallholder maize yields – is largely a function of the extent to which actual smallholder use of inorganic fertilizer is/was profitable under typical market-based input (fertilizer) and output (maize) prices.

In this paper, we use plot-level data from the National Panel Survey (NPS) panel household surveys, which were implemented during the NAIVS period, to address the following research questions:

1) How do observed smallholder maize-N response rates compare with those from agricultural experiment station ‘researcher-managed’ trials?
    a. To what extent do smallholders’ maize-nitrogen response rates vary by zone, and use of complementary inputs and plot management practices?
2) To what extent is smallholder use of inorganic fertilizer and/or improved seed in maize production profitable under typical smallholder conditions, given prevailing fertilizer and maize prices?
    a. How does profitability of fertilizer use on maize vary by zone, soil type, and complementary crop inputs and management practices?
3) What implications do the findings from (1) and (2) have for GoT strategies for improving the profitability of use of fertilizer and improved seed in smallholder maize production, and thereby improve the sustainability of higher maize yields in general in the longer-term, given that continuation of large-scale direct input subsidies appears to be financially unsustainable?

The paper is organized as follows. In section two, we describe the data sources used for descriptive and econometric analysis. Section three provides our conceptual framework and section four our empirical model. Section five discusses estimation issues, and section six our descriptive and econometric results. We conclude in section seven with a summary of findings as well as policy implications.

## 2. DATA SOURCES

### 2.1 Plot-level data on household input use and crop production

In this paper, we used household survey data from two main sources. The first is the National Panel Survey (NPS) implemented by the National Bureau of Statistics (NBS), which consists of a sub-sample of both urban and rural households from the 2005/06 Household Budget Survey. This sub-sample was first interviewed in 2010 and for rural households it asked retrospective questions about household consumption within the past two weeks. In addition, the agricultural component of the NPS survey asks rural households retrospective questions regarding household-, crop- and plot-level information regarding land access and use, crop production and marketing, input use, livestock production and sales, etc during the previous main and short seasons.

The sub-sample was then re-interviewed in 2011 (to cover the 2010/11 main and short seasons) and in 2013 (to cover the 2012/13 main and short seasons). Focusing on only mainland Tanzania, the NPS managed to re-interview n=1,389 households (68%) of the original 2008/09 sample in the two subsequent waves; n=209 (8.9%) were not re-interviewed in any wave; n=393 (17.5%) were re-interviewed in the second but not third wave; and n=111 household (5.5%) were re-interviewed in the third wave but not the second.

**2.2 Village-level data**

Distance to the nearest extension office is contained in the community-level survey implemented with each wave of NPS. Upon releasing each wave of the NPS data with the NBS, the World Bank also provided a range of agro-ecological variables (elevation, cumulative rainfall of wettest quarter, etc) that are generated by matching the village coordinates to secondary geospatial data.

**2.3 Regional monthly wholesale prices of maize**

Monthly wholesale data on maize prices comes from the Agricultural Market Information System (AMIS) of the Ministry of Industry and Trade (MIT). This data is collected on a weekly basis for several key staple crops and livestock products, from 20 markets across the country. There is at least one wholesaler market tracked by AMIS in 20 of the country's 22 regions.

**3. CONCEPTUAL FRAMEWORK**

The aim of this paper is to assess whether or not smallholder fertilizer use on maize – whether they obtained fertilizer at a 50% subsidy or at the full market price – is profitable using standard economic profitability measures within reasonable bounds of risk and uncertainty. In this section, we outline the conceptual framework from which we derive an estimable model by which we estimate the observable factors that affect smallholder maize yields. We begin by recognizing that Tanzanian smallholder farm households are multiproduct firms that typically grow a range of crops and are often involved in livestock and/or a variety of off-farm activities. We assume that these households maximize utility subject to constraints across all these activities. Given these assumptions, our yield models as derived from the constrained utility maximization model can be expressed as follows, as described by Sadoulet and de Janvry (1995):

(1) $$Y = f(X_{\mathrm{w}}, Z^{p}, V^{p}, \mathrm{T})$$

where Y represents smallholder maize yield, and $X_{\mathrm{w}}$ is a vector of inputs chosen by the household (including fertilizer). $Z^{p}$ is a vector of fixed household productive assets and human capital related to maize yield, and $Z^{p}$ represents a vector of village-level agro-ecological factors also related to maize yield. T represents the fixed transaction costs of accessing an output or input market, such as travel time to the nearest town or distance to the nearest fertilizer retailer, as de Janvry et al (1991) and Key et al (2000) such costs can limit farmers' ability to participate in markets.

## 4 EMPIRICAL MODELS

### 4.1 Estimable Model

From the conceptual model above, we estimate the effect of output prices and market access on output supply and input demand as follows:

(2) $Y_{ijt} = \beta X_{ijt} + \gamma_{it} + \omega_{kt} + \varepsilon_{ijt}$

(3) $\varepsilon_{it} = c_i + \mu_{it}$

$Y_{ijt}$ refers to the dependent variable of interest for output supply or input demand for household *i*, plot *j*, village *k*, in year *t* (the 2010/11 and 2012/13 main seasons). $X_{ijt}$ is a plot-level vector of inputs chosen by the household, such as the actual levels of nitrogen per hectare, phosphorous per hectare, use of improved seed (or not) used by the farmer on that plot, type of intercropping used (if any), years since the plot was last fallowed, and the respondent's classification of the plot's soil type. $\gamma_{it}$ a is a vector of fixed household-level productive assets and human capital, financial assets, household receipt of an extension visit, and household consumption characteristics. $\omega_{kt}$ is vector of village-level controls for agro-ecological potential and seasonal rainfall.

The error term $\varepsilon_{it}$ in (3) is a function of two components. The first component $c_i$ represents unobserved time-constant household-level factors such as soil quality, farm management skill, and/or risk preferences that may be correlated with observable household-level determinants of household commercial fertilizer demand. The second component $\mu_{it}$ represents unobserved time-varying shocks that may affect smallholder yields, such as adverse climatic, pest or crop disease events, household-specific health shocks, among others.

### 4.2 Estimating the profitability of fertilizer use on maize

In the absence of data on full production costs such as labor input, value cost ratios are often used to assess the profitability of fertilizer use (Kelly, 2005). The two ratios typically used are the Marginal Value Cost Ratio (MVCR) and the Average Value Cost Ratio (AVCR). In order to compute the MVCR, we first need an estimate of the marginal physical product of nitrogen ($MPP_N$). Theoretically, this derived from the maize yield (production) function (2) above by taking its first derivative with respect to input $N_{ijt}$, as shown in (5) below.

$MPP_{Nijt} = \delta Y_{ijt} / \delta N_{ijt}$ (5)

Empirically, we obtain an estimate of MPP by using the multivariate regression analysis estimator known as Ordinary Least Squares (OLS) of equation (2) above, and the coefficient on the variable measuring "quantity of nitrogen applied per hectare of maize" provides an estimate of $MPP_N$. This is the average maize-nitrogen response rate, and it tells us the additional quantity of maize produced (kg/ha) by the last unit of nitrogen applied (kg/ha), holding all other factors constant.

$MPP_{Nijt} = \delta Y_{ijt} / \delta N_{ijt}$ (5)

We then calculate the marginal value-cost ratio (MVCR) as follows:

$$(MVCR_{ijt}) = (PY_t) * (MPP_{Nijt}) \ / \ w_{ijt} \quad (4)$$

$(PY_t)$ is the annual average price of maize[1] in the marketing period of production year *t*. We note that profitability analysis can use either expected[2] or actual output (maize) prices, and we choose to use actual prices. We do this is because one of our main research questions is whether or not the smallholder fertilizer use observed in the NPS survey was actually profitable for those farmers, assuming they had all obtained fertilizer at the market rate. That is, we are interested to see whether or not farmers' use of fertilizer in those NPS years – whether obtained at market or subsidized rates – led to positive net returns, in which case we might expect such farmers to continue using fertilizer if the returns are high enough to remain profitable even if fertilizer is not subsidized. Thus, we value the additional maize produced (by either the last unit of fertilizer applied, or for all fertilizer used) using the annual average rural retail price (by region) of the marketing year for the main season production from 2010/11 and 2012/13 observed by NPS.

$w_{ijt}$ represents the unit price of fertilizer (w) used by household i on plot j in time t. Although we have estimated the MPP of nitrogen from observed plot-level survey data, when farmers decide whether or not to apply an input like inorganic fertilizer (and the amount to apply), they do not know at the time of application (at planting and early in the season) what their actual MPP of nitrogen will be (given the uncertainty of weather conditions, among other factors). However, our interest is in assessing *ex post* whether or not fertilizer use observed during the NPS survey years was profitable, had the fertilizer all been obtained at commercial rates.

We then compute the average value-cost ratio as follows:

$$(AVCR_{ijt}) = (PY_t) * (APP_{Nijt}) \ / \ w_{ijt} \quad (6)$$

Where $(APP_{Nijt})$ represents the *average* physical product of Nitrogen for household *i* on plot *j* in time *t,* which is typically computed as the household's quantity of maize production (on plot j in time t) divided by the quantity of fertilizer applied to that plot. However, in previous work on profitability of fertilizer use (Sheahan et al, 2013), the APP is computed as follows:

[1] As shown by Sheahan et al (2013), the maize price used by a given farmer in making input use decisions is likely to depend upon the farmer's intended use for his/her maize. For example, farmers growing maize as a surplus or cash crop may well use the average expected sale price in the months following the harvest. By contrast, for those who only sell some of their harvest to ease liquidity constraints but store and consume the rest, the value they place on own maize production is likely to be closer to the opportunity cost of 'not having maize' for consumption at various points during the year – thus the average expected village retail price.

[2] When deciding whether or not to purchase and apply inorganic fertilizer in maize production, a farmer must base their assessment of the likely net returns to fertilizer use on an expected price of maize (and their expected maize-N response rate), given that both post-harvest prices and actual yields that season are not known by the farmer when fertilizer is applied to their maize. Sheahan et al (2013) use expected maize prices in their analysis of the profitability of fertilizer use in Kenya because fertilizer use there is widespread, and their main research question is the extent to which farmers are making fertilizer use decisions that are consistent with profit-maximizing behavior.

$$APPNijt = \frac{[\hat{Y}ijtW - \hat{Y}ijtWO]}{Nijt} \quad (7)$$

$Y_{ijt}^{W}$ is the predicted maize yield for household *i* on plot *j* in time *t* with observed fertilizer use $N_{ijt}$, while $Y_{ijt}^{WO}$ is the predicted maize yield for that same household without fertilizer use. This method of calculating the average product describes the gain in maize yield (kg/ha) for household *i* on plot *j* in time *t* with observed fertilizer use $N_{ijt}$, relative to a counter-factual scenario in which that household had not used any fertilizer.

An AVCR greater than 1.0 means that, for a risk neutral household, the additional value of maize produced from applying nitrogen is greater than the cost of that nitrogen. In other words, an AVCR that exactly equals 1.0=1 implies that the farmer "breaks even", while an AVCR>1 means that the farmer's net returns to using fertilizer are positive. That is, an AVCR>1 means that fertilizer use is 'profitable' and the farmer is better off using fertilizer than not using it.

By contrast, the MVCR tells us how close the farmer is to achieving the economically optimal level of use of an input. For example, an MVCR > 1.0 indicates that the farmer could increase the value of his/her maize production (income) by increasing his/her rate of fertilizer application (i.e., the additional value of maize produced from the last kilogram of fertilizer applied is greater than the cost of that unit of fertilizer). By contrast, if a farmer's MVCR < 1, this implies that the farmer's income would be higher if they used less fertilizer. The profit-maximizing level of fertilizer use would be an MVCR=1 (i.e. the cost of the level of fertilizer use at which the last unit of N applied (kg/ha) equals the value of additional maize produced from that last unit of N.

While above we have indicated that a "risk-neutral" household would view an AVCR>1 as though the technology in question has positive net returns (i.e. is profitable), following Anderson et al (1977), general practice in assessing the profitability of use of a new technology (Kelly, 2005) and that of similar studies (Xu et al, 2009; Sheahan et al, 2013), we adjust the level of the MVCR and AVCR by a risk premium ρ=1. This implies that for fertilizer use to be profitable, the MVCR and/or AVCR should be >= 2.0. This risk premium adjusts the level of returns required for a farmer to assume that the returns from fertilizer use will be greater than not simply the additional costs of the technology itself for various reasons:

1) There is inherent uncertainty in what maize-N response rate the farmer may obtain in a given season (given the unpredictability of weather conditions and other biotic and abiotic stresses);
2) The output price of maize during the post-harvest period is uncertain at the time that the farmer decides whether or not to use fertilizer (and how much to use;
3) The MVCR and AVCR assumes that there are no additional costs of using fertilizer apart from the actual purchase price, yet there are often unobserved transaction costs associated with obtaining fertilizer.

