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ARE AFRICAN FARMERS EXPERIENCING IMPROVED INCENTIVES TO USE FERTILIZER?

By

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Food Security Policy *Research Papers*

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EXECUTIVE SUMMARY

Poor incentives saw fertilizer use in Sub-Saharan Africa (SSA) stagnate throughout the 1990s at roughly 10 kgs per cultivated hectare. This was partly due to the removal of crop price supports and input subsidies alongside input price hikes due to currency depreciation associated with the post-structural adjustment era. Though much has changed since the 1990s, there has been no comprehensive assessment of trends in African farmers' incentives to use fertilizer in the last 15 years.

This paper provides a comprehensive update on the incentives for fertilizer use among African farmers using data from seven countries accounting for about 65% of fertilizer consumption in SSA.

We look at the trends in nitrogen/crop price ratios for key cereals (and their fluctuations) over time, the agronomic crop response rates to applied fertilizer and some underlying drivers of fertilizer cost in SSA such as transportation. We then examine the relationship between incentives and actual fertilizer consumption.

We do not find evidence of improved incentives for fertilizer use in SSA. Rather we find that nitrogen cereal crop ratios remain high and have actually increased for most cereals compared to the 1990s. There has also been an increase in the variability of these ratios, particularly for maize. Transportation and handling costs continue to contribute significantly to the higher prices that smallholders pay. We also find consistent evidence that the agronomic yield response to applied fertilizer in SSA is low on farmer fields, often lower than response rates observed by studies in the 1990s.

A more holistic approach to constraints to fertilizer profitability (costs as well as factors that will increase the efficiency of fertilizer use) is necessary for any sustainable intensification effort in SSA. This includes infrastructure or programs that reduce farmers distance from inputs and increase the agronomic response rates.

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ACRONYMS

ACBIO	African Center for Biosafety
AISE	Ethiopian Agricultural Inputs Supply Enterprise
CAN	Calcium Ammonium Nitrate
CIF	Cost, Insurance and Freight
CFR	Cost and Freight
CGIAR	Consultative Group on International Agricultural Research
CSO	Central Statistical Office
CV	Coefficient of Variation
DAP	Diammonium phosphate
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	FAO Statistical Data Base
FEWS NET	Famine Early Warning Systems Network
IITA	International Institute of Tropical Agriculture
IFDC	International Fertiliser Development Center
IRRI	International Rice Research Institute
Kg	Kilogram
NPK	Nitrogen, Phosphorus and Potassium
SOA	Sulphate of Ammonia
SRID	Statistics and Research Information Directorate
SSA	Sub-Saharan Africa
TSP	Triple Super Phosphate
U.K.	United Kingdom
USA	United States of America

1. INTRODUCTION

Studies based on data from the 1980s and 1990s found that African farmers faced declining incentives to use fertilizer in the post-structural adjustment period, which was characterized by the elimination of crop price supports to farmers and skyrocketing fertilizer prices associated with currency depreciation and the curtailment of input subsidy programs (Kherallah et al. 2002). As a result, fertilizer use in Sub-Saharan Africa stagnated throughout the 1990s at roughly 10 kilograms (kgs) per cultivated hectare (Kherallah et al. 2002). Much has changed since then. Over the past decade, world food and fertilizer prices have risen dramatically and become highly unstable. Soil conditions have changed with an increasing proportion of the region's population living on farmland characterized as *degrading* (Barbier and Hochard 2016). However, since Kherallah et al. (2002) (which is based on data ending in the 1990s), there has been no comprehensive assessment of trends in African farmers' incentives to use fertilizer.

There are at least three important ways in which African farmers' fertilizer use decisions may have been affected over the past several decades. First, there have been major changes in the levels of commodity prices received by African farmers as well as the prices paid for fertilizer. The ratio of output to input prices may thus be one important source of changing incentives to use fertilizer. Second, given the global upheaval in commodity prices in recent years, both food and fertilizer prices have risen and fluctuated greatly. Because farmers' input use decisions are based on expected crop prices after harvest time, which are typically unknown at the time the inputs must be used, risks associated with fluctuations in the prices of crop outputs and fertilizer may have also influenced African farmers' incentives to use fertilizer in recent years.[1] These incentives may vary across countries and across crops because movements in fertilizer-grain price ratios are country and crop specific. In percentage terms, for example, the global price of maize and sorghum have experienced a greater increase over its 1990-2005 average compared to rice (FAOSTAT).

A third source of potential shifts in African farmers' incentives to use fertilizer concerns the agronomic crop response to fertilizer application. We know of no research study that has tracked trends in crop response rates to fertilizer in Africa, though there are *prima facie* indications that response rates may have declined in many parts of the region due to various forms of soil degradation, including loss of soil organic carbon, acidification, erosion, and soil mining leading to micronutrient deficiencies (Stoorvogel and Smaling 1990; Tittonell and Giller 2013; Montpellier Panel 2014; Barbier and Hochard 2016).

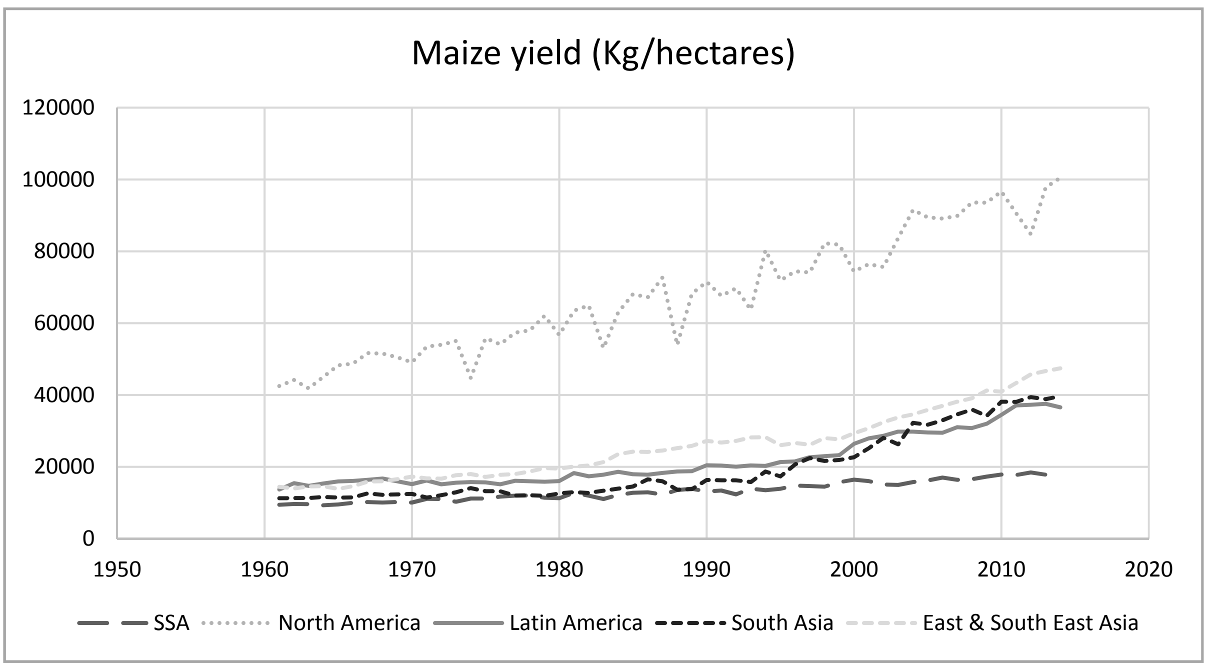
Consequently, this article provides a comprehensive updated assessment of trends in incentives for farmers to use fertilizer in Sub-Saharan Africa (SSA). Specifically we look at fertilizer/crop price ratios (and their fluctuations) and the agronomic response rates to fertilizer for key cereal crops. We also explore the underlying drivers of fertilizer costs in SSA and their role in influencing fertilizer use incentives by African farmers. These drivers include the cost of transportation and other inland costs beyond the landed cost of fertilizer at the port. We then examine the relationship between changes in incentives and actual fertilizer consumption across countries with due attention to country specific context.

[1] Exceptions would be cases where farmers receive a credible offer of a guaranteed price from a buyer such as the government or an out grower scheme.

We use information on fertilizer use as well as fertilizer and cereal prices from seven countries across East, West, and Southern Africa. Together these seven countries account for roughly 63% of the total fertilizer consumed in Sub-Saharan Africa over the 2010-2014 period.[2] We focus on maize, rice, and sorghum, three key crops grown and consumed in the region.[3] Contrary to previously held notions that fertilizer use was largely restricted to high value or export crops, most fertilizer used in the region is applied on cereal crops. Fertilizer application on cereals is common in SSA particularly on maize (Mason, Jayne, and Myers 2012; Liverpool-Tasie et al. 2016; Ricker-Gilbert, Jayne, and Chirwa 2011), followed by other cereals such as teff, barley, and wheat in Ethiopia (IFDC 2012; Minten, Koru, and Stifel 2013), and rice in Nigeria (Liverpool-Tasie 2016) as well as on sorghum and millet in some countries (Heisey and Mwangi 1997; Morris et al. 2007).

Though maize was introduced into Africa in the 1500s, it has since become one of Africa's dominant food crops. There are about fifty species in existence and more maize is produced annually than any other grain (IITA 2013). While maize is largely used as an input for numerous industrial products (and as livestock feed) in many industrialized countries, maize is also a key food staple in SSA, accounting for 30 to 50% of low income household expenditures in East and Southern Africa (IITA 2013). According to IITA, the maize Africa produces is responsible for about 7% of total global production with Nigeria being the largest producer (about eight million tons annually). Africa still imports almost 30% of the required maize from countries outside the continent. The majority of maize production in Africa is rain fed and yields are not only much lower than in other parts of the globe but have also been relatively stagnant (Figure 1).

Figure 1. Maize Yield



Source: Authors calculations based on FAOSTAT.

