

Full Length Research Paper

Fertilizer underuse in Sub-Saharan Africa: Evidence from Maize

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Fertilizer consumption especially in Sub-Saharan Africa countries continues to remain low as compared to other parts of the world. As a result, there has been stagnation and even declined yields across parts of Sub-Saharan Africa over several decades whereas countries that have increased their agricultural productivity have also considerably increased their use of fertilizer. In a bid to increase fertilizer use, a number of studies have been undertaken on the use of fertilizer in Sub-Saharan Africa. However, most of these studies have focused on domestic fertilizer prices and other factors without addressing farmer behaviour in response to changes in international fertilizer prices. This paper therefore examined the effect of international fertilizer prices on the use of fertilizer in maize production in selected African countries for the period 1990-2010 whose data was analyzed using fixed effects regression. Empirical results indicated that aggregate fertilizer demand was positively and significantly correlated with labour and maize seed but negatively and significantly correlated with general world fertilizer price, world phosphorous fertilizer prices and rainfall. On the demand of nutrient fertilizers, world fertilizer prices were negatively and significantly correlated with the demand of all the nutrient fertilizers. Labour and maize seed were positively and significantly correlated with nitrogen fertilizer use while rainfall had a negative and significant correlation with all the nutrient fertilizers. Labour, current and previous year's maize producer prices were positively and significantly correlated with phosphorous use. Given the indication that fertilizer use was low despite its positive influence in maize output, it is recommended that strategies be put in place by relevant stakeholders in respective countries in a bid to boost aggregate and nutrient fertilizer use so as to further increase maize output and these could include price reduction strategies like subsidies and timely availability of fertilizer, reduction in import fee, clearance and warehouse charges at the ports of entry as a way of reducing the final market price.

Keywords. Fertilizer demand; world fertilizer prices; Sub-Saharan Africa

INTRODUCTION

Fertilizer use in most Sub-Saharan Africa (SSA) countries is notably lower than in other developing countries. SSA farmers use only an average of about 9kg of fertilizer per hectare (ha) compared to about 73kg in Latin America and 100-135kg in Asia (Marennya and Barret, 2009). This is despite the fact that fertilizer plays a productivity enhancing role in most of the other regions with higher use of fertilizer. As a result, there has been stagnation and even declined yields across parts of SSA over several decades whereas countries that have increased their agricultural productivity have also considerably

increased their use of fertilizer (Morris et al., 2007).

Considering the key role played by agriculture in most of the SSA countries, several policies and programs have been initiated and implemented in recent decades so as to encourage higher fertilizer adoption in the long run. In the search of these policies and programs, numerous studies undertaken have identified a number of supply

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side and demand side constraints at the regional and country level that limit the development of input markets and consequently fertilizer uptake (Bump et al., 2011). These supply side constraints include a lack of competition among suppliers and distributors within the country or region, poor dealer networks resulting in late or irregular delivery, high transportation costs due to lack of adequate infrastructure, uncertain policy environment and weak regulatory systems, a lack of market information and limited access to finance (Hernandez and Torero, 2013).

To mitigate the constraints, a number of agricultural reforms have been implemented in SSA which have seen increased private sector participation in input and output markets. This has however, only registered marginal increases in fertilizer use with farm and plot level demand for fertilizer remaining inadequate to deal with declines in soil and food supply. This has further resulted in lagged agricultural productivity in SSA over the past several decades, far behind that in other world regions and remains well below that required to meet food security and poverty reduction goals (Poulton et al., 2006). There is also recognition that rural markets which are a major source of inputs to rural farmers, do not work well in SSA. Mineral fertilizers in SSA countries are imported, expensive to ship over land given the poor state of the rural roads and physical security and thus end up being very expensive (Diagne and Zeller, 2001; Jayne et al., 2003; Omamo et al., 2002). As a result, it has been observed that farmers closer to the market have higher chances of using fertilizer. This is due to the variation in price of fertilizer between those far off and those near the market due to the extra costs involved in delivering fertilizer in far flung areas.

To further boost fertilizer use in SSA, a number of countries adopted the input subsidy program to make fertilizer more affordable especially among small-holder farmers. Most of these countries undertook the input subsidy program after the success of the Malawi program and by 2010 at least ten countries had adopted the program (Jayne and Rashid, 2013). However, while there are signs of an increase in fertilizer use, especially in those countries with subsidy programs or other concerted support, fertilizer use still generally remains low (Liverpool-Tasie, et al., 2016). The subsidy programs in most of these countries had some success however, in boosting fertilizer use and food production while they were in place, but improvements in yields were limited (Holmen, 2005).

There is sufficient evidence that majority of SSA farmers use very low rates of fertilizer as compared to other developing countries, with some farmers switching back and forth between using and not using fertilizer from season to season (Duflo et al., 2008). But it has been found that if farmers were provided with fertilizer either for free or at low prices, fertilizer use increased considerably.

For example, Beaman et al. (2013) found that provision of fertilizer to farmers dramatically increased quantity of fertilizer used indicating that free access to fertilizer had a positive effect on use. When fertilizer was provided free, input usage increased overall to increase output since expenditure on fertilizer affected expenditure on other inputs especially labour, an implication that the value of fertilizer consumed has a direct effect on consumption of other inputs.

From prior studies, there is an implication that the price of fertilizer plays a big role in determining fertilizer use in SSA countries. It has been found that only 50% the price of fertilizer is determined at SSA countries level with the landed price of imports at the port of entry generally representing about half of the total fertilizer costs in these countries (Hernandez and Torero, 2013). However, many of these studies have focused on local factors and components of fertilizer costs that have led to sub-optimal consumption of fertilizer with little or no focus on the international component of fertilizer costs. The international component of fertilizer is quite huge and any changes in that component of fertilizer price could have far reaching effects on SSA fertilizer consumption. This study therefore focused on trying to find out how the low consumption of fertilizer both in compound form and in nutrient form is driven by changes in international fertilizer prices besides other factors.

LITERATURE REVIEW

Fertilizer use raises agricultural yields but this differs from country to country as shown by a number of experimental farm results due to different levels of fertilizer use. For instance, Duflo et al. (2008) based on results from experimental farms finds that fertilizer and hybrid seeds increase maize yields from 40 percent to 100 percent. However, in a study in millet production, response to fertilizer is also found to depend on other factors especially rainfall and planting densities (Bationo et al., 1992). But its use has large benefits to farmers under favourable conditions.

Farmers being rational profit maximizers are thus expected to make optimum use of fertilizer so as to get maximum returns in crop production. However, this looks the opposite in most Sub-Saharan Africa as shown by most studies on fertilizer use. SSA has been found to have the lowest fertilizer use of any region in the world with only an average of 8 kg/ha year against a world average of 93 kg/ha year and 200 kg/ha year in East Asia (IFDC, 2006). Africa's fertilizer rates and yields have been found to be lower than any other regions and similar or larger gap exists in between Africa and the rest of the world for other cereals such as Maize (Beaman et al., 2013). The low fertilizer usage has seen a declining per capita agricultural production over the past decades (Kouka et al., 1995; Poulton et al., 2006) making under

usage more prevalent than overdose in most of SSA countries.

This low usage of fertilizer in SSA has been attributed to a number of reasons including lack of adaptation of official recommendations to many farmers and fertilizer use not being easy to correctly use and hence implying that its use may not be profitable for many farmers who do not use the right quantity (Duflo, 2008). Other reasons for low use are limited untimely availability of fertilizer, imperfect markets, riskiness and credit constraints, economies of scale in supply (Liverpool-Tasie et al., 2016) and government pricing policy and market prices (Bationo et al., 1992). There is also widespread recognition that rural markets do not work well in SSA rural area. Mineral fertilizers are overly imported and expensive to transport to most of the rural areas due to poor infrastructure and thus end up being expensive with farmers closer to the markets having higher chances of using fertilizers than those in the rural areas (Diagne and Zether, 2001; Jayne et al., 2003; Omamo et al., 2001).

Those farmers who use fertilizer have also been found to be inconsistent with many of them switching back and forth between using and not using fertilizer from season to season. On the contrary studies have shown that the absolute income gains to fertilizer are reasonably substantial and farmers who use fertilizer have higher income returns than those who don't (Duflo, 2011). Duflo (2011) however further observes that it is possible that even if these returns are high, the absolute income gain from fertilizer does not make it worthwhile if there are significant costs in using fertilizer. He observes that these costs could be in the form of time and money spent to the market, and time spent in learning how to use the fertilizer.

According to Duflo (2011), regardless of the aforementioned challenges, agricultural experts have indicated that fertilizer remains the key to agricultural productivity as it generates high returns. Its intensified use is thus a possible route to improved agricultural productivity. To ensure this intensive use, it has been found that provision of fertilizer to farmers dramatically increases the quantity of fertilizer used indicating that free access to fertilizer has a positive effect on use (Beaman, 2013). This is largely due to the fact that expenditure on fertilizer affects expenditure on other inputs especially labour. An implication that value of fertilizer in both price and quantity consumed has a direct effect on consumption of other inputs. On this basis and other findings, most SSA countries have heavily adopted input subsidy programs so as to boost fertilizer consumption in a bid to meet food demands. This has been coupled with agricultural sector reforms which have also seen increased private sector participation in input and output markets.

