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Fertilizer and sustainable intensification in Sub-Saharan Africa

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ABSTRACT

The paper investigates the important role of fertilizer to enhance sustainable intensification and food security in Sub-Saharan Africa (SSA) based on a multi-disciplinary literature review. The review starts with a macro-perspective taking population growth, economic development and climate change into account. This is complemented with a micro-perspective summarizing findings from comprehensive micro-data in selected African countries. Agronomic, environmental and economic profitability implications of fertilizer use are reviewed. The poor but efficient hypothesis is assessed in light of recent evidence in behavioral economics. Is low fertilizer use due to hard constraints farmers face or partly due to irrational behavior, and what are the policy implications? Two policy approaches, input subsidy and productive safety net programs, are reviewed and their potential roles to enhance sustainable intensification and nutrient use efficiency in SSA agriculture are discussed before I conclude.

1. Introduction

Africa was for decades the least developed continent where economic growth barely kept up with population growth. Agriculture was the dominant sector in most African countries and smallholder farming the main source of livelihood for the large rural majority. Agricultural production expanded through area expansion and yields were stagnant except for some pockets. The Green Revolution that was successful in Asia failed in Africa and adoption rates for improved varieties and fertilizer were low. As late as in Crawford et al. (2006), in their review for the World Bank, reported average fertilizer rates as low as 9 kg/ha in Sub-Saharan Africa, while disappearing fallows, high levels of deforestation, land degradation and nutrient depletion indicated non-sustainable land use. Eight years later, Sheahan and Barrett (2014, 2017) review the most recent Living Standard Measurement Survey data from six African countries, which revealed an extremely heterogeneous pattern of fertilizer use in these six countries. Economic growth has also picked up in many African countries and an economic transformation has started. Further production increase through area expansion is no longer feasible in an increasing number of countries, making land use intensification necessary to meet future food needs of a growing population (Chamberlin et al., 2014). The need to halt deforestation to reduce carbon emissions also creates pressures to stop agricultural expansion into woodlands and forested areas. Tilman et al. (2011) estimate that area expansion is associated with three times as high greenhouse gas emissions as area intensification to achieve the same production increase. Africa is the continent with the lowest cereal yields and lowest production intensity and where the population will increase the most (Mueller et al., 2012; Ray et al., 2013).

The overall objective of this paper is to provide an integrated macro-micro-environment review of the role of inorganic fertilizer in the process of transforming the agricultural sector in Sub-Saharan Africa (SSA) to meet future food security while facilitating sustainable intensification and minimizing environmental damages. More specifically, the paper aims to

a) Review micro data on fertilizer use and intensity of use in selected SSA countries.
b) Review important agronomic and environmental concerns and implications of heterogeneity in profitability and incentives to use fertilizer by farmers.
c) Assess whether the rational small farmer paradigm ('poor but efficient') is adequate to understand their behavior or needs to be complemented with other models which have different policy implications based on recent lessons from behavioral development economics.
d) Assess alternative controversial and potentially important policies used to promote sustainable intensification and food security in SSA.

2. Macro versus micro evidence on fertilizer use in SSA

Nitrogen is the most important nutrient that can enhance crop yields. Zhang et al. (2015) assess the central role of nitrogen (N) to facilitate sustainable intensification. While higher N use is necessary, it

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Table 1
Average inorganic fertilizer use per ha in selected SSA countries, total nutrients.
Sources: Reproduced from Sheahan and Barrett (2017, p. 15) based on LSMS-ISA data.

	% of cultiv. househ. using	Use (kg/ha) across all households		Use (kg/ha) across only fertilizer using households				
		Mean total, all households	Mean nutr.	Mean total	Mean N	Mean P	Mean K	Mean nutr.
Ethiopia	55.5	45	25.2	81	23	22.5	–	45.5
Malawi	77.3	146	56.3	188.8	53.1	19.4	0.4	72.8
Niger	17	4.5	1.7	26.3	7.6	2.6	–	10.3
Nigeria	41.4	128.2	64.3	310.1	93.9	30.8	30.8	155.5
Tanzania	16.9	16.2	7.7	95.6	32	7	6.6	45.6
Uganda	3.2	1.2	0.7	37.5	11.5	8.3	1	20.7
Average	35.2	56.9	26	123.2	36.9	15.1	9.7	58.4

is also problematic unless nitrogen-use efficiency (NUE), calculated as the rate between harvested N and input N in agricultural production, can be enhanced. Using data from 1961 to 2011 for 113 countries they find a pattern similar to the environmental Kuznets curve (EKC) where N pollution first increases and then decreases with economic growth in Western developed countries. They estimate the global NUE ratio to be 0.42 in 2010. Emerging economies such as China and India have not yet reached the EKC turning point as NUE is particularly low in China (0.25) and India (0.30) while it is much better in SSA (0.72) where N use is still low. Large parts of SSA still face an undersupply of N that prevents sustainable intensification. However, SSA has a strong need to increase yields to minimize area expansion and this should be achieved while retaining a relatively high NUE.