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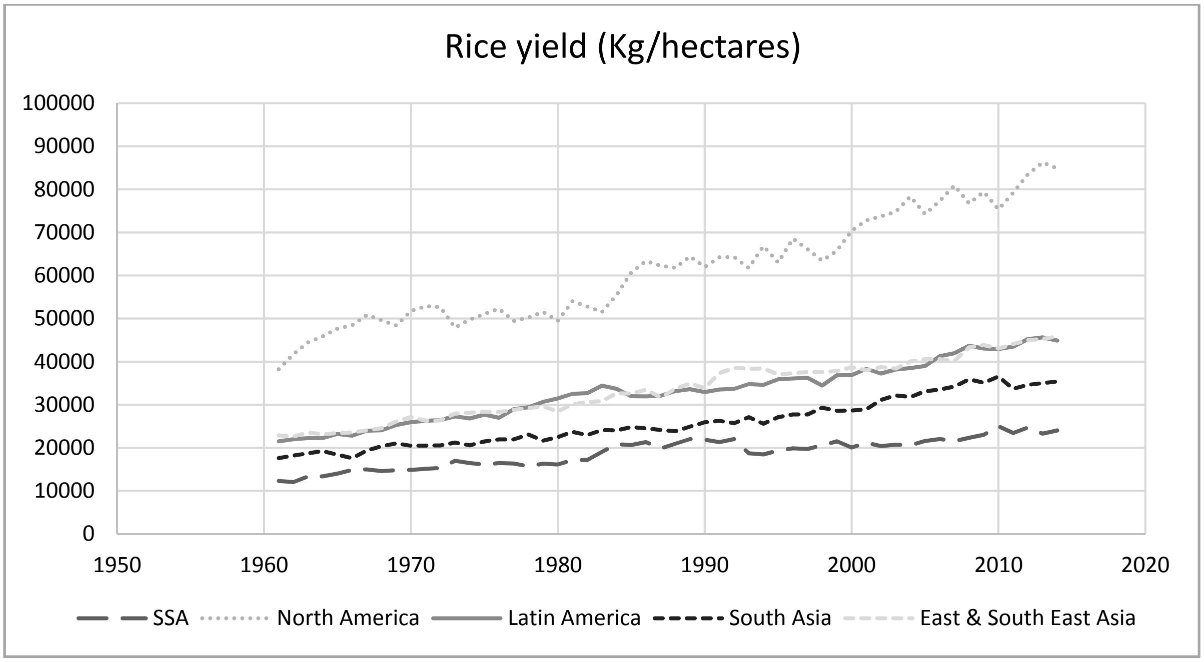
[2] Not including South Africa.

[3] We also consider the relevant ratios and prices for wheat in countries that produce wheat given its importance in the diet of SSA general.

Figure 2. Rice Yield



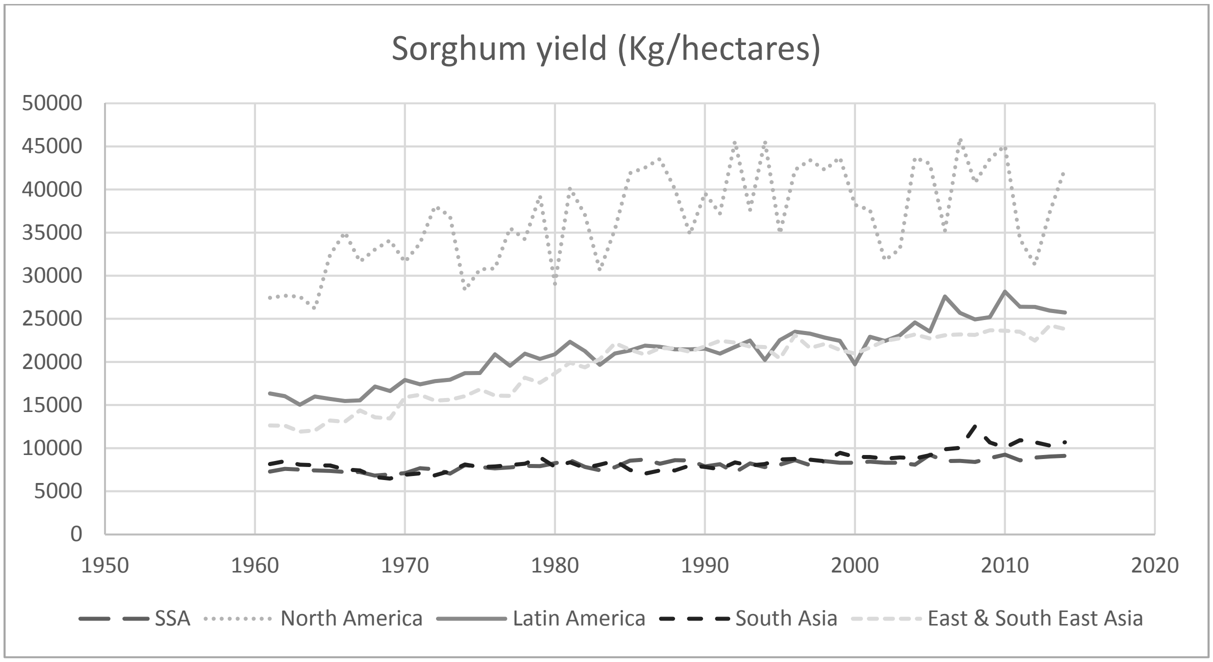
Source: Authors calculations based on FAOSTAT.

Rice is another extremely important crop serves as the staple food for over half the world's population (IRRI 2013). In SSA alone, rice consumption among urban dwellers has consistently grown, doubling since 1970 (Muthayya et al. 2014). Majority of the increased rice consumption in SSA is met with imports. Though the average rice yields in SSA have doubled from just over a 1 ton/hectare in the 1960s to slightly over 2 tons/hectare, the gap in average yields between SSA and other regions of the world has grown. Furthermore, rice yield in SSA remains about half of what is being attained in South East Asia and Latin America, 65% of what is being achieved in South Asia, and less than 30% of the rice yield in North America (Muthayya et al. 2014) (Figure 2).

Sorghum, our third study crop is one of the most important cereals in the world. It is the fifth largest cereal in terms of area of production (CGIAR n.d.). It serves as a staple food crop for many—particularly in Sub-Saharan Africa—and a key ingredient for various industries (for example feed and breweries) in many industrialized nations (FAO 2015). Sorghum production in most of Sub-Saharan Africa is characterized as traditional, subsistence, and small scale with low yields compared to the case in industrialized countries such as the USA where production is mechanized, large scale, and with high input use (CGIAR n.d.). Consequently, while average sorghum yields in North Africa are over 4 tons per hectare, the yields in SSA are still under 1 ton per hectare; quite similar to South Asia (Figure 3).

Given the important role these cereals play in the food security of SSA, African policy makers, development partners, and the research community might benefit greatly from a comprehensive assessment of farmers' incentives to use fertilizer on these crops as they develop and/or modify strategies for promoting fertilizer use in the region. This is particularly important given that there is widespread acceptance that dramatic increases in fertilizer use will be crucial for the region to achieve agricultural and economic transformation.

Figure 3. Sorghum Yield



Source: Authors calculations based on FAOSTAT.

The rest of the article is organized as follows: Section 2 provides an overview of the data used; Section 3 provides a general overview of the trends in fertilizer consumption across SSA compared to the rest of the world and for our study countries; Section 4 presents and discusses the trends in key incentives for inorganic fertilizer use across the study countries; and Section 5 concludes with a comparison of actual fertilizer use to these incentives and some key policy implications.

2. DATA

The main data used are fertilizer and output crop prices from several sources for the seven study countries: Ethiopia, Ghana, Kenya, Malawi, Nigeria, Tanzania, and Zambia. For each country we use data on fertilizer prices and cost build up drawn largely from government sources. Fertilizer price data from Kenya, Tanzania, and Zambia are regarded as wholesale prices; prices in the other countries are considered retail prices close to those paid by farmers in retail shops. For Ethiopia, we used the prices of diammonium phosphate (DAP) and urea obtained from the Ethiopian Agricultural Inputs Supply Enterprise (AISE).[4] For Ghana, we used the retail prices of nitrogen, phosphorus and potassium (NPK), sulphate of ammonia (SOA), and urea obtained from the Statistics and Research Information Directorate (SRID) at the Ministry of Food and Agriculture. Fertilizer prices in Kenya are the DAP wholesale prices at Nakuru obtained from the Ministry of Agriculture data files. Nigerian fertilizer prices were obtained from the Federal Fertilizer department of the Federal Ministry of Agriculture and Rural Development captured in various reports and data sources reflecting the retail price in urban areas. Malawi retail fertilizer prices are for compound nitrogen, phosphorus, and potassium (NPK) 23:21:00 and urea sourced from Ministry of Agriculture data files. Tanzanian prices of DAP, urea, calcium ammonium nitrate (CAN), triple super phosphate (TSP) and NPK were obtained from the Tanzanian Agricultural Inputs Unit - Ministry of Agriculture Food and Cooperatives and reflects the market prices in Dar es Salam and other regional centers. Finally, wholesale prices of Compound D fertilizer in Zambia were obtained from the Ministry of Agriculture data files. In cases where nitrogen was the key variable of interest, the nitrogen equivalent for each kg of fertilizer was calculated using the nitrogen composition of the various fertilizers. For example 1 kg of urea fertilizer contains 0.46 kg of nitrogen and each kg of NPK (15:15:15) which contains 15% nitrogen, phosphorus and potassium contains 0.15 kg of nitrogen. It should be noted that these prices (retail or wholesale) do not count some of the transport costs borne by farmers to get their fertilizer to their farms, and hence, underestimate (but at least consistently so) the real fertilizer-crop ratios faced by farmers. World price for fertilizer are obtained from the World Bank Commodity Price data (The Pink Sheet). It is based on annual using real 2010 U.S. dollars. The cost build up information for fertilizer is obtained from different sources depending on the year and country.[5]

Our cereal prices are largely obtained from the Famine Early Warning System Network (FEWS NET) and the FAO Statistical Data Base (FAOSTAT) supplemented by cereal prices from government sources in the various countries (see Table 1 for details). Since this data is collected at market level, the retail and wholesale prices used are likely higher than the producer prices (particularly for remotely located rural farmers) and thus for countries where FEWS NET output price data is used, we are likely underestimating the true nitrogen crop price ratios. The world price for maize, rice, and sorghum are from the World Bank Commodity Price data. The price of maize is for U.S. maize No. 2 yellow and it is based on fob U.S. Gulf ports. The price of rice is for Thailand 5% broken white rice milled and it is based on weekly surveys of export transactions, government standard, f.o.b. Bangkok. The price of sorghum is for the U.S. No. 2 milo yellow and it is based on f.o.b. Gulf ports.

[4] This is a government parastatal input marketing agency, previously called the Agricultural Inputs Supply Corporation.

[5] All sources are clearly referenced throughout the paper.

Table 1. Types of Grain Prices and Source of Data

Country	Cereals	Type of prices	Source of data
Ethiopia	Maize Wheat	Retail	Ethiopian Grain Trade Enterprise
	Sorghum	Wholesale and retail	FEWS NET* and FAOSTAT
Ghana	Rice	Retail	FEWS NET and FAOSTAT
	Maize	Wholesale	FEWS NET* and FAOSTAT
Kenya	Maize	Wholesale	Ministry of Agriculture data files, compiled by T. Jayne, J. Ariga, and Ministry of Agriculture colleagues. 2005-2015
	Sorghum	Wholesale	FEWS NET
	Wheat	Retail	FAOSTAT
Malawi	Maize Rice	Retail	FEWS NET
Nigeria	Sorghum Maize	Wholesale and retail	FAOSTAT and FEWS NET*
	Rice	Retail	FEWS NET and NBS
Tanzania	Maize	Wholesale and retail	FAOSTAT and FEWS NET*
	Wheat	Retail	FEWS NET
	Sorghum Rice	Wholesale	FEWS NET
Zambia	Maize	Retail	Zambian Central Statistical Office
	Sorghum	Retail	FAOSTAT

Note: *indicate source of wholesale prices.