The fertilizer input subsidies have however been found to have enormous challenges with most countries either

withdrawing or scaling them down due to fiscal constraints, corruption and inefficiencies in their administration (Duflo, 2008; Duflo, 2011; Jayne and Rashid, 2013). The administrative challenges have been in the form of administrative weaknesses that often led to late deliveries of fertilizer and delivery of inappropriate quantities and types of fertilizer, rent seeking activities and manipulation leading to leakages and unsustainably high fiscal burdens on governments (Morris et al., 2007). For instance, Manson et al. (2016) in their evaluation of the political economy of fertilizer subsidy programs in Africa based on a study in Zambia found that the ruling party was targeting subsidized fertilizer to households where it had strong support in previous presidential elections so as to get more votes. In this case the subsidy program was purely for political gain without consideration of the economic benefits of the same.

The subsidy withdrawals however led to massive declines in agricultural output in most of the SSA countries leading to public outcries for their restoration in some countries due to political implications among other reasons. Despite their restoration however, the subsidy programs have been found to have more costs than benefits due to political manipulations with politicians tending to prioritize programs that have visible payoffs from which they can benefit while still in office than investments with long term returns (Bueno de Mesquita et al., 2013). Despite the challenges that faced the subsidy programs, there was however, renewed synergy by governments in SSA to once more play an important role in providing agricultural inputs. For instance, at the Africa fertilizer summit held in Abuja, Nigeria in 2006, there was overwhelming concurrence that fertilizer subsidies were necessary to increase agricultural productivity in SSA (Morris et al., 2007). This was due to a belief that with a new approach to subsidization, the problems that plagued the programs of the past could be avoided. The new programs were to also target the poor smallholders and implemented with a consciousness for supporting the private sector fertilizer market (Banful, 2011). For instance, the input subsidy programs in Malawi, Nigeria, United Republic of Tanzania, Zambia and Kenya had express goals to target the vulnerable groups such as female headed households. However, these programs failed in most of the countries and were withdrawn. Despite these measures, SSA's agricultural sectors have registered only marginal increases in overall fertilizer use with farm and plot level demand for fertilizer remaining inadequate to deal with declines in soil fertility and food supply in most of Sub-Saharan African countries (Marennya and Barret, 2009).

Other studies on factors hindering fertilizer use observe that fertilizer use is mostly unprofitable in most of Africa and they attribute this to price and non-price factors. For instance, Burke et al. (2016) found that higher fertilization rates would be marginally profitable or unprofitable.

Phosphoric fertilizer was also found particularly unprofitable in acidic soils which were common in Zambia and other areas of sub-Saharan Africa while Koussoube and Nauges (2016) found that fertilizer should have been profitable in most cases under the current levels of subsidized fertilizer. Liverpool-Tasie et al. (2016) observed that it was possible to increase profitability of nitrogen application through reduced transportation costs through improvement of in road infrastructure and through establishment of retail depots within the farming communities or in small towns close to the farmers

Jayne et al. (2003) finds that the high physical costs of exchange that hindered marketing activities by all agents both in the private, parastatal and cooperative level. To further achieve a reduction in domestic prices in order to boost fertilizer use, they recommended for a reduction in port fees, coordination of the timing of fertilizer clearance from the port with up-country transport and a reduction on the transport costs with all these estimated to reduce farm gate fertilizer prices in each of the countries by between 11 and 18 percent. On the other hand, Hernandez and Torero (2013) finds that fertilizer use had a positive correlation between market concentrations from a global, cross-country perspective. This had big bearing on fertilizer use especially on low income countries such as SSA countries that were highly dependent on fertilizer imports as the landed price of imports at the ports of entry usually represented a large portion of the fertilizer supply costs in these regions

Carman (1979) found that all price coefficients in fertilizer use had a negative sign and majority were significant. Farm productivity was found to have a strong positive impact on fertilizer use and most of its coefficients were significant while Gunjal et al. (1980) found that fertilizer demand was more elastic with respect to fertilizer prices for grains as compared to oil and cash crop farmers and that, different crops responded in varying degrees to the same economic factors. Crop income coefficients were also found to be significant. On the other hand, Quddus et al. (2008) observed that the demand for phosphorous and nitrogen were price inelastic both in the short-run and in the long-run. The demand for potash was price elastic both in the short-run and in the long-run while Okoroafor et al. (2010) found that demand for fertilizer exhibited a stable long-run equilibrium relationship with its relative price and other explanatory variables used in the model. Similarly, Alene et al. (2008) observed that both price and non-price factors influenced adoption and intensity of fertilizer use with great effect being on fertilizer adoption. Transaction costs were found to have a negative significant effect on both adoption and extent of fertilizer use while Brunelle et al. (2015) observed that an increase in fertilizer prices would in the overall lead to declined crop yields by between 6 and 13 percent entirely attributed to the rising cost of nutrients and not because of biophysical or

climatic reasons. However, Alem et al (2010) finds that higher rainfall levels led to increased fertilizer use and argued that higher rainfall was likely to result in increased crop harvest levels which in turn eased the liquidity constraints facing the households while Kormawa et al. (2003) observes that farm size, social capital, frequency of extension contacts and use of complementary inputs were also found to be major influencers of fertilizer use. Vanlauwe et al (2014) on the other hand notes that appropriate use of fertilizer results in substantial increases in crop productivity and in the availability of crop residues while Abdoulaye and Sanders (2005) indicates that more fertilizer was being used when the millet crop prices were high and that farmers with higher crop incomes were using more fertilizer than those with lower crop incomes.

METHODOLOGY AND DATA

Data

The empirical analysis used a national panel data for the period 1990 to 2010 for ten African countries including Egypt, Ethiopia, Guinea, Kenya, Malawi, South Africa, Togo, Tanzania, Zambia, Zimbabwe, Ghana, Madagascar and Sudan. The data on fertilizer consumption and application rate for maize was obtained from the Iowa State University website which had been derived based on data from the International Fertilizer Association (IFA). The variables in the dataset included commodities (crops), fertilizer consumption in '000 metric tons by crop, country and year for each of the three nutrients (Nitrogen, Phosphorous, Potassium), and the application rate in kilograms per hectare for each of the nutrients by crop, country and year. The Dataset covers four commodities namely maize (corn), cotton, rapeseed and soybeans but this study only focused on maize since data for the other three crops was not available for all the countries under study while maize data was available for all the 10 countries.

The data on area harvested, yield and production quantity for maize was obtained from the FAOSTAT website. The variables in the dataset included, types of crops, area harvested in hectares, yield and production quantities for respective countries. Data on maize used for seed was also obtained from FAOSTAT. However, this data did not give details on the quality of the seeds apart from quantities used. Data on labour input for each crop was not readily available. The USDA Economic Research Service provided the most recent data on labour participation in agricultural production per country. To determine the labour input for each crop, we adopted the method adopted by Yao (1996). Based on Yao's method, it was assumed that the share of labour used for each crop was equal to its output value share to that of total output value for all agricultural activities for

respective countries and years. Agricultural labour in this case was defined as the economically active population in agriculture (Mundlak et al., 2012). To derive the labour input, the following formula was used:

$$N_{jt} = LS_{jt} * VS_{jt}$$

where N_{jt} is the number of labourers engaged in the production of maize in country j and year t , LS_{jt} is the number of people economically engaged in agricultural production in country j and year t and VS_{jt} is the share of maize output value of the total output value of all agricultural activities in country j and year t . VS_{jt} is equal to the total value of maize divided by the gross output value of all agricultural activities in country j in year t . The gross output value includes the value of all crops and livestock in country j and year t .

Data on value of maize and gross output value for all agricultural activities was obtained from FAOSTAT annual estimates for each country and year. Data on fertilizer input for maize was obtained by aggregating the nitrogen, phosphorous and potassium nutrients applied per hectare by country and year. This was derived by using the fertilizer application rates by nutrient type for maize for country j and year t . Data on world fertilizer price index, phosphorous price index and potassium price indices were sourced from the OurworldInData website which presents a collection of data from various sources and for this case FAOSTAT. Data on maize producer price was obtained from FAOSTAT website. On the other hand, data on average annual precipitation for all the countries in all the years was obtained from the World Bank climate data by getting the average of the monthly rainfall data.

Data on world fertilizer price and that of phosphorous and potassium was obtained from the OurworldInData website which presents a collection of data from various sources and for this case FAOSTAT. However, data on world nitrogen fertilizer price could not be found. But in a study on fertilizer prices by the International Coffee Organization, the study uses the price of urea as a reference for nitrogen fertilizer prices (ICC, 2009). Urea comprises only of nitrogen nutrient fertilizer and is a perfect substitute of nitrogen fertilizer and was found to have a similar trend with nitrogen fertilizer and therefore its price could be used as a proxy for nitrogen fertilizer price. Therefore, in this study, data on world urea fertilizer price was used as a proxy for world nitrogen fertilizer price. The data was obtained from the OurworldInData website which presents a collection of data from various sources and for this case FAOSTAT.

