Profitability of fertilizer use in SSA: evidence from rural Malawi

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Profitability of Fertilizer Use in SSA: Evidence from Rural Malawi

Abstract

This study assessed the profitability of fertilizer use by farmers in rural Malawi using a two-wave nationally representative panel data. We find that fertilizer use is generally unprofitable at prevailing market conditions when farmers are assumed to be risk averse. In order for fertilizer use to be profitable on average, the nitrogen use efficiency (NUE) – the kilograms of maize obtained from a kilogram of nitrogen – would have to increase by 136%, 141% and by 50% if maize output is valued at farm gate price, harvest season market price and lean season market price respectively; or fertilizer ought to be subsidized at a rate of at least 72.43%, 71.67% and 41.34% respectively. Although fertilizer subsidy improves the profitability of fertilizer by increasing the maize-nitrogen price ratio, we find that at all rates of subsidy, unless farmers can store their produce and sell during the lean season where output price is relatively higher, they would be at least MK 66.16 and MK 61.81 per kg of subsidized nitrogen better off with the cash equivalent of the subsidy than with subsidized fertilizer when maize is values at farm gate price and harvest season market price respectively. We also find that the government recommended rates of fertilizer application is too high to be profitable at prevailing market conditions, but profitability at this rate of fertilizer application is over 100% higher than profitability at actual rate of application.

JEL classification: C52, C81, Q12, Q18

Keywords: Maize, Fertilizer profitability, Nitrogen use efficiency, Malawi, Fertilizer subsidy

1. Introduction

Improving agricultural productivity is widely regarded as a channel for reducing poverty and food insecurity in sub-Saharan Africa (SSA). This view is based on the heavy reliance of poor and food insecure households on agriculture. Unfortunately, agricultural productivity has been very low in SSA – since the 1960s, average per capita annual growth in agricultural productivity has been less than 1% for the continent as a whole and, at times, negative for some sub-regions (FAO statistics, 2013). The lagging agricultural growth in SSA has mainly been explained by low fertilizer use (Morris et al., 2007). Morris et al (2007) observed that when countries and crops in similar agro-ecological zones are compared, the rate of fertilizer application is much lower in Africa than in other developing regions of the world. Meanwhile, fertilizer use is particularly important in Africa because the continent's soils are inherently poor in nutrients, and over the past decades, land-use practices have further worsened soil fertility through leaching, nutrient mining by crops and inadequate erosion control.

The low use of fertilizer in Africa can be attributed to both demand-side and supply-side factors. The first and most obvious demand-side factor that could potentially explain the low use of fertilizer in Africa relates to profitability. Farmers' demand for commercial fertilizer is weak because fertilizer use is probably unprofitable or only marginally profitable to most farmers. Incentives to use fertilizer are often undermined by the low fertilizer response rate, high variability of crop yields, lack of credit and high fertilizer prices relative to crop output prices. The demand for fertilizer is further exacerbated by lack of information about the availability and cost of fertilizer, the inability of farmers to raise resources needed to purchase fertilizer, and lack of knowledge on the part of many farmers about how to use fertilizer efficiently. On the supply side, the factors the potentially undermine the use of commercial fertilizer by farmers include unfavorable business climate, excessive regulations, an abundance of taxes and fees, and high levels of rent seeking.

With these considerations in mind, the objective of the present study is to use nationally representative household level data from Malawi to understand the profitability of fertilizer use in SSA. Specifically, the study seeks to answer the following questions: 1) What is the level of nitrogen use efficiency (NUE) – kilograms of maize obtained from a kilogram of nitrogen applied –, and how does it vary across the districts of Malawi? 2) To what extent is fertilizer use profitable in maize production? 3) How does fertilizer subsidy affect profitability of fertilizer use? 4) How does government recommended and actual rates of fertilizer application compare with the optimal rate of application?

The study focuses on Malawi for two reason. First, growth in Malawi's agricultural productivity is typical of countries in SSA. For the past two decades, the productivity of most agricultural crops in the country has increased only modestly. Even now, the already modest increase in productivity is further undermined by population growth (MoAFS, 2010). The Ministry of Agriculture and Food Security (2010) estimates that the country's yield gap – the difference between potential yield and the actual yield of the average farmer – ranges from 38-53% for cereals, and 40-75% for legumes (Lobell et al., 2009). This implies substantial room for productivity improvements. Yield improvements likely will be essential for reducing poverty and improving food security in Malawi because there is limited room for area expansion among smallholders (Dorward 2006; Ricker-Gilbert et al. 2014). Second, since the government of Malawi (GoM) has been implementing a large-scale Farm Input Subsidy Program (FISP) from the 2005/2006 agricultural season, focusing on Malawi provides an opportunity to analyze how fertilizer profitability can inform the targeting of large-scale farm input subsidy programs, and how the subsidy program affect the profitability of fertilizer use. In terms of scope and coverage, FISP is perhaps the most well-known farm input subsidy program in Africa. Through FISP, GoM provides approximately 50 percent of the country's agricultural household with coupons that allow for inorganic fertilizer and improved maize seed purchases at up to a 90% discount. For these reasons, results from this study should be broadly applicable elsewhere in the region.

The study adds to literature in terms of the issue it addresses, and the data and methodology used in doing so. To the best of our knowledge, this will be the first study to analyze the profitability of fertilizer use in terms of how it relates to the targeting of large scale farm input subsidy programs. Although the issue of fertilizer profitability has received some attention in the literature, its relationship to the targeting of fertilizer subsidy programs is yet to be explored. Farm input subsidy programs account for substantial proportion of agricultural budgets of African countries thus it is imperative that the inputs are distributed in a manner that maximizes the benefits that accrue. Accordingly, subsidized fertilizer ought to be distributed to areas where it can be used most efficiently i.e. areas where the highest yield response rate can be obtained.

The study uses a nationally representative panel dataset that allows us to control for plot-level unobserved heterogeneity using a garden identifier, where a garden is defined as a continuous piece of land that is not split by river or a path wide enough to fit an ox-cart or vehicle, and can contain multiple plots. The dataset also allows us to account for all the output prices – farm gate price, harvest season market price and lean season market price – that farmer can potentially face. While most farmers sell their produce at the farm gate others sell at nearby market centers and, depending on the month in which sales are made, face either the harvest season price or the lean season price. To our knowledge, this study will the first in the fertilizer profitability literature to control for plot-level unobserved heterogeneity and consider all the possible output prices that farmers can face.

On the methodological front, the study contributes to literature by estimating yield function with a hierarchical model in addition to fixed effects models. Given the spatial differences in soils and other agro-ecological conditions within African countries, yield response to fertilizer application is likely to vary across space, yet this has seldom been accounted in the literature.

2. Conceptual Framework

The goal of this study is to assess the profitability of inorganic fertilizer use in Malawi. In doing so, we derive yield function and the profitability of fertilizer use from the farm profit component of Sing, Squire and Strauss (1986) agricultural household model. Farmers are considered to be firms whose production set is made up of food and cash crops. Maize is the most widely cultivated crop in Malawi – it is cultivated by about 90% of farmers on 70% of their farm plots – and the most important crop in terms of fertilizer application (NSO, 2013). The study therefore focuses on farmers' decision to produce maize using inorganic fertilizer and other inputs, with the objective of maximizing farm profit, π, which is given by:

$$\pi = P_Y Y(I) - P_I I \tag{1}$$

where Y and P_Y are quantity of maize and maize price respectively; I is a vector of inputs used in the production of maize; and P_I is a vector of the prices of the inputs used in the production of maize. The term *Y(I)* represents the agronomic production function where a vector of inputs I, are turned into maize output Y. In the literature, I typically includes growth inputs such as nutrients, seed and water; and facilitating inputs such as labor and pesticides (Frank et al. 1990; Guan et al, 2006)[1]. The agricultural economics literature extend the facilitating inputs to include household characteristics such as wealth, education, household size and dependency ratio (Xu et al, 2009; Sheahan et al. 2012). The present study categorizes the growth and facilitating inputs into plot-level and household-level variables. The plot-level variables include such

[1] Growth inputs those inputs that are directly involved in the biological process of plant growth and development. The facilitating inputs are not directly involved in the growth and development process of plants but influence the response rate of plants to the growth inputs (Guan et al, 2006).

variables as nutrient and seed application rates that vary across plots; and the household-level variables include household characteristics such as wealth and education that vary across households but the same across plots managed by the same household.

In the present study, the production function of Y is given by:

$$Y = f(N, X, H, W) \qquad (2)$$

where Y is maize yield in kilograms of maize per hectare, N is the rate of nitrogen (from inorganic fertilizer) application, X is a vector of other plot-level agronomic inputs including the quantity of seeds sown, the amount of labor used on the plot, whether or not the plot is planted to a hybrid maize variety etc. H is a vector of household-level variables such as asset ownership, quantity of arable land owned by the household, educational status of the household, adult-equivalent household size, dependency ratio etc. that are likely to affect maize production. W is a vector of weather variables including rainfall and temperature. Yield is measured as maize-equivalent output per hectare of land. Maize-equivalent output is used instead of maize output because, as in other developing countries, maize is usually intercropped in Malawi. Total output from any particular plot is converted to maize equivalent output (*ME*) using an output index given by equation 4 (Liu and Myers, 2009; Sheehan et al., 2013):

$$ME_p = Z_{maize,p} + \frac{\sum_s Z_{sp} P_s}{P_m} \qquad (9)$$

where $Z_{maize,p}$ is kilograms of maize harvested from plot *p;* Z_{sp} is kilograms harvested of crop s intercropped with maize on plot *p*; and P_s and P_m are the market price of crop s and maize respectively. Equation (9) reduces to $Z_{maize,p}$ on pure-stand maize plots.

Taking the first order condition of profit maximization with respect to the nutrient variable and rearranging terms results in equation (3) below[2]:

$$P_Y * MP_N = \ P_N \tag{3}$$

where MP_N is the marginal product of nitrogen; and P_Y and P_N represent the prices of maize and nitrogen respectively. Accordingly, the left-hand side of equation (3) is the marginal revenue product of inorganic fertilizer application, measuring the rate at which revenue from maize production increases with the amount used of nitrogen. A household's decision to use inorganic fertilizer in the production of maize is influenced by the extent to which the input is profitable – the higher the profitability of fertilizer use, the higher the incentive for farmers to use the input. From equation (3), the extent of fertilizer profitability to a household is given by $(P_Y * MP_N - P_F)$, thus profitability of fertilizer use depends on the household's yield response rate to fertilizer, the price of maize and the price of fertilizer. MP_N, the only unknown in equation (3), is obtained from the estimation of equation (2).