3. OVERVIEW OF FERTILIZER CONSUMPTION ACROSS SSA

Fertilizer need and use naturally vary across space between countries and within countries; across farmers. Recent evidence indicates that fertilizer nutrient application rates on average, in SSA, remain lower than any other region of the world.6 Furthermore, contrary to almost everywhere else (apart from South Asia, Latin America, and the Caribbean) that have seen increases in nutrient application rates since the 1990s, fertilizer nutrient application rates, on average, in SSA have actually slightly declined over the same period.7 The most recent data available indicates that the average application rate in SSA is under 10% of application rates in East and South East Asia and about 15% of that in South Asia. It is about 10% of the rate in the U.K. and about 20% of the world average (see Table 2).

A closer look at our study countries reflects varying but similarly low fertilizer application rates (Table 3). Since the 1990s, apart from Tanzania and Nigeria (where application rates remain unchanged or slightly lower in 2010-2015 according to FAOSTAT data) fertilizer application rates have generally increased. Most increases are modest with Kenya being the exception. Fertilizer application rates in Kenya have more than doubled from about 18 kg of nutrients per hectare of arable land to 46 kg on average. This compares to more modest increases of 27% for Malawi and 21% for Zambia. Application rates in Nigeria are surprisingly low at 6 kg of nutrients per hectare. This does not account for the significant variability of fertilizer use within the country and is likely partly driven by the large size of arable land, which is over 40 million hectares compared to others, such as 16 million in Ethiopia, under 4 million hectares in Zambia and Malawi.

Table 2. Application Rate (Kg of Nutrients per Hectare of Arable Land)

Region	1980-81	1990-91	1996-97	2002-2005	2005-2010	2010-2015
World	88	100	98	41	43	49 (2014)
U.S.	55	55	62	45	45	53 (2014)
U.K.	188	216	224	118	100	99 (2014)
Latin America and the Caribbean	64	63	71	23	24	31 (2014)
Near East and North Africa	45	67	65	26	24	29 (2014)
Sub Saharan Africa	8	10	9	7	8	9 (2014)
East Asia and Southeast Asia	121	179	238	91	99	112 (2014)
South Asia	37	80	93	45	57	63 (2014)

Source: 1980-2002 is from the FAO Fertiliser Yearbook for regions and from the FOASTAT for U.S. and U.K where values were computed using the consumption of nitrogeneous and phosphate fertilizer divided by arable land and permanent crops area. Data for 2002 onwards are obtained from the FAOSTAT. The values represent the average use per area of cropland for total nutrient nitrogen and total nutrient phosphate P205 reported in Kg/Ha (element code 5159). Based on the regional definition used by the FAOSTAT, Latin America and the Caribean is comprised of Central and South America and the Caribbean; Near East and North Africa is Northern Africa; Sub-Saharan Africa is Western, Middle, Southern and Eastern Africa; East Asia and Southeat Asia is Eastern and South-Eastern Asia; South Asia is Southern Asia. Values that span more than one year represent median values across years.

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[6] Defined as the kilogram of nutrients per hectare of cropland.

[7] Application rates seem to have declined somewhat in the USA compared to 1996-97 but the average over the entire decade for the USA is about 98 kg/ha which is not too different from the 2010 average of 95.

Table 3. Application Rate (Kg of Nutrients per Hectare of Arable Land)

Country	1980-85	1990-95	2000-2005	2005-2010	2010-2015	2010-2015	Arable land (1000 Ha)**
Ethiopia	2.9	11.0	10.8	15.7	17 (2010)	25.2* (2011/12)	16,259
Ghana	3.5	1.6	1.6	5.5	6 (2010)		7,400
Kenya	17.1	17.5	26.7	28.6	46 (2011/2012)		6,330
Malawi	14.6	21.5	26.2	28.2	27.6 (2010)	56.3* (2010/11)	3,940
Nigeria	8.6	9.5	4.7	3.9	6 (2011/2012)	64.3* (2010/11)	40,500
Tanzania	3.2	3.9	3.6	4.5	5 (2010)	7.7* (2010/11)	15,650
Zambia	30.3	19.2	20.5	20.6	23 (2010)		3,736

Source: FAOSTAT (until 2010) and World Bank Agribusiness Indicators reports (2010-2015) Source for cells with asterisk (*) is Sheahan and Barrett (2014) using nationally representative LSMS datasets . Sources for cells with (*) obtained from FAOSTAT where arable land is the sum of arable land and permanent crops area. Arable land is the land under temporary agricultural crops (multiple-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years). Permanent crops are sown or planted once, and then occupy the land for some years and need not be replanted after each annual harvest, such as cocoa, coffee and rubber. This category includes flowering shrubs, fruit trees, nut trees and vines, but excludes trees grown for wood or timber.

While recent data from household surveys confirms generally lower nutrient application rates in SSA compared to the average in other regions of the world, the nitrogen nutrient application rates from household surveys in recent years are significantly higher than those from FAOSTAT data for Nigeria and Malawi. Sheahan and Barret (2014) using data from recently available nationally representative and comparative household surveys in SSA reveal fertilizer nutrient application rates per hectare for Nigeria and Malawi are about 64 kg and 56 kg respectively. Though these figures are significantly higher than the FAOSTAT figures, they are still below the world average or the average for South, East, and Southeast Asia. Thus, it is clear that nutrient application rates in SSA generally (confirmed by our study countries) remains relatively low and has not changed much since the 1990s for many countries.

4. TRENDS IN INCENTIVES TO USE INORGANIC FERTILIZER

4.1. Input/Crop Price Ratios

One reason why fertilizer use in Africa might be much lower than other parts of the world is the profitability of fertilizer use. Kelly (2006) discusses two broad categories of determinants of fertilizer use among smallholders: first the profitability of fertilizer use (absolutely and relative to alternative investments), and second is the ability to acquire the amount of fertilizer desired and use it efficiently. This paper largely focusses on the first issue, profitability. The capacity to use fertilizer efficiently (argued by Kelly (2006) to be largely determined by factors such as credit availability, risk mitigation programs and access to information and new technologies) is beyond the scope of this study. It can also be argued that these factors influence production practices and yields, which in turn affect the expected profitability of the input to farmers. Kelly (2006) and Morris et al. (2007) present a summary of key fertilizer profitability parameters (drawn on Yanggen et al. (1998)) largely based on the relationship between input and output prices and the agronomic response of fertilizer that this paper updates.

The relationship between output and input prices is typically expressed as the ratio of the fertilizer price to the crop output price; more specifically, the ratio of nitrogen to crop prices. Studies from the early and mid-1990s cite nitrogen maize price ratios for Africa ranging between 5 and 10 compared to 2.9 for Asia and Latin America (see Heisey and Mwangi 1997; Pintsrup-Andersen 2000). According to Morris et al. (2007), the ratio of nitrogen to crop price across the globe is said to have ranged between 2 and 3 (for wheat) between 1987 and 2007, and ranging between 2.5 and 3.5 in the mid 2000s in Asia and Latin America. These price ratios are typically lower for rice and higher for maize because rice is usually more expensive than wheat while maize is usually cheaper. Across SSA in the late 1990s (Yanggen et al. 1998; Kelly 2006) the nitrogen price ratios in East and Southern Africa were between 5 and 7 for maize, while they were between 2 and 4 for West Africa.

Recent data from our study countries indicates that the nitrogen/maize price ratios remain high in SSA, typically exceeding their levels in the 1990s (Figure 4). The most recent nitrogen /maize price ratios for Ethiopia, Kenya and Tanzania in East Africa are about 15, 10, and 8 based on the price for DAP fertilizer, which is the most commonly used basal (planting) fertilizer in these countries (Table 4). For urea fertilizer, the nitrogen/maize price ratios are lower at 5 and 2 for Ethiopia and Tanzania respectively.[8] For West Africa, the most recently available nitrogen/maize price ratios for urea and NPK fertilizers are between 4 and 8 (for Ghana) and between 4 and about 7 (for Nigeria) respectively. Nitrogen/maize price ratios for Southern Africa are similar at about 7 for Zambia and between 7 and 15 for Malawi for urea and N–23:21:00 respectively.

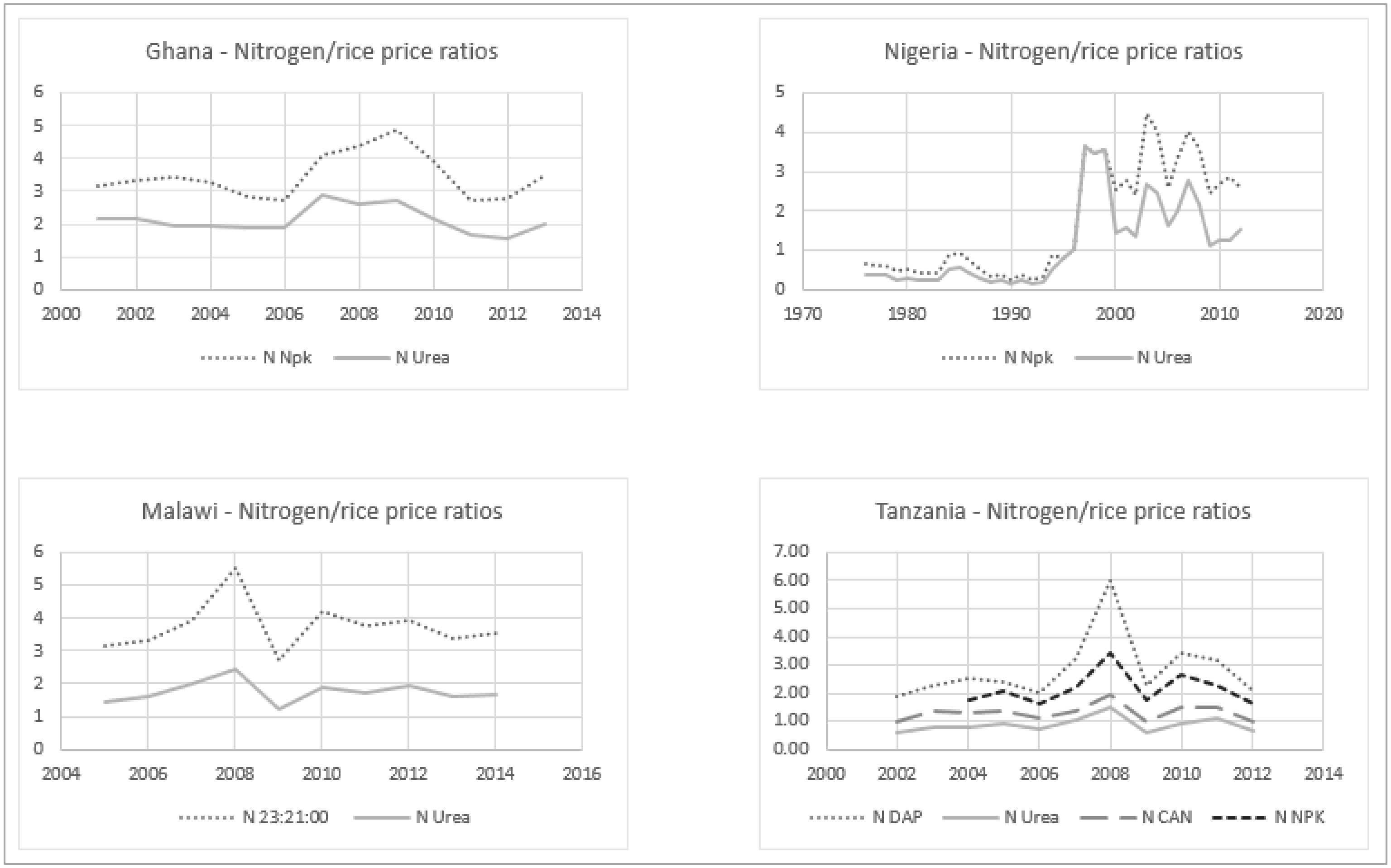
Nitrogen/rice price ratios have not changed much since the 1990s. In West Africa, the ratio in the late 1990s was about 2 (Yanggen et al. 1998; Kelly 2006). This compared to irrigated rice in Asia, which was at 2.5, likely reflecting the higher (lower) price for rice in West Africa (Asia). The nitrogen/rice price ratios are between 2 and 3.5 (for Ghana) and between 1.5 and 2.5 for Nigeria, depending on the type of fertilizer (Figure 5).