Theoretical Model

This study was based on two theoretical models, that is, the theory of production and the derived input demand

theory. In the theory of production, the Cobb-Douglas production function formed the basis for the derivation of the input demand theory as detailed in Rasmussen (1958) and this was used to explain the factors influencing the demand of aggregate fertilizer, nitrogen, phosphorous and potassium nutrient fertilizers.

The specification of the model starts with the basic Cobb-Douglas production function form similarly as used by Yao (1996) and other researchers, given as:

$$Y_{jt} = AH_{jt}^{\alpha} N_{jt}^{\beta} F_{jt}^{\theta} e^{U_{jt}} \dots\dots\dots(1)$$

where Y_{jt} is the physical output of maize in country j and year t , A is a constant term, H_{jt} is the land area for maize in country j and year t , N_{jt} is the labour input for maize in country j and year t , F_{jt} is the fertilizer usage for maize in country j and year t and U_{jt} is a disturbance term for maize in country j and year t . α , β and θ are respectively the land, labour and fertilizer elasticity with respect to maize output. There are 10 countries and therefore;

$j = 1, 2, \dots, 10$ and a total of 21 years, with $t = 1, 2, \dots, 21$.

To examine the factors influencing aggregate fertilizer and individual nutrient fertilizers usage in maize production, the derived input demand theory was used. In this theory, we try to explain the effect of international fertilizer price changes on gross fertilizer usage in maize production. The demand for production resources is a derived demand based on the final product. In crop production, fertilizer is one of the inputs used in the production process alongside other inputs. Economic theory suggests that the amount of fertilizer used will in most cases be a function of expected output prices, the price of fertilizer, price and or quantities of other inputs and the productivity of inputs used in production.

A producer's use function for fertilizer is derived from the underlying production function and the demand for the commodity produced with the fertilizer (Carman, 1979). To derive the input demand function, one starts with the definition of the profit function in terms of output price, the production function, and costs and or quantities associated with the other inputs used.

Given the Cobb-Douglas production function as in equation (1) without the error term:

$$Y = AH^{\alpha} N^{\beta} F^{\theta} \dots\dots\dots(2)$$

Taking P_y as the price of output, P_f as the price of fertilizer, P_h as the rent for land, and P_n as the wage rate, then the fertilizer input use function is expected to be a function with the following parameters:

$$F = F(P_y, P_f, P_h, P_n, A, \alpha, \beta, \theta, C^0) \dots\dots\dots(3)$$

where C^0 is the budget constraint.

Based on previous research results and data considerations, the acreage under maize and number of labour units as earlier determined will be used instead of price of land and wage rate since data on price of land and wage rate for labour used in maize production was not available and was difficult to determine. Also, assuming that there is no budget constraint, the fertilizer input use function will be expected to be a function with the following parameters:

$$F = F(P_y, P_f, H, N, A, \beta, \theta) \dots \dots \dots (4)$$

The presupposed Cobb-Douglas production function will remain as in (2) above:

$$Y = AH^\alpha N^\beta F^\theta \dots \dots \dots (5)$$

This implies that the variable fertilizer input F in (4) is a function of the price of the output, P_y , the price of fertilizer, P_f , acreage under maize, H , number of units of labour, N and the production parameters A , α , β and θ . Since this study intends to investigate the effect of international prices on fertilizer use, then P_f will be used to represent the international price of fertilizer. In this case, the domestic price for fertilizer is substituted by the international fertilizer price. This is based on previous research results which have shown that the international price of fertilizer constitutes about 50% of the domestic fertilizer prices in most African countries and therefore the behavior of international prices has a direct effect on domestic prices. To establish the effect of this behavior, it is necessitated to do the substitution.

To derive the fertilizer input use function, we will base the derivation on the criterion for profit maximization given as:

$$P_f = MPP_f P_y (\equiv VMP_f) \dots \dots \dots (6a)$$

$$P_n = MPP_n P_y (\equiv VMP_n) \dots \dots \dots (6b)$$

$$P_h = MPP_h P_y (\equiv VMP_h) \dots \dots \dots (6c)$$

Given the earlier criterion for discarding P_h and P_n and based on the presupposed Cobb-Douglas production function (5), the criterion for profit maximization (6a) is:

$$\frac{\delta Y}{\delta F} P_y = \theta P_y A H^\alpha N^\beta F^{\theta-1} = P_f \dots \dots \dots (7)$$

Isolating F using (7) generates:

$$\theta A P_y H^\alpha N^\beta F^{\theta-1} = P_f \dots \dots \dots (8a)$$

$$F^{\theta-1} = P_f / (\theta A P_y H^\alpha N^\beta) \dots \dots \dots (8b)$$

$$F^{\theta-1} = P_f ((\theta A)^{-1} P_y^{-1} H^{-\alpha} N^{-\beta}) \dots \dots \dots (8c)$$

$$F = P_f^{1/(\theta-1)} (\theta A)^{-1/(\theta-1)} P_y^{-1/(\theta-1)} H^{-\alpha/(\theta-1)} N^{-\beta/(\theta-1)} \dots \dots \dots (8d)$$

It appears that the use for fertilizer (F) depends on the price P_f , the output price P_y , the acreage under maize (H), the amount of labour (N) and the production parameters θ , α , β and A . In logarithm form, equation (8d) becomes:

$$\ln F = a_0 + a_1 \ln P_f + a_2 \ln P_y + a_3 \ln H + a_4 \ln N \dots \dots \dots (9)$$

Equation (9) leads to our main hypotheses that world fertilizer prices are responsible for the low use of aggregate fertilizer in Sub-Saharan Africa and that world nutrient fertilizer prices are responsible for the low use of nutrient fertilizers in Sub-Saharan Africa respectively.

Empirical models

The study will use the following model to examine the effect of international price on fertilizer use respectively. Given that a Cobb-Douglas production function is used, the fertilizer use function will be linear in the logarithms. Given the fertilizer use varies across countries, a set of country dummy variables were added into equation (9) to take care of country differences in fertilizer demand conditions. To take care of the effect of maize seed and rainfall volatility on production, a measure of quantity of maize seed, S and annual precipitation, Pr , were added to equation (10). Given that gross fertilizer use is used in the analysis and it is a multiple of acreage, the land variable was omitted from equation (9). The fertilizer use equation to be estimated for the aggregate fertilizer when land is omitted and the effect of quantity of maize seed used, rain and country dummies are taken care of was specified as in (10):

$$\ln F = a_0 + a_1 \ln P_f + a_2 \ln P_{yjt} + a_3 \ln P_{yjt-1} + a_4 \ln S_{jt} + a_5 \ln N_{jt} + a_6 \ln Pr_{jt} + \sum_{j=2}^{10} C_j D_j + U_{jt} \dots \dots \dots (10)$$

Where:

F_{jt} = gross quantity of fertilizer used in maize production in country j and year t , P_f = world fertilizer price index (WFPI), S_{jt} = Quantity of maize seed used in country j and year t , N_{jt} = amount of labour used in maize production country j and year t , P_{yjt} = maize producer price (MPP) for maize for country j and year t , P_{yjt-1} = lagged maize producer price (MPP) for maize for country j and year t , Pr_{jt} = precipitation for country j and year t , D_j = a dummy variable for country j and C_j is the difference between the intercept for country j and that for the first country, U_{jt} = the error term while $a_0 - a_6$ are parameters of estimation

For simplicity, replacing P_j by WFPI and P_y by MPP the equation will be as follows:

$$\ln F = a_0 + a_1 WFPI + a_2 \ln MPP_{jt} + a_3 \ln MPP_{jt-1} + a_4 \ln S_{jt} + a_5 \ln N_{jt} + a_6 \ln Pr_{jt} + \sum_{j=2}^{10} c_j D_j + U_{jt} \dots \dots \dots (11)$$

Equation 11 was also used to determine the effect of international nutrient fertilizer prices, that is, NITP, PhoPI and PotPI, on aggregate fertilizer use in place of international fertilizer price of aggregate fertilizer. Where: NITP = World urea price in US\$ per metric ton, PHOPI = world phosphorous fertilizer price index and POTPI = world potash fertilizer price index

Equation (11) was modified and used to individually estimate the use for nitrogen, phosphorous and potash nutrient fertilizers as modified in the following three equations. The global fertilizer price index, WFPI, was substituted by the world urea price as a proxy for world price of nitrogen fertilizer, world phosphorous and potassium fertilizer price indices in the estimation of the demand for nitrogen, phosphorous and potash nutrient fertilizers in equations 12, 13 and 14 respectively as:

$$\ln NIT_{jt} = b_0 + b_1 \ln NTIP + b_2 \ln MPP_{jt} + b_3 \ln MPP_{jt-1} + b_4 \ln S_{jt} + b_5 \ln N_{jt} + b_6 \ln Pr_{jt} + \sum_{j=2}^{10} C_j D_j + U_{jt} \dots \dots \dots (12)$$

$$\ln PHO_{jt} = c_0 + c_1 \ln PHOPI + c_2 \ln MPP_{jt} + c_3 \ln MPP_{jt-1} + c_4 \ln S_{jt} + c_5 \ln N_{jt} + c_6 \ln Pr_{jt} + \sum_{j=2}^{10} C_j D_j + U_{jt} \dots \dots \dots (13)$$

$$\ln POT_{jt} = d_0 + d_1 \ln POTPI + d_2 \ln MPP_{jt} + d_3 \ln MPP_{jt-1} + d_4 \ln S_{jt} + d_5 \ln N_{jt} + d_6 \ln Pr_{jt} + \sum_{j=2}^{10} C_j D_j + U_{jt} \dots \dots \dots (14)$$