3. <u>Empirical Model</u>

In order to study the profitability of fertilizer use by farmers in Malawi, the yield function in equation (2) is specified using fixed effects (district, enumeration area, household and garden) and multilevel models[3]. These specifications will together provide a good evaluation of the robustness of our estimates to model specifications. The fixed effects model is specified generally as:

$$Y_{ijt} = \beta_1 N_{ijt} + \ X_{ijt}\beta_x + \ W_{ijt}\beta_w + \varepsilon_{ijt} \tag{4a}$$

$$\varepsilon_{ijt} = \ c_i + \ \varepsilon_{ijt} \tag{4b}$$

[2] The first order condition of the profit function is taken with respect to only the inorganic fertilizer variable because inorganic fertilizer is the variables of interest.

[3] A garden is defined as a continuous piece of land that is not split by river or a path wide enough to fit and ox-cart or vehicle, and can contain one or more plots.

where i and t represent plot and time respectively; j is the indicator for fixed effects (district, enumeration area, household or garden); ε_{ijt} is a composite error term made up of time-invariant (c_i) and time-varying (ε_{ijt}) unobserved factors; β_1 is nitrogen use efficiency (NUE), i.e. the response rate of maize to nitrogen application (henceforth NUE); and β_x and β_w are other parameters to be estimated. The rest of the variables are as defined above.

We considered multilevel specifications in addition to the fixed effects specifications because it enables us to estimate households-specific and garden-specific NUE. The estimation of NUE at such disaggregated levels is of particular interest in this study because it allows us to analyze the variation in NUE, and subsequently the profitability of fertilizer use, at the lowest disaggregated level possible. The use of multilevel models has two additional advantages. First, the data for the analysis has a hierarchical structure: plots are nested within gardens which are in turn nested within households (farm households in Malawi and other parts of developing countries usually cultivate crops on multiple plots). The existence of such a hierarchy in the data has implications for statistical validity and should therefore not be ignored (Goldstein, 1995; Elhorst, 2014; Carrado and Fingleton, 2011). The multilevel model accounts for the hierarchical structure between plots, gardens and households by modelling variations at all levels. Moreover, yield from plots belonging to the same garden and household are likely to be correlated because they share the same management and related conditions. The multilevel specification corrects for these intra-garden and intra-household correlations[4]. Second, the multilevel model distinguishes (explicitly) between plot-level and household-level covariates in the model by allowing for the coefficients of the plot-level variables to vary within gardens and households. This is particularly important in this study because of the interest in observing the geographical variation of NUE. For want of space, we leave the multilevel specification out of this version of the paper; it can be however be made available upon request. .

Fertilizer Profitability

[4] The use of single-level models (which assume that yields are independent across plots) in the presence of intra-household in yield will lead to spuriously small standard errors, which will in turn result in too short confidence intervals and too small p-values.

Fertilizer profitability is measured with Marginal Value Cost Ratio (MVCR) which represents the extent by which farm income will increase if the rate of nutrient application increases. MVCR is expressed as:

$$MVCR = \frac{NUE * P_{maize}}{P_N} \quad (8)$$

Where NUE is the response rate of maize to nitrogen application; and P_{maize} and P_N are the prices of maize and nitrogen respectively. We consider three prices of maize in the profitability analyses – farm gate price, harvest season market price and lean season market price. While most farmers sell their produce at the farm gate, others sell at nearby market centers and depending on the month in which sales are made, face either the harvest season price or the lean season price. Thus the maize prices that we use in the analyses reflects all the possible maize prices that farmers are likely to face. P_N , the price of nitrogen, is computed using the prices and nitrogen composition of chitowe (NPK 23:21:0 +4S) and the urea fertilizers, the two main fertilizers used in maize production. Following Xu et al. (2009), let *f* be the amount of each of chitowe and urea required for a kilogram of nitrogen. Given the 1:1 application ratio of chitowe and urea and their nitrogen components (23% for chitowe and 46% for urea), we have the following expression: $23\%f + 46\%f = 1$; and solving for *f* results in $f = 1.449kg$. This means that a kilogram of nitrogen costs approximately 1.449 kilograms of each of chitowe and urea; hence [$P_N = 1.449 * (price\ of\ chitowe + price\ of\ urea)$].

Using MVCR, the decision of whether or not fertilizer is profitable depends on the assumption made about farmers' risk tolerance. For risk-neutral households, fertilizer use is deemed profitable if MVCR is greater than one, an indication that an increase in the rate of fertilizer application will increase income from maize production. For risk averse households, an MVCR of at least two (meaning a risk premium of one) has been recommended in the literature to be required in order for fertilizer to be profitable (Xu et al., 2009; Sauer and Tchale, 2009; Bationo et al., 1992; FAO, 1985). We adopt this rule of thumb in this paper so as to account for the uncertainty and many unobserved costs associated with fertilizer use in Malawi.

Data and Sample Selection

The data used in the analysis is a two-wave panel dataset collected by the national Statistical Office of Malawi (NSO) with support from the World Bank Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) program. The survey for the first wave of the dataset (Malawi's Integrated Household Survey – IHS3) was conducted from March 2010 through March 2011, and covered 12,271 households in 768 enumeration areas (i.e. 16 households from each EA). A sub-sample of the households considered in IHS3 were re-surveyed in 2013 to create the second wave of the dataset (Integrated Household Panel Survey - IHPS). IHPS tracked and re-interviewed 4000 households (3,247 original households, and 753 split-off households) from 204 of the 768 enumeration areas.

The households that were not resampled in IHPS were dropped from the dataset. We further dropped households from the urban enumeration areas because farming in Malawi is predominantly rural. In the rural households, because of the maize focus of the study, we concentrated on farm plots on which maize is the main crop. In the end, the sample size for the 4,913 maize plots (2,228 from IHS3 and 2685 from IHPS).

4. Results

4.1 Descriptive statistics

The descriptive statistics of the variables in the yield function are presented in table 2. The average maize yield in the 2009/2010 agricultural year was 1,240.61kg/ha and increased significantly to 1536.27kg/ha (24% increase) in the 2012/2013 agricultural year. The average yield estimates are higher than those reported for Nigeria over the same period of time (1154 kg/ha in 2010 and 1282 kg/ha in 2012), but lower than the average reported for Kenya (2707 kg/ha over 1997, 2000, 2004, 2007 and 2010) and Zambia (1779 kg/ha in 2009) (Liverpool-Tasie et al. 2015; Sheahan et al. 2012; Xu et al. 2009).

One would expect the increase in yield between the two agricultural seasons to have resulted from an increase in the use of improved inputs such as inorganic fertilizer and hybrid seed, but the use of these inputs in our sample actually decreased significantly between the seasons: the rate of nitrogen application decreased by about 13% (from 49.18 to 43.37 kg/ha), and the percentage of plots planted to hybrid maize varieties decreased by 4 percentage point (from 43.0% to 38.6%). Over the same period, labor utilization rate, seed application rate, the number of plots on which organic fertilizer was applied, and the number of plots on which the right type of basal fertilizer was applied increased significantly; and the average plot size and the number of plots managed by females decreased significantly. The combined yield-increasing effect of the significant changes in these variables probably outweighed the yield-decreasing effect of the decrease in the use of inorganic fertilizer and hybrid seed. The increase in yield could also have been partly due to farmers becoming relatively more efficient in the use of farm inputs in crop production.

Soil erosion appears to be a concern in maize production in Malawi. Nearly 40% of the plots used in maize production showed signs of erosion which could probably have been caused by the fact that about the same proportion of plots are sloppy. Depending on the extent, soil erosion can potentially have a yield-decreasing effect by washing away the top soil and eventually depleting the soil of major nutrients. The high proportion of erosion-affected plots notwithstanding, only about 15% of the plots are reported by farmers to be of poor soil quality (about 45% of the plots are reported to be of good soil quality and the rest are reported to be of fair quality).

4.2 Production Function Results

Results of the maize production function are presented in table 3. The results are presented for seven model specifications: pooled OLS, district fixed effects, enumeration area fixed effects, household fixed effects, garden fixed effects, two-level multilevel model where plot and household are the first and second levels respectively, and a two-level multilevel model where plot and garden are the first and second levels respectively. The different specification provides a good evaluation of the robustness of our estimates. The coefficient of the nitrogen variable, the variable of interest, does not vary much across models, implying that our estimate of the NUE is robust to model specifications.

Depending on the estimator used, a kilogram increase in the rate of nitrogen application increases yield by 9.24 to 11.89 kilograms, corroborating the widely held notion that the use of inorganic fertilizer is important for improvement in agricultural productivity. We provide a detailed analysis of the fertilizer NUE in section 4.3 below. Yield on plots on which the rate of nitrogen application was above the recommended rate is about 332.63 kg/ha lower than it is on plots on which the recommended rate was followed. It is usually recommended that basal fertilizer application in maize production be done within a week after planting in order to ensure higher yields. The results indicate that compliance with this recommendation increases yield by about 169.24kg/ha, all thing being equal. The results further indicate that the use of organic fertilizer increases agricultural productivity by about 126.46 kg/ha.

There is a significant, inverse relationship between plot size and maize yield. All things being equal, a hectare increase in plot size will decrease yield by 847.80 kg/ha. Larger farms are usually not farmed as intensively as smaller farms and therefore are underutilized, resulting in lower productivity. This inverse relationship between plot-size and productivity is common in the literature (Carletto et al. 2011).

Labor utilization has a positive and significant effect on maize yield. All things being equal, a day increase in total tabor (sum of family, hired and exchange labor) increases maize yield by 0.95 kg/ha. The positive effect is expected because labor (family or hired) is needed for cultural practices such as land preparation, weeding, mulching, fertilizer application and pest control without which yield would be very low.

Soil quality has a positive and significant yield-increasing effect. The estimates show that, on average, yield on plots of good and fair quality is about 259.84kg/ha and 179.14kg/ha respectively higher than yield on plots of poor soil quality.

The gender and years of education of plot manager also significantly affect maize yield. Yield on female-managed plots is 113.27kg/ha lower than it is on male-managed plots. In a similar study in which agricultural productivity was measured by value of output per hectare, Kilic et al (2014) observed that productivity of female-managed plots is 25% lower than on productivity on male-managed plots. The authors find that 82% of the gender differential in agricultural productivity is attributable to differences in endowments. It has been shown that closing this gender gap in agricultural productivity can potentially reduce the poverty rate by 2.2% and accordingly lift 23000 people out of poverty each year in Malawi (World Bank, 2015). Our estimates also show that a year increase in the education of plot managers will all things being equal increase yield by 10.535 kg/ha.

Maize yield is also positively affected by ownership of agricultural tools and durable assets. A unit increase in the index of agricultural tools and durable assets will all things being equal increase yield by 68.96kg/ha and 93.73kg/ha respectively. The positive relationship between asset ownership and maize yield is expected because farmers with more equipment are more likely to purchase and use fertilizer and other modern inputs in crop production.

Rainfall has a positive and significant effect on maize yield. A millimeter increase in total annual rainfall increase maize yield by 1kg/ha, all things being equal. This finding suggests that increasing farmers' access to irrigation facilities could help boost agricultural productivity.