[8] This is driven by the higher nitrogen content per kg of urea fertilizer compared to others such as NPK and DAP and thus a lower unit cost for nitrogen.

Figure 4. Fertilizer Maize Price Ratios across Study Countries

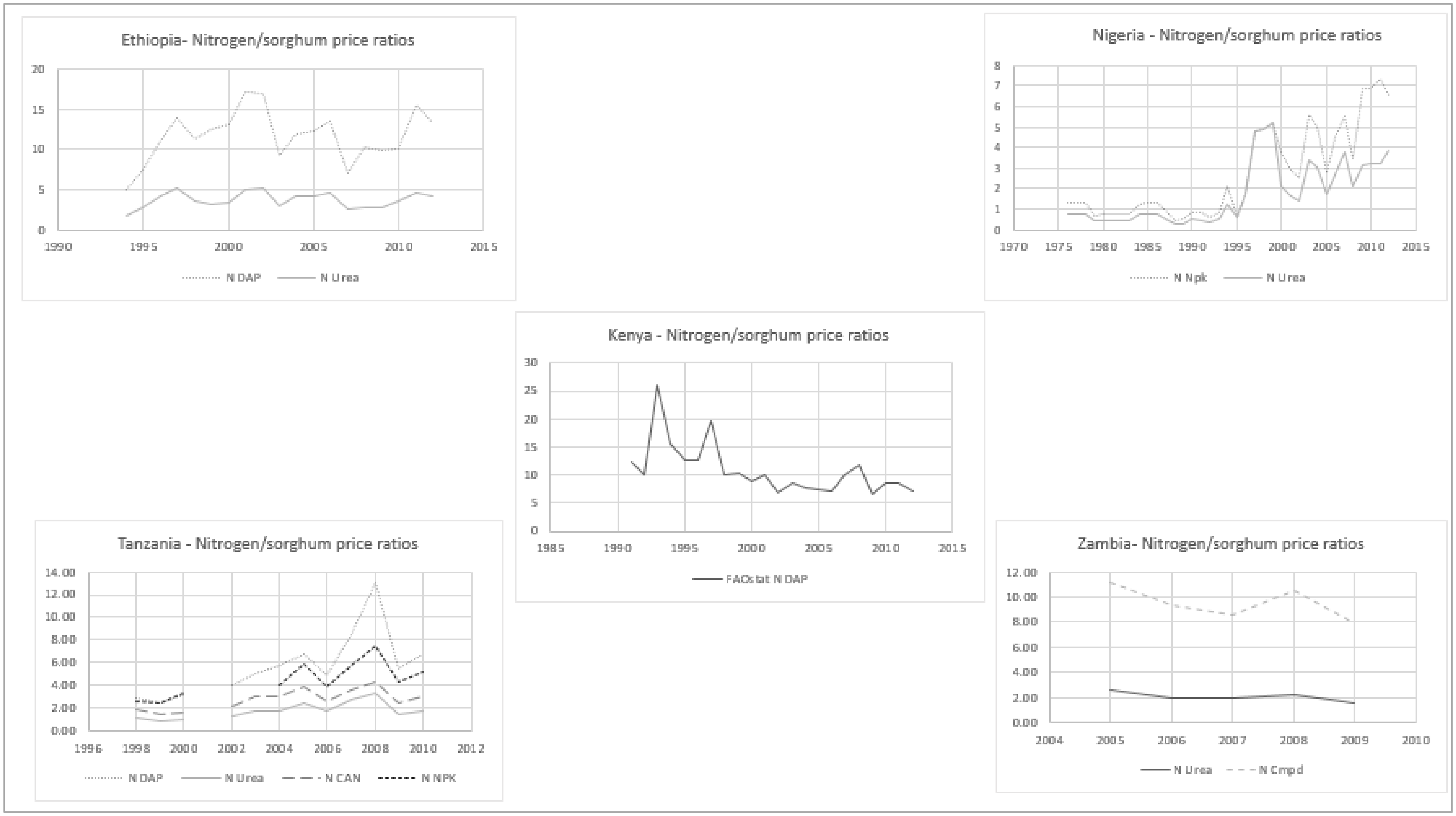
Source: Authors calculations based on output price data from countries statistical agencies, FAOSTAT and FEWS NET and fertilizer prices from various government agencies in the different countries.

Figure 5. Fertilizer Rice Price Ratios



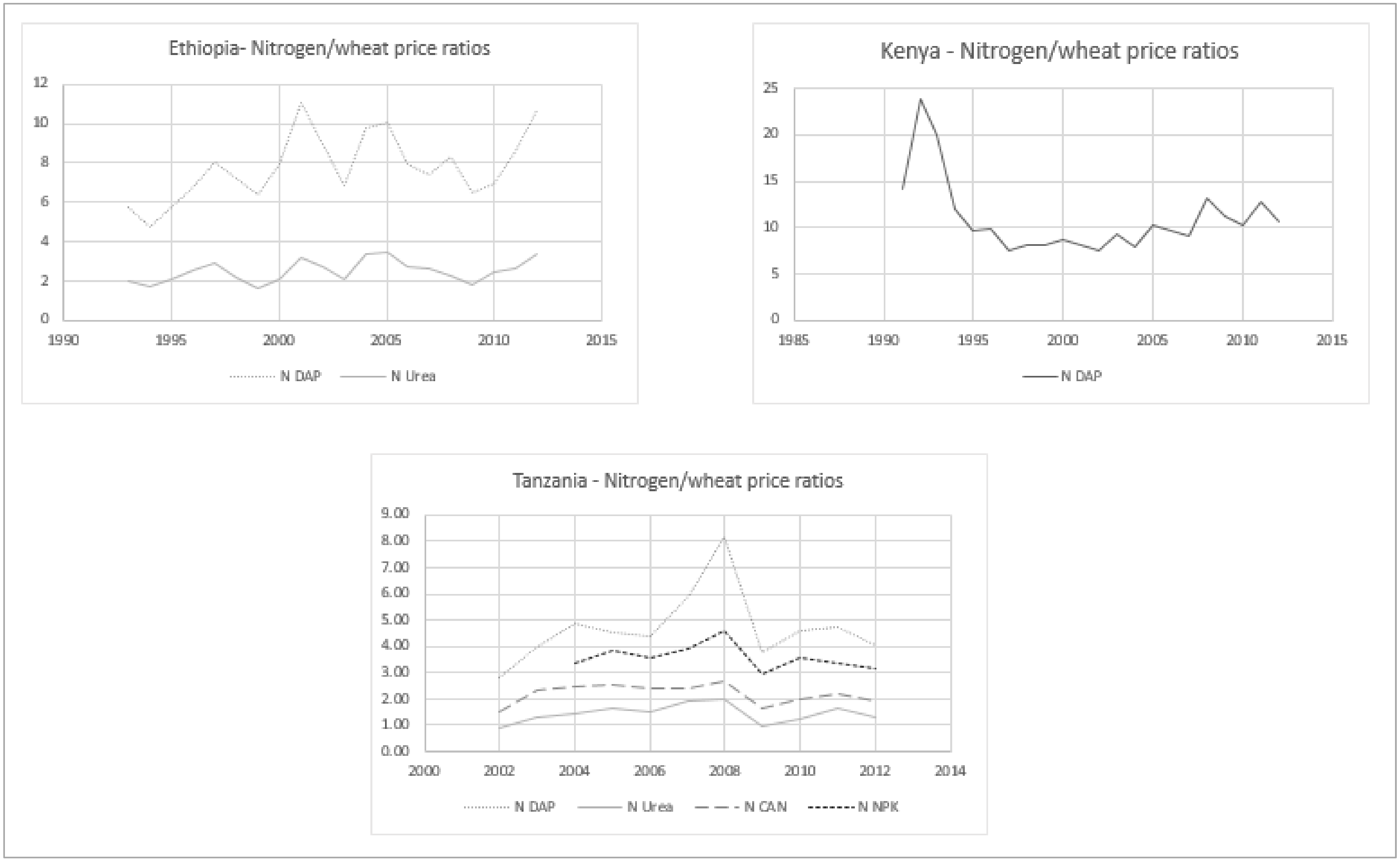
Source: Authors calculations based on output price data from countries statistical agencies, FAOSTAT and FEWS NET and fertilizer prices from various government agencies in the different countries.

Figure 6. Fertilizer Sorghum Price Ratios



Source: Authors calculations based on output price data from countries statistical agencies, FAOSTAT and FEWS NET and fertilizer prices from various government agencies in the different countries.

Figure 7. Fertilizer Wheat Price Ratios



Source: Authors calculations based on output price data from countries statistical agencies, FAOSTAT and FEWS NET and fertilizer prices from various government agencies in the different countries

Table 4 reveals lower median price ratios in Nigeria and Ghana for the 2010-2015 period compared to the 2000-2010 levels. This is likely driven by the general spike in fuel and cereal prices towards the end of that period. The current nitrogen rice price ratios in Tanzania and Malawi do not appear to have changed much from the levels in the previous decade (1 and 1.7 respectively for urea and 3 and 4 for DAP).