Where: NIT = gross quantity of nitrogen fertilizer used in maize in country j and year t , PHO = gross quantity of phosphorous fertilizer used in maize in country j and year t , POT = gross quantity of potassium fertilizer used in maize in country j and year t , NITP = World urea price in US\$ per metric ton, PHOPI = world phosphorous fertilizer price index, POTPI = world potash fertilizer price index, N_{jt} = amount of labour used in maize production country j and year t , P_{yjt} = maize producer price (MPP) for maize for country j and year t , Pr_{jt} = precipitation for country j and year t , D_j = a dummy variable for country j and C_j is the difference between the intercept for country j and that for the first country, U_{jt} = the error term and $b_0 - b_6$, $c_0 - c_6$ and $d_0 - d_6$ are parameters of estimation. Equations 12, 13 and 14 were also used to determine the effect of world fertilizer prices (WFPI) on the use of individual nutrients by replacing the respective nutrient international price with WFPI.

Estimation Methods

Panel data was used in the investigation on the examination of the factors influencing fertilizer use in the ten selected African countries over the period between 1990 and 2010. Hausman test was used to confirm that

fixed effects specifications were preferred to random effects specifications for the data used in this study. In the two empirical models, fixed effects with country dummies were used in estimating aggregate fertilizer demand and individual nutrient fertilizer demand. This was in a bid to take care of country differences in maize production and fertilizer use conditions. This study employed STATA statistical packages in its analysis. The coefficients as presented in model one results were read directly as elasticities for three variables, that is, land, labour and quantity of maize seed, while that of fertilizer used and rainfall (precipitation) were read in unit form. The sign and significance of the coefficients indicate the direction of the impact by the independent variables on the dependent variable. The coefficients as presented in model two and three were read directly as elasticities while the sign and significance of the coefficients similarly indicated the direction of the impact by the independent variables on the dependent variables.

To decide between fixed effects and random effects estimation an Hausman test was done with the null hypothesis that the preferred model was random effects versus the alternative hypothesis the fixed effects. The Hausman test basically tests whether unique errors are correlated with the regressors and the null hypothesis is that they are not correlated, that is; H_0 : difference in coefficients not systematic. After conducting the test in the three models used in the study, all the three Hausman tests gave a $\text{prob} > \chi^2 = 0.000$ and since this was less than 0.05, fixed effects regression was used in the two models.

Heteroskedasticity tests are conducted to check the variances of error terms in the model. The constant variability should be present for the error term in order to validate the results (White, 1980). For this study, in all the models the option robust was used in the Stata commands during regression so as to obtain heteroscedasticity-robust standard errors.

RESULTS AND DISCUSSION

In this section we provide the results regarding the effect of international fertilizer price on aggregate fertilizer demand and on the demand of individual nutrient fertilizers (nitrogen, phosphorous and potassium) as used in maize production in the 10 selected African countries. Besides international fertilizer price, other factors under consideration included amount of labour, quantity of maize seed, precipitation and maize producer price which was used as a proxy for farm income from maize output. The section starts with a presentation on summary statistics of the key variables.

Statistics summary of the data of main variables used in the study

Table 1 below presents a summary of the main variables

Table 1. Summary of main variables of the study

Variable	Observations	Mean	Std. Dev.	Min	Max
Yield (tonnes per ha)	210	2.154619	1.82117	.2867	8.3705
Maize Seed (tonnes)	210	34950.95	17617.37	3532	79619
Area under maize (ha)	210	1375888	980884.7	109215	4661000
Labour (thousands)	210	576.392	516.7735	37.97452	2407.969
Agg fertilizer use (kg/ha)-All	210	73.19619	143.1729	.4	698.7
Nitrogen fert. (kg/ha)	210	61.68995	133.5072	.2307912	650.2961
Phosphorous fert. (kg/ha)	210	9.124544	9.443988	.0641008	37.53669
Potassium fert. (kg/ha)	210	2.386668	3.07963	0	13.92674
Average annual rainfall (mm)	210	69.03734	35.86956	1.714464	164.6493

used in the study. From the summary, the minimum yield in tonnes per ha was 0.2867 tonnes and the maximum attained yield across the 10 countries was 8.3705 tonnes per ha while the average yield was 2.15 tonnes per ha. On gross annual maize seed used, the minimum amount used was 3532 tonnes while the highest usage was 79619 tonnes. Overall, from the trends section it was observed that there was generally an increasing trend on maize output even though there were a number of fluctuations as depicted from the standard deviation.

On land area under maize production, the minimum land area used for maize production was 109215 ha while the maximum land area used for maize production was 4661000 ha. However, from the study data on land area under maize, it was observed that the acreage under maize crop continued to increase over the years during the study period an indication that more land was either being diverted from other crops to maize production, or land under natural resources like forests was being put into cultivation in most of the countries. This could have been in a bid to increase gross production of maize so as to address the food insecurity issues in the region.

The minimum amount of aggregate fertilizer used in maize production was 0.4 kilograms per ha and the maximum amount was 698.7 kilograms per ha while the average application rate was 73.2 kilograms per ha. This average was however much higher than previously reported in other studies but still lower than application rates in other similar developing countries like those in Asia. It was also observed that fertilizer use especially in South Africa and Egypt was quite high as compared to the rest of the countries and this could have been responsible for the high average. For instance, with the exclusion of Egypt's fertilizer use, the average fertilizer use per ha drops to 26.8 kilograms per ha, a further confirmation of the low fertilizer demand in SSA. The statistics summary as further shown in Table 5 in the appendix on fertilizer use per ha by country indicates that apart from Egypt, South Africa and Zimbabwe, the other seven countries were using very low rates of fertilizer application with that of Zimbabwe declining rapidly towards the end of the study period as shown in Figure

31. These statistics are a further confirmation of the very low use of fertilizer in SSA countries and this reinforces the motivation to investigate the behaviour of fertilizer use in response to world fertilizer price changes which is undocumented empirically.

The minimum nitrogen nutrient fertilizer used was 0.23 kilograms per ha and the maximum application rate was 650.6 kilograms per ha while the average nitrogen application rate was 61.7 kilograms per ha. This average however drops to a mere 18.3 kilograms per ha when Egypt's nitrogen fertilizer use is excluded. Overall, nitrogen fertilizer use was relatively higher as compared to the two other nutrient fertilizer, that is, phosphorous and potassium, possible reason being that fertilizer was being used in more than once during the maize production cycle, that is, during plant and during top dressing of maize and generally because nitrogen was found to be the least costly of the three nutrients.

On phosphorous nutrient fertilizer use, the minimum application rate was 0.064 kilograms per ha and the maximum application rate was 37.54 kilograms per ha while the average use rate was 9.12 kilograms per ha. This average however drops to a mere 7 kilograms per ha when Egypt's phosphorous fertilizer use is excluded an indication of very low phosphorous use in SSA. Overall, phosphorous fertilizer use was second to that of nitrogen fertilizer use as in most countries it was used in combination with nitrogen to form compound fertilizer that was being used during the planting time of maize. However, it was found to be more costly than nitrogen but less expensive as compared to potassium fertilizer.

On the other hand, potassium nutrient fertilizer was the least used with the fertilizer not being used at all in two countries for the entire study period and the maximum rate was 13.93 kilograms per ha while the average application rate was 2.4 kilograms per ha. This average however drops to a mere 1.6 kilograms per ha when Egypt's potassium fertilizer use was excluded. Despite the meagre use of potassium, it was observed that its use had a large effect on maize yield as countries using potassium had a comparatively higher maize yield than those that were not using potassium fertilizer. The low or no use of potassium fertilizer could be attributed to the

Table 2. Aggregate fertilizer use estimation

VARIABLES	(1)	(2)	(3)	(4)	(5)
	lnF	lnF	lnF	lnF	lnF
lnWFPI	-0.202** (0.0970)	-0.195* (0.113)			
lnN	0.532*** (0.125)	0.493*** (0.140)	0.520*** (0.130)	0.469*** (0.145)	0.474*** (0.144)
lnS	0.406*** (0.137)	0.434*** (0.142)	0.369*** (0.142)	0.420*** (0.139)	0.386*** (0.139)
lnPr	-0.418** (0.165)	-0.397** (0.172)	-0.425** (0.166)	-0.401** (0.171)	-0.393** (0.169)
lnMPP	0.191 (0.130)	0.160 (0.182)	0.105 (0.141)	0.141 (0.205)	0.142 (0.165)
lnlag_MPP		0.0249 (0.196)		0.0943 (0.194)	0.0248 (0.202)
lnNITP			-0.115 (0.0818)		
lnPhoPI				-0.283** (0.121)	
lnPotPI					-0.197 (0.140)
Constant	12.73*** (1.666)	12.66*** (1.743)	13.41*** (1.788)	12.71*** (1.762)	13.30*** (1.712)
Country Dummy	Yes	Yes	Yes	Yes	Yes
Observations	194	183	183	183	183
R-squared	0.931	0.931	0.930	0.931	0.931

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

very high cost of the nutrient fertilizer among other factors. This is because it was found that of the three nutrients, potassium nutrient fertilizer was the most expensive. This is also as pointed out in the literature that potassium fertilizer use was not profitable and this could be attributed to its high cost.