4.3 Nitrogen use efficiency (NUE)

What is the level of NUE and how does it vary across the districts of Malawi? Generating the NUE at the most disaggregated level possible is of particular interest in this study. Our use of a two-level multilevel model allows for the estimation of NUE at the garden level. Using this model, we estimate the NUE to range from 2.82kg to 25.98kg with a mean and standard deviation of 11.82 and 2.42 respectively (figure 1). Figure 1 also shows that the NUE ranges between 10 and 15 for majority of the gardens (75%); between 5 and 10 for 16% of the gardens; between 15 and 20 for about 8% of the gardens; and at least 20 for only about 1% of the gardens.

On average, the NUE is quite low. This low NUE is likely to be one of the main reasons why the use of commercial fertilizer is very low in the country. The fertilizer use literature suggests that, the low NUE that we find in this study is not an isolated case in SSA. The NUE has been estimated to be between 8kg and 13kg in Nigeria, and between 11kg and 20kg in Kenya

(Liverpool-Tasie et al. 2015; Matsumoto and Yamano, 2011; Marenya and Barrett 2009; Sheahan et al, 2012). In terms of fertilizer (not just nitrogen application), NUE has also been very low in some parts of SSA – 0.2kg to 2kg in Nigeria and 0.12kg in the Mfantseman municipality of the Central Region of Ghana (Onuk et al., 2010; Gani and Omonona, 2009, Liverpool-Tasie et al. 2015).

We estimate the mean NUE for each district and use these estimates to categorize the districts into five groups. Such categorization will be useful in guiding the geographical targeting of the farm input subsidy program that the government is currently implementing because coupons to be redeemed for subsidized inputs by beneficiaries are distributed through a decentralized process that begins with the headquarters of the Ministry of Agriculture and Food Security (MoAFS) allocating the coupons to districts. The NUE ranges from 12.37 to 13.27 for the first group, 11.8 to 12.36 for the second group, 10.95 to 11.79 for the third group, 10.38 to 10.94 for the fourth group, and 9.63 to 10.37 for the fifth group (figure 4a). The first group of districts consists of Dowa, Ntchisi and Chiradzulu; the second group of consists of Mchinji, Kasungu, Nkhota kota, Salima, Karonga, Ntcheu, Mangochi and Blantyre; the third group consists of Chitipa, Nkhata Bay, Lilongwe, Dedza, Balaka and Zomba; the fourth group consists of Machinga, Mwanza, Phalombe and Thyolo; and fifth group consists of Neno, Mulanje, Chikwawa and Nsanje. Overall, the mean NUE for the districts in the central region are relatively higher than those in the northern and southern regions in that order. We also find a strong, positive correlation (0.88) between the spatial distribution of the NUE and the spatial distribution of maize yield, implying that districts with the highest mean NUE have the highest mean yield (figures 4a and 4b).

4.4 Fertilizer profitability results

To what extent is the use of fertilizer profitable in maize production? At commercial price of inorganic fertilizer, the marginal value cost ratio (our measure of fertilizer profitability) is estimated to be 0.81 when maize is valued at farm gate price, 0.82 when maize is valued at harvest season market price, and 1.32 when maize is valued at lean season market (figure 2). These estimates show that the use of commercial fertilizer in the production of maize is not profitable for risk averse farmers irrespective of the maize price that farmers face. For risk neutral farmers however, the use of commercial fertilizer in maize production is profitable on average when maize is valued at lean season market price, but unprofitable when maize is valued at farm gate price and harvest season market price. The garden level analyses show that, under the assumption of risk aversion, fertilizer use is profitable on only less than 1% of gardens when maize is valued with farm gate price or harvest season price of maize, and profitable on 17.54% when maize is valued with lean season market price (figure 3a). Under the risk neutrality assumption however, the number of gardens on which fertilizer use is profitable increases to 30.84% at farm gate price of maize; 35.35% at harvest season market price of maize and 78.75% at lean season market price of maize (figure 3b).

Generally, the estimates show that the profitability of fertilizer use in maize production is encouraging under the assumption of risk neutrality and when maize is valued with the lean season market price. However the assumption of risk neutrality is not likely to hold in Malawi because of the uncertainty and additional costs associated with use of fertilizer in crop production. Also because ownership of crop storage facilities is very limited (only about 20% of farmers own some storage structure) farmers generally have limited ability to defer the selling of maize to the lean season when prices are relatively higher. Hence the only practical scenario is the assumption of risk aversion and the valuation of maize at farm gate price and harvest season market price. Under these scenarios, the estimates show that fertilizer use is not profitable on average, and profitable on only less than 1% of gardens. At the district-level, under the assumption of risk aversion, fertilizer use is on average not profitable in all the districts when maize is valued at farm gate or harvest season market price, but profitable in Mulanje and Blantyre, and nearly profitable in Karonga, Mangochi, Neno, Chiradzulu, Phalombe, Chikwawa and Nsanje when maize is valued with the lean season market price (figure 5). Apart from Karonga which is located in the Northern region of the country, all the other districts in which fertilizer use if profitable or nearly profitable, are located in the Southern region. The low profitability of commercial fertilizer use is probably a major contributing factors to the limited use of commercial fertilizer by smallholder farmers in Malawi.

Profitability of fertilize use can be improved by increasing NUE and/or increasing the maize-nitrogen price ratio. On average, in order for fertilizer to be profitable, the NUE will have to increase to 28.06kg (136.08%) when maize is valued at farm gate price, 28.71kg (141.52%) when maize is valued at harvest season market price; and 17.78kg (49.58%) when maize is valued at lean season market price (figure 6). At the garden level, in order for fertilizer use to be profitable, NUE would have to increase by more than 100% on 67% of the gardens when maize is valued at farm gate price, and 65% of the garden when maize is valued at harvest season maize price in order to make fertilizer profitable (figure 7). Also, NUE will have to increase by 40-100% on about 24% of the gardens in order for fertilizer to be profitable when maize is valued at either farm gate price or harvest season price (figure 7). These estimates reveal that, in order for the use of fertilizer to be profitable, NUE increase by a big margin. The NUE on experimental plots in Malawi, which we consider to be the maximum attainable NUE, has been estimated to be 17kg (Harou et al., 2015). Hence we consider the 135.08% and 141.52% increase in NUE required to make fertilizer use profitable when maize is valued with farm gate price and harvest season market price to be impractical. The 49.58% increase in NUE required to make fertilizer use profitable when maize is valued at the lean season market price is however attainable. Although this study does not directly investigate how NUE can be improved, our production function estimates provides some indications to that effect. As indicated in the previous section, compliance with the recommendation for inorganic fertilizer application such as timely application of basal fertilizer and not applying fertilizer beyond the recommended rate has yield-increasing effect. Thus NUE could be improved if farmers comply with these recommendations.

4.5 Subsidy and fertilizer profitability

How does fertilizer subsidy affect the profitability of fertilizer use? What is the optimal rate of fertilizer subsidy – the rate of subsidy required to make fertilizer profitable? Would farmers be better off with the cash equivalent of fertilizer subsidy then using subsidized fertilizer to produce maize? The estimates indicate that, as expected, reducing the price of fertilizer via inorganic fertilizer subsidy, all things being equal, boosts the profitability of the use of fertilizer in maize production. For instance when maize is valued at farm gate price, 25%, 50%, 75% and 90% fertilizer subsidy increases the average MVCR from 0.81 to 1.02, 1.38, 2.11 and 3.11 respectively (figure 8a). In terms of the number of gardens on which fertilizer is profitable, we find these rates of subsidy will increase the number of gardens on which fertilizer is profitable from 0.80% to 6.44%, 25.41%, 67.02% and 84.42% respectively (figure 8b). The MVCR estimates and the estimates of the number of gardens on which fertilizer is profitable when maize is valued with harvest season market price is very similar to the corresponding estimates for when maize is valued with farm gates price. The estimates are however relatively higher when maize is valued at lean season maize price – the MVCR increases from 1.32 to 1.66, 2.24, 3.44 and 5.07 at 25%, 50%, 75% and 90% subsidy rates respectively; and number of gardens on which fertilizer use is profitable increases from 17.54% to 37.4%, 69.31%, 88.75% and 92.19% respectively (figure 8a and 8b). It is clear from these estimates that even with fertilizer subsidy, the profitability of fertilizer use in the production of maize is still low when maize is sold at the farm gate price or harvest season market price, but quite encouraging when maize is sold at the lean season market price. This assertion is further highlighted by the optimal rate of subsidy that we estimate to be very high – 72.43%, 71.67% and 41.34% when maize is valued at farm gate price, harvest season price and lean season market price respectively (table 4).

In order to put the effect of the fertilizer subsidy on the profitability of fertilizer use in maize production into perspective, we compared the cash amount of fertilizer subsidy with how much the average farmer will gain from using subsidized fertilizer in maize production. We find that at all rates of fertilizer subsidy, unless farmers are able to store their produce and sell in the lean season, the average farmer is MK 66.16 per kg of subsidized nitrogen better off with the cash equivalent of the subsidy than participating in the subsidy program if maize is valued at the farm gate. If farmers are able to store maize and sell in the lean season however, they will be MK 111.70 per kg of subsidized inputs better off with the subsidized inputs than with the cash amount of the subsidy. We could not account for the opportunity cost and the other operational costs associated with maize production in our estimation, both of which will make the cash equivalent of the subsidy more favorable than the subsidized inputs. Hence although fertilizer subsidy increases the profitability of fertilizer use, farmers would, on average, be better off with the cash equivalent of the subsidy than with subsidized inputs at current market and agronomic conditions, unless farmers are able to sell in the lean season.

4.6 Profitability of government recommended rates

How profitable is government recommended rate of fertilizer application? As a final exercise, we investigate the profitability of fertilizer use at rates recommended by the Ministry of Agriculture and Food Security of Malawi (MoAFS). We converted the actual fertilizer application rates to their respective nitrogen application rates and then compute the corresponding NUEs at the garden level using the estimates from our production function. With this NUE and the prices of nitrogen and the various prices of maize, we compute the MVCR of the government recommended rates to be 1.75 at farm gate maize price, 1.80 at harvest season maize price, and 2.83 at the lean season maize price (Figure 9).

The estimates therefore show that at current prices, when risk aversion is assumed, the application of nitrogen at the government rates of application is not profitable when maize is valued at either farm gate price or harvest season market price; but profitable when maize is valued at the lean season market price. In terms of the number of gardens on which fertilizer use is profitable, we find that fertilizer use at government rates of nitrogen application is profitable on only 27% and 30% of gardens when maize is valued at the farm gate price and harvest season maize price respectively; and profitable on 68% of plot when maize is valued at lean season market price (figure 10). This finding follows from the fact the recommended rate is higher than what we compute to be the optimal application rate on most plots. The estimates further show that although the profitability of fertilizer use at the government rate of application is unprofitable on average at current prices, applying fertilizer at this rate is over 100% more profitable than the rate at which farmers are currently applying (figure 9). Figure 11 however reveals that the actual rate of N application on majority of the plot is lower than lower than the optimal rate of N application. This means that at current rate application, fertilizer profitability can be improved my increasing the rate of application.