In summary, adding a risk premium of 1.0 helps to approximate the rate of return at which fertilizer use is profitable enough for a farmer to take the risk of investing in fertilizer use on a rainfed crop like maize, given the uncertainty of rainfall and post-harvest maize prices.

### 4.3 Maize yield specification

4.3.1 Functional form

There is a large literature that address the choice of functional form in studies of crop productivity, with two general categories of approaches. The first uses a quadratic or other polynomial form, which by imposing concavity on yield response to inputs is consistent with the observation of diminishing marginal returns in crop production processes. The second approach argues that the polynomial neglects the fact that minimum levels of certain inputs are necessary for growth, and thus are based on the von Liebig functional form. However, this approach assumes that either the limiting factor of production is known, or, if unknown, is the same for all observations. Burke (2012) notes that while such an approach may be appropriate for experimental trial data -- where control of inputs and agro-ecological conditions may be quite controllable -- the inherent heterogeneity of smallholder crop production as captured by survey data makes the polynomial approach more appropriate. Burke's intuition is supported by work by Berck and Helfand (1990), which shows that under heterogeneous conditions, the results from polynomial and linear response and plateau (LRP) approaches (the latter being a form of von Liebig) converge, implying that the polynomial is more appropriate for use with the spatial and temporal variability inherent in longitudinal household survey data. We use a quadratic functional form for reasons given by Burke (2012) and because this is the form used by a number of similar studies (Traxler and Byerlee, 1993; Xu et al, 2009; Burke, 2012; Sheahan et al, 2013).

4.3.2 Measures of time-constant agro-ecological potential and time-varying season-specific agro-ecological conditions

To control for spatial variation in agro-ecological potential (on average), we include village-level information on elevation (meters above sea level). Given that nearly all maize production in Tanzania is rainfed, we include a village-level measure of the cumulative rainfall during the wettest quarter of the year.[3] To control for the average effect on maize yields each year from unobserved factors, we include binary indicators for the final two survey waves (2010/11 and 2012/13).

4.3.3 Plot-level use of inorganic and organic fertilizer and complementary inputs

Based upon information from the survey respondent regarding the type and quantity of fertilizer used on a given plot, we convert fertilizer quantity applied to a given plot to nitrogen and phosphorous. We also add the farmer's estimate of quantity (kgs) of manure applied to each plot, as organic fertilizer can increase soil fertility and thus fertilizer response rates. We note that the NPS survey effort did not include soil testing, thus we do not observe the amount of key macro and micro nutrients actually available in the soil at planting or after fertilizer application.

Because hybrids and improved OPVs generally respond better to fertilizer than traditional varieties (assuming adequate rainfall), we include a binary variable that =1 if the household used an improved OPV or hybrid on that maize plot. We also include a binary indicator that

[3] This rainfall variables are derived from rainfall estimates based on data from satellites (such as on cloud cover and cloud top temperatures) and rain stations, which are combined to interpolate estimates of decadal (10-day period) rainfall, which can be matched to sample households/villages using global positioning system (GPS) coordinates. Rainfall estimates were matched to 1360 sample households using GPS coordinates, and to the village for the remaining households (World Bank, 2010/2012/2014).

=1 if the household planted maize with a legume that season, given evidence from Kenya that intercropping maize with leguminous crops improves maize yield (Rao and Mathuva, 2002). Another complementary input for crop production is the education level of the manager of a given plot, as adoption of improved inputs and their proper application has been found in other studies to be positively correlated with higher education levels (Feder, Just, and Zilberman, 1985; Foster and Rosenzweig, 1995; Foster and Rosensweig, 1996). The NPS plot-level data tells us which individual in the household 'decided what to plant' on any given plot.[4] We assume that this implies that this individual is the 'plot manager', and we therefore use that individual's number of years of schooling as a plot-level measure of human capital.

4.3.4 Plot-level cropping patterns and soil information

The survey instrument asks respondents when each plot they cultivate was last fallowed, and we use their response of 'years since fallow' as a proxy for soil fertility. However, about 90% of the plots with maize were reported to have 'never been fallowed'. For these cases, we used information available for all plots on 'year the plot was acquired' along with three different assumptions of the years since the plot was likely fallowed. Because fallowing rates can vary considerably across districts due to variation in population density, we computed the median 'years since fallow' by ward. We then generated three different values of 'years since fallow' for those plots declared to have 'never been fallowed'. First, we define 'year since fallow' = "year plot was acquired" minus "ward median years since fallow". Second, "year plot was acquired" minus (0.5 * "ward median years since fallow"). Third, we define "years since fallow" = "year plot was acquired'. This enables us to test the sensitivity of our assumption of "years since fallow" for those plots declared to have 'never been fallowed'. We use the second assumption above for our results below.

The survey instrument also asks the respondent to indicate the general soil structure of each plot, prompting them with the following options: sandy, clay, loam or other. As there were very few cases of 'other', we combine these with clay, make that the intercept, and generate binary indicators that =1 if the plot soil is 'sandy' (as per the farmer's knowledge) and another than =1 if the plot soil is 'loam'.

4.3.4 Household-level factors

To control for inter-household variation in assets related to crop production, we include various household-level factors in our yield specification. We include the log of the total value of the household's farm/home assets as a measure of household wealth, which serves as a proxy for either credit access or the ability to self-finance inputs that require cash (such as inorganic fertilizer, improved seeds, hired labor, etc). Because we do not have village-level data on agricultural wages, and because the majority of labor used in smallholder maize production in Tanzania is family labor, we use the number of prime-age adults (ages 15 to 64) divided by the total area of the plot as a proxy for availability of family labor (along with its square). Finally, we also include the household's total landholding given the conventional wisdom that smaller farms tend to have higher returns per hectare to inputs (the 'inverse productivity' effect).

[4] Information regarding who makes this decision is provided for about 60% of the maize plots we observe; for those with missing information, we assume that the 'plot manager' is the household head and thus use his/her years of education for cases with missing information on the plot manager.

There are various ways by which knowledge can be disseminated regarding the potentially positive net benefits of using inputs like inorganic fertilizer and improved seed, as well as their proper application. For example, a household might receive a visit or participate in a demonstration led by a government or non-government extension agent, receive an extension pamphlet, and/or perhaps learn farmer-to-farmer from either trained or untrained farmers. The NPS survey instrument collected information at the household-level on whether or not the household received an extension visit in a given year, the content of the visit, and the source of the extension agent. We use this information to generate two separate binary indicators for household receipt of an extension visit that pertained to "crop production or marketing". The first is an indicator that =1 if the household received an extension visit from a government extension agent (from any source) that pertained to agricultural production, the second =1 if the household received an extension visit from 'private sector', 'NGO' or 'farmer cooperative'.[5] We note that the knowledge gained from an extension visit may have an effect on crop production (or not, depending on whether the farmer decides to act on the advice) not only in the year of the extension visit, but also in later years. Thus, we define the extension indicator for each household to =1 if they received an extension visit that year, and any subsequent NPS panel year.

*A priori*, we would expect that household receipt of a visit by an extension agent (which could be from the public extension system, a fertilizer or seed company, NGO, etc) should be expected to increase the probability that the household follows the recommended fertilizer application rate and timing as prescribed by the NAIVS program and/or other evidence-based application information. For example, anecdotal evidence suggests that some farmers who are not properly informed about optimal fertilizer application rates may take the fertilizer they received at a subsidized rate from NAIVS (two 50 kg bags, intended for one acre of maize) and spread it over more than one acre of maize. Because this variable could potentially be endogenous, we outline below how we test for endogeneity of household receipt of an extension visit.

4.3.4 Interaction terms

Because agronomic research shows that the returns to inorganic fertilizer and improved seed are conditioned by a wide range of agronomic factors and complementary input decisions, and that many of these factors have positive and/or negative interaction effects, we interact N, P, manure and improved varietal use with each other and with agro-ecological factors such as rainfall, elevation, soil quality, and years since fallow.

## 5. ESTIMATION ISSUES

### 5.1 Controlling for unobserved time-constant heterogeneity $c_i$

If unobservable time-constant characteristics such as soil quality, farm management ability, or risk preferences are correlated with household's input use decisions, this can lead to a form of endogeneity termed "omitted variable bias" by Wooldridge (2002) that results in biased coefficient estimates. In addition to the actual soil fertility of a given plot, other important factors that are unobserved by our data include the household's seeding rate and

[5] "Private sector" extension likely refers to extension agents that work for some of the larger fertilizer and/or seed companies.

the timing of fertilizer application. The household data set used in this paper is longitudinal, which offers the analytical advantage of enabling us to control for time-constant unobservable household-level characteristics ($c_i$). To control for these unobserved time-constant household characteristics, we use a fixed effect (FE) estimator, as it requires no assumption regarding the correlation between observable determinants (vector $X_{it}$) and unobservable heterogeneity ($c_i$). Use of the FE estimator combined with information on 'years since fallow' should minimize if not eliminate the potential for bias from unobserved soil quality, given that factors such as soil organic matter (SOM) do not change quickly over time. Assuming that the household uses the same seeding rate and fertilizer application timing over time, use of FE would also control for unobserved heterogeneity across households regarding those input decisions.

Using OLS-FE implies that any time-constant variables such as elevation, soil type, etc are included within the household-level fixed effect (i.e. one cannot estimate a partial effect from time-constant regressors if we use OLS-FE). However, our primary interest is in estimating Maize-N response, and how it varies by agro-ecological factors, use of other inputs etc, thus if any of these interaction terms are time-constant, they do not drop out of our estimated model given that the nitrogen application rate (kg/ha) is not time-constant.

### 5.2 Controlling for unobserved shocks $\mu_{it}$

While the FE approach outlined above controls for time-constant unobserved household heterogeneity ($c_i$), our maize-N response rate estimates may still be subject to another source of endogeneity bias. This could occur if unobserved time-varying shocks $\mu_{it}$ are correlated with explanatory variables $X_{it}$ of interest in (2). Such unobserved time-varying shocks could include adverse climatic, pest or crop disease events, household-specific health shocks, etc. However, we do have some observed factors that may help to control for such unobserved time-varying shocks. For example, we include in each model a year dummy that =1 for the second (third) year of the panel wave, and this will pick up the average effect of all unobserved factors (across the whole sample). We also include the actual cumulative rainfall during the wettest quarter of the year.

### 5.3 Testing for potential endogeneity of household receipt of extension visit

If household receipt of an extension visit is correlated with unobserved household-level factors (such as farm management skill or lack thereof), this source of endogeneity is controlled for via our use of OLS with plot-level fixed effects. However, because this regressor could be correlated with time-varying factors, we follow Ricker-Gilbert et al (2011) to test for correlation between time-varying factors and household receipt of an extension visit an adapted Control Function (CF) approach developed by Rivers and Vuong (1988) to control for a continuous endogenous explanatory variable. As with the 2SLS approach to instrumenting for an endogenous variable, the CF approach requires an instrumental variable (IV) that satisfies two criteria. First, the IV must have a significant effect on the endogenous variable (binary indicator that =1 if household received an extension visit related to agricultural crop production) used in the reduced form regression. Second, we must assume that our instruments are not correlated with the dependent variable of the structural equation (quantity of commercial fertilizer demanded), conditional on the other observable factors -- a maintained assumption that cannot be tested.

As distance from village to the nearest extension office was not observed by NPS, we instead use “number of years the head’s spouse has lived in the village” as an IV for a “household receipt of a government extension visit.” We use the natural log of “distance from the village to the district capitol” as an IV for “household receipt of a non-government extension visit”.  Because we are separately controlling for factors typically correlated with use of improved inputs such as agro-ecological potential and wealth levels (in the set of controls $X_{it}$), as well as controlling for time-constant unobservable factors (thru use of OLS-FE), there is little reason to suspect that our IVs would be correlated with any remaining time-varying factors in the error term of smallholder plot-level maize yield, as described by equation (3).

### 5.3 Panel Attrition

For our econometric analysis below, we only use plots with maize from NPS households that were interviewed in each of the three waves of this panel.  Panel household surveys typically have to contend with at least some sample attrition over time, given that some households move away from a village over time and others dissolve as part of a typical household life-cycle. If households that are not re-interviewed are a non-random sub-sample of the population, then using the re-interviewed households to estimate the means or partial effects of variables during one of the later panel time periods may result in biased estimates.

To test for attrition bias in our input demand regression (2), we follow the regression-based approach described in Wooldridge (2002) and define an attrition indicator variable that is equal to one if the household dropped out of the sample in the next wave of the panel survey, and equal to zero otherwise. This binary variable is then included as an additional explanatory variable in each regression model for each crop, which is run using all household observations from 2007/08 (in panel villages only). If the coefficient on this binary variable is statistically different from zero, this indicates the presence of attrition bias with respect to that model.