Micro data from Living Standard Measurement Survey (LSMS-ISA) data, compiled by Sheahan and Barrett (2014, 2017), are presented in Table 1. The LSMS-ISA data cover 22,000 households in the six countries. The Table shows average fertilizer nutrient rates per ha of cultivated land for cultivating households in these countries.

The data reveal that there are large cross-country variations and that incidence of use and nutrient use levels are quite high in some countries (Malawi, Nigeria, Ethiopia). Sheahan and Barrett (2014, 2017) also notice large within-country heterogeneity, especially in large countries like Ethiopia and Nigeria. Maize is the crop attracting most inputs, even more than cash crops. The data also reveal an inverse relationship between fertilizer use intensity and plot size as well as farm size. The inverse plot size-input use intensity relationship may partly be due to plot size measurement error but such measurement error should be fairly small in the LSMS data where plot sizes were measured with GPS (Carletto et al., 2013). The LSMS-ISA data also show that credit does not play an important role as a source of funding for accessing inputs, except in Ethiopia among these six countries. Less than one percent of the farm households used credit to obtain inputs. Sheahan and Barrett found that national-level factors explained nearly half of the variation in inorganic fertilizer use demonstrating the critical importance of national-level policies and institutions to facilitate sustainable intensification.

It is challenging to identify policies that can cost-effectively stimulate sustainable intensification and discourage area expansion while ensuring food security and poverty reduction. This requires a fundamental understanding of the decision environment of smallholder farm households that represent the large majority of land users in SSA. This requires a deep understanding of the production systems embedded in local agro-ecologies as well as market and institutional characteristics. This includes an understanding of what drives production, investment and consumption decisions of these land users.

3. An agronomic perspective and economic profitability

An agronomic understanding is important for assessing the potential for sustainable intensification of agriculture. Integrated Soil Fertility Management (ISFM) is an approach designed to obtain such an understanding and is defined as "a set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs and improved germplasm, combined with the knowledge of how to adapt these practices to local conditions, aimed at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity. All inputs need to be managed following sound agronomic principles" (Vanlauwe et al., 2010, 2015).

Conservation Agriculture (CA) is an another related approach to sustainable intensification that includes the three principles crop rotation/intercropping, permanent soil coverage, and minimum soil disturbance (Giller et al., 2009). CA can contribute to raise SOM and has been promoted in several SSA countries (Giller et al., 2015). CA has been seen as a solution to many of the problems in smallholder agriculture in SSA and its dissemination has received a lot of support from donors (Hobbs et al., 2008; Giller et al., 2009, 2015). While high adoption rates have been achieved in South-America and Australia in large scale mechanized agriculture, adoption rates have been disappointing among small-holders in SSA (Arslan et al., 2015; Giller et al., 2009, 2015), and this may be related to low short-term returns and high initial labor or cash costs to control weeds manually or by herbicides. Vanlauwe et al. (2014) argue that CA must be accompanied with a fourth principle in SSA, adequate use of inorganic fertilizers, to raise the production of organic matter and crop yields, as the amount of available organic matter otherwise will be too low for CA to function well.

An ISFM approach integrating fertilizer application with organic manure utilization and soil and water conservation may be a better approach to "tunnel through" the EKC and retain a high NUE (Zhang et al., 2015).

Large local heterogeneity in soils quality and nutrient content makes it more costly and difficult to fine-tune fertilizer supply and recommendations to local soil variation. Several studies have revealed that such heterogeneity may be large. E.g. Marenya and Barrett (2009) found that land degradation and poor soil quality are associated with low soil organic matter (SOM) content and this commonly limits the yield response to mineral fertilizer application. In their study in Western Kenya they found that about one-third of the plots in their survey had degraded soils that limited the marginal productivity of fertilizer use such that it became unprofitable at prevailing prices. The fact that poorer farmers are more likely to have such degraded plots can make it harder to stimulate fertilizer adoption without a complementary SOM package that is needed to enhance fertilizer use efficiency. A recent study be Bhargava et al. in Tanzania combines farm plot level LSMS-ISA data with biophysical remote sensing data on soil organic matter content from Africa Soil Information Service (AfSIS) and Land Degradation Surveillance Framework (LDSF). The study finds a strong positive correlation between soil carbon content and agricultural profitability. Fertilizer plays a limited role as it is used only on a small share of the land.

Suri (2011) used survey data from 1996 to 2004 in Kenya to study the marginal returns to improved maize and fertilizer technology adoption. She finds substantial heterogeneity in the returns. A small