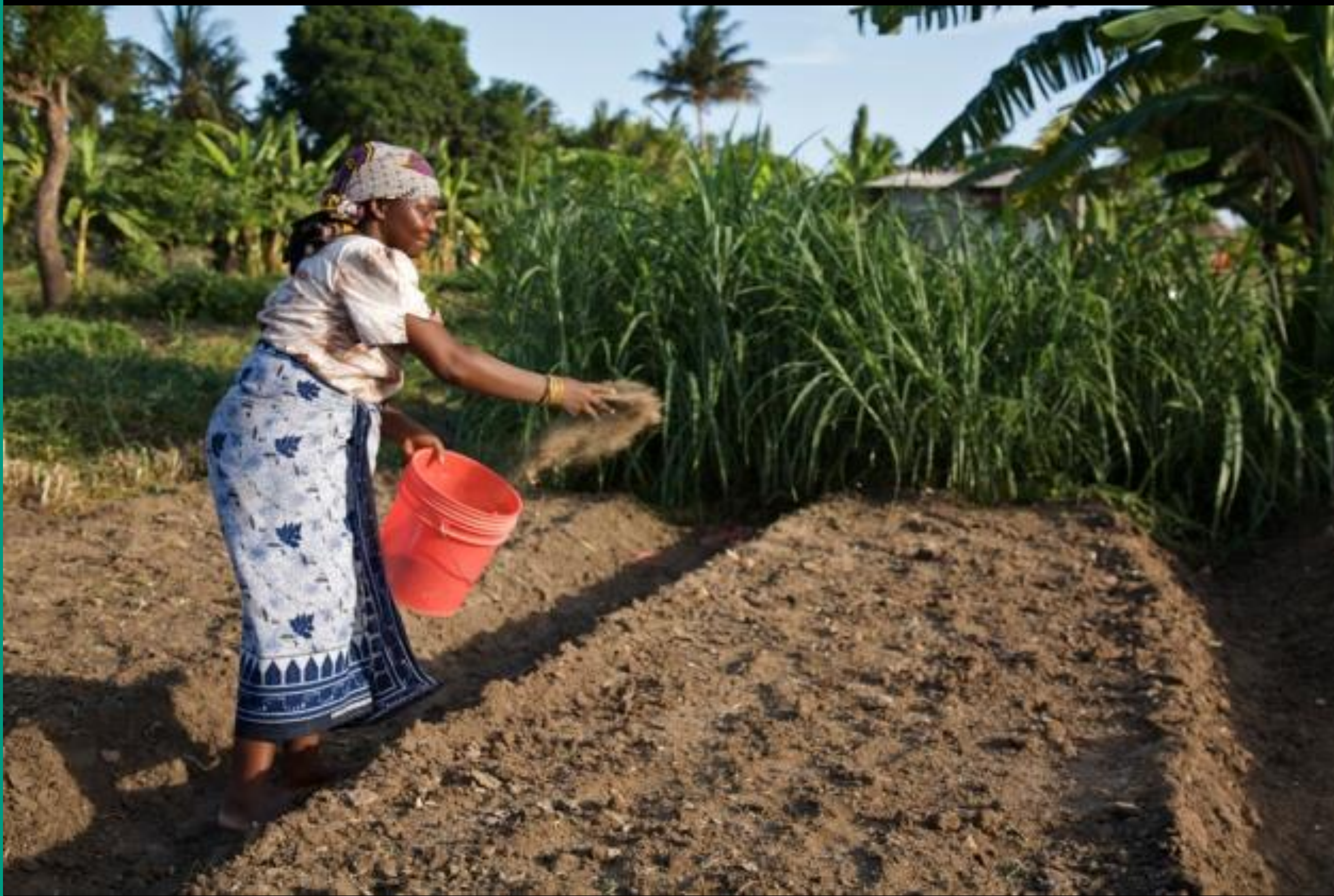
Norwegian University of Life Sciences (NMBU)

Fertilizer and Sustainable Intensification in Africa

Stein T. Holden



Norwegian University of Life Sciences
Centre for Land Tenure Studies

Centre for Land Tenure Studies Working Paper 1/18
ISBN: 978-82-7490-265-7

Fertilizer and Sustainable Intensification in Africa[1]