5. Conclusions and Policy Recommendations

The study uses a two-wave nationally representative household panel data from Malawi to assess the profitability of inorganic fertilizer use in maize production. Specifically, the study assessed the extent to which fertilizer use in profitable, the gap between actual and optimal NUE, the effect of fertilizer subsidy on the profitability of fertilizer use, and the profitability of government recommend rates of fertilizer application. In addition to using nationally representative data and assessing the effect of fertilizer subsidy on the profitability of fertilizer use, the study contributes to the existing literature by controlling for plot-level fixed effects, using multilevel model to generate household and garden specific NUE; and accounting for all the possible prices that farmers are likely to face in both input and output markets.

We find that fertilizer use is on average not profitable at commercial prices of fertilizer and all prices of maize that farmers can potentially face when farmers are assumed to be risk averse, an assumption that is likely to hold in Malawi and other parts of SSA. At the garden level, fertilizer use is only profitable on less than 1% of gardens when maize is valued at either farm gate price or market season price and profitable on only 17% of gardens when maize is valued at the lean season market price. At the district-level fertilizer use is not profitable in all the districts of Malawi when maize is valued at farm gate price and harvest season price; but profitable in two districts (Blantyre and Mulanje) and nearly profitable in seven other districts (Karonga, Mangochi Neno, Chiradzulu, Phalombe, Chikwawa and Nsanje) when maize is valued at lean season market price.

In order to make fertilizer more profitable at prevailing market conditions, we find that, the current average NUE of 11.89 would have to increase by at least 136%, 141% and by 50% if maize output is valued at farm gate price, harvest season market price and lean season market price respectively; or fertilizer ought to be subsidized at a rate of at least 72.43%, 71.67% and 41.34% respectively. We also find that, at all rates of fertilizer subsidy, unless farmers are able to store their produce and sell in the lean season, the average farmer is MK 66.16 (MK 61.81) per kg of subsidized nitrogen better off with the cash equivalent of the subsidy than participating in the subsidy program if maize is valued at the farm gate (lean season market) price. If farmers are able to store maize and sell in the lean season however, farmers would be MK 111.70 per kg of subsidized inputs better off with the subsidized inputs than with the cash amount of the subsidy on average. Finally, the study finds that the government recommended rate of fertilizer application is too high for fertilizer to be profitable on average; but the profitability of fertilizer use at this rate of application is over 100% higher than profitability at rates that farmers actually apply.

Based on the findings of this study, in order to improve the profitability of fertilizer use in maize production, we make three recommendations. First, NUE ought to improve. Applying basal fertilizer within a week after planting has a yield-increasing effect, hence in order to raise NUE farmers should be encouraged to comply with this recommendation. Also, the Ministry of Agriculture and Food Security should consider revising the current recommended rates of fertilizer application to lower levels to ensure higher NUE.

Secondly, rural agricultural households should be encouraged to store and sell most of their produce during the lean season when prices are relatively high by adopting grain storage technologies such as Purdue Improved Crop Storage (PICS) bags that has been proven to be very efficient and cost-effective. Thirdly, efforts should be made to reduce the real costs of input supply (Jayne and others, 2003), to increase output prices through improved output market integration (Gabre-Madhin and others 2003), or to reduce transaction costs through improved institutions (Kydd and others 2001).

We also recommend that, in the context of fertilizer profitability, it is also important for the government to consider transferring the cash equivalent of fertilizer subsidy to beneficiaries instead of subsidized inputs, unless farmers can be encouraged to store their produce and sell during the lean season.

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Table 2: Descriptive Statistics

	Pooled		2010		2013	
	Mean	SD	Mean	SD	Mean	SD
Maize yield (Kg/ha)	1,401.659	1,071.563	1,240.611	920.973	1,536.273***	1,166.269
Nitrogen application rate (Kg/ha)	46.014	44.657	49.181	44.595	43.367***	44.599
Below recommended nitrogen application rate (1/0)	0.791	0.412	0.771	0.426	0.808***	0.400
Above recommended nitrogen application rate (1/0)	0.143	0.356	0.161	0.372	0.129***	0.341
Applied basal fertilizer on time (1/0)	0.284	0.456	0.355	0.482	0.224***	0.424
Applied inorganic fertilizer twice (1/0)	0.746	0.437	0.778	0.422	0.720***	0.448
Fertilizer used is basal fertilizer	0.507	0.500	0.484	0.500	0.527***	0.499
Applied organic fertilizer (1/0)	0.162	0.364	0.131	0.335	0.187***	0.385
Seed rate (Kg/ha)	25.019	21.447	22.814	25.273	26.863***	17.437
Used hybrid seed (1/0)	0.406	0.492	0.430	0.496	0.386***	0.489
Pure stand (1/0)	0.467	0.500	0.511	0.499	0.431***	0.499
Plot size (ha)	0.409	0.265	0.422	0.255	0.398***	0.272
Labor (days)	135.580	98.763	119.599	80.505	148.937***	109.886
Soil is of good quality (1/0)	0.444	0.496	0.457	0.498	0.433	0.495
Soil is of fair quality (1/0)	0.420	0.495	0.409	0.492	0.429	0.497
Plot is sloppy (1/0)	0.449	0.497	0.451	0.498	0.446	0.496
Plot is swampy (1/0)	0.159	0.362	0.158	0.358	0.160	0.365
Soil is sandy clay (1/0)	0.548	0.495	0.554	0.495	0.542	0.496
Plot show signs of erosion (1/0)	0.378	0.486	0.380	0.489	0.376	0.482
Female plot manager (1/0)	0.309	0.457	0.297	0.453	0.318	0.460
Age of plot manager (years)	42.608	15.184	41.783	14.927	43.298***	15.353
Years of education of plot manager	4.822	3.840	4.735	3.830	4.895	3.847
African Adult Male Equivalent	3.961	1.648	3.843	1.597	4.059***	1.683
Dependency ratio (%)	122.008	90.398	124.345	92.688	120.054***	88.426
Distance to boma (Km)	38.023	27.151	49.483	27.265	28.443***	23.413
Index of ownership of agricultural tools	0.289	1.354	0.508	1.695	0.105***	0.934
Index of ownership of durable goods	-0.793	1.552	-0.568	1.573	-0.981***	1.509
Annual mean rainfall (mm)	827.249	80.186	830.507	86.039	824.526***	74.715
Annual Mean Temperature (°C * 10)	215.331	17.816	215.482	18.045	215.205	17.625

*** $p<0.01$

Table 3: Maize Production function (full model)

						Multilevel models (Level 1 = Plot)	
VARIABLES	OLS	EA FE	District FE	HH FE	Garden FE	Level 2 = HH	Level 2 = Garden
N application rate (Kg/ha)	12.092***	10.637***	11.284***	9.237***	11.213***	11.552***	11.887***
	(1.698)	(1.741)	(1.678)	(2.248)	(3.174)	(1.484)	(1.521)
Nitrogen application rate (Kg/ha) squared	-0.017	-0.015	-0.016	-0.014	-0.027	-0.017*	-0.018*
	(0.011)	(0.011)	(0.010)	(0.013)	(0.016)	(0.009)	(0.009)
Below recommended N application rate	59.641	-4.043	21.955	-14.258	57.552	69.972	82.740
	(83.920)	(83.399)	(83.242)	(87.246)	(100.810)	(76.992)	(78.777)
Above recommended N application rate	-281.236***	-214.159**	-240.122***	-199.043**	-236.136***	-211.968**	-233.993***
	(93.450)	(87.359)	(86.948)	(92.964)	(62.194)	(84.074)	(88.874)
Applied basal fertilizer on time	153.624***	114.642***	114.864***	184.009***	171.070**	172.323***	169.239***
	(39.746)	(40.853)	(41.541)	(66.360)	(78.907)	(40.290)	(36.331)
Applied inorganic fertilizer twice	-347.788***	-294.479***	-310.228***	-320.883***	-350.493***	-324.236***	-332.633***
	(66.514)	(68.833)	(68.249)	(94.044)	(127.063)	(59.125)	(58.246)
Fertilizer used is basal fertilizer	194.653***	224.489***	206.447***	196.515***	259.993***	180.716***	182.223***
	(38.478)	(36.026)	(37.399)	(49.299)	(73.855)	(34.260)	(33.186)
Applied organic fertilizer	132.084**	135.516***	132.407***	121.343**	87.521**	136.256***	126.458***
	(51.262)	(43.187)	(47.636)	(52.494)	(36.686)	(42.020)	(40.595)
Seed rate (Kg/ha)	3.769***	3.314***	3.164***	3.651***	2.513*	3.625***	3.453***
	(0.920)	(0.870)	(0.892)	(0.951)	(1.293)	(0.809)	(0.789)
Used hybrid seed	31.985	38.291	26.574	51.413	136.536*	30.901	40.850
	(33.965)	(29.982)	(33.007)	(38.839)	(69.693)	(30.243)	(30.724)
Pure stand	-86.076**	-174.341***	-175.919***	-191.329***	-210.800***	-109.635***	-101.360***
	(40.030)	(36.081)	(34.995)	(42.867)	(48.028)	(31.010)	(30.209)
Plot size (ha)	-676.112***	-883.008***	-894.862***	-1,401.012***	-1,800.821***	-916.596***	-847.798***
	(222.339)	(235.539)	(214.805)	(350.108)	(395.619)	(189.547)	(183.287)
Plot size (ha) squared	193.891	275.557*	273.539*	581.543**	752.706**	344.274***	286.124**
	(146.553)	(163.325)	(152.918)	(259.038)	(314.832)	(130.718)	(127.525)
Labor (days)	0.925***	0.913***	0.934***	0.952***	0.962***	0.942***	0.950***
	(0.209)	(0.206)	(0.207)	(0.268)	(0.282)	(0.197)	(0.183)
Soil is of good quality	283.499***	219.820***	239.698***	168.253***	178.885**	253.805***	259.843***
	(50.273)	(50.062)	(48.692)	(54.691)	(75.471)	(41.783)	(41.783)
Soil is of fair quality	173.437***	147.593***	156.578***	181.907***	230.479***	179.355***	179.136***
	(50.434)	(43.679)	(44.756)	(49.679)	(62.539)	(40.327)	(40.557)
Plot is sloppy	-47.802	-44.742	-41.290	-76.431*	-78.986	-59.257*	-53.645*
	(35.259)	(34.091)	(35.148)	(39.650)	(66.640)	(31.338)	(31.160)
Plot is swampy	-5.287	-33.823	-8.920	-83.808	-115.656	-32.024	-26.390
	(38.283)	(37.309)	(35.238)	(52.386)	(89.498)	(40.500)	(39.466)
Soil is sandy clay	25.051	33.122	33.361	-13.825	-8.740	24.675	29.723
	(35.023)	(33.549)	(31.709)	(38.385)	(57.240)	(30.402)	(29.994)
Plot show signs of erosion	38.679	-11.732	-15.097	5.421	46.803	31.250	41.151
	(46.275)	(43.577)	(42.716)	(53.265)	(45.854)	(36.397)	(34.315)
Female plot manager	-102.625***	-107.605***	-90.399**	-150.468**	-198.198**	-111.814***	-113.273***
	(36.295)	(36.724)	(35.365)	(63.280)	(82.736)	(34.716)	(32.751)
Age of plot manager	-1.483	-0.993	-1.201	2.853	0.612	-0.704	-1.126
	(1.377)	(1.275)	(1.285)	(1.939)	(2.211)	(1.185)	(1.106)
Years of education of plot manager	13.855***	8.181*	10.930**	8.614	-7.623	10.638**	10.353**
	(5.201)	(4.752)	(4.830)	(10.485)	(12.591)	(5.020)	(4.674)
African Adult Male Equivalent	-5.412	-0.071	-2.932	10.825	29.695	-5.356	-5.070
	(13.647)	(14.650)	(13.647)	(27.334)	(38.042)	(12.150)	(10.909)
Dependency ratio	0.289	0.245	0.215	0.226	0.046	0.298	0.249
	(0.195)	(0.188)	(0.183)	(0.286)	(0.272)	(0.197)	(0.186)
Distance to boma	0.481	-0.455	-0.354	-0.809	-0.219	0.068	0.373
	(0.803)	(0.885)	(0.896)	(0.983)	(1.314)	(0.616)	(0.568)
Index of ownership of agricultural tools	77.715***	52.832***	67.763***	-6.816	-7.012	56.861***	68.958***
	(19.448)	(13.962)	(17.097)	(19.674)	(28.193)	(14.832)	(13.108)
Index of ownership of durable goods	88.175***	98.621***	92.435***	83.865***	108.644***	92.980***	93.727***
	(15.353)	(15.597)	(15.075)	(27.362)	(30.276)	(13.880)	(12.545)
Annual mean rainfall(mm)	0.815**	1.472	0.903	3.411*	3.403	1.049***	1.006***
	(0.374)	(1.116)	(0.599)	(1.871)	(3.007)	(0.250)	(0.236)
Annual mean temperature (°C * 10)	-8.853***	-5.212	-4.313*	-10.718	-17.927	-7.751***	-7.841***
	(1.897)	(3.797)	(2.587)	(6.943)	(12.535)	(1.274)	(1.204)
Year (2013)	347.955***	307.908***	313.956***	272.768***	263.957***	317.304***	317.289***
	(40.732)	(42.329)	(43.804)	(48.234)	(45.960)	(33.288)	(30.993)
Agro-ecological zone fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	1,662.699***	810.346	980.193	524.097	2,302.636	1,424.072***	1,428.150***