## 6. RESULTS

### 6.1 Descriptive analysis of maize plots and input use

#### 6.1.1 Fallowing, cropping patterns, and use of improved inputs

We first note that the percentage of fields planted with maize that were fallowed in the previous year is not high in 2008/09 (9.6%), yet this percentage declines dramatically to only 2.8% in 2012/13 (Table 1).  Subsequently, the average number of years since the plot was last fallowed increases over time.  However, when we look at the percentage of fields planted without maize that were fallowed in the prior year, these values are at least double those of fields planted with maize in each year (18% in the southern highlands; average of 21% overall in 2008/09) (Table 2).  While the fallowing of non-maize fields also falls over time, this decline is only seen in the third panel wave (2012/13) and the decline is not as steep (from 21% in 2010/11 to 14.9% in 2012/13).

**Table 1. Cropping, input use, and plot management of maize fields by year**

| 2008/09<br>zone | % fallowed last year | Years since fallow | % mono-cropped | % int-cropped w/legume | % applied inorganic fertilizer | % used improved maize seed | % used i.fert & IMS | % applied manure | % used manure & i.m.seed | % plots that are loam | % plots that are clay | % plots that are sandy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S.High | 9.4 | 16.3 | 45.5 | 34.9 | 30.1 | 8.9 | 5.9 | 12.7 | 1.8 | 74.3 | 8.4 | 13.1 |
| Northern | 5.5 | 17.6 | 19.8 | 40.5 | 16.5 | 28.6 | 13.2 | 31.3 | 11.1 | 79.9 | 7.1 | 12.3 |
| Eastern | 4.8 | 15.6 | 34.9 | 24.3 | 1.7 | 10.9 | 1.5 | 3.4 | 1.9 | 78.9 | 15.8 | 5.4 |
| Central | 17.9 | 12.8 | 48.4 | 38.5 | 5.6 | 9.6 | 3.2 | 20.1 | 0.8 | 64.0 | 17.2 | 17.8 |
| Lake | 10.4 | 17.2 | 23.5 | 44.1 | 1.1 | 20.0 | 0.5 | 8.2 | 2.1 | 42.2 | 18.2 | 35.8 |
| West | 7.5 | 14.2 | 25.3 | 57.0 | 10.8 | 6.9 | 2.0 | 9.3 | 0.0 | 75.9 | 14.0 | 10.1 |
| South | 8.6 | 14.5 | 13.7 | 22.3 | 2.2 | 4.7 | 0.0 | 1.1 | 0.0 | 48.2 | 11.4 | 39.8 |
| Total | 9.3 | 15.8 | 35.4 | 36.2 | 14.5 | 12.1 | 4.1 | 12.1 | 2.3 | 67.9 | 12.4 | 17.4 |
| | | | | | | | | | | | | |
| **2010/11** | | | | | | | | | | | | |
| S.High | 7.4 | 18.3 | 46.2 | 36.6 | 36.8 | 9.3 | 6.3 | 14.6 | 2.1 | 65.8 | 18.3 | 14.0 |
| Northern | 5.3 | 19.5 | 21.1 | 48.6 | 16.3 | 30.9 | 10.2 | 32.1 | 10.3 | 82.4 | 7.4 | 9.1 |
| Eastern | 6.9 | 16.7 | 36.3 | 26.0 | 1.9 | 5.1 | 0.0 | 3.6 | 0.5 | 71.4 | 21.7 | 6.3 |
| Central | 1.6 | 15.8 | 50.8 | 20.7 | 4.9 | 4.2 | 1.4 | 20.8 | 2.1 | 68.2 | 13.8 | 17.9 |
| Lake | 17.4 | 15.4 | 27.4 | 48.4 | 0.7 | 9.4 | 0.7 | 13.1 | 2.5 | 68.3 | 13.2 | 18.5 |
| West | 2.4 | 17.2 | 33.9 | 35.9 | 13.8 | 0.0 | 0.0 | 7.6 | 0.0 | 70.0 | 17.1 | 12.8 |
| South | 4.6 | 14.9 | 17.0 | 16.3 | 2.9 | 3.3 | 0.0 | 1.4 | 0.0 | 34.5 | 16.6 | 49.0 |
| Total | 7.0 | 17.2 | 37.6 | 34.0 | 17.3 | 8.7 | 3.4 | 13.5 | 2.3 | 66.6 | 16.5 | 16.1 |
| | | | | | | | | | | | | |
| **2012/13** | | | | | | | | | | | | |
| S.High | 2.0 | 20.2 | 43.7 | 35.5 | 31.3 | 14.6 | 6.1 | 14.2 | 1.7 | 56.4 | 21.4 | 16.9 |
| Northern | 1.3 | 20.5 | 29.9 | 49.8 | 15.6 | 56.5 | 11.1 | 34.8 | 22.2 | 72.8 | 13.6 | 11.5 |
| Eastern | 2.7 | 18.2 | 35.8 | 27.2 | 0.7 | 18.2 | 0.0 | 4.6 | 0.5 | 71.1 | 15.3 | 7.1 |
| Central | 2.3 | 16.8 | 58.8 | 21.0 | 6.2 | 11.4 | 4.4 | 24.8 | 4.3 | 60.7 | 12.3 | 25.3 |
| Lake | 6.2 | 18.8 | 26.6 | 39.7 | 0.7 | 30.7 | 0.0 | 16.6 | 6.2 | 69.8 | 14.9 | 13.6 |
| West | 2.3 | 18.7 | 35.8 | 50.7 | 12.7 | 11.1 | 3.0 | 10.2 | 2.2 | 75.4 | 14.0 | 8.7 |
| South | 2.2 | 17.8 | 13.8 | 16.4 | 2.4 | 5.6 | 0.0 | 1.6 | 0.0 | 45.6 | 11.5 | 42.3 |
| Total | 2.8 | 19.1 | 37.1 | 35.1 | 14.4 | 20.2 | 3.8 | 14.9 | 4.3 | 63.6 | 16.5 | 16.4 |

Source: NPS survey data. n= 2,820 (2008/09); n=2,269 (2010/11); n=2,928 (2012/13)

**Table 2. Plot-level fallowing among non-maize plots**

| | Plots cultivated without maize | | | | | | All plots | | |
|---|---|---|---|---|---|---|---|---|---|
| | % plots fallowed in previous year[1] | | | mean years since last fallow year[1] | | | % plots with some maize planted[1] | | |
| Zone | 2008/09 | 2010/11 | 2012/13 | 2008/09 | 2010/11 | 2012/13 | 2008/09 | 2010/11 | 2012/13 |
| S.Highlands | 19.2 | 16.0 | 13.4 | 16.1 | 18.0 | 19.6 | 71.6 | 60.8 | 76.9 |
| Northern | 13.7 | 17.2 | 14.0 | 19.1 | 19.9 | 21.5 | 66.8 | 51.2 | 65.4 |
| Eastern | 21.3 | 23.5 | 20.1 | 15.1 | 17.0 | 18.8 | 61.0 | 45.3 | 64.8 |
| Central | 23.1 | 6.4 | 10.9 | 13.3 | 17.8 | 18.5 | 45.8 | 46.4 | 46.8 |
| Lake | 22.9 | 35.9 | 17.8 | 16.7 | 17.9 | 19.3 | 43.7 | 21.1 | 46.7 |
| West | 24.0 | 26.8 | 19.6 | 15.1 | 16.6 | 18.2 | 55.4 | 29.1 | 59.7 |
| South | 19.0 | 19.2 | 10.7 | 14.6 | 14.5 | 17.0 | 54.0 | 40.8 | 62.9 |
| Total | 21.0 | 22.4 | 15.7 | 15.8 | 17.5 | 19.1 | 58.2 | 41.7 | 61.2 |

Source: NPS survey data. Notes: 1) computed using plots that were cultivated in the main season indicated

Given that 60 to 75% of plots in all zones but the Lake zone and the drier Central zone are planted with maize in each of these seasons, the low fallowing rate and long duration between fallows on maize plots is worrying because it is well-known that unless a farmer employs cropping, plot management and/or input use to maintain soil nutrient levels, then continuous cropping – especially with a crop like maize – can mine micro and macro nutrients from the soil over time. This is especially important within the context of a smallholder maize yield improvement strategy such as that of NAIVS because grain responses to inorganic fertilizers can be far below potential if micronutrient and SOM levels are low (Marenya and Barrett, 2009). As we might expect, the zone with the highest population density (northern highlands) – and subsequently the highest number of adults per hectares cultivated (Table 3) has the lowest rate of fallowing both maize and all other plots (Table 1, Table 2).

We also find that, relative to growers in other zones, those in the northern highlands are more likely to use an improved maize variety (27.5%), apply manure to maize (32%), to combine inorganic or organic fertilizer with an improved variety, and/or to intercrop maize with a legume (45%). Each of these decisions are ways in which to increase yields via yield-enhancing input use or use of cropping systems that restore and/or maintain soil nutrient levels. There are a number of potential explanations for the relative lack of improved maize seed use in the southern highlands relative to the northern regions. First and foremost, Tanzania's maize (and other seed) companies are based in Arusha (northern region), thus growers in the north have long had better access to improved seed than those in the south.[6] Second, population density

[6] In 2011/12 and 2012/13, the average distance to nearest seed seller is similar in the south and north, but that is likely due to the fact that NAIVS targeted the south with more vouchers than any other zone. Unfortunately, we do not have access to a measure of distance to nearest seed seller for 2008/09 (first year of NAIVS), and this question was not included in the Ag Census of 2007/08.

in Arusha and Kilimanjaro are so high that the economic incentives for land-saving inputs (such as improved seed) are undoubtedly higher than in the south.

Third, maize prices in the north are consistently higher than in the south, due to strong export demand from Kenya. When these three factors are taken together, it suggests first that growers in the south are likely to have simply had less exposure to improved seed varieties than those in the north (prior to NAIVS), and that the economic returns to seed are likely higher in the north due to more favorable output (maize) prices. In addition, during key informant interviews with seed companies in Arusha, they told us that in several zones of the country, their perception is that farmers believe that they can attain sufficient yield gains with fertilizer alone and that the additional cost of seed is not worth the additional yield gain. That said, the lack of improved seed use in the south even after several years of NAIVS suggests a need for further investigation, which we address to some extent in the profitability analysis section.

As noted in the section above, additional factors that can affect maize yield include access to extension, availability of family labor, rainfall and elevation. Government extension and/or non-government extension visits were received by sample households across all zones, though it appears that households in the higher potential areas (southern highlands and northern zones) were more likely to have received a visit from a government extension agent in that year (or in a previous NPS survey wave year) (Table 3). This may be due to the fact that NAIVS targeted predominantly more of its input subsidy vouchers to those zones, and/or that it is easier for extension agents there to visit more households per week given higher population densities. The higher population densities of the southern highlands and northern zones is seen in the higher average number of adults per hectare (Table 3). In addition, the greater average seasonal rainfall in the southern highlands is clear from Table 3.

6.1.2 Plot-level average and median maize yields by year

Smallholder maize yields during the NPS survey yields have a strong positive skew, thus the mean is considerably higher than the median in each zone (Table 4). As expected, average and median yields in the high potential zones in the southern (northern) highlands are higher than other zones. Also as expected, maize yields from plots on which inorganic fertilizer is used are the highest average yields with the exception of the northern highlands and eastern zones (Table 4). It is important to note that inorganic fertilizer is only one of a few inputs which the farmer can control, while there are a large number which he/she cannot. In addition, returns to fertilizer itself are highly conditioned by complementary input use (i.e. varietal choice, sufficient and timely weeding, etc) and both soils, weather, and elevation (temperature) conducive to optimal maize-fertilizer response and maize yields in general.