By Stein T. Holden

School of Economics and Business/
Centre for Land Tenure Studies,
Norwegian University of Life Sciences
P. O. Box 5003, 1432 Ås, Norway
Email: stein.holden@nmbu.no

Abstract

The paper investigates the important role of fertilizer to enhance sustainable intensification and food security in Sub-Saharan Africa 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. An assessment is made whether small farmers in Africa should be considered rational or partly irrational agricultural decision-makers and whether this can affect fertilizer use. I then discuss some controversial and promising policy approaches that may have the potential to enhance sustainable intensification and nutrient use efficiency in African agriculture before I conclude.

Key words: Sub-Saharan Africa, fertilizer, sustainable intensification, food security, policy.

JEL codes: Q18; Q12; Q56.

[1] Valuable suggestions and comments have been received from Derek Byerlee. The usual disclaimers apply.

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 2006 Crawford et al., 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) review the most recent Living Standard Measurement Survey data from six African countries and reveal an extremely heterogeneous pattern of fertilizer use in these six countries. Economic growth has also picked up in many African countries and a rapid 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. The need to halt deforestation to reduce carbon emissions also creates pressures to stop agricultural expansion into woodlands and forested areas. Integrated Soil Fertility Management (ISFM) will have to be a key in the transformation towards sustainable intensification of agricultural practices.

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,

a) Assess past, present and future needed changes in fertilizer use in SSA, and its implications for the sustainability of land use and food security, given population changes and climate change
b) Review micro data on fertilizer use and intensity of use in selected SSA countries
c) Review important agronomic and environmental concerns and implications for heterogeneity in profitability and incentives to use fertilizer by farmers
d) Assess whether the rational small farmer paradigm ("poor but efficient") is adequate or needs to be complemented with new policy components based on lessons from behavioral development economics
e) Assess alternative controversial and potentially important policies used to promote sustainable intensification and food security in SSA.

2. The big picture: Facts and figures

Tilman et al. (2011) predict global food demand to double between 2005 and 2050 due to population growth and changes in the diet associated with economic development. This growing demand also puts more pressure on the environment in terms of a need to intensify agricultural production and/or expand production into new areas. Both types of expansion lead to higher emissions of greenhouse gasses (GHG). Tilman et al. (2011) estimate that area expansion is associated with three times as high GHG emissions as area intensification to achieve the same production increase. The most environmentally friendly way to increase global food production is therefore through intensification of production in areas where intensity is still low.

Africa is the continent with highest yield gaps and lowest production intensity and where the population will increase the most (Mueller et al. 2012; Ray et al. 2013). Mueller et al. (2012) argue that Eastern Europe and SSA show considerable "low-hanging" intensification opportunities for major cereals from a yield gap perspective. They find that yields of maize in West Africa in particular are limited by nutrient access what water and nutrient access jointly limit maize yields in East Africa. Overall, they think that closing the maize yield gap to 50% (2.5t/ha) in SSA primarily requires addressing nutrient deficiencies while reaching to 75% of the yield gap (3.6t/ha) would require substantial expansion of irrigation and further nutrient applications.

Zhang et al. (2015) assess the central role of nitrogen (N) to facilitate sustainable intensification. While higher N use is necessary it is also problematic unless nitrogen-use efficiency[2] (NUE) can be enhanced. Using data from 1961-2011 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 rate 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 Sub-Saharan Africa (0.72) where N use is still low. Large parts of Africa still face an undersupply of N that prevents sustainable intensification. Pollution due to excessive N use is primarily a problem in other continents. However, Africa has a strong need to increase yields to minimize area expansion and this should be achieved while retaining a relatively high NUE.

3. Micro evidence on fertilizer use in SSA

Macro data on fertilizer use in selected SSA countries, based on FAO and World Bank World Development Indicators are contrasted with micro data from Living Standard Measurement Survey (LSMS-ISA) data, compiled by Sheahan and Barrett (2014), presented in Table 1. The LSMS-ISA

[2] Nitrogen-use efficiency (NUE) is calculated as the rate between harvested N and input N in agricultural production.

data covers 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.