	(598.780)	(1,294.931)	(867.096)	(2,492.269)	(4,859.146)	(409.097)	(380.119)
Observations	4,913	4,913	4,913	4,913	4,913	4,913	4,913
R-squared	0.283	0.246	0.318	0.226	0.247	--	--
Number of groups	--	194	26	2,135	3,365	2,135	3,365

Robust standard errors in parentheses. EA = Enumeration area; HH = Household. *** p<0.01, ** p<0.05, * p<0.1.

Table 4: Optimal rate of subsidy for fertilizer profitability (i.e rate of subsidy at which fertilizer use is just profitable)

Maize price	Optimal fertilizer subsidy rate (%)
Farm gate price	72.43
Harvest season market price	71.67
Lean season market price	41.34

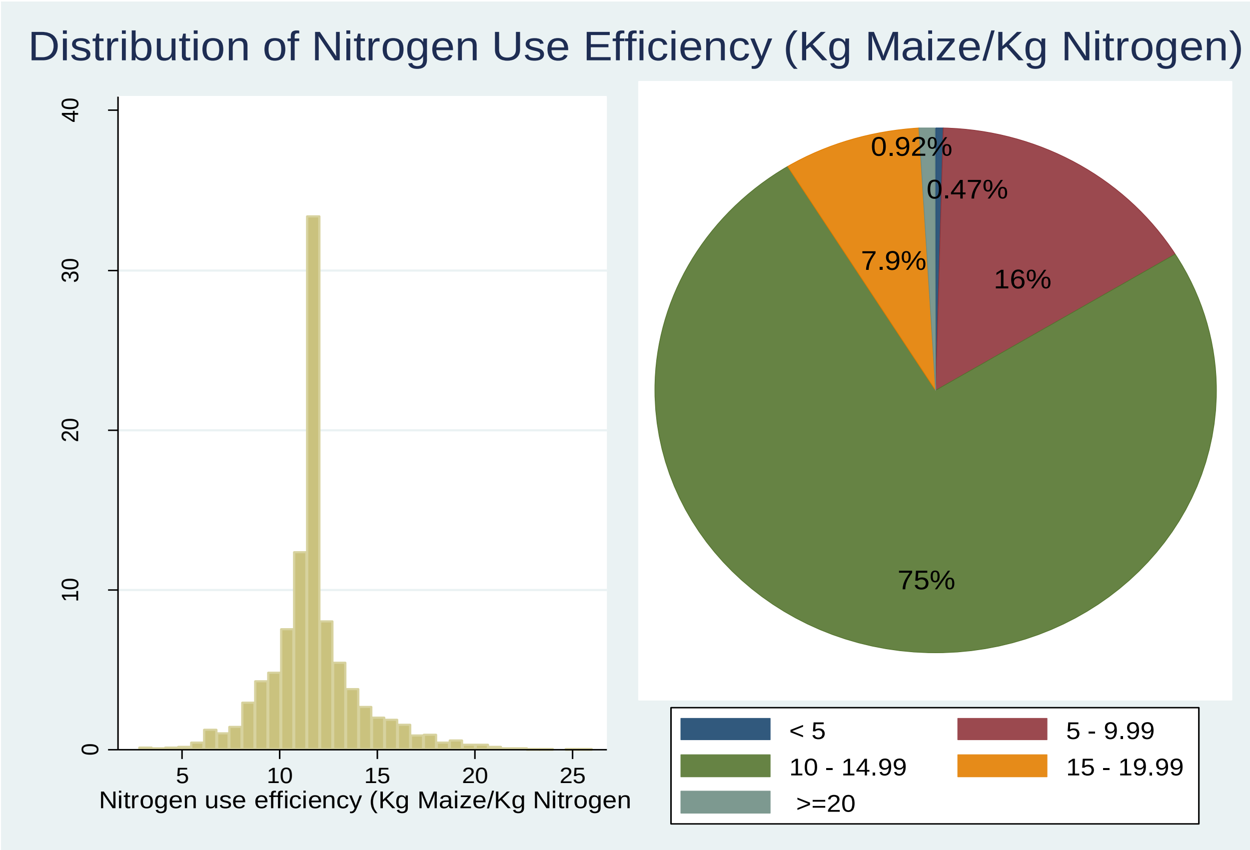


Figure 1: Distribution of NUE to fertilizer based on multilevel model (Level 1 = plot; Level 2 = garden). Mean: 11.82; Minimum: 2.82; Maximum: 25.98; Standard deviation: 2.42