**Table 3. Plot-level measures of household or village-level characteristics**

| 2008/09 | % HHs received extension visit[1] | | | | | |
|---|---|---|---|---|---|---|
| zone | GoT | Priv Sector, NGO, etc | # HH adults 15-64 per ha | Years of education of plot manager | Rainfall wettest quarter (mm) | Elevation (m) |
| S.High | 16.0 | 5.0 | 3.7 | 6.3 | 677 | 1,426 |
| Northern | 19.7 | 8.9 | 3.1 | 7.2 | 168 | 1,279 |
| Eastern | 11.2 | 1.2 | 2.0 | 6.3 | 308 | 615 |
| Central | 36.2 | 7.3 | 1.7 | 6.1 | 408 | 1,146 |
| Lake | 14.4 | 8.5 | 2.5 | 6.7 | 477 | 1,235 |
| West | 4.6 | 9.8 | 1.6 | 6.0 | 535 | 1,217 |
| South | 10.5 | 6.4 | 2.2 | 6.6 | 540 | 389 |
| Total | 16.6 | 5.9 | 2.8 | 6.4 | 500 | 1,149 |
| | | | | | | |
| **2010/11** | | | | | | |
| S.High | 11.3 | 8.1 | 4.4 | 6.6 | 656 | 1,438 |
| Northern | 10.8 | 2.6 | 3.9 | 7.5 | 300 | 1,345 |
| Eastern | 3.9 | 1.5 | 3.5 | 6.0 | 461 | 597 |
| Central | 5.1 | 6.5 | 2.3 | 6.2 | 343 | 1,191 |
| Lake | 10.9 | 4.8 | 4.0 | 6.8 | 441 | 1,251 |
| West | 3.9 | 5.3 | 2.8 | 6.3 | 464 | 1,218 |
| South | 3.4 | 4.2 | 3.0 | 6.6 | 875 | 371 |
| Total | 8.2 | 5.5 | 3.7 | 6.5 | 534 | 1,155 |
| | | | | | | |
| **2012/13** | | | | | | |
| S.High | 7.4 | 4.6 | 4.5 | 6.6 | 628 | 1,392 |
| Northern | 7.8 | 1.5 | 4.2 | 6.9 | 283 | 1,365 |
| Eastern | 0.7 | 0.7 | 3.4 | 6.3 | 343 | 641 |
| Central | 12.3 | 3.8 | 2.6 | 6.2 | 373 | 1,183 |
| Lake | 8.3 | 3.6 | 3.4 | 6.9 | 509 | 1,238 |
| West | 5.2 | 15.6 | 3.3 | 6.7 | 540 | 1,269 |
| South | 3.3 | 1.1 | 3.7 | 6.7 | 591 | 387 |
| Total | 6.7 | 4.4 | 3.8 | 6.6 | 503 | 1,161 |

Source: NPS survey data. Notes: 1) Household reported receipt of an extension visit related to agricultural production that year.

**Table 4. Plot-level average and median maize yields, with and without inorganic fertilizer or manure application by year**

| **2008/09** | ---------------- Plot-level maize yield (kg/ha) ----------------- | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | All growers | | No inorganic or organic fertilizer applied | | applied inorganic fertilizer | | applied manure | |
| zone | mean | median | mean | median | mean | median | mean | median |
| S.Highlands | 1,410 | 1,006 | 1,176 | 848 | 1,852 | 1,307 | 1,549 | 1,113 |
| Northern | 1,249 | 949 | 1,225 | 970 | 1,458 | 934 | 1,622 | 1,176 |
| Eastern | 1,136 | 756 | 1,162 | 756 | 578 | 757 | 1,502 | 1,051 |
| Central | 1,125 | 887 | 1,039 | 824 | 2,076 | 1,716 | 1,249 | 830 |
| Lake | 1,207 | 563 | 1,176 | 486 | 1,132 | 910 | 1,036 | 771 |
| West | 1,269 | 716 | 1,083 | 685 | 1,794 | 1,548 | 1,204 | 706 |
| South | 640 | 392 | 636 | 391 | 880 | 812 | 919 | 537 |
| Total | 1,233 | 798 | 1,108 | 710 | 1,781 | 1,301 | 1,373 | 938 |
| | | | | | | | | |
| **2010/11** | | | | | | | | |
| S.Highlands | 1,549 | 1,113 | 1,447 | 981 | 1,730 | 1,300 | 1,435 | 1,235 |
| Northern | 1,622 | 1,176 | 1,651 | 1,123 | 1,850 | 1,519 | 1,487 | 832 |
| Eastern | 1,502 | 1,051 | 1,529 | 1,059 | 1,895 | 2,470 | | |
| Central | 1,249 | 830 | 1,159 | 729 | 1,658 | 970 | 1,616 | 932 |
| Lake | 1,036 | 771 | 989 | 627 | 4,776 | 4,776 | 1,166 | 1,029 |
| West | 1,204 | 706 | 1,261 | 772 | 1,110 | 671 | 728 | 291 |
| South | 919 | 537 | 931 | 543 | 696 | 518 | 398 | 518 |
| Total | 1,373 | 938 | 1,305 | 875 | 1,700 | 1,270 | 1,378 | 953 |
| | | | | | | | | |
| **2012/13** | | | | | | | | |
| S.Highlands | 1,454 | 988 | 1,284 | 891 | 1,843 | 1,235 | 1,409 | 787 |
| Northern | 2,049 | 1,511 | 2,054 | 1,497 | 2,376 | 1,853 | 1,794 | 1,246 |
| Eastern | 1,471 | 970 | 1,441 | 943 | 1,415 | 1,415 | 2,150 | 2,062 |
| Central | 1,181 | 692 | 1,135 | 679 | 1,368 | 872 | 1,387 | 762 |
| Lake | 1,176 | 741 | 1,136 | 714 | 1,457 | 1,457 | 1,379 | 819 |
| West | 1,205 | 659 | 1,169 | 593 | 1,509 | 1,141 | 1,146 | 768 |
| South | 1,061 | 599 | 1,049 | 593 | 1,851 | 1,644 | 353 | 475 |
| Total | 1,382 | 852 | 1,282 | 785 | 1,842 | 1,375 | 1,485 | 904 |

Source: NPS surveys

**6.2 Econometric analysis of plot-level maize yields**

6.2.1 Test for Panel Attrition

Approximately 7% of plots on which maize was grown in 2008/09 were cultivated by households that were not re-interviewed in either of the two follow-up survey waves (2010/11 or 2012/13). The results of our regression-based attrition test find that the binary indicator of attrition is not significant (p=0. 0.736). We next add interaction terms between the attrition dummy and our key regressors: quantity of nitrogen applied (kg/ha), years since fallow, and use of an improved variety. The interaction between nitrogen quantity applied and the attrition dummy is not significant (p=0.595) nor are the combined terms interacted with attrition significant (p=0.393). Given that these results suggest that there is not panel attrition bias with respect to our smallholder maize yield model and the regressors of most interest to us, we proceed by applying the household sampling weights from the first wave 2008/09 to observations from subsequent waves (without an adjustment for panel attrition).

Of the n= 3,752 plots cultivated with maize observed across the three survey waves, 86.3% of these were cultivated by households that were interviewed in all three waves, 9% from households interviewed in the first two waves only, and 4.7% from households interviewed in the first and third wave. In the following analysis, we use an unbalanced panel of plots (on which maize was cultivated that main season) from households that were observed in at least two of the three survey waves.

6.2.2 Panel years used in the analysis

Unfortunately, the plot-level input use section of the NPS survey instrument in 2008/09 only recorded up to one type (and quantity) of inorganic fertilizer applied to a given crop,[7] while those for 2011/12 and 2012/13 prompted farmers to name up to two types of inorganic fertilizer (and the quantity of each) applied to each plot. The latter two years of NPS survey data show us that while 70 to 75% of smallholders who used inorganic fertilizer on maize only used one type (usually urea), about 20 to 25% also applied a basal fertilizer (DAP, NPK, etc). Thus, it is very likely that the quantity of fertilizer (N, P) per hectare that we observe in 2008/09 is lower than it actually was, given that there is likely some 'missing' data on the total fertilizer used on maize in that year for at least some farmers. The implications for the purposes of this paper is that if we use data from the 2008/09 survey wave to estimate the effect of nitrogen and phosphorous use on maize yields, there is likely to be an upward bias in our estimate of the partial effect of N and P because the observed fertilizer use of about 25% or so of farmers who applied fertilizer to maize is likely lower than actual fertilizer use per hectare.[8] We therefore we proceed with the following econometric analysis using only plot-level data from 2011/12 and 2012/13.

[7] The plot-level crop inputs section of the survey instrument in 2008/09 only enabled enumerators to ask respondents whether or not they applied one type of inorganic fertilizer on a given crop (and then asked for the quantity applied of that type of fertilizer).

[8] In fact, when we use all three years of NPS plot-level data, we find slightly higher maize-N response rates, but as noted already, this is very likely an upward bias due to missing data on fertilizer quantity applied to maize (for at least some farmers).

6.2.3 Test for endogeneity of household receipt of extension visit

As noted in Section 5.3 above, we use a control function approach to test for two potential endogenous variables related to household receipt of an extension visit. The first stage of this approach is to estimate a separate probit regression for the two extension binary indicators, as a function of all the regressors in equation (2), plus the instruments for both potentially endogenous variables, noted above. The partial effect on the IV "number of years the spouse lived in the village" is significant (p=0.027) and positive in the probit of "1=household received visit by government extension agent". Likewise, the partial effect of the IV "log of distance from village to district capitol" is significant (p=0.028) and positive in the probit of "1=household received a visit by a non-government extension agent." We then add the endogenous variables and the residuals from each first stage probit to the plot-level OLS model of maize yield (3). We find that the residual from the probit of government extension visit is not significant (p=0.399), nor is the residual from the probit of non-government extension significant (p=0.653). The implication is that both of our binary extension indicators are exogenous in our maize yield regression, after controlling for other observable factors.

6.2.4 Observable determinants of plot-level maize yield

In this section, we assess the extent to which observable factors that affect smallholder maize yields have expected signs and significance. Because the coefficients from the OLS regression reported in Table 5 do not give us the actual partial effects of factors with quadratic (squared) terms, we compute the partial effects of key variables separately (Table 6). Our specification includes measures of quantity of nitrogen (N) and phosphorous (P) applied per hectare (kg/ha) but not their squared terms, as the squared terms were not significant. This is perhaps not surprising given that among fertilizer users, median fertilizer use is only 176 kg/ha, which is considerably less than the NAIVS blanket recommended level of 247 kg/ha. Thus, the lack of evidence of diminishing marginal returns to N or P may indicate that the observed fertilizer use exhibits linear returns, on average.

First, as expected, we find significant and positive effects of the quantities of both nitrogen and phosphorous applied. For example, an additional kg/ha of N increases maize yield by 7.5 kg/ha (i.e. this is the maize-N response rate), while an additional kg/ha of P increases maize yield by 8.2 kg/ha (Table 6) – holding all other factors fixed at average levels. Likewise, an additional kg/ha of manure increases maize yield by 0.10 kg/ha. Although the coefficient on use of an improved maize seed variety (OPV or hybrid) is positive and sizeable at 104, it is not close to being significant. Given that below we find that households that use fertilizer achieve higher maize-N response rates if they also use an improved variety, the lack of a significant positive effect of improved maize seed by itself may be due to the fact that hybrid varieties are bred to perform best when combined with inorganic fertilizer, and quite a few improved seed users do not use fertilizer[9].

[9] Unfortunately, the NPS data do not enable us to distinguish between OPV and hybrid seed.

**Table 5. Plot-level OLS regression of smallholder maize yield, 2010/11, 2012/13**

| | OLS-FE at household level | |
|---|---|---|
| | Dept Var = maize yield (kg/ha) | |
| Explanatory variable | Coefficient | P-value |
| Year dummy (1=2013) | -79.03 | 0.549 |
| ln(wettest quarter cumulative rainfall (mm)) | 4,877 | 0.261 |
| ln(wettest quarter cumulative rainfall (mm)), squared | -389.2 | 0.251 |
| Qty of Nitrogen applied to maize (kg/ha) | 12.15 | 0.544 |
| Qty of Phosporous applied to maize (kg/ha) | 120.9* | 0.0242 |
| 1=improved OPV or hybrid seed | 1,868 | 0.394 |
| Qty of manure applied to maize (kg/ha) | -0.292 | 0.394 |
| Qty of manure applied to maize (kg/ha), squared | -9.37e-07 | 0.120 |
| years since fallow | 24.99 | 0.750 |
| years since fallow, squared | -0.126 | 0.779 |
| 1=maize was intercropped with non-legume | 514.4 | 0.780 |
| 1=maize intercropped with legume | -1,287 | 0.458 |
| 1=plot soil is sandy | 1,490 | 0.502 |
| 1=plot soil is loam | -1,683 | 0.317 |
| 1=HH has title to plot | 114.9 | 0.321 |
| # of HH members age 15-64 (#/ha) | 21.06 | 0.261 |
| # of HH members age 15-64 (#/ha), squared | 0.994 | 0.129 |
| Total landholding size (ha) | 4.015 | 0.416 |
| ln(total farm asset value) | -4.29e-05 | 0.475 |
| Education of the plot manager (years) | 12.99 | 0.673 |
| 1=HH received extension visit, government | -27.67 | 0.932 |
| 1=HH received extension visit, non-govt | -647.9+ | 0.0940 |
| Qty of N (kg/ha)*ln(wettest quarter rainfall) | 1.461 | 0.604 |
| Qty of N (kg/ha)*elevation | -0.00400* | 0.0466 |
| Qty of N (kg/ha)*1=year 2013 | 2.206 | 0.207 |
| Qty of N (kg/ha)*Qty of P (kg/ha) | -0.0174 | 0.484 |
| Qty of N (kg/ha)*1=used improved variety | 3.584 | 0.184 |
| Qty of N (kg/ha)*# of HH members age 15-64 (#/ha) | 0.0203 | 0.886 |
| Qty of N (kg/ha)*Qty of manure (kg/ha) | 0.000479 | 0.252 |
| Qty of N (kg/ha)*1=years since fallow | -0.113+ | 0.0936 |
| Qty of N (kg/ha)*1=maize intercropped w/legume | -1.585 | 0.412 |
| Qty of N (kg/ha)*1=maize intercropped w/non-legume | -5.687+ | 0.0542 |
| Qty of N (kg/ha)*1=HH received extension visit, GoT | 0.779 | 0.688 |
| Qty of N (kg/ha)*1=HH received extension visit, non-GoT | 2.769 | 0.158 |
| Qty of N (kg/ha)*plot manager education (years) | -0.800+ | 0.0666 |
| Qty of N (kg/ha)*1=plot soil is sandy | -2.441 | 0.532 |
| Qty of N (kg/ha)*1=plot soil is loam | -2.287 | 0.387 |