Table 1. Average fertilizer use per ha in selected SSA countries, total nutrients

Country	FAOSTAT (2010 data)				LSMS-ISA (2010-2012 data)							
	Use (kg/ha)				% of cultiv. househ. using	Use (kg/ha) across all households			Use (kg/ha) across only fertilizer using households			
	Mean N	Mean P	Mean K	Mean nutr.		Mean total	Mean nutr.	Mean total	Mean N	Mean P	Mean K	Mean nutr.
Ethiopia	10.4	10.8	0	21.2	55.5	45	25.2	81	23	22.5	–	45.5
Malawi	23.1	4.5	4.3	31.9	77.3	146	56.3	188.8	53.1	19.4	0.4	72.8
Niger	0.3	0.1	0.1	0.5	17	4.5	1.7	26.3	7.6	2.6	–	10.3
Nigeria	2	0.3	0.3	2.6	41.4	128.2	64.3	310.1	93.9	30.8	30.8	155.5
Tanzania	4.4	0.6	0.7	5.7	16.9	16.2	7.7	95.6	32	7	6.6	45.6
Uganda	0.7	0.3	0.3	1.3	3.2	1.2	0.7	37.5	11.5	8.3	1	20.7
Average	6.8	2.8	1	10.5	35.2	56.9	26	123.2	36.9	15.1	9.7	58.4

Sources: Compiled by Sheahan and Barrett (2017) based on FAOSTAT and LSMS-ISA data

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). There is a striking difference between the FAO data and the LSMS-ISA data in the case of Nigeria. Sheahan and Barrett (2014) 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 within-farm inverse relationship is still poorly understood. 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. In the next section I will review some agronomic perspectives related to promoting sustainable intensification in Africa.

4. An agronomic perspective and economic profitability

Land degradation has been found to be a widespread phenomenon in Africa (Stoorvogel and Smaling 1990; Tilahun et al. 2016). Lesschen et al. (2007) have refined the methodology of Stoorvogel and Smaling (1990) for assessment of nutrient balances and apply it to a case study in Burkina Faso. They find that especially food crops such as maize, sorghum and millet have a strongly negative soil nutrient balance. There is therefore a substantial risk that nutrient mining will undermine long-term land productivity in cereal-based system.

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 is an area where “the devil is in the details” and 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.

An agronomic understanding is important for assessing the potential for sustainable intensification of agriculture. Integrated Soil Fertility Management (ISFM) is and approach designed to obtain such an understanding (Vanlauwe et al. 2011). Vanlauwe et al. (2011) define ISFM to contain the following essential components: proper fertilizer management, use of improved varieties, the combined application of organic inputs and fertilizer, and adaptation of input application rates to within-farm soil fertility gradients where these are important.

An important basic question is whether it is realistic to think of applying precision agriculture to enhance NUE in smallholder agriculture in SSA? This will require a combination of research and extension efforts. Better mapping of soils and production systems may help to more precisely identify local fertilizer needs both in terms of composition of nutrients in fertilizers and the dosage and timing of application. It is then about the strategic planning and programming of the production and dissemination in a cost-effective way. Public-private partnerships will be required for such a strategy to work.

Ethiopia has recently embarked on a strategy to make detailed soil maps and based on this identify more appropriate fertilizer blends by district taking into account important nutrients such as N, P, K, S, Zn, B and Fe (ATA 2014). Ethiopia tries as part of its agricultural transformation agenda to develop the supply chain to provide more appropriate fertilizers based on local needs assessment. It remains to be seen how successful they will be in enhancing fertilizer use efficiency and stimulating sustainable intensification.

Large local heterogeneity in soils quality and nutrient content makes it more costly 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.

Conservation Agriculture (CA) is an approach to sustainable intensification that includes the three principles crop rotation/intercropping, permanent soil coverage, and minimum soil disturbance. CA can contribute to raise SOM and has been promoted in several SSA countries (FAO 2015). Adoption rates have been disappointing and this may be related to low short-term returns (Arslan et al. 2015; Fisher et al. 2017a;b). 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, a strategy proposed by Zhang et al. (2015). I will discuss policies that could facilitate this in part 6 after a broader assessment of recent policy approaches and behavioral studies.