Nitrogen-sorghum price ratios were about 6 in East and Southern Africa and 2–4 in West Africa in the 1990s (Morris et al. 2007). This compared to 2 for sorghum in Asia. Apart from nitrogen from urea (which yields nitrogen sorghum price ratios for Tanzania and Zambia that are about 2, the nitrogen crop price ratio's for the study countries remain high and beyond their levels in the 1990s. For West Africa, the nitrogen price ratio for Nigeria in 2012 was between 4 and 7 (for urea and NPK respectively) compared to the 2–4 range for West Africa in the 1990s and persistently higher than their previous levels in the last two decades (see Figure 6 above). For Kenya, the median nitrogen/sorghum price ratio between 2010 and 2015 is about 9 (very similar to the average for the sub-region in the 1990s) but slightly lower than its previous levels in the mid and late 1990s, which was about 12. Ethiopia's nitrogen/ sorghum price ratio are also high ranging between about 5 and 14 depending on the fertilizer type.

The results for wheat are similar. Nitrogen/wheat price ratio's in Kenya are over 10 while those for Ethiopia are between about 3 and 9 for urea and DAP fertilizers respectively in the 2010-2015 period (see Figure 7 above). As was the case for rice, nitrogen/wheat price ratios in Tanzania have remained relatively constant over the last decade at about 5 for DAP and 1.5 for urea.

Generally, these results confirm that the nitrogen crop price ratios for major cereals in SSA have not improved since the 1990s. In many countries, these ratios not only remain high but appear to have actually increased over time. To investigate if this increase over time suggested by the descriptive trends in the movement of the nitrogen crop ratios was more than a random change, we estimate a simple linear time trend model. Following Wooldridge (2015), we estimate:

$$y_{CT} = \alpha_0 + \alpha_1 T + \alpha_2 C + e_{TC},\ T = 1, 2, \dots,\ C = 1,2,3 \dots, \qquad 1$$

where y_{TC} is nitrogen crop ratios in county *C* in time *T*, and e_{tc} is an independent, identically distributed sequence with$E(e_{TC}) = 0, Var\ (e_{TC}) = \sigma_e^2$. Holding all other factors fixed, α_1 measures the change in nitrogen crop ratios over time.

The econometric results support the descriptive statistics (Table 5). The ratios vary significantly across countries but on average have increased significantly over time. Where significantly different from Zero, the nitrogen crop ratios have increased on average by between 0.10 and 0.15 annually for maize, 0.06 and 0.10 for rice and by about 0.03 and 0.09 for wheat and maize respectively.

Table 4. Trends in the Nitrogen Crop Price Ratios (1 kg N/1 kg Crop) over Across Study Countries

Country	N/Maize ratio (1990-2000)	N/Maize ratio (2005-2010)	N/Maize ratio (2010-2015)	N/rice ratio (1990-2000)	N/rice ratio (2005-2010)	N/rice ratio (2010-2015)	N/sorghum ratio (1990-2000)	N/sorghum ratio (2005-2010)	N/sorghum ratio (2010-2015)	N/wheat ratio (1990-2000)	N/wheat ratio (2005-2010)	N/wheat ratio (2010-2015)
Ethiopia (DAP)	11.2	12.7	13.9	-	-	-	11.4	10.2	13.4	6.6	7.7	8.6
Ethiopia (Urea)	3.3	4.5	4.5	-	-	-	3.4	3.2	4.5	2.1	2.6	2.6
Ghana (NPK)	-	7.6	6.2	-	4	3.1	-	-	-	-	-	-
Ghana (Urea)	-	4.2	3.6	-	2.4	1.8	-	-	-	-	-	-
Kenya (DAP)	12.4	15.5	13.2	-			12.4	8.1	8.5	9.7	10.3	10.7
Malawi (23:21:00)	-	14.2	17.7	-	3.6	3.8	-	-	-	-	-	-
Malawi (Urea)	-	4.8	5.4	-	1.8	1.7	-	-	-	-	-	-
Nigeria (NPK)	1.5	4	6.9	0.9	2.9	1.8	1.8	5	6.8	-	-	-
Nigeria (Urea)	0.6	2.6	3.2	0.2	2.7	1.3	0.5	2.9	3.2	-	-	-
Tanzania (DAP)	4.8	8.8	9.7	-	2.8	3.2	2.9	6.7	6.7	-	4.6	4.6
Tanzania (Urea)	1.7	2.7	2.5	-	1	1	1	2.1	1.8	-	1.6	1.3
Zambia (Urea)	5.1	7.2	6.7	-	-	-	-	2	-	-	-	-
Zambia (N Compound)	24.2	32.7	32.66	-	-	-	-	9.4	-	-	-	-

Source: Authors calculations based on output price data from countries statistical agencies, FAOSTAT and FEWS NET and fertilizer prices from various government agencies in the different countries.

Table 5. Linear Time Model Estimation of Nitrogen/Crop Price Ratios

	Maize			Rice		Sorghum		Wheat	
	DAP	Urea	NPK	Urea	NPK	DAP	Urea	DAP	Urea
Time	0.08	0.09***	0.15***	0.06***	0.10***	-0.14	0.09***	-0.05	0.03*
Ethiopia									
Ghana		-1.48***							
Kenya	-0.20					2.10		4.27**	
Malawi		-0.90		-1.01***					
Nigeria		-7.34***	-7.85***	-3.04***	-4.23***		-4.62***		
Tanzania	-8.40**	-8.43***		-4.29***		-0.62	-6.37***	-1.22	-1.58***
Zambia		-5.87***					-6.80***		
Constant	11.83***	3.06***	5.67***	1.73***	2.77***	13.09***	2.78***	8.31***	2.14***
Observations	64	110	50	66	50	53	68	53	31

Source: Authors calculations based on output price data from countries statistical agencies, FAOSTAT and FEWS NET and fertilizer prices from various government agencies in the different countries. Maize prices in Zambia are sourced from the Zambian Central Statistical Office (CSO) while fertilizer prices are from the Ministry of Agriculture data files compiled by Jones Govereh, Nicole Mason, Bill Burke and Thom Jayne. Fertilizer and maize prices in Kenya are sourced from the Ministry of Agriculture data files, compiled by Thom Jayne, Joshua Ariga, and Ministry of Agriculture colleagues. 2005-2015 fertilizer prices in Malawi are sourced from the Fertilizer association of Malawi.

Notes: Maize reference is Ethiopia for DAP and urea, Ghana for NPK. Rice reference is Ghana. Sorghum reference is Ethiopia. Wheat reference is Ethiopia. Note: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

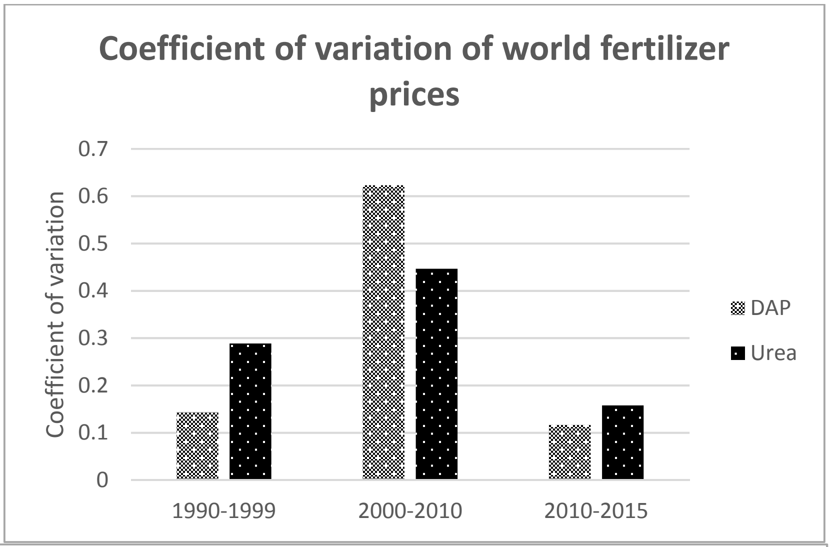
4.2. Risk and Coefficient of Variation

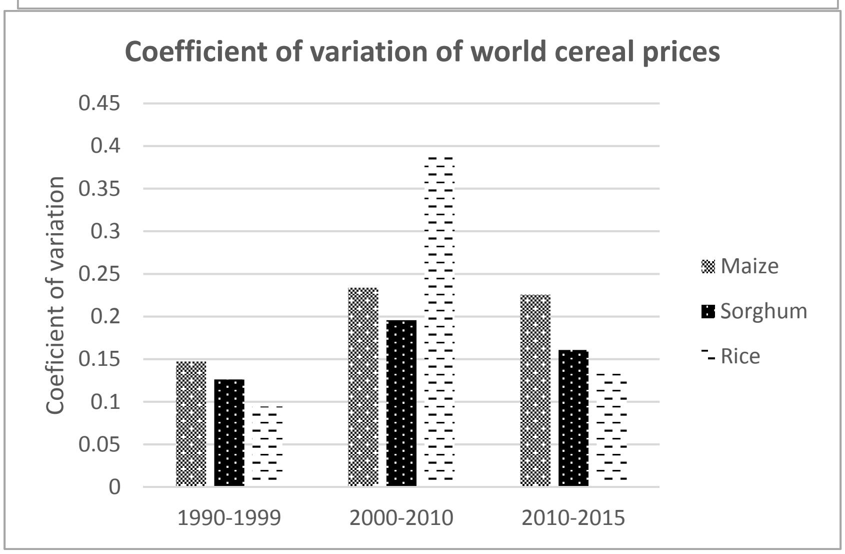
A third factor likely to affect farmers' incentives to use fertilizer partially captured by the price ratio parameter is the fluctuation in crop and fertilizer prices. These fluctuations are often exacerbated by climate change as well as policies and other factors affecting crude oil and crop prices. Figures 4-7 indicate that in addition to the increase in the levels of nitrogen crop price ratios, there has also been an increase in the variability of the price ratios, particularly since 2000. To capture the riskiness of fertilizer use, we also explore if and how the coefficient of variation (CV) of the world price for major cereals and fertilizer has changed since the 1990s and how that corresponds with what is happening within the study countries. The CV is the ratio of the standard deviation of the ratios to the mean.

There was a general rise in the CV for the real world price of major cereals and fertilizer in the 2000-2010 period (Figure 8). This was driven in part by the hike in cereal prices in the second half of the decade; the CV in the real world price for both fertilizer and cereals appear to have settled at lower levels compared to the 2005-2010 period. However, while the CV of fertilizer prices has settled at levels lower than the 1990s the CV of rice, maize and sorghum are all at levels higher than the 1990s and sometimes the early 2000s. Between 1990 and 1999, the CV of the world price for rice, sorghum, and maize were all under 15% and from rice (at about 10%) to maize at 15%. Between 2010 and 2015, the ranking order for the crops remains but are now between about 16% and 22% (Figure 8).