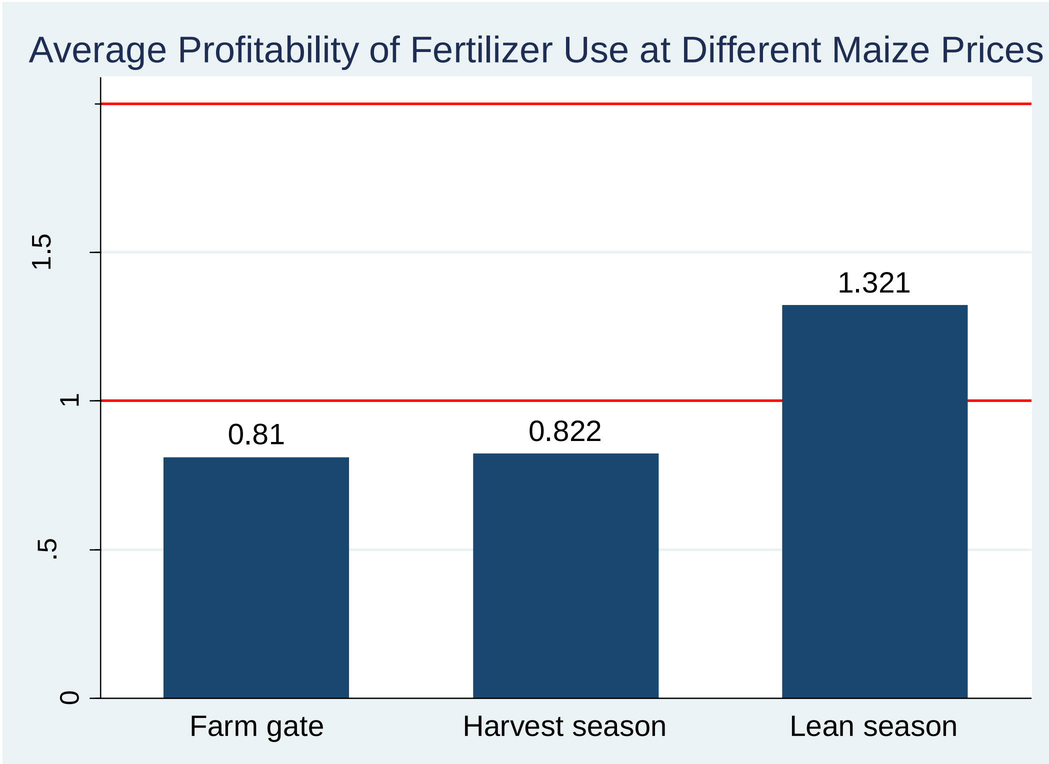


Figure 2: Average profitability of fertilizer use at different prices of maize

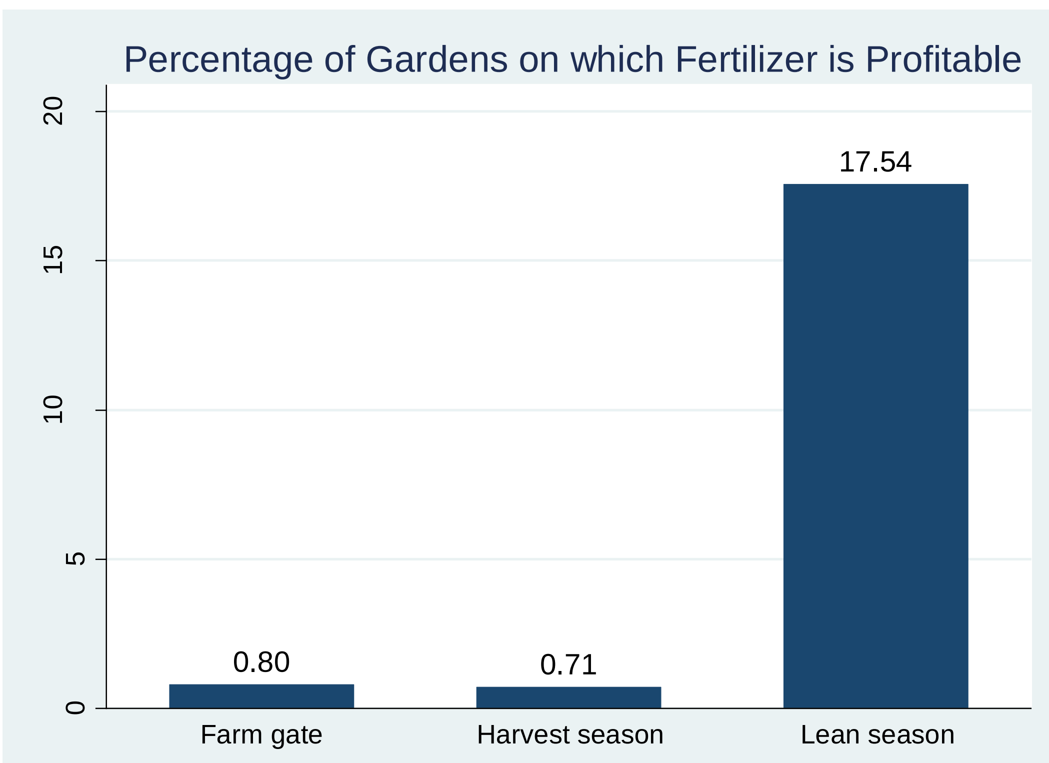


Figure 3a: Percentage of gardens on which fertilizer is profitable

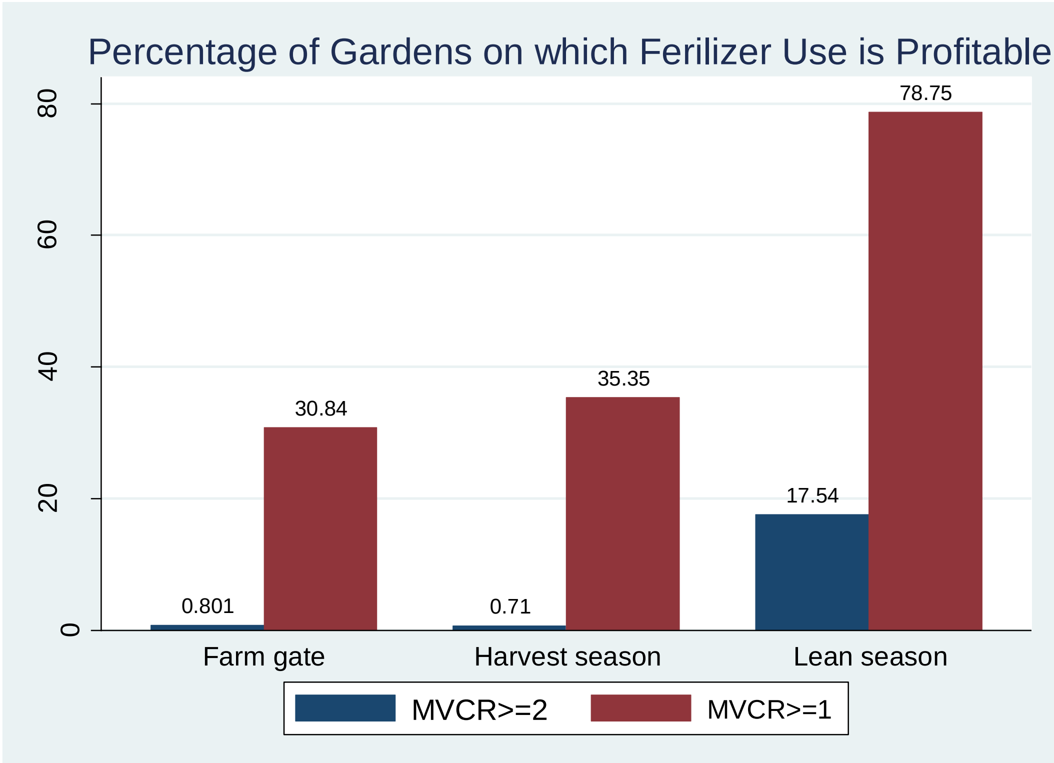


Figure 3b: Percentage of gardens on which fertilizer use is profitable

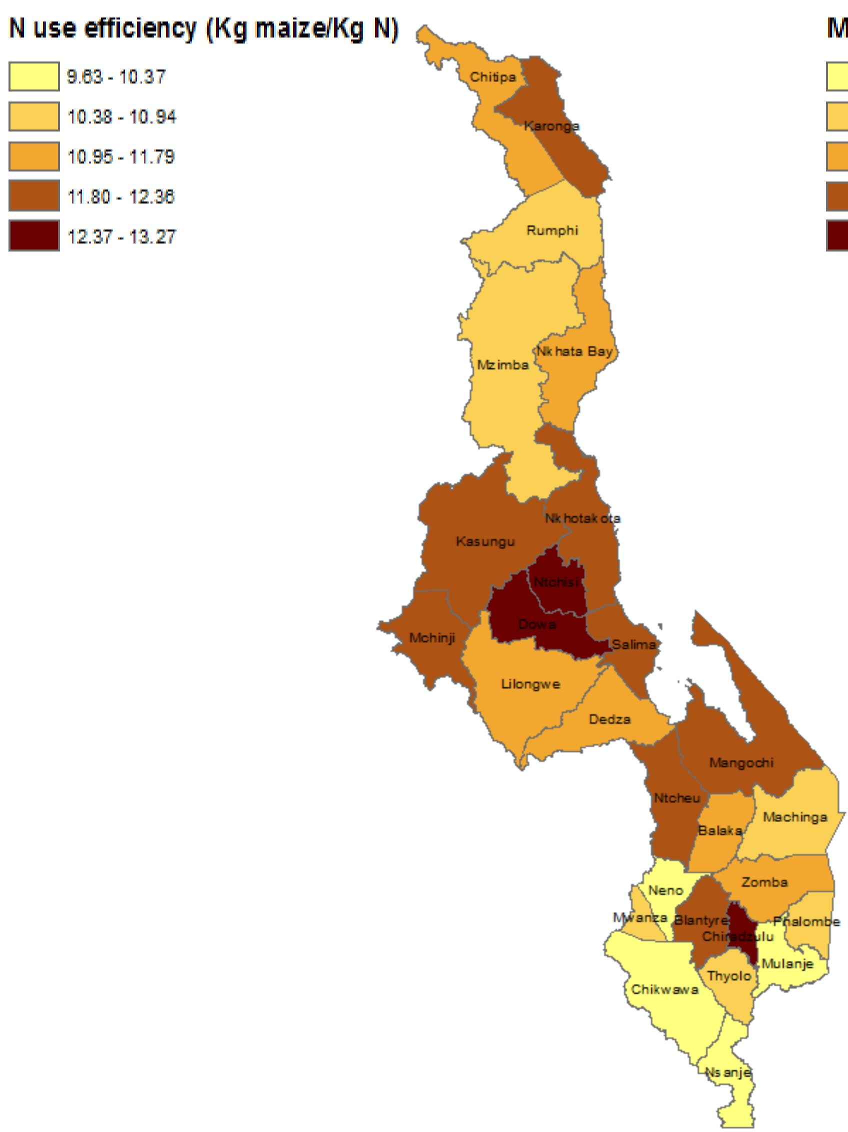


Figure 4a: Spatial distribution of fertilizer use efficiency