Suri (2014) uses survey data from 1996-2004 in Kenya to study the marginal returns to improved maize and fertilizer technology adoption. She finds substantial heterogeneity in the returns. A small share of the survey sample farmers have not adopted the technology even though returns are very high and this appeared to be due to supply constraints and poor infrastructure. A larger share of the sample had lower but positive returns but had adopted. A third group had about zero returns and switched in and out of the technology. Her findings therefore appear to contradict the findings of Duflo et al. (2011) in Kenya that farmers underinvest because they are irrational and manage their income in a time-inconsistent way.

5. Poor but efficient, too poor to be efficient, or predictably irrational?

Schultz (1964) argued that small farmers are poor because of resource and market constraints and not because of their own in-efficiency. The “poor but efficient” view of small farmers has later been the dominant paradigm in development economics. The idea about “poverty traps” has more recently gained popularity (Sachs et al 2004; Carter and Barrett 2006) and has been an important basis for expanding development aid and support to agriculture in SSA, including support to input subsidies. Others have criticized the idea that poverty is a trap, such as Collier (2008) who suggests that four other traps bring a more diverse understanding of the factors constraining development in Africa; the conflict trap, the natural resource trap, the landlocked with bad neighbors trap, and the bad policy trap. He classifies one billion people to live in countries that belong to these traps and 70% of these people live in Africa.

A poverty-population-environment trap is another narrative that builds on Malthus (1798) and is combined with studies on natural resource management and degradation. This narrative brings us closer to the role of soil nutrients, nutrient mining, soil degradation and incentives for conservation and fertilizer use that are central issues here (Stoorvogel and Smaling 1990; Shiferaw and Holden 1998; Holden et al. 2005a; Barbier 2010; Tilahun et al. 2016). A more optimistic narrative is that of Boserup (1965) who argued that population growth would lead to economic development through investments in infrastructure, technology development, human capital development and this could also lead to more investment in conservation and reduced degradation. The stronger economic growth we have seen in SSA in the new millennium may point towards a Boserupian path but climate change and environmental degradation represent serious threats.

A fundamental question is how rational smallholder farmers in Africa are? Is there a need to question the poor but efficient hypothesis? Research in behavioural economics since the 1970s seems to indicate that people in many situations do not behave according the mainstream economic theory such as Expected Utility theory. And they do not follow the standard discounted utility model with a constant discount rate derived from the market rate of interest. Much of behavioural economics research has used university students in the Western countries and there are reasons to question therefore whether these findings are valid in developing country settings (Henrich et al. 2010). Perhaps poor people are more rational because they cannot afford to be as irrational as rich people? However, there is also the possibility that poverty forces people to become more myopic and less able to invest as the concern for short-term needs is given precedence over long-term investments? There is evidence that poverty is associated with high discount rates and that the causality goes from poverty and to high discount rates (Holden et al. 1998). Poverty has also been found to be associated with soil mining and less investment in conservation as returns to such investments are delayed (Shiferaw and Holden 1998). Hyperbolic and quasi-hyperbolic models of behaviour in intertemporal choice have been found to robustly predict inter-temporal decisions over varying time horizons and such behavior may lead to under-investment also among smallholder farmers and lead to severe environmental degradation unless interventions are introduced to enhance investment incentives. Liquidity and credit constraints may lead to similar effects. However, it is not obvious what the optimal intervention design is to internalize this type of externality and whether the benefit of the intervention would be higher than the cost (a necessary requirement to call these forms of externality market failures). It is possible that smart policy designs can help overcome some of these problems but such designs may have to be very context-specific and targeted which is challenging.

Duflo et al. (2011) proposed to use nudging to stimulate fertilizer use by farmers based on experimental evidence from Kenya. Based on their finding that farmers underinvested in fertilizer even though fertilizer use was highly profitable, they designed an experiment where fertilizer was offered at harvest time rather than at planting time and found that this may be a low-cost approach to enhancing fertilizer use and better than offering subsidized fertilizer at planting time. Farmers appeared to be unable to hold on to cash from harvest time when they sold their crops and until planting time when they usually bought their inputs. A simple nudge intervention could therefore represent a win-win solution that would enhance input use without high subsidy costs. However, their findings are partly contradicted by the findings of Marenya and Barrett (2009) and Suri (2014) who found low marginal returns to fertilizer and limited profitability to be a major constraint for a large share of their samples based on data from the same country. There may be a need to complement use of inorganic fertilizer with organic manure and good agricultural practices to increase the marginal returns to fertilizer. Simple "blueprint" approaches may fail.