We calculate the CVs for the study countries as the ratio of the standard deviation of the nitrogen crop ratios to the mean over 5-year periods since 1995. There is significant variation across countries but a few points stand out. The CV of the nitrogen maize price ratios for most countries remains largely unchanged or higher than the levels in the 1990s and early 2000s (see Table 6). Ethiopia and Nigeria are exceptions; where we see a consistent reduction in the CVs of the nitrogen maize price ratio over time. The low CV of nitrogen crop ratio's in the last five years is maintained in Nigeria for all crops. However, for Ethiopia the CV of nitrogen crop ratios for wheat is actually higher in the 2010-2015 period compared to the 1990s and even the 2005-2010 for DAP and relatively unchanged for Sorghum compared to the 1990s for DAP. Apart from Tanzania and Ghana, the CV for the nitrogen rice price ratio appears to have declined for most countries in 2010-2015 compared to the 1990s.The variation across countries likely reflects the effects of country level policies and factors worthy of consideration. Given the importance of maize as a main staple in many of the study countries, the high and increasing variability in the nitrogen maize price ratio is likely to serve as a disincentive to fertilizer use for the crop.

Figure 8. Change in Levels and Variability of the World Price of Fertilizer and Cereals





Source: Authors' calculations based on World Bank commodity price data (Pink Sheet). DAP (diammonium phosphate), standard size, bulk, spot, f.o.b. U.S. Gulf. TSP, bulk, spot, beginning October 2006, Tunisian origin, granular, fob; previously U.S. origin, f.o.b. U.S. Gulf. Urea, (Black Sea), bulk, spot, f.o.b. Black Sea (primarily Yuzhnyy) beginning July 1991; for 1985-91 (June) f.o.b. Eastern Europe. For Maize, graph is based on FAOSTAT. Maize (U.S.), no. 2, yellow, f.o.b. U.S. Gulf ports. Rice (Thailand), 5% broken, white rice (WR), milled, indicative price based on weekly surveys of export transactions, government standard, f.o.b. Bangkok. Sorghum (U.S.), No. 2 milo yellow, f.o.b. Gulf ports.

Table 6. Coefficient of Variation (CV) of Nitrogen/Crop Price Ratios

	Maize				**Rice**				Sorghum				Wheat			
Country	1995-2000	2000-2005	2005-2010	2010-2015	1995-2000	2000-2005	2005-2010	2010-2015	1995-2000	2000-2005	2005-2010	2010-2015	1995-2000	2000-2005	2005-2010	2010-2015
Ethiopia (DAP)	0.20	0.33	0.11	0.08	-	-	-	-	0.19	0.23	0.21	0.21	0.14	0.14	0.23	0.27
Ethiopia (Urea)	0.28	0.30	0.20	0.06	-	-	-	-	0.22	0.21	0.25	0.13	0.21	0.24	0.27	0.19
Ghana (NPK)	-	0.19	0.25	0.25	-	-	0.10	0.17	-	-	-	-	-		-	-
Ghana (Urea)	-	0.15	0.30	0.31	-	-	0.06	0.20	-	-	-	-	-		-	-
Kenya (DAP)	0.30	0.20	0.27	0.20	-	-	-	-	0.31	0.14	0.23	0.10	0.10	0.11	0.14	0.12
Malawi (23:21:00)	-	-	0.28	0.22	-	-	0.27	0.09			-	-	-	-	-	-
Malawi (Urea)			0.30	0.28	-	-	0.25	0.08			-	-	-	-	-	-
Nigeria (NPK)	0.53	0.25	0.35	0.03	0.52	0.28	0.20	0.06	0.54	0.34	0.35	0.06	-	-	-	-
Nigeria (Urea)		0.27	0.22	0.13	-	0.31	0.34	0.11		0.37	0.28	0.10	-	-	-	-
Tanzania (DAP)	0.22	0.20	0.42	0.23	-	0.12	0.45	0.25	0.13	0.29	0.40	-	-	0.22	0.31	0.09
Tanzania (Urea)	0.13	0.25	0.33	0.31	-	0.16	0.33	0.24	0.16	0.37	0.32	-	-	0.24	0.26	0.16
Zambia (Urea)	0.50	0.23	0.20	0.18	-	-	-	-	-	-	0.19	-	-	-	-	-
Zambia (N Compound)	0.54	0.21	0.20	0.15	-	-	-	-	-	-	0.14	-	-	-	-	-

Source: Authors calculations based on output price data from countries statistical agencies, FAOSTAT and FewsNet and fertilizer prices from various government agencies in the different countries. Maize prices in Zambia are sourced from the Zambian Central Statistical Office (CSO) while fertilizer prices are from the Ministry of Agriculture data files compiled by Jones Govereh, Nicole Mason, Bill Burke and Thom Jayne. Fertilizer and maize prices in Kenya are sourced from the Ministry of Agriculture data files, compiled by Thom Jayne, Joshua Ariga, and Ministry of Agriculture colleagues. 2005-2015 fertilizer prices in Malawi are sourced from the Fertilizer association of Malawi. Note: These are median values for the indicated range.

4.3. Fertilizer Cost Build Up

Two closely related factors that affect the incentives for fertilizer use in SSA (through the actual cost incurred by farmers to use fertilizer) are the domestic cost of fertilizer relative to the world price of fertilizer and the acquisition cost of fertilizer to smallholders which reflects the cost of fees (and other charges imposed at country borders and check points) as well as the transportation costs from border to main cities and from cities, to small towns and rural villages.

One argument for the higher nitrogen crop price ratios in the late 1980s and early 1990s was the economies of scale in fertilizer procurement not being enjoyed by most African countries. Due to small import quantities, Shepherd and Soter (1987) found that the median cost of imported fertilizer at a countries border (Cost, Insurance, and Freight-CIF) fertilizer for seven countries in Africa was about double the CIF costs in Asia. The ratio of CIF to world prices for most of the study countries is between 1.5 and 2. By the time fertilizer gets to the ports of most countries it is already one and a half times the world price. For countries such as Malawi and Zambia that are landlocked, the cost by the time it gets to Lilongwe and Lusaka from Beira, Mozambique is typically more than double the world price. The only exception is Kenya where a reasonably well developed distribution system maintains the ratio at about 1.1 (Table 7). This contrasts with present day Asia where countries including India (2016) and Thailand (2013) have CIF/World price ratios of 1.1 and 1.2 respectively or Latin America where nations such as Brazil (2015) and Mexico (2013) also have CIF/World price ratios of 1 and 1.3 respectively (Table 7).

4.4. Transportation and Inland Cost

For many smallholders in SSA, the cost to use fertilizer is typically higher than the market price due to numerous transactions costs associated with fertilizer use. The price data used in this analysis largely reflects the fertilizer prices in urban areas and large towns and is likely to be an underestimate of the actual cost faced by most rural farmers who use the product. Similarly where retail (or wholesale output prices) in key markets in the study countries are used, they are likely to overstate the price received by many rural farmers, thus understate the true nitrogen price ratios farmers face. In addition to cost such as making arrangements to identify where fertilizer is available and the need to make multiple trips before the input is secured, a key factor that affects many rural farmers is high transportation costs. In addition to high prices, Morris et al. (2007) found fertilizer use to be unprofitable in many parts of SSA because of high transportation costs. More recently, Sheahan (2012) found that transportation costs increased the cost of nitrogen for maize producers by 25-50% on average. High transportation cost have also been shown to reduce the profitability of fertilizer use in Ethiopia and Nigeria (Minten, Koru, and Stifel 2013; Liverpool-Tasie 2016).

Table 8 confirms that high transportation costs remain a challenge to fertilizer users in SSA. Inland costs, particularly transportation and handling costs (including bagging, unloading and storage) typically constitute between 30 and 50% of the final retail price of fertilizer in the study countries. The only exception is Ethiopia where inland costs are just over 10% of the final price. For other landlocked countries including Zambia and Malawi, transportation cost from the import port to the capital city adds about 25% to the price of urea fertilizer (Table 9). In Nigeria, over 30% of the difference between the wholesale price and the import price is due to transportation (Liverpool-Tasie and Takeshima 2013). These costs increase further as you move to the rural areas. The transportation cost to the rural areas further increases the price of fertilizer by another 10% and 5% in Zambia and Malawi respectively (Table 9).

Table 7. Ratio of Local Retail Price of Urea over FOB International Price of Urea for Selected African Countries

Country	1990-2000	2000-2010	2010-2015 B
Ethiopia	2.0*		2.1 (2010)*****
Ethiopia			1.4 (2012) A
Ghana			1.3 (2011) B
Malawi		1.22 C	1.5 (2011) C
Nigeria		1.19***	1.4 (2012)*****
Tanzania			1.4 (2012)*****
Kenya	1.4**	1.2****	1.1 (2011)*****
Zambia		1.22***	1.9 (2012)*****
Zambia	1.93 C	1.72 C	1.5 (2012) C

Country	Countries In Asia and Latin America (year)
1.2	Thailand (2013) D
1	Brazil (2015) E
1.3	Mexico (2013) E
1.1	India (2016) F

Source: *IFDC (1993). ** Ministry of Agriculture of Kenya. *** Gregory and Bumb (2006). **** IFDC (2005). ***** World Bank Agribusiness Indicator Reports. Sources for cells designated by 'A' Rashid et al. (2013). 'B' Bumb, Johnson, and Fuentes (2011). Kenya CIF Mombassa. Ethiopia CIF Assab (1990-2000), Cost and Freight (CFR) ex Djibouti local price due to prefixed exchange rate (2013), Zambia border price in May 2012. 'C': Crop Forecast Surveys, Central Statistical Office, Government of Zambia, and Jayne et al. (2015). 'D': Chemonics and IFDC (2007). 'E' Argus Media. 'F'. Sahu-VCCIRCLE.

Table 8. Cost Build Up Due to Transportation and Other Inland Costs

Country	Share of final fertilizer price	Inland costs (transportation and handling)	Fees/taxes as share of final price
Ethiopia (2000-2010)	-	-	-
Ethiopia (2010-2015)-2010	0.78	0.11	0
Ghana (2000-2010) -2009	0.52	0.48	0.02
Ghana (2010-2015) -2011	0.50	0.50	0
Kenya (2000-2010)	-	-	-
Kenya (2010-2015)- 2011	0.73	0.24	0.03
Malawi (2000-2010)- 2003	0.54	0.46	0
Malawi (2010-2015)- 2011/12	0.58	0.42	0
Nigeria (2000-2010)- 2003	0.49	0.47	0.04
Nigeria (2010-2015) – 2011/12	0.69	0.31	0
Tanzania (2000-2010)	-	-	-
Tanzania (2010-2015) – 2012	0.59	0.41	0
Zambia (2000-2010) – 2003	0.51	0.48	0
Zambia (2010-2015)-2010/11	0.6	0.4	0

Source: 2010 onward are from the World Bank Agribusiness Indicators reports. Zambia and Malawi are courtesy of David Mather in association with Jayne et al. 2015. Nigeria data for 2003 was obtained from Liverpool-Tasie and Takeshima (2013) based on Gregory and Bumb (2006).