On maize seed used for production, the average gross annual use was 34,950 tonnes of seed with the highest gross annual usage being 79,618 tonnes while the least gross annual usage was 3532 tonnes. Despite the data showing an increase in total quantities of gross annual usage of maize seed in maize production, there was no information on the quality of the maize seed used. However, the increase in gross usage could be attributed to the expansion in acreage under maize during the study period as earlier reported.

On labour usage in maize production, the summary statistics indicate that the average annual labour used in maize production among the countries under study was about 576 thousand labourers and the maximum was about 2704 thousand labourers while the least was about 516 thousand labourers. The data an indication of high labour usage and this could be attributed to the fact that much of the maize produced in Africa is labour intensive with minimal use of machinery especially among the smallholders who form the majority.

Lastly, the minimum average annual rainfall was 1.72 mm and the highest was 164.65 mm while the average

annual rainfall was 69 mm an indication of rainfall fluctuations and large variations across the countries under study. The huge variations could be due to frequent droughts in the region coupled with some seasons of relatively high rainfall. It was observed that while in some countries there was high rainfall recorded in given years, other countries recorded relatively low rainfall amounts and vice versa an indication of rainfall vulnerability across the region.

Factors affecting fertilizer use in maize production in Sub-Saharan Africa

This sub-section presents regression findings for the second research question on the variables affecting fertilizer use in Sub-Saharan Africa, that is, amount of labour, quantity of maize seed, precipitation, maize producer price and international (world) fertilizer price. The independent variable of interest was the effect of world fertilizer price on fertilizer use on maize output in Sub-Saharan Africa. The results were estimated based on equation (11) using fixed effects regression with country dummies and the elasticities of the independent variables are as presented in Table 2. The estimations generate consistent and expected results for all the variables and also indicate that the coefficients are different from zero. To address any possible challenges of heteroscedasticity, robust was included in the Stata

command when running the results using fixed effects regression with country dummies. The Hausman test was carried out and had a $\text{prob} > \chi^2$ of .0000 implying that fixed effects estimations were preferred to random effects estimations. The results in column 1 were estimated without the previous year's maize producer price while the results in column 2 were estimated with both current and previous year's maize producer prices and since in both cases maize producer price influences fertilizer use positively, the results in column 2 were used in the interpretation. The results in column 2 in Table 2 present results for fertilizer use response to world fertilizer price (WFPI) while results in columns 3, 4 and 5 present results for fertilizer use in response to international nutrient (nitrogen, phosphorous and potassium) fertilizer prices. The R^2 values for all estimations are very high at .93 implying that over 93 percent of fertilizer use for maize production is explained by the included independent variables in all the regressions.

From the results in Table 2, a number of findings can be drawn. Firstly, fertilizer use in maize production is negatively and significantly correlated with world fertilizer prices (WFPI) including the world prices of the individual nutrients (NITP, PhoPI and PotPI) as shown in columns 2, 3, 4 and 5. The elasticity of world fertilizer price is 0.195 at 0.1 significance level as shown in column 2. This implies that a decline in world fertilizer prices (WFPI) by 1 percent increases fertilizer demand by 0.195 percent an indication that world fertilizer price plays a key role in influencing fertilizer use in maize production in SSA countries with its increase leading to less use of fertilizer which in effect could lead to a decline in output. This scenario could be due to the fact that if world fertilizer prices increased, this could cause a spillover effect in form of a price transmission to the domestic fertilizer price resulting in subsequent increases in domestic price of fertilizer. During the price transmission process, a number of other factors like import bureaucracies also contribute the increase in the domestic prices of the importing countries. This in turn could make fertilizer more expensive to most of the maize producers who could in effect either reduce the quantities of fertilizer used or avoid using fertilizer altogether. The results were also in line with those of Gunjal et al. (1980); Alene et al. (2008); Okoroafor et al. (2010) and Massumoto and Yamaro (2011) among other studies who found that fertilizer prices (domestic) were negatively affecting fertilizer use.

Similarly, the results in column 3, 4 and 5 indicate that fertilizer use is negatively correlated with world nutrient fertilizer prices of all the three nutrients even though only that of phosphorous is statistically significant (at 0.05 significance level), an indication that an increase in the world price of any of the three nutrients used in maize production in sub-Saharan Africa could lead to a decline in the amount of aggregate fertilizer used. For instance,

the elasticities of world fertilizer price of nitrogen, phosphorous and potassium fertilizers as presented in column 3, 4 and 5 are 0.101, 0.283 and 0.197 respectively and are all negative in sign an implication that if world fertilizer prices of nitrogen, phosphorous and potassium increased by 1 percent respectively, then aggregate fertilizer use decreased by 0.101, 0.283 and 0.197 percent respectively even though only that of phosphorous nutrient fertilizer is significant. The finding on fertilizer use in response to world fertilizer prices is consistent with the law of demand which indicates that if a product's price increases then its use declines and vice versa *ceteris paribus*. In this case, the implication could be that an increase in world prices of any of the three nutrients leads to an increase in domestic fertilizer price of the nutrients and this ends up having a negative effect on their use in SSA countries hence cumulatively leading to a decline in aggregate fertilizer use. These results were also in harmony with those of Gunjal et al. (1980); Alene et al. (2008); Okoroafor et al. (2010) and Massumoto and Yamaro (2011) who found that fertilizer prices (domestic) were negatively correlated with fertilizer use even though they were not specific to any nutrient fertilizer as their studies focused on general fertilizer use.

Secondly, fertilizer use in maize production in SSA is positively and significantly correlated with labour (N) used in maize production in all the regressions in column 2, 3, 4 and 5 as shown in Table 2. The elasticity of labour in column 2, 3, 4 and 5 is 0.493, 0.520, 0.469 and 0.474 respectively and all are significant at 0.01 significance level. This implies that labour use significantly influences fertilizer demand in SSA countries with an increase in quantity of labour by 1 percent leading to an increase in fertilizer use by about 0.5 percent in all the four scenarios. This could be due to the fact that majority of the maize producers in SSA are smallholders who have little access to machinery for farm operations and hence maize being intensively labour produced implying that to use more fertilizer in maize production it could definitely require more labour in the application process both during planting time and top-dressing of maize. Adequate labour is thus necessary for timely and adequate use of fertilizer. These results are also in line with those of deGraft-Johnson et al. (2014) who found that improved technologies like chemical fertilizers were more easily adopted and intensely used if adequate labour was available especially in rain-fed agriculture. This is a plausible result given that in much of SSA region majority of the labour is engaged in agriculture as also indicated by Gollin et al (2014) Gollin et al who argue that developing countries have most of the workers in agriculture and that there are huge cross-country differences in the quantity of grain output per worker and at least as large differences as those of the agricultural sector as a whole.

Thirdly, fertilizer use in maize production is positively

Table 3. Nutrient fertilizers use estimations

VARIABLES	(1) lnNIT	(2) lnNIT	(3) lnPho	(4) lnPho	(5) lnPot	(6) lnPot
lnWFPI	-0.0562 (0.115)		-0.561*** (0.118)		-0.807*** (0.283)	
lnN	0.525*** (0.147)	0.549*** (0.135)	0.481** (0.187)	0.413** (0.195)	0.393 (0.276)	0.370 (0.284)
lnS	0.492*** (0.157)	0.422*** (0.154)	0.158 (0.146)	0.101 (0.147)	0.000571 (0.217)	0.199 (0.218)
lnPr	-0.426** (0.180)	-0.461*** (0.177)	-0.305 (0.189)	-0.316* (0.187)	-0.628* (0.339)	-0.612* (0.327)
lnMPP	0.0980 (0.192)	0.0354 (0.150)	0.379** (0.178)	0.293 (0.182)	-0.0716 (0.485)	-0.0969 (0.401)
lnlag_MPP	-0.0343 (0.201)		0.133 (0.190)	0.302* (0.180)	0.213 (0.521)	0.160 (0.536)
lnNITP		-0.00005 (0.0894)				
lnPhoPI				-0.749*** (0.144)		
lnPotPI						-0.811** (0.377)
Constant	11.91*** (1.876)	12.45*** (2.453)	12.36*** (2.056)	12.78*** (1.973)	16.61*** (3.688)	18.93*** (3.734)
Country Dummy	Yes	Yes	Yes	Yes	Yes	Yes
Observations	183	194	183	183	143	143
R-squared	0.932	0.932	0.901	0.903	0.773	0.777

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

and significantly correlated with the quantity of maize seed (S) used in production in all the regressions in column 2, 3, 4 and 5 as shown in Table 3. The elasticity of maize seed in column 2, 3, 4 and 5 is 0.434, 0.369, 0.420 and 0.386 respectively and all are significant at 0.01 significance level. This implies that maize seed quantity used significantly influences fertilizer use in SSA countries with an increase in quantity of maize seed by 1 percent leading to an increase in fertilizer use by about 0.4 percent in all the four scenarios. This could be due to the fact that an increase in maize seed use in production implies a higher maize plant population which in effect could require more fertilizer for sustained high production hence the positive correlation between the two variables. However, the increase in maize seed quantity could in effect lead to high crop densities that in turn could not only require increase in supplementary inputs like labour, but could also lead to lower yields as in the relationship between maize output and quantity of maize seed used. This could be due to intra-competition among the maize crops and therefore reasonable maize spacing and seed quality could dictate the amount of seed used as earlier suggested by Bationo et al. (1992) and Martey et al. (2019).