Holden and Lunduka (2013b) investigated the potential of this approach of offering inputs at harvesting time rather than at planting time with a framed field experiment in Malawi. They found the potential of the approach to be less encouraging there as output prices were found to be very low at harvest time and to have almost doubled by planting time. Selling maize at harvest time to buy fertilizer then would give them much less fertilizer than if they waited with selling their maize until planting time. Fertilizer prices do not show similar seasonal price fluctuations.

6. A review of selected policies

The main policy instruments used to promote agricultural input use (intensification) include; a) development of improved agricultural technologies that enhance factor productivity and reduce production risks, b) investment in more efficient agricultural extension systems to disseminate information about improved technologies and management; c) provision of credit for purchase of agricultural inputs; d) investment in infrastructure to reduce transportation costs and input prices and enhance access to output markets; e) provision of subsidies to promote inputs that otherwise are underused; f) provision of index-based weather insurance (IWI) to reduce production risk and enhance technology adoption; and g) establishment of productive safety nets to enhance investment in public goods such as irrigation investments and land conservation through labor mobilization. There is no space to evaluate each of these in detail in this review. I therefore focus on those approaches (fertilizer subsidies, IWI and safety nets) that have been most controversial and subject to most recent research and testing.

It is far from obvious what the optimal mix of interventions to simulate sustainable intensification of agriculture in SSA is. This is likely to be context-dependent in this highly heterogeneous area.

Fertilizer subsidy programs

While many economists have argued strongly against use of subsidies to promote input use except for overcoming short-term knowledge/familiarity constraints, input subsidies regained popularity among policy-makers in many African countries after the apparent success of Malawi in particular with its targeted input subsidy program in the period 2006-2010. The spending on input subsidy programs in ten African countries amounted to $1.05 billion or 28.6% of public expenditures on agriculture in 2011 (Jayne and Rashid 2013). The relative success of fertilizer subsidy programs has for this reason also attracted a lot of interest among researchers and only a brief summary can be provided here of the findings in this literature.

The urgency of food insecurity issues and high priority to short-term effects and political support/popularity may have caused a bias towards use of input subsidies rather than long-term investments in infrastructure, research and technology development. The argument has been that it is cheaper to import fertilizer than to import food to meet the food needs of the food insecure. If this were a temporary solution to a drought or some other shock, that created temporary food shortages, such a subsidy may be defended, but as a permanent solution to a food insecurity problem, it could create dependency on subsidies and hinder other forms of adaptation to reduce food insecurity. This would drain resources that could otherwise have been invested in sustainable intensification and rural transformation that would enhance food security in the longer run.

Economists use the identification of market failures as a basis for identifying the need for interventions. The non-existence of markets may not imply a market failure, however. The cost of establishing a market where it does not exist may be higher than the benefits obtained from its establishment. Pervasive characteristics of many SSA rural economies such as immobility of land, low population densities in remote rural areas, seasonality in rain-fed agriculture, covariate risk, and moral hazard in human behavior result in pervasive market imperfections[3] for which there are no quick fix solutions. This implies e.g. that an intervention to establish a credit market where it does not exist may be a policy failure as it does not eliminate the market failure. Forcing or

[3] I prefer the concept market imperfection to characterize non-perfect markets, including missing market situations, and reserve the concept market failure to situations where one can be sure that the cost of intervention to improve the market is lower than the benefit from the intervention. Only in such a situation would it also be a policy failure not to intervene to eliminate the market failure.

stimulating people to take credit in a risky environment may make them even more vulnerable if exposed to bad states of nature. This is especially true in environments with covariate risk and with climate change possibly pushing towards hotter and wilder weather conditions.