Table 9. Detailed Urea Cost Build Up in Kenya, Malawi, Zambia, and Tanzania

	Zambia (2010/11)	Malawi (2011/12)	Kenya (2011/12)		Tanzania (2016)	
Durban (Zambia) Beira (Malawi) CIF Price of urea	$365	$626	$487	Mombassa CIF Price of urea	$280	CIF
Transport Durban to Lusaka/Beira to Lilongwe	$115	$147	$15	warehouse handling	$362.95	Cost per ton Ex-Dar warehouse
			$103	Transport Mombassa to Nakuru	$90.91	Transport cost to Kigoma
			$29	wholesale profit margin (6%)	$36.36	Companies margin per ton (10%)
Lusaka /Lilongwe wholesale price of urea	$480	$774	$605	Nakuru wholesale price of urea	$399.31	Price per ton Ex-Dar to agro-dealers
Share of final wholesale price due to transport	0.24	0.24	0.17		36.36	Agro-dealers margin
Wholesaler costs	-	$8			$435.68	Price to Farmers Ex-Dar es Salaam
Wholesale profit margin (7%)	$34	$124			$526.59	Price to Farmers Ex-Kigoma
Transport Lusaka to rural retail	$40	$22	$15	transport to rural retail		
Price paid by retailers for urea	$554	$928				
Increase in rural price due to local transport	0.08	0.03	0.02		0.21	
Retail costs (Zambia) /retail finance cost (Malawi)	$15	$10	$25	financing costs		
Increase in rural prices due to finance costs	0.03	0.01	0.04			
Retail profit margin (7%)	$39	$93	$36	wholesale-retail markup (6%)		
Rural retail IPP of Urea	$608	$1,030	$681	Rural retail IPP of Urea		

Source: Gathered by David Mather for Jayne et al. (2015). Rejoinder to the comment by Andrew Dorward and Ephraim Chirwa on Jayne et al. 2013. Tanzania is from Msolla (2016).

Table 10. Distance to Nearest Market (km)

Country	Distance to nearest fertilizer dealer (2010-2015)	Distance to nearest market (2010-2015) D	Distance to nearest fertilizer dealer 1990-2000)	Distance to nearest market 1990-2000)	Agro-input dealers density (Agro dealers/ 1000 farmers)
Ethiopia		42*			0.53
Ghana	70 A				0.84
Kenya	2.3 (in 2010) 4.9 (in 2014)	4.0 (in 2010) 4.9 (in 2014)	3.4 (in 2007) 8.7 (1997)	4.6 (in 2007)	0.58
Malawi		18*			
Nigeria		68*			0.28
Tanzania	4* B	67*			0.13
Zambia	13.1 (in 2004) 25.6 (in 2008)				-

Source: World Bank Agribusiness indicators reports. A Krausova and Banful (2010). B Sheahan and Barrett (2014). Data for Kenya from Tegemeo Household Surveys Various Years. Data for Zambia comes from CSO/MACO/FSRP (2004 and 2008). The reason for the jump in distance to nearest fertilizer dealer in Zambia argued by Chapoto and Jayne (2011) to be due to over a decade of government implementation of its FISP subsidy program, which undercut the market for many commercial retailers and drove them out of business. D. Authors' calculation based on LSMS ISA data. Note. * denote median distances.

Liverpool-Tasie et al. (2016) find rural transportation costs alone increase the cost of applied nitrogen for maize farmers in rural Nigeria of about 20%, on average in 2012. The most recently available data on rural farmer distance to nearest markets indicates that apart from Kenya where average distance is about 5 km, distances range between about 20% for Ethiopia to almost 70 km in Nigeria and Tanzania (Table 10).

While improving rural infrastructure is ideal, a lot can still be done at current levels of infrastructure. Programs that encourage the setup of input dealers and retail depots within communities or in smaller towns closer to farmers could go a long way. According to the World Bank agribusiness report for our study countries, the Agro-input dealers density (Agro dealers/1000 farmers) is less than 1 (see Table 10).

4.5. Yield Response

Another key parameter affecting the profitability of fertilizer use is the technical relationship between fertilizer and crop yield, that is how much additional output you get from an additional unit of a fertilizer nutrient such as nitrogen. Inorganic fertilizer is the primary source of nitrogen, a key driver of cereal growth and often the limiting factor for crop growth on small holder farms (Snapp et al. 2016). This is particularly important in SSA where yields are lowest and soil fertility decline is an ongoing and widespread problem (Stoorvogel and Smaling 1990; Montpellier Panel 2014).

We present recent evidence on the yield response to applied nitrogen in SSA from empirical studies and compare these across regions and over time. Recent evidence indicates that yield performance for experiment station plots and researcher –managed farmer trials tend to be much higher than those obtained on actual farmer fields (Vanlauwe et al. 2011; Whitbread et al. 2013; Snapp et al. 2016). Consequently we focus on evidence based on actual farmer fields not researcher managed trials or experimental stations as this is more likely to reflect the true situation for farmers in SSA.

For the most part maize yield responses across SSA are similar to or lower than those in 1990s and 2000-2010 period (Table 11). Yield responses in West and Southern Africa appear to be significantly lower than East Africa with studies in Kenya consistently reporting higher yield response rates. From the early 2000s to 2010, West Africa had rates averaging 11 (Morris et al. 2007) while studies in East/South Africa reported higher rates of 14 (Morris et al. 2007).[9] The higher average in this region might be partly attributable to Kenya where rates were as high as 17. 6 (Marenya and Barrett 2009). In fact, the rates in Kenya were almost the double of those reported in Malawi in Southern Africa. Available yield response to nitrogen post 2010 tend to be slightly lower in West Africa with Nigeria reporting rates as low as 8.9 (Liverpool-Tasie et al. 2016). Besides Kenya, countries in East and Southern have response rates similar or lower than those in Nigeria (Table 11).

Similar results obtain for sorghum with yield responses on farmer fields remaining very low and typically lower than the 1990s where different. The yield response to applied nitrogen was between 3 and 6 kg. Though limited evidence post 2010 reveals a median yield response of less than 3 kg for Nigeria (Omonona et al. 2016; Mohammed et al. 2011; Sadiq et al. 2015; Baiyegunhi, Fraser, and Adewumi 2010). This compares to rates of between 3 and 4 kg found in the 1990s (Table 12).

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[9] Note that this number from Morris et al. (2007) is based on Yanggen et al. (1998), which are mostly experimental studies.

Table 11. Trend in Maize Yield Response to Inorganic Fertilizer

1990-2000	2000-2010	2010 and after
		8.9 - Nigeria Liverpool Tasie et al. (2016)
	17.6 - Kenya Marenya and Barrett (2009	11.0-16.1 local/recycled HYV 14.1 - 19.8 purchased HYV - Kenya Matsumono and Yamano (2011)
		17.5 - Kenya Sheahan, Black, and Jayne (2013
		11 on time planting 12 late planting - Ethiopia Minten, Koru, and Stifel (2013)
		11.7 - Tanzania Pan and Christiaensen (2012)
		5.7 highlands 7.8 other areas – Tanzania Mather et al. (2016)
9.5-16.5 local - Malawi 14-18 hybrids – Malawi Wiyo and Feyen (1999	9.1 - Malawi Holden and Lunduka (2010)	5.33 monocrop 8.84 intercropped - Malawi Snapp et al. (2014)
		6.6-11.5 - Malawi Ricker-Gilbert, Jayne, and Chirwa (2011)
		9.6 traditional 12 improved – Malawi Chibwana et al. (2014)
		negative to 9 – Malawi Chirwa and Dorward (2013)
		11.94 – Malawi Darko (2016)
	16.2 - Zambia Xu et al. (2009)	9.6 - Zambia Burke (2012)

Source: Authors.

Table 12. Trend in Rice and Sorghum Yield Response to Inorganic Fertilizer

1990-2000	2000-2010	2010 and after
	31-33 – Nigeria Offodile et al. (2010) – rice	8.8- Nigeria- Liverpool-Tasie (2016) - rice
	3.7 – Nigeria Oniah, Kuye, and Idiong (2008)	27.6 – Nigeria Adedeji et al. (2014) – rice
		10.7 – Nigeria Akighir and Shabu (2011) - rice
		-0.17- Nigeria Omonona et al. (2012) – sorghum
	2.65.- Nigeria Baiyegunhi, Fraser, and Adewumi (2010)-sorghum	<2 – Nigeria Omonona et al. (2016) - sorghum
		1.83-Nigeria Mohammed et al. (2011) - sorghum
		2.49 – Nigeria Sadiq et al. (2015) - sorghum

Source: Authors.

Though generally low yield responses to applied nitrogen were found for rice post 2010, the results are mixed. In Nigeria alone, rice yields from case studies done for specific regions across the country between the early 2000s and 2010 reveal rice yield response rates ranging from 3.7 (Oniah, Kuye, and Idiong (2008)) to 33 (Offodile et al. (2010)). A recent study based on nationally representative data post 2010 found a low rate of 8.8 (Liverpool-Tasie et al. (2016)). This compares to negative values found by Omonona, Lawal, and Oyebiyi (2012) and a high rate of 27.6 for rice farmers in Kwara State in North Central Nigeria found by Adedeji et al. (2014).

Based on these recent empirical evidence from several countries, it appears that there is significant scope to expand the profitability of nitrogen application through increasing the yield response of applied nitrogen. With such low yield responses, it is likely not going to be enough to just increase the quantity of fertilizer used by smallholders. Attention needs to be given to factors that could increase the efficiency with which applied nitrogen is used by crops.

This includes paying attention to soil characteristics and organic matter content as well as to ways of improving farm management practices such as the timing of fertilizer application, weeding and pest control, crop rotation and intercropping.

4.5.1. Soil Quality

Two key soil fertility constraints in many regions of SSA are low reserves of inherent nutrients and soil acidification due to continuous cultivation (Jones and Wild 1975). Soil organic matter helps to hold on to nutrients later released to crops when needed that would otherwise be lost through leaching and runoff. With poor soil organic matter, the efficiency of inorganic fertilizers is typically low. Similarly, the soil pH (potential Hydrogen) level is also important for the efficient absorption of nutrients from inorganic fertilizers. Merely applying inorganic fertilizer can result in fertilizer wastage of up to 70% for extremely acidic soils with pH level of 4.5 or below (The Mosaic 2013).

4.5.2. Management Practices

Increasing farmer access to and use of good quality complementary inputs such as irrigation facilities, good quality seed, and other more efficient methods of fertilizer use or crop management are also important. Despite the potential benefit from using complementary inputs, there is typically limited use of complementary inputs on the same plot by small-holders in SSA (Sheahan and Barrett 2014). Table 13 supports this with recent data from nationally representative household surveys in the study countries. Very few farmers are using complementary inputs together such as irrigation, improved seed, and inorganic fertilizer. This is less than 1% in Nigeria and Ethiopia, slightly above 1% in Tanzania, and about 3% in Kenya. These low statistics seem to be largely due to the low use of irrigation in these countries. About 40% of Ethiopian farmers and close to 30% of their Kenyan counterparts use improved seeds and inorganic fertilizer together versus less than 10% for Nigeria and Tanzania. Apart from Ethiopia and Kenya where over 65% of farmers apply organic manure, fewer than 25% of farmers tend to use organic manure. The use of manure in conjunction with inorganic fertilizer is even lower. Less than 5% of farmers in Nigeria, and Ghana, and about 5% in Tanzania use both. Kenya is an exception where about 25% of farmers report using both manure and inorganic fertilizer. When asked if they had received advice on new seed, pest control fertilizer use, or compositing, less than 10% of smallholders in Nigeria and Tanzania responded affirmatively. Though better than Nigeria and Tanzania, extension service access in Malawi is 18%, lower than Ethiopia and Kenya whose extension services reach over 20% of smallholders.