Fourthly, rainfall (Pr) negatively and significantly influences fertilizer use in maize production in SSA as shown in all the regressions in column 2, 3, 4 and 5 as

shown in Table 2. The elasticity of rainfall in column 2, 3, 4 and 5 is 0.397, 0.425, 0.401 and 0.393 respectively and all are significant at 0.05 significance level. This implies that rainfall significantly influences fertilizer use in SSA countries with a decrease in rainfall by 1 percent leading to an increase in fertilizer use by about 0.4 percent in all the four scenarios an indication that fertilizer use in maize production is highly vulnerable to weather conditions. The negative correlation could be due to that fact that excessive rainfall could discourage most farmers from applying high quantities of fertilizer as much of it could be carried away by the rain water even though at the same time increase in rainfall could mean that whatever amount of fertilizer applied is able to be used by the crops unlike during dry periods. Therefore, this calls for adequate rainfall amounts that are neither excess or insufficient amounts. Kassie et al. (2015) also observes that in most of SSA countries, the predominantly rural populace depends on rain-fed agriculture an indication that rainfall shocks in the region could lead to fluctuations in fertilizer use which could further lead to fluctuations in maize output. This is also as found by Fufa and Hassan (2006) and Alem et al. (2010), who found that rainfall shocks had negative effects on fertilizer use.

Lastly, the effect of both current maize producer price (MPP) and previous year's maize producer (lag_MPP) prices is positive as shown in column 2 but all coefficients

are insignificant as shown in Table 2. For instance, the elasticity of current maize producer price (MPP) in column 2, 3, 4 and 5 is 0.160, 0.105, 0.141 and 0.142 respectively but insignificant. This implies that current maize producer price (MPP) influences fertilizer use in SSA countries positively with an increase in current maize producer price (MPP) by 1 percent leading to an increase in fertilizer use by about over 0.14 percent in all the four scenarios an indication that fertilizer use in maize production is positively correlated with current maize producer price (MPP).

On the other hand, the elasticity of previous year's maize producer (lag_MPP) prices in column 2, 4 and 5 is 0.029, 0.0943 and 0.0248 respectively but insignificant. This implies that previous year's maize producer (lag_MPP) prices influences fertilizer use in SSA countries positively with an increase in previous year's maize producer (lag_MPP) prices by 1 percent leading to an increase in fertilizer use by 0.029, 0.0943 and 0.0248 percent respectively an indication that fertilizer use in maize production is positively correlated with previous year's maize producer (lag_MPP) prices. The result implies that an increase in maize producer price, either previous or current, could induce more fertilizer use in production both in the current and proceeding year in most of the time as also found by Abdoulaye and Sanders (2005). The results are also in harmony with those of Matsumoto and Yamono (2011) who found that even though crop income positively influenced fertilizer use in maize production, the incomes were not sufficient enough to meet the fertilizer prices due to high relative prices. These studies argue that the maize incomes that accrue to the producers especially the smallholder farmers are not sufficient to meet their competing consumption needs implying that the producers are not able to spare sufficient funds for not only purchase of adequate amounts of fertilizer, but time purchase for use at the right time. This could be a further justification as to why the result for both previous and current maize producer prices are not statistically significant. This could possibly require an intervention from the states of respective countries and other stakeholders in not only developing mechanisms to ensure that fertilizer is easily accessible and affordable but also that the producer incomes are boosted possibly through better market access and other strategies that could ensure that the producers have sufficient funds for timely and adequate use of fertilizer so as to boost maize output. This could also require that the fixed costs of accessing fertilizer are also addressed so as to promote fertilizer use and as suggested by Duflo et al. (2007) include time and money spent to the market and time spent learning on how to use fertilizer as these costs could further hamper fertilizer. Duflo et al. (2008) further suggests that to ensure adequate fertilizer use, farmers should be given the option of buying fertilizer immediately after harvest as

this led to an increase in in fertilizer use by almost 33 percent in the proportion of farmers using fertilizer, an effect comparable to that of a 50 percent reduction in the price of fertilizer. This could be due to the fact that immediately after harvest farmers could still be in possession of high income from maize sells and could be in a position to make enough fertilizer purchases unlike long after harvest. Once fertilizer is purchased this also increases the possibility that it will be used in sufficient quantities and at the right time.

Factors affecting nutrient fertilizer use in maize production in Sub-Saharan Africa

This sub-section presents regression findings for the third research question on the effect of international fertilizer prices on nutrient fertilizer use in Sub-Saharan Africa. It also looks at the effect of other factors alongside international fertilizer prices, that is, amount of labour, quantity of maize seed, precipitation and maize producer price both current and previous year's maize producer prices and how they relate with fertilizer use. On international fertilizer price, the analysis looks not only at the effect of general international fertilizer price on the use of each of the three nutrients, that is, nitrogen, phosphorous and potassium, but also on the effect of the respective international nutrient fertilizer price on use of the three nutrients as shown in Table 3. The independent variable of interest was the effect of world fertilizer price on fertilizer use in maize production in Sub-Saharan Africa. The results were estimated based on equation 12, 13 and 14 which were an extension of equation 11. Fixed effects regression with country dummies were used in the analysis after doing the Hausman test as reported in section 3.5.1 and the elasticities of the independent variables are as presented in Table 3. To address any possible challenges of heteroscedasticity, robust was included in the Stata command when running the results using fixed effects regression with country dummies. Since it was not possible to get data on world nitrogen fertilizer price, the world urea fertilizer price was used as a proxy for the world nitrogen price. This is as explained earlier on and as used in other studies.

The estimations generated consistent and expected results for all the variables and also indicates that the coefficients are different from zero. The results in column 1, 3 and 5 are estimated to test the effect world fertilizer price (WFPI) on the use of the three nutrients while the results in column 2, 4 and 6 are estimated with individual world nutrient fertilizer prices, that is world nitrogen fertilizer price (NITP), world phosphorous fertilizer price index (PhoPI) and world potassium fertilizer prize index (PotPI), in place of international fertilizer price (WFPI) alongside other independent variables. In all the estimations, both current and previous year's maize have been included in the estimations at the same time except

in column two since in previous estimations their separation was not found to have distinct differences. The R^2 values for the first and second columns are very high at .932 and .932 respectively implying that over 93 percent of nitrogen fertilizer use for maize production is explained by the included independent variables while the R^2 for the third and fourth columns are .901 and .903 respectively implying that over 90 percent of the phosphorous fertilizer use in maize production is explained by the included independent variables. On the other hand, the R^2 for the fifth and sixth columns are .773 and .777 implying that over 77 percent of the potassium fertilizer demand is explained by the included independent variables. The R^2 for the fifth and sixth columns are slightly lower due to the fact that fewer countries were using potassium fertilizer as compared to those using nitrogen and phosphorous fertilizers as shown by the number of observations in columns 1, 2, 3 and 4.

From the results in Table 3, a number of findings can be made. Firstly, both international fertilizer price (WFPI) and international nitrogen fertilizer price (NITP) negatively influence the use for nitrogen fertilizer in SSA countries as shown in Table 4 columns 1 and 2. The elasticity of international fertilizer price (WFPI) is 0.0562 whereas that of international nitrogen price is 0.0005 as in columns 1 and 2 respectively. This implies that a decrease in international fertilizer price (WFPI) by 1 percent leads to an increase in nitrogen fertilizer use in maize production by 0.0562 percent while a decrease in international price of nitrogen fertilizer by 1 percent leads to an increase in nitrogen fertilizer use by 0.0005 percent. However, the results for both variables were not significant. Generally, despite the insignificance of the results, they were as expected since an increase in international prices could lead to an increase in their domestic prices which could in turn lead to a reduction in nitrogen fertilizer used as most users could find it more expensive to use the required amounts. The insignificance of the result could also be due to the low price of nitrogen fertilizer implying that changes in its international market prices could have an insignificant negative effect on its use in maize production in the SSA as depicted by the size of the elasticities. This negative finding was also in line with many previous studies which found negative relationships but based on domestic fertilizer prices like that of Quddus et al. (2008); Fufa and Hassan (2006); Hernandez and Torero (2013) among others.