The Starter-Pack input subsidy program was introduced in Malawi after the input credit program collapsed in the early-mid 1990s. It is not obvious that a new input credit program should replace the current Farm Input Subsidy Program (FISP) in Malawi. FISP has become an expensive undertaking for the Malawian government while still in high demand locally. While Malawi has become one of the countries with highest fertilizer use intensities in its smallholder agriculture in SSA, the majority of smallholders are still net buyers of maize, their main staple crop to which most of the fertilizer is applied. The financial constraints the country faces has forced a scaling-down of the subsidy program and the future of the program is under debate. So what has been learnt from the impact studies of fertilizer subsidy programs in Malawi and other SSA countries to date?

Ricker-Gilbert et al. (2011), using data from Malawi for the period after the targeted subsidy program was scaled up, found that access to subsidized fertilizer was associated with a substantial crowding out of demand for commercial fertilizer. Similar crowding out effects have also been found in Zambia by Xu et al. (2009) and Mason and Jayne (2013) and in Nigeria by Takeshima and Nkonya (2014). A reason for a relatively strong crowding out effect in Malawi could be targeting errors. Although the program officially aimed to target resource poor smallholders, targeting errors are present and related to local power structures such that wealthier farmers who would have afforded to purchase commercial fertilizer also managed to access substantial quantities of subsidized fertilizer directly through the program or indirectly through leakages from the program (Holden and Lunduka 2010; Mason and Jayne 2013).

In remote locations and where fertilizer use is a new thing there may also be crowding in effects due to learning and networking effects from introducing fertilizers through input subsidies. This has been found in an experimental study in Mozambique (Carter et al. 2014). The crowding-out effect is likely to be lower if the subsidy helps households overcome liquidity constraints that otherwise would constraint fertilizer purchases at commercial price. Holden and Lunduka (2013b), combining a household survey and a framed field experiment, find evidence of high demand for fertilizer in Malawi and that liquidity constraints contribute to sub-optimal effective demand.

There are fewer studies of the general equilibrium and longer-term impacts of fertilizer subsidies. Holden et al. (2005b) used a micro-meso-level computable general equilibrium model for a surplus grain producing area in Ethiopia and find that an output tax ploughed back as a fertilizer subsidy both reduce the land degradation externality and reduce poverty. Arndt et al. (2015) use an economy-wide model for Malawi to estimate the impacts of the FISP there. They find that when taking the indirect effects of the program into account the benefit-cost ratios of the program increase by 60% compared to partial equilibrium calculations. They find the program to be pro-poor and create double dividends through higher and more drought-resilient yields.

Drought tolerant crops and varieties

The threat of climate change looming behind has also triggered more focus towards the need to develop drought resilient crops and farming systems. One of the developments has been more Drought Tolerant (DT) maize varieties which have been disseminated in a number of SSA countries such as in Malawi where the take-up has been most rapid. Recent research shows that this is partly because of the dissemination of free seeds through the input subsidy program (Holden and Fisher 2015). Holden and Quiggin (2017a) have shown that the combination of access to DT maize seeds through the subsidy program and exposure to droughts has enhanced DT maize adoption and even more so among risk averse farmers. Holden and Quiggin (2017b) show that "probabilistic risk aversion", implying that the majority of farmers overweight the probability of bad weather outcomes, result in lower use of risk-increasing inputs such as fertilizer on risky crop varieties. They find that DT maize, which is less risk-increasing in this sense than other improved maize varieties, is less prone to this problem. The dissemination of DT maize varieties thus also enhances fertilizer use. DT maize is most efficient in reducing risk due to late droughts (dry spells) while it does not protect against early droughts except early maturing DT maize may be replanted after an early severe drought.