**Table 5, continued**

| | | |
|---|---|---|
| Qty of P (kg/ha)*ln(wettest quarter rainfall) | -17.75* | 0.0331 |
| Qty of P (kg/ha)*elevation | -0.00750 | 0.404 |
| Qty of P (kg/ha)*1=year 2013 | 6.296 | 0.230 |
| Qty of P (kg/ha)*1=used improved variety | -0.121 | 0.982 |
| Qty of P (kg/ha)*# of HH members age 15-64 (#/ha) | 0.0689 | 0.847 |
| Qty of P (kg/ha)*1=years since fallow | -0.0379 | 0.844 |
| Qty of P (kg/ha)*1=maize intercropped w/legume | 2.852 | 0.582 |
| Qty of P (kg/ha)*1=maize intercropped w/non-legume | -8.026 | 0.164 |
| Qty of P (kg/ha)*1=HH received extension visit, GoT | 1.830 | 0.773 |
| Qty of P (kg/ha)*1=HH received extension visit, non-GoT | -3.795 | 0.624 |
| Qty of P (kg/ha)*plot manager education (years) | 1.186 | 0.287 |
| Qty of P (kg/ha)*1=plot soil is sandy | -7.638 | 0.257 |
| Qty of P (kg/ha)*1=plot soil is loam | -3.002 | 0.581 |
| 1=used improved variety (IV)*ln(wettest qtr rainfall) | -296.0 | 0.365 |
| 1=used IV*plot manager education | 5.796 | 0.868 |
| 1=used IV*1=HH received extension visit, GoT | 24.73 | 0.945 |
| 1=used IV*1=HH received extension visit, non-GoT | -31.64 | 0.941 |
| 1=used IV*1=year 2013 | -78.50 | 0.742 |
| 1=used IV*1=maize intercropped w/legume | 106.2 | 0.694 |
| 1=used IV*1=maize intercropped w/non-legume | 263.2 | 0.360 |
| 1=used IV*# of HH members age 15-64 (#/ha) | -26.02 | 0.129 |
| 1=used IV*1=plot soil is sandy | 138.9 | 0.694 |
| 1=used IV*1=plot soil is loam | 15.75 | 0.958 |
| Qty of manure (kg/ha)*ln(wettest qtr rainfall) | 0.0559 | 0.336 |
| Qty of manure (kg/ha)*elevation | -4.00e-05 | 0.508 |
| Qty of manure (kg/ha)*1=use improved variety | -0.0670+ | 0.0604 |
| Qty of manure (kg/ha)*years since fallow | 0.00198 | 0.238 |
| Qty of manure (kg/ha)*1=maize intercropped w/legume | 0.0104 | 0.853 |
| Qty of manure (kg/ha)*1=maize intercropped w/non-leg | -0.0318 | 0.494 |
| Qty of manure (kg/ha)*1=year 2013 | 0.0529 | 0.136 |
| Qty of manure (kg/ha)*# of HH members age 15-64 (#/ha | 0.00350 | 0.138 |
| Qty of manure (kg/ha)*1=plot soil is sandy | -0.0481 | 0.642 |
| Qty of manure (kg/ha)*1=plot soil is loam | 0.0576 | 0.198 |
| ln(wettest quarter rainfall)*years since fallow | -4.703 | 0.699 |
| ln(wettest quarter rainfall)*1=plot soil is sandy | -272.5 | 0.437 |
| ln(wettest quarter rainfall)*1=plot soil is loam | 277.2 | 0.296 |
| ln(wettest quarter rainfall)*1=maize intercropped w/leg | 205.9 | 0.441 |
| ln(wettest quarter rainfall)*1=maize intercropped w/no | 25.38 | 0.928 |
| 1=maize intercropped w/legume*elevation (m) | -0.166 | 0.845 |
| 1=maize intercropped w/legume*1=year 2013 | -64.05 | 0.648 |
| 1=maize intercropped w/legume*years since fallow | 4.878 | 0.556 |

**Table 5, continued**

| | | |
|---|---|---|
| 1=maize intercropped w/legume*1=plot soil is sandy | 87.79 | 0.692 |
| 1=maize intercropped w/legume*1=plot soil is loam | 82.84 | 0.638 |
| 1=maize intercropped w/non-legume*elevation (m) | 0.257 | 0.199 |
| 1=maize intercropped w/non-legume*1=year 2013 | -120.7 | 0.455 |
| 1=maize intercropped w/non-legume*years since fallow | 2.189 | 0.809 |
| 1=maize intercropped w/non-legume*1=plot soil is sand | 22.06 | 0.931 |
| 1=maize intercropped w/non-legume*1=plot soil is loam | -496.1* | 0.0167 |
| Constant | -14,116 | 0.318 |
| Number of observations (plots) | 3,035 | |
| Number of households | 1,216 | |
| Household-level fixed effects included | YES | |
| R-squared | 0.152 | |

Source: Authors' computations from NPS survey data 2010/11, 2012/13

**Table 6. Partial effects of selected explanatory variables from regression in Table 5.**

| | OLS-FE at household level | |
|---|---|---|
| | Dept Var = maize yield (kg/ha) | |
| Explanatory variable | Partial effect | P-value |
| Year dummy (1=2013) | -74.906 | 0.510 |
| ln(wettest quarter cumulative rainfall (mm)) | 143.399 | 0.607 |
| Qty of Nitrogen applied to maize (kg/ha) | 7.497 | 0.000 |
| Qty of Phosporous applied to maize (kg/ha) | 8.147 | 0.084 |
| 1=improved OPV or hybrid seed | 103.913 | 0.456 |
| Qty of manure applied to maize (kg/ha) | 0.102 | 0.003 |
| years since fallow | -6.895 | 0.135 |
| 1=maize was intercropped with non-legume | -39.718 | 0.692 |
| 1=maize intercropped with legume | 135.984 | 0.149 |
| 1=plot soil is sandy | -216.024 | 0.104 |
| 1=plot soil is loam | -92.755 | 0.348 |
| 1=HH has title to this plot | 114.911 | 0.321 |
| 1=HH received extension visit, government | -8.978 | 0.978 |
| 1=HH received extension visit, non-govt | -629.314 | 0.113 |
| # of HH members age 15-64 (#/ha) | 26.727 | 0.065 |
| Total landholding size (ha) | 4.015 | 0.416 |
| ln(total farm asset value) | 0.000 | 0.475 |
| Education of plot manager (years) | 7.406 | 0.800 |

Source: Authors' computations from NPS survey data 2010/11, 2012/13

Given the high demands for labor in land preparation and weeding in maize production, and the fact that the labor in smallholder maize production is primarily provided by family members, it is not surprising that we find that an additional adult aged 15-64 per hectare increases maize yield by 26.7 kg/ha. As expected, we also find a nearly significant effect of fallowing on maize yield (p=0.13), as an additional year since the last fallow (of the plot) reduces maize yield by 6.8 kg/ha (Table 6). Another nearly significant effect (p=0.14) is that smallholders who plant maize in an intercrop with legumes enjoy an average yield of 135 kg/ha higher than those that do not. The positive effect of intercropping legumes may represent nitrogen fixed by legumes that season, or more likely reflects N fixed by a similar maize/legume intercrop in the previous season. Another unsurprising finding is that maize yields on sandy soil are on average 216 kg/ha lower, as sandy soils leach nutrients much faster relative to clay, loam or other soils.

The effect of the cumulative rainfall in the wettest quarter on yield is positive as expected, though is not significant (Table 6). It appears that household receipt of a non-government extension visit in 2008/09 (or a later year) by non-government extension (i.e. private sector, NGO, cooperative) results in a nearly significant (p=0.11) yield *loss* of 629 kg/ha, which is counter to what one would expect to find. That said, this partial effect takes all other variables at their average levels, and there are not a lot of cases of households that receive a non-government extension visit (Table 3), and even fewer from among them who also apply inorganic fertilizer and/or improved seed. For example, below we find that households that received either government or non-government extension have considerably higher maize-N response rates than those without a visit. Given that result plus the fact that some of these non-government visits are by NGOs (some of which target resource-poor farmers), it may be that this binary indicator may be capturing the lower yields of resource-poor farmers who are not using improved inputs.

### 6.3 Smallholder maize-N response rates and the profitability of fertilizer use on maize

#### 6.3.1 By zone

We find that the average maize-N response rate (i.e. also called the marginal physical product of nitrogen or MPP) in the southern highlands is 7.0 kg of maize per kg of N, while it is 7.1 in the northern zone (Table 7). By contrast, the maize-N response rate in the other zones[10] is 7.8 (Table 7). With the exception of the Western zone, median quantities of N applied per hectare (Table7) are considerably higher in the high potential zones, thus we would expect that marginal returns to N would be somewhat lower in areas where N application rates are considerably higher, if N application rates were high enough to reach the part of the MPP curve that slopes downward due to diminishing marginal returns to a variable input (when the level of other inputs is held constant).[11] However, because we did not find concavity in the relationship between N use and maize yields (i.e. the squared N term was not significant), the fact that the high potential zone maize-N rate is lower than that of the medium/lower potential zones,

[10] We do not attempt to compute the average maize-N response rate for zones outside of the southern highlands and northern zones because of the relatively small numbers of observations of fertilizer use outside of those high potential zones.

[11] While the Lake zone has high median application rate of N, this comes from only a few cases.

combined with higher N application rates in higher potential zones, suggests instead that the MPP curve itself is lower for high potential zones relative to other zones. *A priori*, one might expect that the MPP curve for smallholders in higher potential zones to be higher than that of medium/lower potential zones, given that the southern highlands has more rainfall on average than the East, Central, and South zones. On the other hand, that yield advantage may well be offset by two crop/plot management practices more common in the southern highlands than elsewhere. First, average years since fallow for maize plots is somewhat higher in this zone (Table 1) – and fallowing is almost non-existent in the Arusha region in the north. Second, the southern highlands has the highest percentage of maize plots that are mono-cropped (Table 1). The combination of infrequent use of inorganic fertilizer in the southern highlands prior to NAIVS (only 21% of smallholder maize producers) with continuous cultivation (very infrequent fallowing) and monocropping of maize suggest that these practices have led to lower levels of residual N and soil organic matter in the soils of the southern highlands, which may well offset the yield advantage of higher seasonal rainfall.

**Table 7. Profitability of smallholder fertilizer use on maize by zone**

| | % maize fields with N applied | | Median N/kg applied | | Mean across survey years[1] given observed quantity of Nitrogen (N) applied | | | |
|---|---|---|---|---|---|---|---|---|
| Zone | 2010/11 | 2012/13 | 2010/11 | 2012/13 | Maize-N response rate (MPP) | Average Product of N (APP) | MVCR | AVCR |
| S.Highlands | 36.8 | 31.3 | 57.0 | 61.8 | 7.0 | 8.2 | 1.00 | 1.17 |
| Northern | 16.3 | 15.6 | 66.7 | 88.9 | 7.1 | 9.9 | 1.33 | 1.86 |
| Eastern | 1.9 | 0.7 | 18.5 | 5.0 | 7.8 | 11.8 | 1.40 | 2.12 |
| Central | 4.9 | 6.2 | 36.3 | 25.9 | 7.8 | 11.8 | 1.49 | 2.26 |
| Lake | 0.7 | 0.7 | 127.8 | 71.0 | 7.8 | 11.8 | 1.33 | 2.01 |
| West | 13.8 | 12.7 | 71.3 | 68.1 | 7.8 | 11.8 | 1.22 | 1.85 |
| South | 2.9 | 2.4 | 5.8 | 91.0 | 7.8 | 11.8 | 1.44 | 2.18 |

Notes: 1) MPP and APP derived from plot-level maize yield regression using 2010/11 & 2012/13 data; MVCR & AVCR computed using expected maize and fertilizer prices by region for 2008/09, 2010/11, & 2012/13.