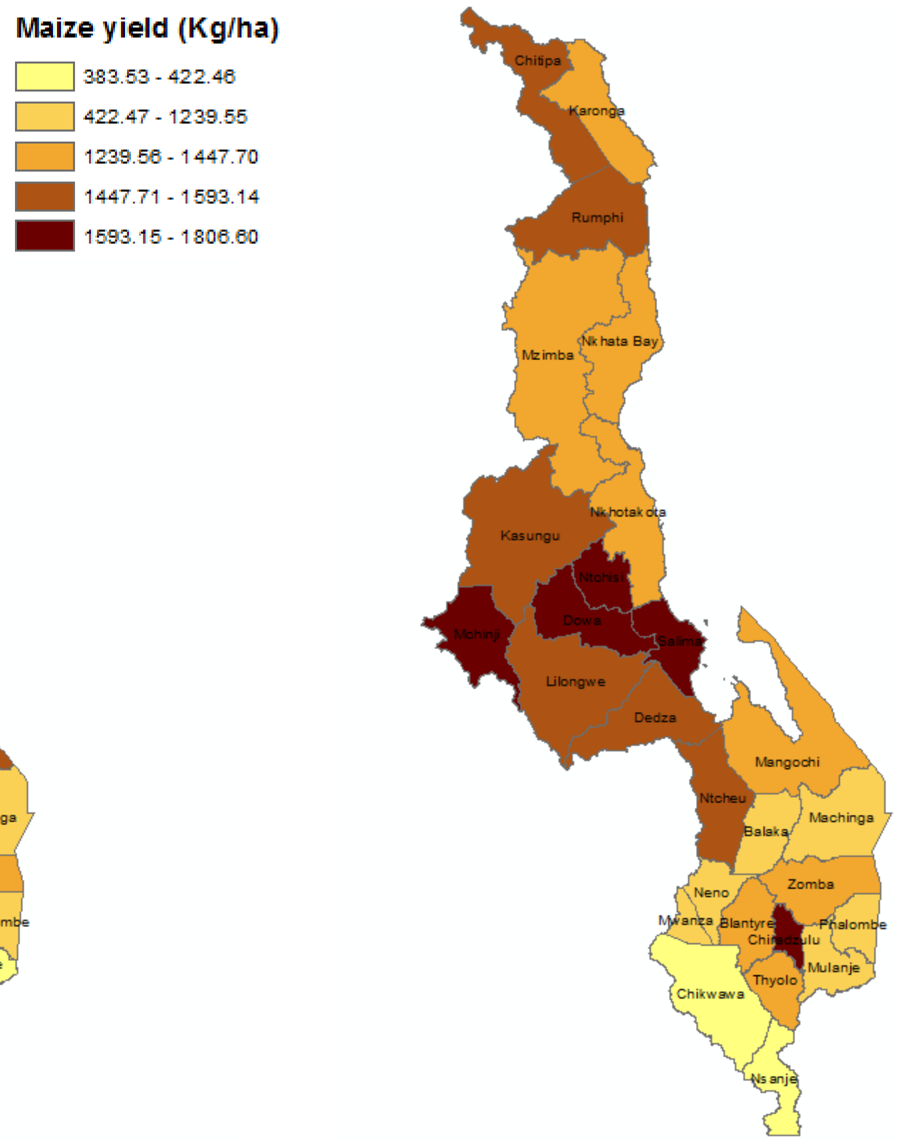


Figure 4b: Spatial distribution of maize yield

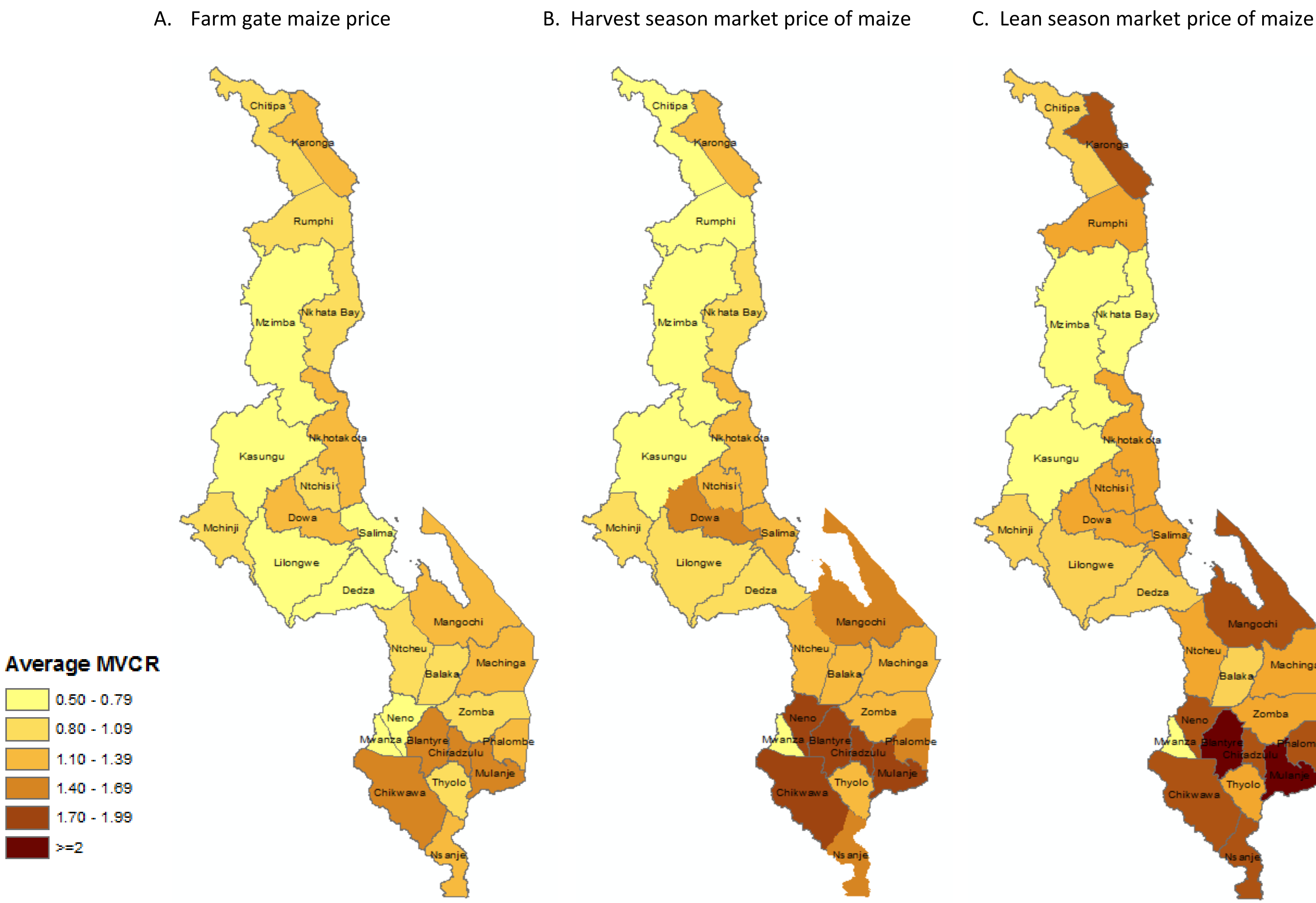


Figure 5: Spatial distribution of profitability of fertilizer use at different prices of maize

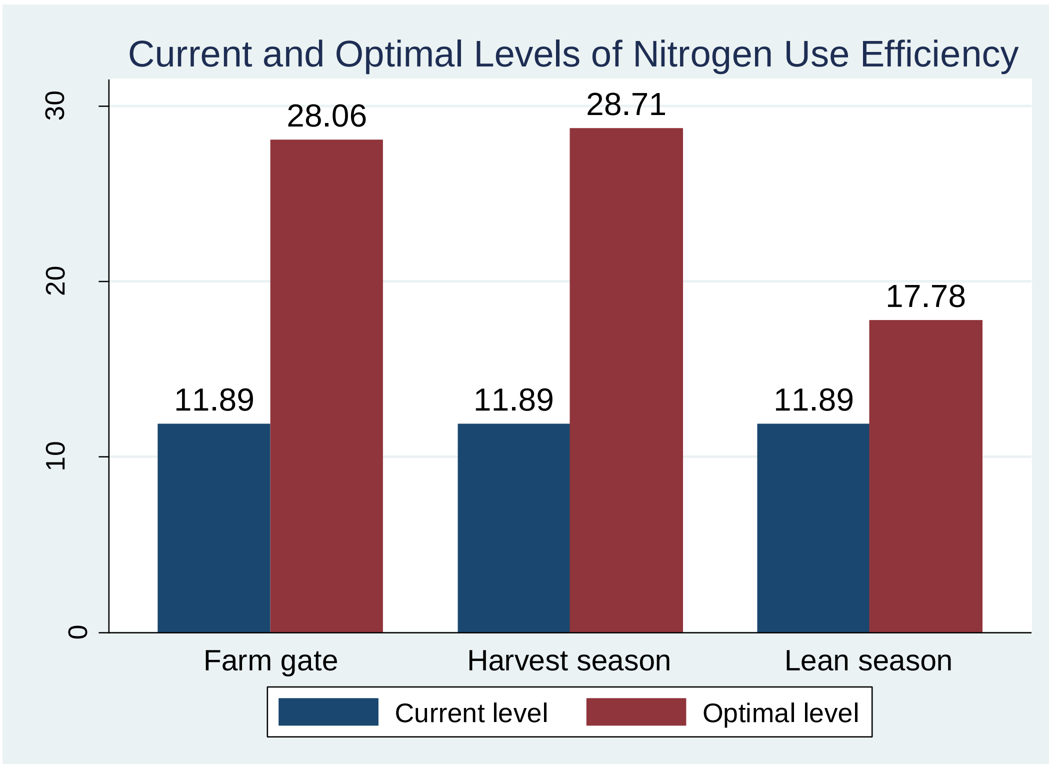


Figure 6: Current and optimal levels of nitrogen use efficiency

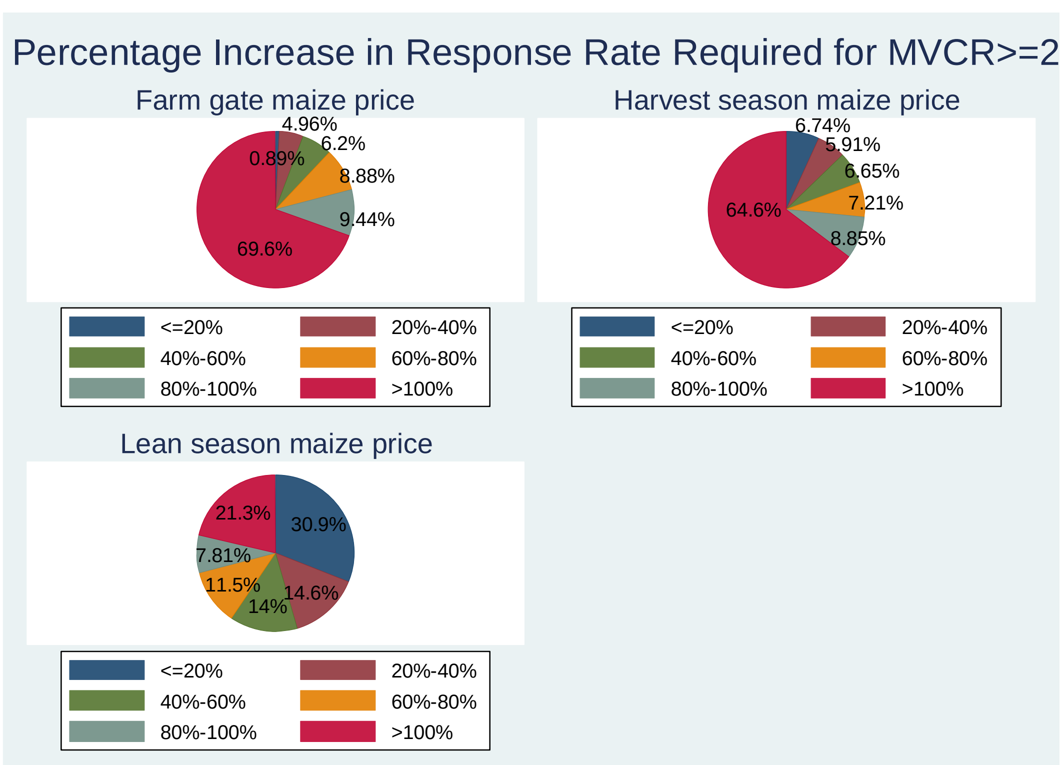
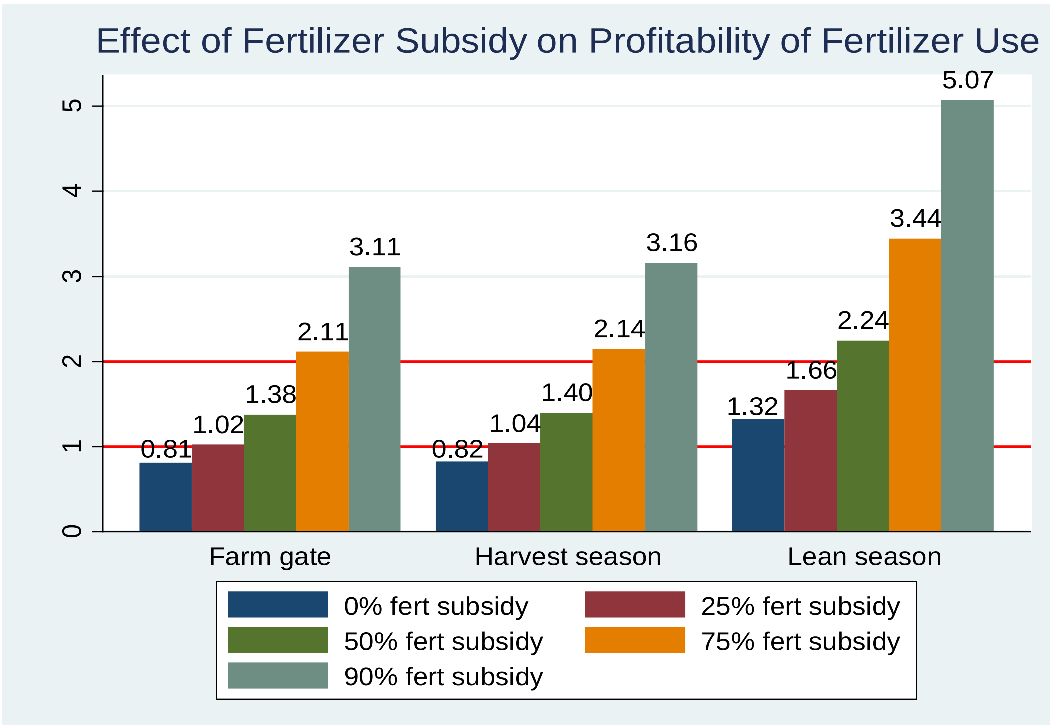