Table 13. Management Practices

Country	Percent of farmers visited by extension agent	Percent of farmers using improved seed and fertilizer together	Percent of farmers using complementary inputs (improved seed, fertilizer and irrigation)	Percent of farmers applying organic manure	Percent of farmers applying inorganic fertilizer	Percent of farmers applying both organic and inorganic fertilizer
Ethiopia	27.5	38.2	0.009	66.4*	55.5*	25.5
Ghana	NA	NA	NA	1.8**	33**	<2**
Kenya	20.9	28.3	2.9	70.6	69.5	47.6
Malawi	17.5	24.9	0.3	17.6*	77.3*	12.1
Nigeria	7.7	6.0	0.3	3.4*	41.4*	2.6
Tanzania	8.0	8.6	1.15	20.3*	16.9*	5.1
Zambia						

Source: For statistics with asterisk*, Sheahan and Barrett (2014), **Jayne et al. (2015) All other statistics are based on authors' calculations based on most recent waves of publicly available LSMS ISA data and Tegemeo (2014). Note: For Nigeria, agricultural advice is defined as farmer received advice on new seed, pest control, fertilizer use, or composting (manure).

For crop management, Snapp et al. (2014) found plots with intercropped maize had a higher yield response to applied nitrogen compared to mono-cropped plots. Furthermore, where distinctions are made between local varieties and improved varieties, yield responses are higher for improved varieties (Wiyo and Feyen 1999; Chibwana et al. 2014). Other studies find improvements in yield response from early planting compared to late planting for maize (Minten, Koru, and Stifel 2013), from multiple weeding (Kamanga et al. 2014) or plot location in favor of highlands compared to other areas (Mather et al. 2016).

These indicate that there is ample room for improving the yield response from applied nitrogen for major cereals that needs to be studied more and which need to feature more in the debate on fertilizer use in SSA. Another issue that we do not discuss but is worthy of attention is fertilizer quality. While hard to confirm without detailed information on the actual composition of applied inorganic fertilizer, poor fertilizer quality is another potential explanation for the low yield response and profitability of applied inorganic fertilizer.

5. CONCLUSIONS

This paper provides a comprehensive assessment of the more recent trends in incentives to use fertilizer for farmers in SSA. Specifically we examine the trends in nitrogen/crop price ratios for key cereals in SSA, their fluctuations over time, and the agronomic crop response rates to applied fertilizer. We also explore the role that various factors affecting the actual cost of fertilizer for smallholder farmers in SSA have played in influencing farmers' incentives to use fertilizer over the past decade.

We do not find evidence of improved incentives for fertilizer use in SSA. Rather, we find that nitrogen cereal crop ratios remain high and have actually increased for most cereals compared to their levels in the 1990s. In addition to the general rise in fertilizer prices, there has also been an increase in the variability of these fertilizer/cereal price ratios, particularly for maize. Though input taxes tend to have declined in most countries, in-country transportation and handling costs continue to contribute significantly to the higher prices that smallholders pay for fertilizer. We find consistent evidence that the agronomic yield response to applied fertilizer in SSA is low on farmer fields for maize, rice, and sorghum (compared to researcher-managed trials), often lower than response rates observed by studies in the 1990s. At current nitrogen-crop price ratios, and with increasing variability in recent years coupled with no improvement in yield response rates to nitrogen over time, it is no surprise that fertilizer use rates for the Sub-Saharan Africa region remain low in absolute terms and significantly lower than in other regions of the world. There are of course specific pockets where smallholders obtain relatively high fertilizer response rates, where fertilizer use is generally profitable on cereal crops, and where demand for fertilizer is high, such as parts of western Kenya, Ethiopia, and northern Tanzania, to name a few (Jayne et al. 2016). There are also countries where household data shows high fertilizer use rates alongside low yield responses such as Nigeria and Malawi (Liverpool-Tasie et al. 2016; Snapp et al. 2014).

However, in general, the incentives for farmers to use fertilizers at full commercial cost is not improving over time. Furthermore, given current yield response rates, simply increasing the quantity of fertilizers used by farmers will not be enough to achieve the desired productivity gains necessary to achieve and maintain food security in the region. Generally, a more holistic approach that addresses the constraints to fertilizer profitability (fertilizer costs as well as factors that will increase the efficiency of fertilizer use) is necessary for any sustainable intensification effort (Jayne and Rashid 2013). Government investments in transport infrastructure, programs that reduce the distance farmers have to go to access inputs and advice, and consistent policies regarding input promotion programs will likely contribute to lower commercial fertilizer prices for African farmers. Furthermore, programs to help farmers improve the quality of their soils through integrated soil fertility management practices may help farmers achieve higher agronomic crop response rates to fertilizer application and, thereby, raise the profitability of using fertilizer (Vanlauwe et al. 2011). Local production of fertilizer does not appear to be a viable economic option for most countries because current levels of demand are too low for economies of scale to be realized (ACBIO 2014). If neighboring countries worked to develop regional fertilizer markets, the benefits of local production relative to the costs might become more favorable. Various approaches to reducing farm level risk can also reduce costs and increase demand. Options range from simply selling inputs in smaller quantities to the introduction of weather insurance schemes now being tested on a limited scale.

APPENDIX

Table A1. Trend in Maize Yield Response to Inorganic Fertilizer

1990-2000	2000-2010	2010 and after
15* - W. Africa (Yanggen et al. 1998)	11* - W. Africa Morris et al. (2007)	8.9 - Nigeria Liverpool Tasie et al. (2016)
4-22* - Nigeria Uyovbisere, E. O., and Lombim, G. (1991)	19* - Togo Wopereis et al. (2006)	
7-32* - Cameroon Lele, Christiansen, and Kadiresan (1989)		
10-20* - W. Africa Shalit, H., and Binswanger, H. P. (1985)		
0-35* - Ghana Edmeades et al. (1991)		
17* - East and Southern Africa (Yanggen et al. 1998)	14* E/S Africa Morris et al(2007)	
	17.6 - Kenya Marenya and Barrett (2009	11.0-16.1 local/recycled HYV 14.1 - 19.8 purchased HYV - Kenya Matsumono and Yamano (2011)
		17.5 - Kenya Sheahan, Black, and Jayne (2013)
		11 on time planting 12 late planting - Ethiopia Minten, Koru, and Stifel (2013)
		11.7 - Tanzania Pan and Christiaensen (2012)
		5.7 highlands 7.8 other areas – Tanzania Mather et al. (2016)
		13* Short rainy season (September-December) 39* Long rainy season (March-July) - Kenya Ngome et al. (2013)
9.5-16.5 local - Malawi 14-18 hybrids – Malawi Wiyo and Feyen (1999)	9.1 - Malawi Holden and Lunduka (2010)	5.33 monocrop 8.84 intercropped - Malawi Snapp et al. (2014)
8-38* local - Malawi 8-52* hybrid - Malawi Heisey and Mwangi. (1997)		6.6-11.5 - Malawi Ricker-Gilbert, Jayne, and Chirwa (2011)
9.5-16* local - Malawi and Zambia 17-19* improved - Malawi and Zambia Jones and Wendt (1995)		9.6 traditional 12 improved – Malawi Chibwana et al. (2014)

Table A1. cont.

1990-2000	2000-2010	2010 and after
15-20* local - Malawi 17.4-25* improved - Malawi Kumwenda et al. (1996)		negative to 9 – Malawi Chirwa and Dorward (2013)
		11.94 – Malawi Darko (2016)
		19.3* One weeding 38.7* Two weeding - Malawi Kamanga et al. (2014)
		15* Local 50* hybrid – Malawi and Zimbabwe Whitbread et al. (2013)
		23* local 25* hybrid - Malawi Harou et al. 2014
11* local - Zambia 18* hybrid - Zambia Jha, D., and Hojjati, B. (1993).	16.2 - Zambia Xu et al. (2009)	9.6 - Zambia Burke (2012)
6-26* - Zimbabwe Mataruka, Makombe, and Low (1990)	17* local - Sub Saharan Africa 26* hybrid - Sub Saharan Africa Vanlauwe et al. (2011)	

Source: Authors. *indicates yield responses from experimental trials.

Table A2. Trend in Rice and Sorghum Yield Response to Inorganic Fertilizer

1990-2000	2000-2010	2010 and after
12* – West Africa (Yanggen et al. 1998) – rice	31-33 – Nigeria Offodile et al. (2010) – rice	8.8 – Nigeria Liverpool-Tasie (2016) – rice
11* – Burkina (Donovan et al. 1999) – rice	3.7 – Nigeria Oniah, Kuye, and Idiong (2008)	27.6 – Nigeria Adedeji et al. (2014) – rice
12-39* – Cameroon Lele, Christiansen, Kadiresan (1989) – rice		10.7 – Nigeria Akighir and Shabu (2011) – rice
12* – Mali (Donovan et al. 1999) – rice		
9-16* – Senegal (Donovan et al. 1999) – rice	6.5-24.2* – Nigeria Ezui et al. (2010) rice	
7* – Burkina (Nagy, Ohm, and Sawadogo 1990) – sorghum	<4-12* – Ivory Coast Toure et al. (2009) –rice	4.6* – Benin Worou et al. (2013) – rice
13* – Niger (Bationo et al. 1994) – sorghum	6.8-10* – West Africa Becker, Wopereis, and Johnson (2001) – rice	6.6* – Ethiopia Habtegebrial, Mersha, and Habtu (2013) – rice
3-8* improved practices – Nigeria 4-9* local practices Lele, Christiansen, Kadiresan (1989) – sorghum	11* – SSA Morris et al(2007) – rice	
3.9* – Cameroon Lele, Christiansen, Kadiresan (1989) – sorghum	6.96-7.39*– Ghana Moro, Nuhu, and Toshiyuki (2008) – rice	-0.17– Nigeria Omonona, Lawal, and Oyebiyi (2012) – sorghum
4-6* – Senegal Lele, Christiansen, Kadiresan (1989) – sorghum	2.65.– Nigeria Baiyegunhi, Fraser, and Adewumi (2010) –sorghum	<2 – Nigeria Omonona et al. (2016) – sorghum
6* – Ethiopia (Mulat et al. 1997) – sorghum		1.83–Nigeria Mohammed et al. (2011) – sorghum
4-21* – Kenya Lele, Christiansen, Kadiresan (1989) – sorghum		2.49 – Nigeria Sadiq et al. (2015) – sorghum
10-13* – Tanzania Lele, Christiansen, Kadiresan (1989) – sorghum		

Source: Authors. *Indicates yield responses from experimental trials.

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