Regardless of the zone, the maize-N response rates are less than 50% of those reported from recent agricultural research zonal trials (Mlingano ARI, 2013a). While it is common for farmer yields and maize-N response rates to be lower than those of researcher trials – which typically use improved inputs applied at optimal rates and times – this nevertheless demonstrates that there is an enormous gap between actual and potential smallholder returns to fertilizer use in maize production, on average. More significantly, the low average maize-N contributes to a relatively low average variable cost ratio (AVCR) of only 1.17 in the southern highlands, 1.86 in the northern zone, and 1.85 in the west (Table 7). As will be discussed more in Section 6.4 below, this means that in these zones, fertilizer use on maize is not profitable enough to fully compensate for production and market price risk, thus it means that fertilizer use is marginally profitable for the average smallholder in these zones (especially in the southern highlands).

6.3.2 Variation by use of complementary input and plot management practices

Although maize-N response rates are quite low on average, our results in Table 8 demonstrate that there are various ways by which smallholders can improve their maize-N response rates and thus their net financial returns to fertilizer use. Because we have interacted N with a number of other complementary inputs (such as P, manure, improved seed use), plot level characteristics (years since fallow, intercrop type, soil type) and agro-ecological factors (rainfall, elevation), we next consider how maize-N response rates vary (on average) by use (or not) of these complementary inputs.

First, we find that use of an improved maize seed (OPV or hybrid) generates a considerably higher maize-N response of 10.2 as compared with the 7.1 achieved by fertilizer users who do not use an improved variety (Table 8). Second, households that have a title to their land have a higher maize-N response rate (8.6) relative to those without a title (6.7) (Table 8). Conventional wisdom holds that households with more secure land tenure are more likely to fallow their land and/or make other investments to improve soil health and/or water retention. However, as we are controlling separately for years since fallowed, the plot-level binary indicator for 'title' may be picking up unobserved plot or crop management practices over time or perhaps simply higher productivity from a better quality plot.

**Table 8. Maize-N response rates and profitability of fertilizer use by complementary input use**

| | Mean across survey years[1] given observed quantity of Nitrogen (N) applied | | | |
|---|---|---|---|---|
| Complementary plot input use & soil type[1] | Maize-N response rate (MPP) | Average Product of N (APP) | MVCR | AVCR |
| used improved seed | 10.2 | 11.2 | 1.73 | 1.90 |
| did not use improved seed | 7.1 | 8.0 | 1.20 | 1.36 |
| HH had extension visit (GoT) 2008/09 or later [3] | 8.1 | 10.0 | 1.37 | 1.70 |
| HH had extension visit (other) 2008/09 or later [3] | 9.6 | 10.0 | 1.63 | 1.70 |
| HH did not have extension visit since 2008/09 | 7.2 | 7.9 | 1.22 | 1.34 |
| HH has title to plot | 8.6 | 10.9 | 1.46 | 1.85 |
| HH does not have title to plot | 6.7 | 7.4 | 1.14 | 1.26 |
| plot fallowed within last 6 yrs | 9.1 | 8.9 | 1.54 | 1.51 |
| plot last fallowed within 7-12 yrs | 8.5 | 10.9 | 1.44 | 1.85 |
| plot last fallowed within 13-18 yrs | 7.7 | 9.6 | 1.31 | 1.63 |
| plot last fallowed within 19-25 yrs | 7.0 | 7.9 | 1.19 | 1.34 |
| plot last fallowed within 26+ yrs | 6.1 | 7.4 | 1.04 | 1.26 |
| sandy soil | 7.3 | 8.2 | 1.24 | 1.39 |
| clay / other soil | 9.4 | 10.2 | 1.60 | 1.73 |
| loam soil | 7.0 | 8.6 | 1.19 | 1.46 |

Third, we find that fallowing has a large positive effect on average maize-N response rates, as plots fallowed within the last six years have a response rate of 9.1, yet this rate declines significantly the more years it has been since the plot has been fallowed (Table 8). Although NPS data does not contain actual measures of macro and micro nutrients prior to fertilizer application, this finding of a negative relationship between years since fallow and maize-N response rates is consistent with the empirical findings from Kenya (Marenya and Barrett, 2009) that grain-N response rates decline considerably as soil organic matter declines – and SOM falls over time in the absence of fallowing and/or ISFM practices that can maintain SOM.

Fourth, we find a large positive effect of an extension visit on maize-N response rates. For example, households that received a government extension visit related to agricultural production (in that season or an earlier season) have an average maize-N response rate of 8.1, those with a non-government extension visit a maize-N response rate of 9.6, while households without an extension visit have a maize-N rate of 7.2 (Table 8). Because we are controlling separately for education and wealth (and we tested for the potential endogeneity of receipt of an extension visit), the positive effect of receipt of an extension visit on maize-N response rates may indicate that the household received technical assistance regarding proper fertilizer use (i.e. timing and fertilizer application rate) and/or use of complementary inputs or crop/plot management practices (i.e. seeding rate) and applied those recommended practices – none of which are observed by the NPS data. For example, we observe that households that received an extension visit applied fertilizer at rates much closer to those recommended by NAIVS (247 kg/ha), in the higher potential zones are more likely to have used both basal and top-dressing fertilizer, and fallowed their plot more recently, on average (Table 9). These factors could well explain the higher relative maize-N response rates of households that received an extension visit.

Another potential way to improve maize-N response rates is for the household to implement timely weeding of their maize plots. While NPS data does not record the number of weedings nor their timing, it does tell us the 'person-days' spent (from family labor and from hired labor) on a given plot for various activities, such as land preparation, weeding, harvest, etc. We do not see a positive correlation between plot manager education or extension visit and greater number of person-days per hectare spent on weeding (Table 9). However, there could be other factors we do not observe that are recommended by extension agents and then applied – such as following an optimal planting date, using the recommended seed density, applying fertilizers at the appropriate times, and performing weeding when needed.

Fifth, we find that plots with sandy soil have a lower maize-N response rate than those with clay/other soil (Table 8). However, given that sandy soils leach nutrients considerably faster than other soils, we would have expected to have found that the response rate on sandy soils to be considerably lower than both clay and loam plots, yet it is similar to that of loam plots. While more investigation is needed to try to understand the unexpected relationship between soil types and maize-N responses, we do note that when considering the effect of soil type on yield, we did find that plots with sandy soils have yields that are 216 kg/ha lower, on average.

**Table 9. Plot-level input use and/or plot management decisions by household receipt of extension visit since 2008/09 or not**

| Smallholder input decisions among those who applied fertilizer to maize | Zone | HH received extension since 2008/09? Govt | Other | None |
|---|---|---|---|---|
| Median fertilizer quantity applied to maize (kg/ha) | Hi | 243.5 | 237.5 | 173.0 |
| | Low | 84.5 | 319.7 | 134.0 |
| 1=HH used basal & topdressing (%) | Hi | 42.5 | 60.8 | 35.0 |
| | Low | 8.3 | 34.6 | 19.5 |
| 1=HH used improved maize variety with inorganic fertilizer (%) | Hi | 23.1 | 21.2 | 22.5 |
| | Low | 20.0 | 7.8 | 22.3 |
| 1=plot fallowed within the last 6 years (%) | Hi | 11.0 | 15.2 | 8.0 |
| | Low | 24.0 | 0.0 | 8.3 |
| Mean years since plot was fallowed | Hi | 18.7 | 17.0 | 21.5 |
| | Low | 15.4 | 16.0 | 18.5 |
| Median days/ha of family/hired labor for weeding | Hi | 20.6 | 31.7 | 29.6 |
| | Low | 25.9 | 32.0 | 36.1 |

## 6.4 Profitability of improved inputs in smallholder maize production

### 6.3.1 Profitability of fertilizer use on maize by maize-N response rate

To assess the profitability of fertilizer use on maize, we use the formula for AVCR as described above, wherein the numerator is the difference between the average physical product of fertilizer (maize yield / quantity of N applied) in a 'with fertilizer' or 'without fertilizer' scenario, multiplied by the expected value of the difference in maize grain produced by using fertilizer (i.e. we use the expected village-level annual average maize price).[12] This is divided by the cost of N used on that plot, which we compute by first deriving the price of N from each kg of DAP or urea, and then assuming that a typical fertilizer user's fertilizer cost is 85% from urea and 15% from DAP (this is based on what we observe). The prices per kg of maize and N from DAP and urea are shown in Appendix Table 1.

We find that the low average maize-N contributes to a relatively low average variable cost ratio (AVCR) of only 1.17 in the southern highlands, 1.86 in the northern zone, and 1.85 in the west (Table 7). This means that in these zones, fertilizer use on maize does better than breaking even (it is profitable), yet fertilizer use on maize is not profitable enough to fully compensate for production and market price risk. Thus, fertilizer use is marginally profitable for the average

[12] We generate an expected village-level retail price of maize for each region by first computing the average annual average wholesale price of maize during the year prior to planting and multiplying this by 1.2 in order to adjust the wholesale price for transportation costs from the regional capital to an average village. We use the annual average price as the approximate value of maize to smallholders, though in reality, those who are net sellers may base their fertilizer use and quantity decision on the expected farmgate sale price of maize in the post-harvest period, while those who are net buyers may well base their input use decisions on the expected farmgate buying (retail) price of maize throughout the year.

smallholder in these zones (especially in the southern highlands). The implication of this finding for Tanzania the profitability of fertilizer use on maize in key production areas such as the southern highlands is low enough that it remains to be seen to what extent these farmers' experience with fertilizer use on maize – which during these three NPS survey years was greatly facilitated by NAIVS – will result in sustained demand for commercially-priced fertilizer for use on maize. That is, although NAIVS helped to improve smallholder fertilizer access for use on maize (and experience using it on maize) from 2008-2014, more risk averse farmers may not purchase fertilizer at commercial rates for use on maize as their returns are simply not sufficiently high enough to enable the farmers' fertilizer use on maize to be profitable enough to cover potential production and/or market price risks.

While the southern highlands and northern zones have similar maize-N response rates, the AVCR is considerably higher in the northern zones because maize prices are higher there (Appendix Table 1). In fact, although the southern highland maize producers have the advantage of greater expected rainfall, they have relatively poor market access relative to other zones. That is, they are physically further from large centers of demand for maize grain, and road infrastructure is considerably less dense than it is in the north (which further decreases the prices that southern highland farmers receive for maize grain).

We next note that the MVCR in the southern highlands = 1.0. This implies that farmers there are already using fertilizer at a rate that maximizes their net returns to fertilizer use. In other words, their average and marginal returns would actually fall if they used more fertilizer than they currently do. The fact that smallholder maize producers in the southern highlands are only achieving an AVCR of 1.17 (marginally profitable) while maximizing their net returns clearly indicates that they need to improve their maize-N response rates. Evidence from Table 8 indicates that these smallholders can improve maize-N response rates by combining fertilizer use with complementary inputs such as use of an improved variety, more frequent fallowing, and access to extension advice about crop production. As we will discuss in the conclusion section, there are also strategies by which the GoT can help these smallholder improve their net returns to fertilizer use by improving expected maize prices and lowering the costs of fertilizer.

For zones that have an AVCR>=2.0, this implies that fertilizer use on maize is sufficiently profitable to cover for production and market price risk. However, the maize-N rates are low enough on average that farmers across Tanzania could dramatically improve their net financial returns to fertilizer use if they were to adopt not only inorganic fertilizer use in maize production, but also complementary inputs such as use of an improved variety, more frequent fallowing, access to extension advice about crop production, etc. Regardless of zone, the maize-N response rates and corresponding AVCRs in all zones are low enough that in order for smallholder maize intensification to continue and advance further (beyond the period of NAIVS subsidies), MAFL should consider shifting considerably attention and resources from its primary goal of NAIVS (improving access to fertilizer and improved seed) to improving farmers' understanding of the wide range of complementary inputs and plot-management practices that combined can help them dramatically improve not only their maize-N response rates but also their maize yields with or without fertilizer or improved seed use.

6.3.2 Profitability of improved seed use in maize production

As noted above, a smallholder who combines use of an improved variety with N enjoys a higher maize-N response rate (on average). Yet, we noted above that a relatively low percentage of smallholders in the southern highlands use an improved variety with inorganic fertilizer, as compared with those in northern regions. As noted above in Section 6.1.1, farmers in the north have historically had better physical access to improved seed, thus smallholders in the south have historically had limited access to improved varieties and thus limited experience with them (prior to the NAIVS period). We also noted that maize prices are relatively higher in the north and that seed companies perceive that many growers do not believe that seed provides sufficient additional returns to justify their cost (they believe that fertilizer by itself is sufficient). We test this hypothesis by using the average physical product of improved seed use by region, multiplying this by the expected price of maize per kg in a given region, and dividing by the average village price of improved seed in the region.

Before proceeding to discuss the results shown in Table 10, we first need to note some data limitations of our computations, which mean that the results should be viewed as an approximation. First, as NPS does not record the quantity of seed used per hectare, we assumed that farmers used the recommended 10 kg/acre (and this was the amount provided free via NAIVS). Second, the NPS did not record any information about seed type other than distinguishing between "traditional variety" and "improved (hybrid or OPV)" seed. This is unfortunate because there are a number of different seed brands that may perform differently with or without fertilizer, and hybrids are typically bred to require inorganic fertilizer use for optimal results.