Figure 7: Percentage increase in NUE required for MVCR>=2



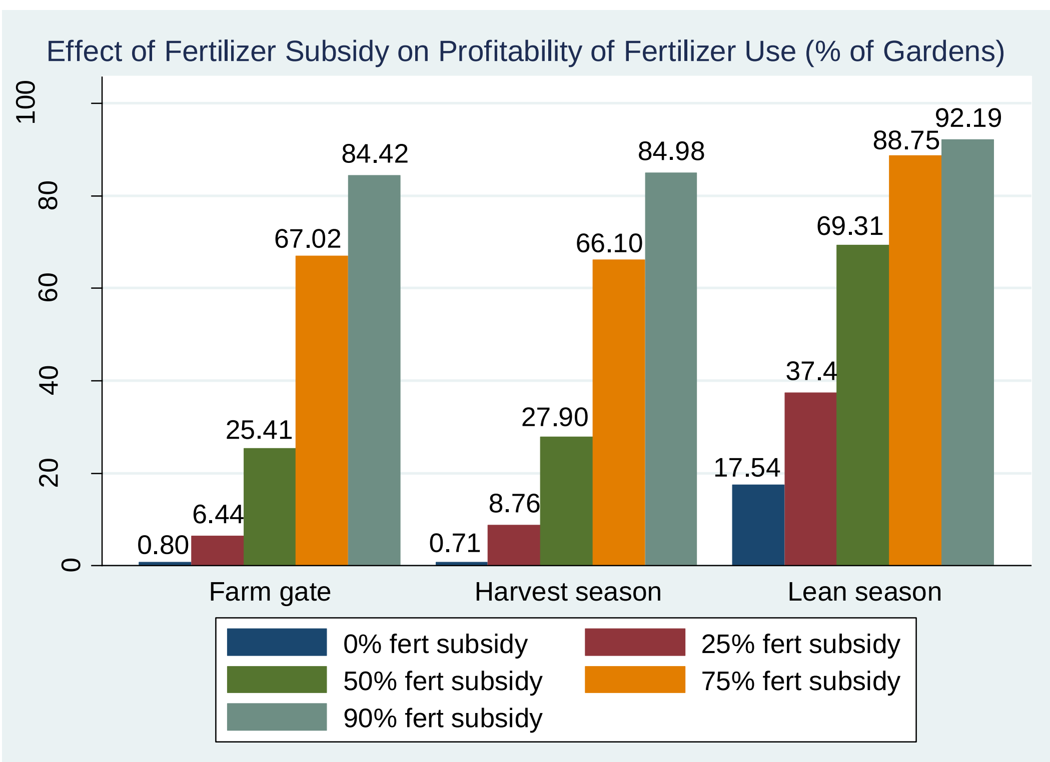


Figure 8a: Effect of fertilizer subsidy on profitability of fertilizer use (MVCR)

Figure 8a: Effect of fertilizer subsidy on profitability of fertilizer use (% of gardens)

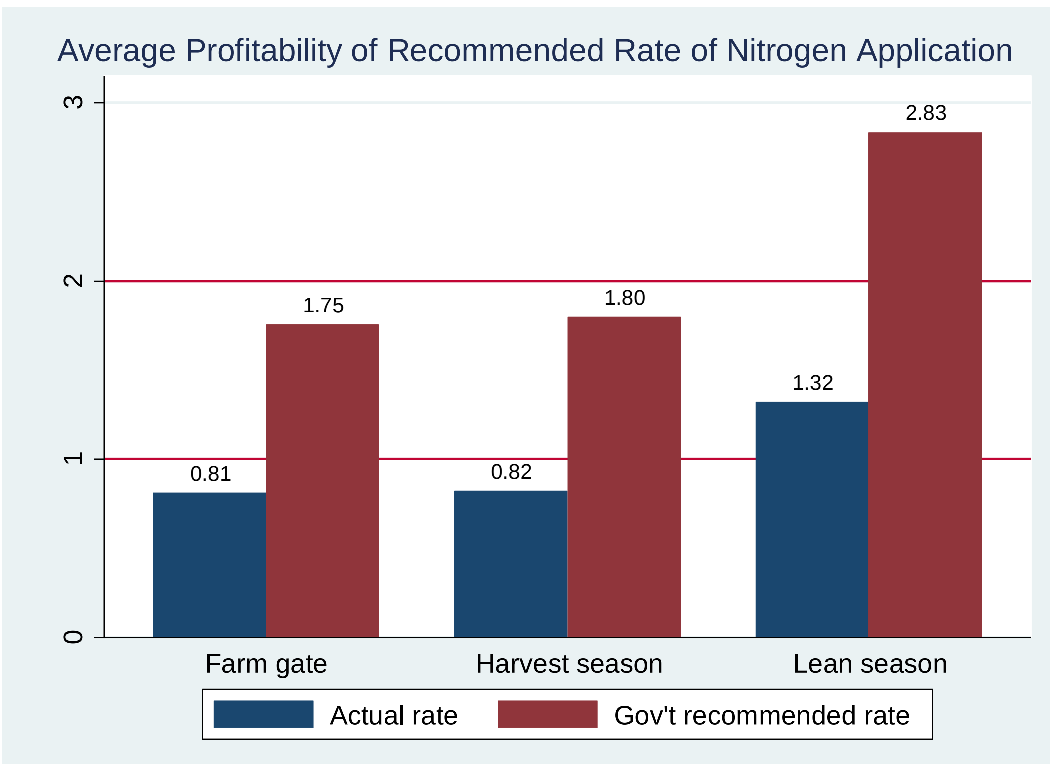


Figure 9: Average profitability of government recommended rate of fertilizer application

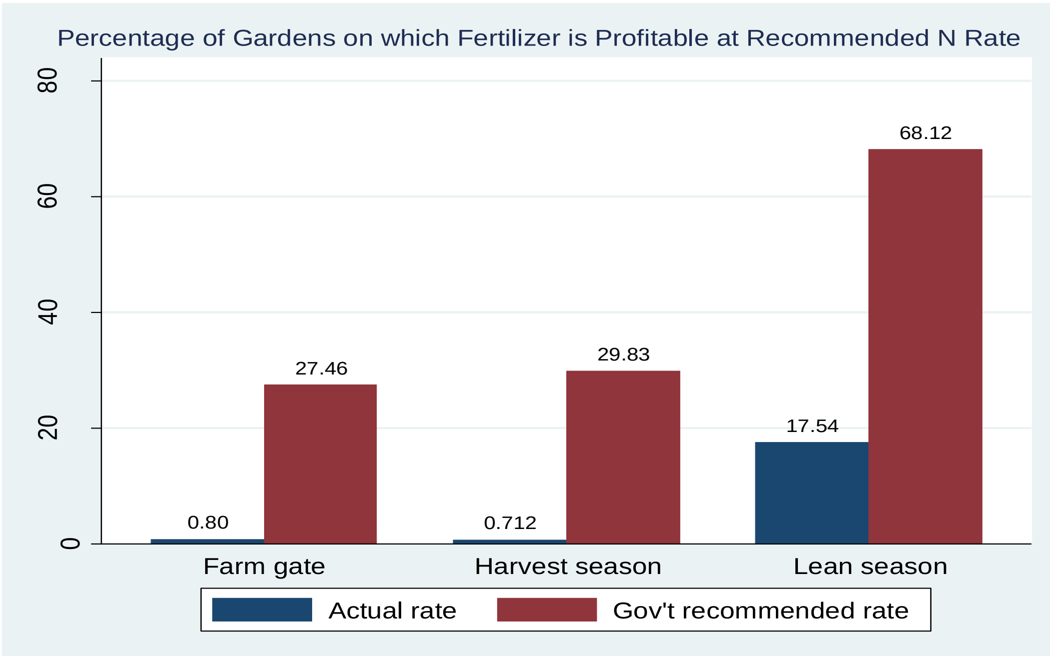


Figure 10: Average profitability of government recommended rate of fertilizer application

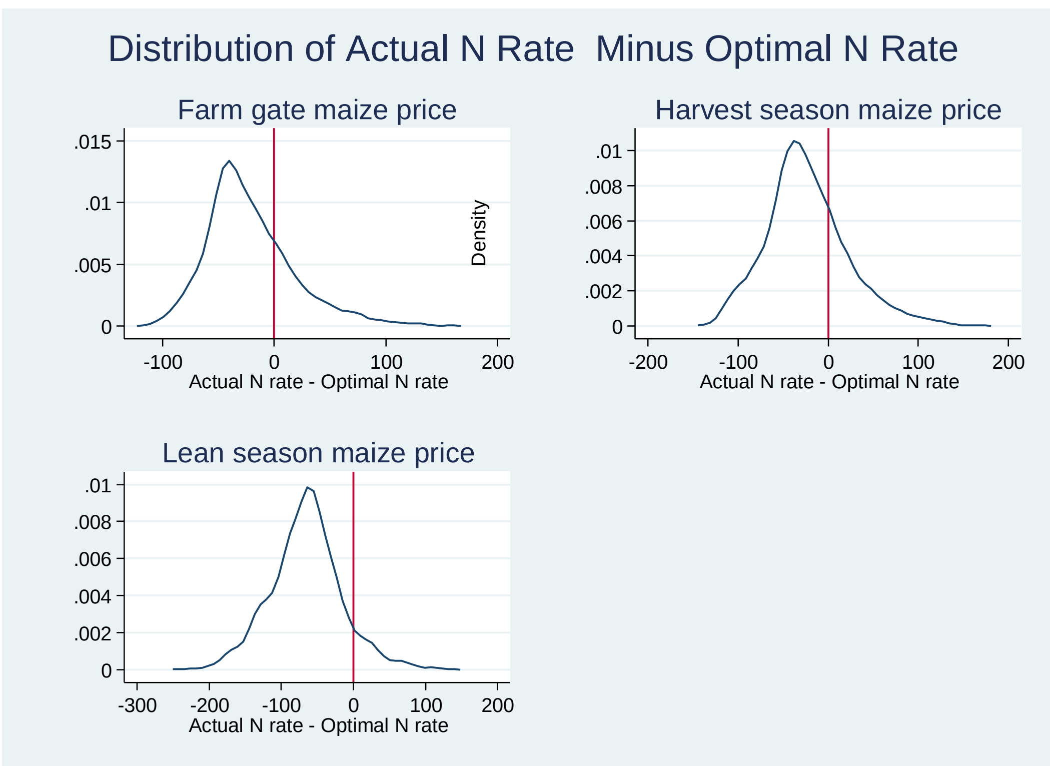


Figure 11: Distribution of recommended N application rate minus optimal N application rate