Secondly, on the use of phosphorous nutrient fertilizer, the estimations in column 3 and 4 respectively show that international fertilizer price (WFPI) and international phosphorous fertilizer price (PhoPI) negatively and significantly influenced phosphorous fertilizer use. The elasticity of international fertilizer price (WFPI) and that of international phosphorous fertilizer price with respect to phosphorous fertilizer demand are 0.561 at 0.01

significance level and 0.749 at 0.01 significance level respectively as in columns 3 and 4. This implies that a decrease in international fertilizer prices (WFPI) by 1 percent leads to an increase in phosphorous fertilizer use by over 0.56 percent while a decrease in international phosphorous fertilizer price (PhoPI) by 1 percent leads to an increase in phosphorous fertilizer use by 0.749 percent. This indicates that international fertilizer price, both for general world price and world phosphorous nutrient fertilizer have a big effect in the use of phosphorous fertilizer in maize production in SSA countries with world phosphorous fertilizer price having the most effect on its use. This is an indication that phosphorous fertilizer use was responding more to changes in its own world fertilizer prices than general increases in world fertilizer price implying that if its price increased in the international market, then the price was automatically transmitted to the domestic market price of phosphorous fertilizer and hence making it more expensive leading to a reduction in its use. This result is plausible and is as was expected due to the high cost of phosphorous nutrient fertilizers implying that if its price came down in the international market, then this could be transmitted to the domestic market making it less expensive and therefore more farmers could be able to afford it and thus increase phosphorous fertilizer use, a necessity for increased maize yields. The results were also in line with those of Quddus et al. (2008); Fufa and Hassan (2006); Hernandez and Torero (2013) among others who also found an inverse relationship between domestic fertilizer price and fertilizer demand.

Thirdly, on the use of potassium nutrient fertilizer, both the international fertilizer price (WFPI) and international potassium fertilizer price (PotPI) have a negative and significant effect on the phosphorous fertilizer use in maize production in SSA countries as shown in Table 3, columns 5 and 6 respectively. The elasticities of demand of international fertilizer price (WFPI) and international potassium fertilizer price (PotPI) are 0.807 at 0.01 significance level and 0.811 at 0.01 significance level respectively implying that a decrease in international fertilizer price (WFPI) by 1 percent could lead to an increase in potassium fertilizer use by 0.807 percent while a decrease in international potassium fertilizer price (PotPI) by 1 percent could lead to an increase in potassium fertilizer use by over 0.811 percent. The results in table 4 indicate that changes in international fertilizer prices have the highest effect on the use of potassium fertilizer in SSA countries. The result also indicates that potassium fertilizer use was responding more to changes in its own world fertilizer prices than general increases in world fertilizer price implying that if its price increased in the international market, then the price was automatically transmitted to the domestic market price of potassium fertilizer and hence making it even more expensive than it already is, leading to a

further reduction in its use. Overall, potassium fertilizer use is the highest affected among the three nutrients by changes in international fertilizer prices, followed by phosphorous and nitrogen fertilizers in that order. This scenario could be due to the fact that potassium fertilizers are the most expensive followed by phosphorous and then nitrogen fertilizer and hence a small reduction in price could have the highest effect on the most expensive fertilizer as compared to cheaper fertilizers. This result on world potassium price is in harmony with Donovan (2013) who argues that farm operators in poor countries avoid using productivity enhancing intermediaries because doing so increased their consumption risk and in this cases, further increase the price of potassium fertilizer in the international market could lead to an increase its price in the domestic market hence making it more risky to use. Also given the high poverty levels in the region, many farmers could be avoiding the use of sufficient quantities potassium fertilizer due to associated costs and meagre resources. This argument is further supported by Dufflo et al. (2008) who argues that even if the returns to fertilizer are high, the absolute income gain from using fertilizer does not make it worthwhile if there are significant fixed costs in using the fertilizer, a situation very similar to that of potassium fertilizer due to its high cost compared to the other nutrients.

Fourthly and similarly as in the use of aggregate fertilizer, labour (N) use in maize production is positively correlated with the use of all the fertilizer nutrients as shown in Table 3. The elasticity of labour with respect to nitrogen fertilizer use is 0.525 and 0.549 and all are significant at 0.01 significance level as shown in columns 1 and 2 implying that in both cases an increase in labour by 1 percent leads to an increase in nitrogen fertilizer use by over 0.5 percent an indication that an increase in nitrogen fertilizer use could require more labour. Similarly, the elasticity of labour with respect to phosphorous fertilizer demand is 0.481 and 0.413 all significant at 0.05 significance level as shown in columns 3 and 4 in Table 4 implying that an increase in labour by 1 percent is required to increase phosphorous fertilizer use by 0.481 and 0.413 percent respectively. On the other hand, though positively correlated with potassium fertilizer demand as expected, the effect of labour is not significant. Its elasticity with respect to potassium demand is 0.393 and 0.370 respectively as shown in columns 5 and 6 in Table 4 implying that an increase of labour by 1 percent is required to increase potassium fertilizer use by almost 0.4 percent even though the result isn't significant. Overall, labour use has the highest effect on nitrogen fertilizer use followed by phosphorous and potassium fertilizer use in that order. This could be due to the application of nitrogen fertilizer twice by most farmers during planting and top-dressing of maize as opposed to phosphorous fertilizer which is used only once by most farmers during planting and given that fertilizer

application in maize production in SSA is mostly labour intensive. The least effect on potassium fertilizer use could be due to its low use in maize production in SSA. This is a plausible result given that in much of SSA region majority of the labour is engaged in agriculture and hence the positive correlation. The result is also in harmony with that of Gollin et al (2014) who argue that developing countries have most of the workers in agriculture.

Fifthly, maize seed (S) use has a significant effect only on the use nitrogen fertilizer. The two are positively correlated with an elasticity of 0.492 and 0.422 both significant at 0.01 significance level as shown in columns 1 and 2 in Table 3. This implies that an increase in maize seed use by 1 percent leads to an increase in nitrogen fertilizer use by over 0.4 percent and this could be due to a corresponding increase in the number of maize plants as a result of using more maize seed which could require more nitrogen fertilizer during planting and top dressing in order to achieve higher or similar returns. On the other hand, maize seed use has a positive but insignificant effect on the demand for phosphorous fertilizer. Though positively correlated, the result is insignificant with an elasticity of 0.158 and 0.101 as shown in Table 3 columns 3 and 4. On the effect of maize seed use on potassium fertilizer, the result is positive but insignificant with a very low elasticity of 0.000571 and 0.199 an indication that quantity of maize seed used has very little and insignificant effect on the demand of potassium fertilizer in maize production. Implying that quantity of maize seed used in maize production does not significantly influence the amount of potassium fertilizer used. The results are in harmony with those of Martey et al. (2019) who found a positive relationship between fertilizer use and maize seed.

The sixth finding is that rainfall (Pr) has a negative effect on the use of all the three nutrient fertilizers. On its effect on nitrogen fertilizer use, the elasticity of rainfall is 0.426 and 0.461 all significant at 0.05 significance level as shown in column 1 and 2 in Table 3 an implication that a decrease in rainfall by 1 percent leads to an increase in nitrogen fertilizer use by over 0.4 percent which is a very big response. On the other hand, the effect of rainfall on phosphorous fertilizer use is negative but insignificant when international aggregate fertilizer prices are used in the estimation in column 3 while when international phosphorous fertilizer price is used in the estimation in column 4, rainfall has a negative and significant effect with an elasticity of 0.316 at 0.1 significance level implying that a reduction in rainfall by 1 percent leads to an increase in phosphorous fertilizer use by 0.316 percent. However, rainfall is found to have the highest effect on potassium fertilizer followed by nitrogen fertilizer and then phosphorous fertilizer even though at a lesser significance level. The elasticity of rainfall with respect to potassium fertilizer use is 0.628 and 0.612 both significant at 0.1 significance level as shown in columns 5

and 6 in Table 3. This implies that a reduction in rainfall by 1 percent leads to an increase in potassium fertilizer use by over 0.6 percent. Overall, the nutrient fertilizer use in maize production in SSA is found to very vulnerable to weather conditions with a decrease in rainfall triggering more demand for the nutrients an indication that individual nutrient fertilizer use was negatively as influenced by rainfall as was aggregate fertilizer use as earlier explained. This is also as found by Fufa and Hassan (2006) and Alem et al. (2010), who found that rainfall shocks had negative effects on fertilizer use.