**Table 10. Profitability of use of improved maize seed, with and without fertilizer use**

| Zone and use of improved maize seed (IMS) | APP | 3-year AVCR |
|---|---|---|
| used IMS - southern highlands | 8.0 | 0.97 |
| used IMS - northern zone | 6.4 | 1.01 |
| used IMS - other zones | 7.4 | 1.52 |
| used IMS & inorganic fertilizer - southern high | 12.0 | 1.45 |
| used IMS & inorganic fertilizer - northern | 13.0 | 2.06 |
| used IMS & inorganic fertilizer - other zones | 12.5 | 2.57 |

Source: APP estimated from regression showed in Table 5, maize prices from Appendix Table 1, village-level fertilizer prices from NPS.

We first note that the APP of use of improved maize seed (IMS) is considerably higher when IMS is combined with fertilizer, as we would expect to find (Table 3). We find that the three-year average AVCR of improved maize seed (IMS) without fertilizer use is 0.97 in the southern highlands, 1.01 in the northern zone, and 1.52 elsewhere (Table 10). The fact that net returns to IMS in high potential zones is only at the 'break-even' point is perhaps due to the fact that many of these IMS are likely hybrids, which are bred to give optimal yield response when combined with fertilizer. Thus, when smallholders use IMS combined with fertilizer, the AVCR in the southern highlands is 1.45 and 2.06 in the north. As we noted with the AVCRs for fertilizer, although the APP of IMS is similar between the southern highlands and northern zones, what makes the AVCR of IMS higher in the north (relative to the south) are higher maize prices due to closer proximity to large urban markets (Arusha, Nairobi).

The fact that the AVCR in the southern highlands is less than 2.0 is relatively consistent with what seed companies have heard from farmers in the southern highlands – that farmers believe that the returns to seed when combined with fertilizer are not high enough to justify use of improved maize seed. However, given that our estimates are an approximation due to data limitations, plot-level trials (and demo plots) of IMS use with and without fertilizer by private companies and by zonal research centers could provide smallholders in the southern highlands with more direct and concrete evidence of the relative returns to IMS use.

## 7. CONCLUSIONS

### 7.1 Motivation for this paper

In order to address the long-term challenge of improving smallholder demand for and access to inorganic fertilizer and improved seed for maize production, in 2008/09 the GoT scaled-up an existing pilot targeted voucher scheme that by 2012/13 had provided up to 2.5 million smallholders with access to a limited quantity of inorganic fertilizer and improved maize seed at subsidized prices. One of the main goals of this program was to provide a relatively low-risk learning opportunity and experience for smallholders who previously had not used fertilizer on maize to see for themselves how the returns to use of fertilizer and improved seed in maize production compare with the additional costs. While the program succeeded in getting vouchers primarily to smallholders who had previously not used fertilizer on maize (Mather et al, 2016b), the extent to which this dramatic increase in smallholder experience with fertilizer in maize production leads to a sustainable increase in smallholder demand for market-priced fertilizer is likely to be in large part a function of how profitable fertilizer use on maize is/was for these smallholders, considering their actual maize-fertilizer response and the typical market-based input (fertilizer) and output (maize) prices they face.

In this paper, we use plot-level data from two separate large-scale panel household surveys implemented during the NAIVS period to address two main research questions. First, what is the maize-nitrogen response rate under smallholder conditions in Tanzania, and how does it vary by zone, complementary crop inputs and management practices? Second, is inorganic fertilizer use on maize profitable under typical smallholder conditions and at prevailing fertilizer and maize prices, and how does profitability vary by zone, use of complementary inputs, etc?

### 7.2 Main findings

We have three main over-arching findings. First, we find that maize-N response rates are, on average, only about 50% of those obtained under zonal research trial conditions, even in higher potential zones such as the southern highlands. This implies that there is considerable potential for improving maize-N rates, as discussed more below.

Second, these low response rates contribute to AVCRs that indicate that fertilizer use on maize is only marginally profitable, on average (i.e. AVCRs<2.0 in the southern highlands, north and west). In short, while farmers using fertilizer are doing better than breaking even (on average), their returns from fertilizer use are not large enough to compensate them for the considerable uncertainty they face in both production (weather conditions) and market (price) conditions. Standard assessment criteria thus suggest that fertilizer use on maize is not profitable enough to provide an incentive to smallholders to use fertilizer on maize (at commercial prices), on average, given average maize-N response rates and typical fertilizer and maize prices.

Third, our results suggest that there are several means by which smallholder maize-N response rates can be improved:

a) Combined use of an improved variety with N yields higher a maize-N response rate (on average)
b) Response rates (and profitability of fertilizer use) are considerably higher if the farmer fallowed the plot within the last 6 to 12 years
c) Response rates are higher for households that received an extension visit related to crop production. Although more work is needed to trace the effect of extension access on complementary input use that improves maize-N response rates, it is clear that household receiving extension are more likely to have used both basal and top-dressing fertilizer and/or to have used an average quantity of fertilizer per hectare closer to the recommended application rate than other households.

The GoT's main agricultural growth strategy since 2008 (and the largest single item in their annual budget for most years since then) has been to use a large-scale fertilizer subsidy program (NAIVS) to improve smallholder access to fertilizer and improved seed for maize production, and to do so in a way that builds longer-term and sustainable smallholder demand for market-priced fertilizer/seed in maize production. The GoT succeeded in primarily targeting vouchers to farmers who had not previously used fertilizer on maize, thus NAIVS provided very valuable experience for voucher recipients to experiment with fertilizer on their own plots at lower financial risk (Mather et al, 2016b). However, the results from our analysis show that fertilizer use on maize is only marginally profitable in key production regions of the country (southern highlands, north), thus it is doubtful if the gains in farmer use of fertilizer on maize under NAIVS will be sustained when an increasing number of farmers must pay the market price for fertilizer (as NAIVS continues to scale down or stop).

In summary, our analysis thus strongly suggests that regardless of whether NAIVS continues or not, the GoT must consider alternative and/or complementary strategies at this point in time (beyond NAIVS) that can help to improve the profitability of fertilizer use on maize, and thereby build on the gains in smallholder experience with fertilizer use from 2008 to the present. This begs the question of what is the appropriate role for the GoT in influencing the three key components of the profitability of fertilizer use on maize:

1) How can smallholder maize-N response rates be increased?
2) How can expected maize sale prices levels and predictability be improved?
3) How can the unit cost of fertilizer be lowered for inland regions?

**7.3 Strategies to improve smallholder maize-fertilizer response rates**

<u>7.3.1 Knowledge generation – updated soil maps & fertilizer recommendations</u>

The overwhelming focus of funding under NAIVS was to improve farmer physical access to fertilizer and reduce its cost by 50%. However, <u>our results show that for fertilizer use to be profitable, farmers need more than just access to fertilizer, they need to adopt a package of improved inputs and crop/plot management practices</u>. This implies that the GoT need to adopt a more holistic approach in designing strategies to facilitate sustainable improvements in smallholder maize yields, that goes beyond a primary focus of improving physical access to fertilizer and subsidizing the price of fertilizer or access to a loan for it. In addition, it is clear from the existing MAFC district-level fertilizer recommendations (from 1993) that blanket fertilizer recommendations are not appropriate. Thus, thus there is an urgent need to increase focus and funding on the generation and dissemination of updated knowledge of soil conditions throughout the country as well as knowledge of best practices (input use and plot management) needed to increase smallholder maize yields.

First, Tanzania's existing soil map is over 30 years old (De Pauw, 1984), thus there is an <u>urgent need for widespread soil sampling and in order to update knowledge of current soil characteristics.</u> Fortunately, there are currently two efforts underway toward a goal of providing an updated soil map for all currently cropped areas by 2017. These include the GoT Tanzania Soil Information System (TanSIS) and the Taking Maize Agronomy to Scale in Africa (TAMASA) project, which are coordinating their efforts so as to avoid duplication (Meliyo, 2015).

Second, there is a need for <u>widespread agricultural research trials to update existing fertilizer recommendations for maize, rice, etc</u>. The existing district-level recommendations for most of the country are from 1993 (MoF, 1993), and soil testing and fertilizer response trials organized by Mlingano in 2010 and 2011 in 11 districts showed that updated recommendations are in fact needed, due to negative changes since 1993 in soil health (Mlingano ARI, 2013a). For example, a related report noted that in many areas, levels of soil organic matter, macro and micro nutrients were lower than they had been when the last systematic soil testing and maize yield trials were organized (1993-1994) (Mlingano ARI, 2013b). Mlingano's finding is not alone, as a remote sensing assessment a few years ago found that 40 percent of cultivated land in Tanzania is degraded (Bai et al, 2008). Thus, in several districts, the GoT official fertilizer recommendations called for increased application rates of certain fertilizers, while other areas that previously had been assessed to be suitable for profitable use of fertilizer on maize are now considered to not be (ibid, 2013b).

The National Soil Service project has also recently done trials in an additional 12 districts, though it plans to continue until covering all districts. In addition, the recent evidence of low soil fertility noted above (ibid, 2013b)and our results suggest that significant efforts should be made to evaluate not only optimal fertilizer use in a given district, but also agronomic and economic returns to various forms of Integrated Soil Fertility Management (ISFM), such as maize/legume intercropping, crop rotations, improved fallows, etc, that are needed to help improve and maintain a level soil fertility required for inorganic fertilizer to be profitable.

7.3.2. Effective dissemination of new fertilizer recommendations & best practices

Our results show that there is a large positive effect of a household receipt of an extension visit on maize-N response rates and thus the profitability of fertilizer use on maize. Yet, the majority of smallholder maize producers never receive a visit. Although the extension system has been rapidly increasing the number of total extension agents in recent years, the farmer-to-agent ratio is still very high. The good news is that there are existing methods of knowledge dissemination that can complement extension agents (i.e. farmer field schools), as well as new innovations in extension that can complement and/or improve upon existing methods by taking advantage of new information technologies. For example, video training sessions via tablet may be more cost-effective than setting up and maintaining demonstration plots, while extension agents may be able to reduce travel time and costs if they or their district office can use text messaging to disseminate information. However, while public/private extension services may work well in Tanzania for smallholders growing cash crops, the only extension that subsistence smallholder maize growers are likely to receive is from the GoT. Thus, a combination of increased funding and institutional innovation is needed to improve the coverage of public extension that targets and reaches these kinds of smallholders.

However, simply increasing funding for public extension will not be sufficient unless extension agents (combined with other means of information dissemination to smallholders) disseminate up-to-date *and* appropriate fertilizer recommendations and other best practices needed for sustainable increases in smallholder maize yields. For example, recent research in four key regions found that agro-dealers and extension agents know the NAIVS blanket fertilizer recommendations for maize, but not the 1993 district-specific ones (Mather *et al*, 2016a). In addition, in villages targeted by NAIVS across 11 regions, a majority of voucher recipients did not know the recommended application rates for urea or DAP on maize in 2011, and virtually none of the non-recipients knew them (*ibid,* 2016a). Of those who responded, most gave the NAIVS blanket recommendations. These results suggest that the NAIVS blanket fertilizer recommendations do not appear to have been effectively disseminated to farmers, as most farmers do not know them (even in villages targeted by NAIVS).

The findings above suggest a need for more effective linkages between zonal agricultural research stations and district-level extension offices, in order to ensure that technical information disseminated to farmers is both appropriate and up-to-date. Yet such linkages are difficult to manage if a program like NAIVS, which was designed in a top-down manner, continues to promote blanket fertilizer recommendations. For example, MAFC's own district-level recommendations from 1993 indicate that blanket recommendations for fertilizer use on maize are not appropriate in the first place. Given that NAIVS implementers managed to fix district-level prices for the top-up amounts paid by recipients for subsidized fertilizer, this begs the question of why NAIVS did not coordinate with the agricultural research and development directorate and the national extension system to deliver district-level recommendations for maize and fertilizer to extension agents in areas targeted by NAIVS .

**7.4 Strategies to improve expected maize sales price levels that smallholders receive and their predictability**

As demonstrated in our profitability analysis above, higher maize prices (such as in the north) can improve the profitability of an input such as fertilizer, and thus provide a greater incentive for smallholders to apply fertilizer to maize. However, recent research has found that the implementation by the GoT of a maize export ban between July to December 2011 resulted in maize prices that on average were 8.7% lower across the country than they would have been in the absence of an export ban, and that maize prices in Songea would have been 31% higher in December 2011 without the ban that year (Baffes et al, 2015). Thus, in 2010/11, farmers who applied fertilizer to maize received considerably lower net returns to fertilizer than they would have in the absence of the export ban.