The seventh observation is that current maize producer price (MPP) was found to have a positive effect on nitrogen and phosphorous fertilizers' use but a negative effect on potassium fertilizer use. However, the results were all not significant except for those in column 3 in Table 3. The implication was that if current maize producer prices increased, then the use of both nitrogen and phosphorous fertilizers increased while the use of potassium fertilizer tended to decline. For instance, the elasticity of current maize producer price on nitrogen use is 0.098 and 0.0354 but not significant as shown in columns 1 and 2 in Table 3 an implication that an increase in current maize producer price by 1 percent leads to an increase in nitrogen fertilizer use by almost 0.1 percent. Similarly, the elasticity of current maize producer price with respect to phosphorous fertilizer use is 0.379 at 0.05 significance level and 0.294 as shown in columns 3 and 4 respectively with the earlier elasticity of 0.379 implying that an increase in current maize producer price by 1 percent significantly leads to an increase in phosphorous use by 0.379 percent. On the other hand, the elasticity of current maize producer price on potassium fertilizer is 0.0716 and 0.0969 as in column 5 and 6 of Table 3, but not significant. The result though not significant, implies that an increase in current maize producer price leads to a decline in potassium fertilizer use in maize production. This could be due to the fact that potassium fertilizer is the most expensive nutrient of the three and farmers could be reducing on its use so as to maximize on margins. In this case it is observed that as current maize producer prices increased, use of nitrogen and phosphorous fertilizers increased and the use of potassium fertilizer declined. This result is as was expected since an increase in maize prices meant an increase in farmers' incomes which means they could be able to afford more nitrogen and phosphorous fertilizers. As for the negative effect, it has been found that potassium use in maize production is not profitable due to high costs and this could be the reason that instead of an increase in its use when maize producer prices increased, its demand declined possibly since quantities used were found unprofitable to use it.

Lastly, the previous year's maize producer price (lag_MPP) was found to negatively influence the use of nitrogen fertilizer but positively influenced the use of both

phosphorous and potassium in the current period even though the results were all insignificant except for those for phosphorous fertilizer in column 4 of Table 3. For instance, the elasticity of previous year's maize producer price on the demand of nitrogen fertilizer is 0.0343 but not significant as shown in columns 1 implying that a decrease in previous year's maize producer price by 1 percent leads to an increase in nitrogen fertilizer use by 0.0343 percent in the current period. This result is as was not expected as it implies that increase in maize price in the current period led to declines in nitrogen fertilizer use in the year that followed. On the other hand, the elasticity of the previous year's maize producer price on phosphorous fertilizer use is 0.133 as in column 3 but not significant and 0.302 at 0.1 significance level as in column 4. The latter elasticity implies that an increase in previous year's maize producer price by 1 percent leads to an increase in phosphorous fertilizer use by over 0.3 percent in the current period. This result was as expected since an increase in maize price leads to increased incomes which could allow for savings for expenditure on phosphorous fertilizer in the following year given its higher cost than that of nitrogen. Similarly, the elasticity of previous year's maize producer price on potassium demand is 0.213 and 0.160 as shown in columns 5 and 6 but both are insignificant. This result implies that there is a positive but insignificant relationship between previous year's maize producer price and current potassium fertilizer use with an increase in the price by 1 percent leading to an increase in the demand for potassium fertilizer by almost 0.2 percent in the current year. Despite being insignificant, the result is as was expected as increase in maize price meant more income with possible savings for possible expenditure on potassium fertilizer and other inputs in the year to follow.

Summary of key findings

On factors affecting aggregate fertilizer use, International fertilizer price (WFPI), international phosphorous nutrient fertilizer price (PhoPI) and rainfall were found to negatively and statistically significantly affect the use of fertilizer. On the other hand, land, labour and maize seed use were positively and statistically significantly influencing fertilizer use in maize production. Current and previous year's maize producer prices were found to be positively influencing fertilizer demand but they were not statistically significant.

On factors affecting nutrient fertilizers' use, changes in international fertilizer price (WFPI) were found to be negatively influencing the demand of the three nutrient fertilizers, that is, nitrogen, phosphorous and potassium nutrient fertilizers but only statistically significantly influencing the demand of phosphorous and potassium. Labour use was found to positively and statistically significantly influence the demand of nitrogen and

phosphorous but though positive it was not significantly influencing the demand for potassium fertilizer. Maize seed was found to positively influence the demand of all the three nutrients, that is, nitrogen, phosphorous and potassium nutrient fertilizers, but was only statistically significant in the demand of nitrogen fertilizer. On the other hand, rainfall was found to be negatively and statistically significantly influencing the demand of the three nutrients except for only one case in the demand for phosphorous fertilizer when the international price of phosphorous fertilizer was not included in the estimation of its demand. In this case it was negative but not significant. Further, current maize producer price was found to be positively influencing the use of only nitrogen and phosphorous nutrient fertilizers but only statistically significant in the use of phosphorous fertilizer while it was found to be negatively influencing the use of potassium fertilizer though not significant. On the other hand, previous year's maize producer price was found to have a negative effect on the use of nitrogen fertilizer though not significant while it had a positive effect on the use of both phosphorous and potassium fertilizers though only significant for phosphorous fertilizer when international price of fertilizer was included in the estimation. International nitrogen fertilizer price was also found to be negatively influencing the use of nitrogen fertilizer but not statistically significant. On the other hand, international phosphorous and potassium fertilizer prices were found to be negatively and statistically influencing the demand for phosphorous and potassium nutrient fertilizers respectively.

CONCLUSIONS AND RECOMMENDATIONS

The results showed that of the variables affecting aggregate fertilizer demand, only five variables were statistically significantly influencing fertilizer demand and these were international fertilizer price (WFPI), international phosphorous fertilizer price (PhoPI), labour, maize seed and rainfall. Out of the five variables, labour and maize seed were positively correlated with aggregate fertilizer use while international fertilizer price, international price of phosphorous fertilizer and rainfall were negatively correlated with aggregate fertilizer use in maize production.

The results further showed that of the variables affecting nutrient fertilizer demand, only international price of aggregate fertilizer was found to statistically significantly influence the demand of all the nutrient fertilizers, that is, nitrogen, phosphorous and potassium fertilizers. International aggregate (compound) fertilizer prices were found to be negatively correlated with the demand of all the nutrient fertilizers. On the other hand, labour, maize seed and rainfall were all found to statistically significantly influence the demand for nitrogen nutrient fertilizer. Labour and maize seed use were

positively correlated with nitrogen fertilizer use while rainfall was found to be negatively correlated with the demand of nitrogen nutrients. Labour was also found to be positively and statistically correlated with the demand for phosphorous nutrient fertilizer an indication that more phosphorous use could require more use of labour which is a plausible finding. Current and previous year's prices were found to only statistically significantly influence the demand for phosphorous fertilizer and were positively correlated implying that an increase in the price of maize triggered an increase in the amount of phosphorous used both in the current and the following year.

Based on the above conclusions, it was recommended that to increase fertilizer use it was necessary to put in place strategies that could lead to reduction in price of both compound and nutrient fertilizers in the domestic market and this could require the relevant government departments in respective countries to come up with strategies that could help them reduce the fertilizer import prices such as reduction in import fee, clearance and warehouse charges at the ports of entry as a way of reducing the final market price. It is also recommended that domestic governments seek financial assistance from foreign governments like The People's Republic of China and other economies so as to run fertilizer subsidies in order to boost its consumption. The respective governments could also where possible pursue the possibility of lobbying for the fertilizer producing multinational companies to establish local production industries where possible as a means of reducing the final cost of fertilizer by minimizing on transport and other costs. All these strategies could lead to declines in fertilizer prices leading to more fertilizer use. Coupled with adequate labour and maize seed quality and quantities, this could further lead to increases in maize output. On rainfall, weather vulnerabilities like drought could be mitigated so as to reduce rainfall shocks that affect fertilizer use negatively. Such mitigation measures could include water harvesting and other irrigation supplementary means. These could ensure assurance to maize producers of sufficient water for maize production at all times and hence increase fertilizer use which could in turn increase maize output. Farm households should also be encouraged to make savings from farm and other non-farm income sources for fertilizer purchases during production time as this could help in boosting fertilizer use in subsequent maize production seasons.

Contribution of the study

Overall, this study makes a valuable addition to the literature on fertilizer use in Sub-Saharan African countries since most previous studies have usually focused on the effects of domestic fertilizer prices on fertilizer use, ignoring the role of international fertilizer

prices on fertilizer use. This study finds that world fertilizer prices negatively correlate with fertilizer use in maize production in SSA countries both in aggregate form and in nutrient form with the demand of phosphorous and potassium nutrient fertilizers being the most affected of the three nutrients and therefore, world fertilizer price could be responsible for fertilizer underuse in SSA countries. This negative correlation is as a result of the price transmission effect from the international market to the domestic market even though other factors were kept constant. The price transmission is normally coupled bureaucracy, import duties and handling during the fertilizer importation process all this add up to the increased costs of fertilizer after landing in the domestic markets. For instance, an increase in the price of fertilizer at the international market level leads to a subsequent increase in fertilizer price in the domestic market as an adjustment to the new world market and vice versa. This adjustment in prices similarly affects the domestic prices of individual nutrient fertilizer. Increase in the price of the nutrient fertilizers has a direct effect on their use since the increase in their world prices leads to decreased use by producers in importing countries and this further leads to a decline in overall fertilizer use in production. Given this finding, it is highly recommended that with the existing budgetary constraints in most of SSA countries as found in other previous studies, SSA governments should consider seeking for financial assistance for use in the fertilizer sector, from foreign governments especially The People's Republic of China which has had an ongoing close economic collaboration with most African countries. This will help to make fertilizer more readily accessible and affordable for use by most farming households which will have confounding positive effects on not only fertilizer use in maize production but also general crop and livestock production in the region.

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