Yet, an unpredictable change in trade policy does not only results in adverse effects on farmers and other value chain actors in the season in question who made investments that season, but can have lasting negative effects on private sector investment. For example, farmers do not know what maize prices will be in the post-harvest period at the time that they need to decide whether or not to use fertilizer (and how much to use) -- they must make their fertilizer use decision based on their expectation of what maize prices will be in the post-harvest period. Thus, there is an inherent link between the predictability of trade policy and sustained technology adoption, because higher and more stable/predictable maize prices tends to increase smallholder demand for yield-enhancing inputs such as fertilizer or improved seed. By contrast, maize price instability can reduce smallholder farmer adoption of and sustained use of improved inputs such as fertilizer, by making the net returns more difficult to predict, and therefore more risky. For example, research using panel household data from Kenya finds that an increase in maize price volatility has a significant negative effect on the adoption of fertilizer for use on maize (Marenya et al, 2011).

While government intervention in food staple markets is typically made with good intentions (to stabilize prices and/or prevent price spikes), paradoxically, the result of intervention typically is greater price instability than would have occurred in the absence of government intervention. For example, research using 15-30 years of monthly market price data from Zambia, Kenya, Malawi, Tanzania, Ethiopia, Mozambique, and Uganda demonstrates that countries with the least government intervention in maize markets had the most stable maize prices over the period of data available (Chapoto and Jayne, 2009). One of the main reasons for this is because increased uncertainty in trade and marketing policy for a given staple crop typically leads private sector marketing actors (importers/exporters, wholesalers, retailers) to have less confidence in their ability to anticipate future maize/grain output prices (as they are unsure of whether or not the government may change the *status quo* trade policy again). This loss of confidence in their ability to predict future grain prices leads them to reduce both their long-term investments (storage facilities) and short-term investments (in grain), either of which results in thinner markets and thus higher food price instability (Tschirley and Jayne, 2010).

Although the GoT pledged in 2013 to stop using maize export bans, potential exporters now must obtain an export permit from a district official in order to export maize, and approval of such permits is sometimes refused (i.e. a region in the southern highlands has recently declared a maize export ban). Thus, continuing grain price uncertainty caused by unpredictable export bans and/or removal of import tariffs may well be undermining the gains made during NAIVS in smallholder demand for commercial fertilizer for use in maize and rice production. There is thus an urgent need for GoT to adopt predictable, transparent, rules-based trade & marketing policies to reduce the risk/uncertainty of farmer, trader, and wholesalers' expectations of future maize prices.

Second, if the Presidential Delivery Bureau's (PDB) Big Results Now (BRN) initiative to establish warehouse receipt systems for maize and rice is successful, Collective Warehouse Based Marketing Systems (COWABAMAs) could help to sustain smallholder demand for yield-enhancing inputs such as fertilizer by enabling participating farmers to obtain much better prices for their surplus maize, while also providing them with a source of credit for inputs the following season.

**7.5 Alternative strategies to reduce the unit costs of fertilizer for smallholders**

Urea and DAP are the most commonly used fertilizers on maize, and both are imported. However, approximately 40% (33%) of the cost of urea (DAP) in rural Tanzania are domestic costs including port charges, transportation to an inland region, and wholesaler/retailer costs and margins (IFDC, 2012). These costs can be considerably reduced with a combination of investments and regulatory reforms:

1) Increased investment in improved port infrastructure (IFPRI, 2012).
2) Regulatory reform to enable the Tanzania Fertilizer Regulatory Authority (TFRA) to truly be a 'one-stop-shop' for importers to meet internationally-recognized regulatory standards – currently there are overlapping mandates among a large number of regulatory agencies, which result in costly delays in unloading ships and duplication of effort (and taxes). This will require amendment of existing legislation for a variety of regulatory agencies so that TFRA is the sole regulatory authority for the importation of fertilizer.
3) Reform of railway management of TAZARA and between Dar es Salaam-Kigoma, Dar es Salaam-Moshi, Tanga-Moshi and Tabora –Mpanda – maize/fertilizer are bulk commodities that could be shipped much cheaper to inland regions, but fertilizer importers report that they use truck transportation because of the unreliability of rail.
4) Increased investment in rural trunk and feeder roads to lower transportation costs for both farm inputs and outputs. Road investments should focus on reducing transport costs on rural roads, because they account for the largest share of transport costs, despite the shorter distances covered (World Bank, 2009b). For example, transport

costs are four times higher per ton/kilometer on rural roads than on tarmac roads (ibid, 2009b).

Investment in (1) port and (4) road infrastructure would both reduce village-level costs of fertilizer while improving the prices at which farmers can sell their surplus maize. Likewise, improved ports/infrastructure will reduce input costs for both farm and non-farm businesses while increasing the output prices that they receive. This helps to explain why evidence from southeast Asia shows that rural roads consistently have the highest rate of return of all potential rural investments in reducing poverty (EIU, 2008; Fan et al, 2008) – considerably higher than that of input subsidies. We note below two empirical studies show that the rate of return (in terms of income growth) in Tanzania is 9 times higher for rural roads than it is for NAIVS.

In addition, a recent study (Ariga and Jayne 2009) argues that Kenya's impressive growth in smallholder fertilizer use during the 2000s was due to synergies between liberalization of input and maize markets and investment in public goods (such as in rural roads) in support of smallholder agriculture (both beginning in the 1990s), which appear to have stimulated investment by the private sector in both maize and fertilizer marketing. These investments led to dramatic reductions in average distances from the farm to private fertilizer retailers and lower real fertilizer prices over time (*ibid*, 2009), which these authors credit with driving increases in smallholder fertilizer use since 1997. For example, as of 2007, between 85 to 95% of smallholder maize producers in medium to high potential zones in Kenya applied inorganic fertilizer to maize (Mather and Jayne, 2015). The case of Kenya therefore demonstrates that a stable policy environment – with respect to fertilizer, land, and maize markets – can induce an impressive private sector response over time that has helped to make fertilizer accessible to most small farmers (Minde et al 2008).

In Appendix Table 2, it is clear that fertilizer use on maize is much more common in Kenya than in Tanzania, as even the low potential Eastern Lowlands zone of Kenya had a larger percentage of maize growers applying fertilizer to maize (61.8%) in 2009/10 than the region in Tanzania with the highest percentage of maize growers using fertilizer on maize (Iringa, with 58%) in the same year. Distance from the village to the nearest paved road represents a very important proxy for transportation costs either incurred by smallholders who bring their maize to a paved road, or costs deducted from their sales price if they sell their maize in the village to a trader. Likewise, distance to the nearest fertilizer retailer is a proxy for the search and transportation costs that smallholders incur if they do not have a retailer in their village. While distance to paved road and the nearest fertilizer retailer are only two of many variables that affect a smallholder's decision regarding fertilizer use on maize, it is clear Kenyan smallholders are much closer on average to the nearest paved road and the nearest fertilizer retailer than Tanzanian smallholders, with the exception of Arusha and Rukwa (Appendix Table 2).

The implication for Tanzania of the finding noted above from Kenya (Ariga and Jayne 2009) is that investment in rural trunk and feeder roads – combined with stable and predictable maize trade policy – can create an environment in which smallholders can be physically closer to both input dealers and markets, thus lowering their fertilizer costs and raising their maize sale prices. Such a combination appears to have been a key to Kenya's achievement in dramatically increasing both the percentage of maize growers using fertilizer and their application rates.

**7.6 Alternatives strategies (other than NAIVS) for increasing rural household incomes**

There is considerable evidence that between 2008/09 and 2013/14, NAIVS succeeded in its primary goals of:

a) Managed to effectively target a strong majority of vouchers to farmers who actually fit the program's targeting criteria (World Bank, 2014; Mather et al 2016b); and
b) By meeting the targeting criteria in most cases, NAIVS introduced smallholder maize/paddy farmers to the use of fertilizer (and to a lesser extent, improved seed) for farmers who had not used it before (World Bank, 2014; Mather et al, 2016b)
c) Helping to 'jumpstart' private investments in the private sector fertilizer supply chain, which will likely improve the physical access of many smallholder maize growers to agro-dealers even after NAIVS stops relative to their access prior to NAIVS (Mather et al, 2016a).

However, now that the 'learning' and 'jumpstart' effects of NAIVS have largely been achieved as intended by 2013/14 (Mather et al, 2016a), continuing NAIVS will likely result in much lower income growth and poverty reduction than shifting expenditure from NAIVS into increasing the provision of several traditional public goods, which can lead to considerably larger increases in income growth from both agricultural and non-agricultural economic activities, relative to NAIVS. For example, evidence from Tanzania on the growth and poverty reduction effects of various types of public expenditures (Fan et al, 2005) shows that the national average benefit-cost ratio for investments in rural roads is 9.1,[13] in agricultural research and development is 12.0, and in rural education is 9.0. By contrast, the official public expenditure review of NAIVS (World Bank, 2014) shows that the average national benefit-cost ratio of NAIVS for maize growers was 1.3 (though this ranged from 0.58 in Ruvuma to 2.77 in Rukwa).[14] This evidence suggests that increased investment in rural roads, agricultural research and rural education are not only vital to increasing the level and sustainability of smallholder maize yields, as noted above (by making fertilizer use more profitable, and by increasing the adoption of ISFM practices to maintain and improve soil fertilizer), but that they can also achieve much higher income growth per million Tsh invested than can the same amount invested in NAIVS.

[13] The highest returns were found in the southern highlands, central and western zones, and lower returns in the northern highlands.

[14] The World Bank's rate of return analysis did not include a multiplier effect. However, even if a traditionally assumed multiplier effect level were applied to that analysis, the benefit-cost ratio of NAIVS would still be much lower than that of rural roads, ag research, and rural education.

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**Appendix Table 1. Maize and fertilizer prices used for profitability assessment by year**

| Prices | | | 2008/09 | 2010/11 | 2012/13 |
|---|---|---|---|---|---|
| Farmgate maize price (Tsh/kg) | S.Highlands | | 479 | 498 | 458 |
| | North | | 638 | 674 | 575 |
| | Eastern | | 644 | 638 | 532 |
| | Central | | 645 | 678 | 601 |
| | Lake | | 628 | 745 | 617 |
| | West | | 567 | 701 | 568 |
| | South | | 685 | 591 | 592 |
| Price of DAP (Tsh/kg) | S.Highlands | | 1,931 | 1,636 | 1,440 |
| | North | | 1,931 | 1,636 | 1,440 |
| | Eastern | | 1,931 | 1,636 | 1,440 |
| | Central | | 1,931 | 1,636 | 1,440 |
| | Lake | | 2,231 | 1,926 | 1,680 |
| | West | | 2,231 | 1,926 | 1,680 |
| | South | | 1,931 | 1,636 | 1,440 |
| Price of Urea (Tsh/kg) | S.Highlands | | 1,287 | 1,128 | 1,200 |
| | North | | 1,287 | 1,128 | 1,200 |
| | Eastern | | 1,287 | 1,128 | 1,200 |
| | Central | | 1,287 | 1,128 | 1,200 |
| | Lake | | 1,487 | 1,328 | 1,400 |
| | West | | 1,487 | 1,328 | 1,400 |
| | South | | 1,287 | 1,128 | 1,200 |

Source: Maize prices are in real 2012/13 Tsh terms and are from the MIT Agricultural Marketing System; these are the annual average regional wholesale prices, with a 20% markup for the average value of village retail maize prices. Urea prices are the median household-level purchase price by year in the southern highlands, with a +200 Tsh price increase for the Lake and West zones; due to low numbers of DAP prices in the NPS data, we base these farm-gate prices on the farm-gate urea price (from NPS) multiplied by the ratio between DAP/urea from “annual average go-down DAP/urea prices” from the Directorate of Agricultural Inputs, MALF.

**Appendix Table 2. Village access to paved road, input retailer, and percentage of smallholder maize growers applying fertilizer to maize, Tanzania and Kenya**

| Country | Distance from village to nearest paved road (km) | Distance from village to nearest input or fertilizer retailer[1] (km) | % of smallholder maize growers using inorganic fertilizer |
|---|---|---|---|
| *Tanzania (2009/10) by region* | ------ mean ----- | | -- % -- |
| Arusha | 15.5 | 3.5 | 12.7 |
| Kilimanjaro | 5.3 | 11.0 | 36.7 |
| Morogoro | 25.4 | 11.1 | 2.8 |
| Ruvuma | 4.6 | 6.0 | 45.3 |
| Iringa | 18.7 | 31.1 | 59.4 |
| Mbeya | 33.7 | 29.8 | 48.3 |
| Rukwa | 27.0 | 49.0 | 13.4 |
| Kigoma | 15.6 | 30.3 | 4.4 |
| | | | |
| *Kenya (2009/10) by zone* | | | |
| Eastern Lowlands | 10.9 | 3.1 | 61.8 |
| Western Lowlands | 5.3 | 4.3 | 14.8 |
| Western Transitional | 7.9 | 4.1 | 79.9 |
| High Potential Maize | 6.9 | 5.0 | 89.8 |
| Western Highland | 5.2 | 2.7 | 92.9 |
| Central Highland | 5.0 | 1.5 | 87.6 |