Index-based weather insurance

Index-based weather insurance (IWI) holds the advantage that it may help to overcome the covariate risk problem through hedging risk over larger geographical areas. By using data from local weather stations as basis for identification of locations where specified threshold levels are exceeded to qualify for payout, the system has overcome the moral hazard problem and reduced the monitoring and measurement costs. Whether there will be sufficient demand for such insurance given the size costs and benefits from the approach is questioned. Payouts may have to be quite frequent and that increases the administrative costs and reduces the degree of compensation. The variation in actual weather and production outcomes on farms may also differ from that at the nearest weather station and this causes the basis risk problem that the insurance does not cover. Insurance buyers risk having paid for insurance and experience very bad yields, but still not get compensation because the weather situation at the weather station was not bad enough. Various attempts to introduce IWI have not been able to get substantial demand without subsidizing the offers (McIntosh et al. 2013; Binswanger- Mkhize 2012). Hess and Hazell (2009), when assessing 28 index-based pilot insurance programs that were implemented from 2004 to 2009, found only three unsubsidized index insurance schemes that have reached more than 10,000 clients. These insured only the cost and none of them were in SSA. Insurance functions better for wealthier farmers as poor farmers typically are liquidity constrained and have low effective demand (Binswanger- Mkhize 2012). It is therefore not realistic to think that expanding IWI without subsidies is a powerful policy instrument to enhance fertilizer use among smallholders in SSA. If climate change results in higher weather-related risks, the policy solution is not IWI at smallholder level. Insurance may have higher potential for local providers of credit and inputs to help then overcome covariate risk.

Productive safety net programs

The productive safety net policy program (PSNP) has been a primary tool to enhance food security in Ethiopia since 2005. While the Food-for-work (FFW) approach had been used widely in the country also before that, the PSNP identified chronically food insecure communities and households that were entitled as participants of the program for a five years period which later was extended for another five years for households not yet ready for "graduation" from the program. The program may only indirectly affect input use through its insurance effect, cash and/or food supply effect, and the investment in pubic goods effect. Much of the labor mobilized through the program has gone into investments in soil and water conservation and may for that reason have long-term productivity and sustainability effects. There exists also some evidence that FFW and PSNP can to some extent increase the probability of using chemical fertilizers and the extent of their use (Holden et al. 2006; Bezu and Holden 2008; Villegas et al. 2016). One should expect that NUE should be enhanced on conserved land and this should also enhance the returns to fertilizer use.

7. A candidate example of a win-win-win policy

Economists have typically argued for incentive-based rather than command-and-control policies also in the environmental conservation area. In reality, it is an empirical question whether the price-based, law-based policy, or a combination of these is optimal from society's perspective.

One of the challenges of subsidies and taxes is that they often lead to quite complex substitution-, crowding in and crowding out effects at the micro-level and to general equilibrium and dynamic effects if scaled up. This is particularly complex when efficiency, equity, sustainability and political feasibility issues are closely inter-related such as in our case. These complexities makes it hard to predict the overall outcomes of subsidies or taxes.

While the World Bank World Development Report 2008 was positive about the idea "smart subsidies", the issue of nutrient depletion has not caught much attention in relation to the new fertilizer subsidy programs where the targeting has rather been focused on poverty and food security than enhancing sustainable intensification and NUE.

Nutrient mining will undermine long-term land productivity and may be seen as an environmental externality. Economists use the ideas of Pigou to argue for the use of Pigouvian taxes to internalize (=remove) such negative externalities. However, imposing taxes on poor land users may possibly even lead to more land degradation. Pigou argues that subsidies may be used in cases where there are economies of scale. Stimulation of technology adoption is another argument used and that I already have discussed related to fertilizer subsidies. If too little use of fertilizer leads to nutrient mining and falling land productivity, and a subsidy of fertilizer would boost fertilizer use and lead to more sustainable food production, introducing such a Pigouvian subsidy may be defended. But this is an empirical question requiring careful assessment of all costs and benefits. Various modelling studies have indicated that such a policy may work in certain contexts (Holden et al. 2005a)

There is, however, a risk that fertilizers become a substitute for conservation in a nutrient deficient environment and it is therefore important to link such as subsidy to a conservation requirement ("interlinkage policy") (Holden and Binswanger 1998; Holden et al. 2005b). This may imply a combination of a command-and-control and an incentive based policy and it will require strong local institutions for targeting and enforcement. The Productive Safety Net Program in Ethiopia is unique in the sense that it has aimed to "kill several birds with one policy tool". Tigray Region of Ethiopia received the Future Policy Gold Award 2017 from World Future Council and United Nations Convention to Combat Desertification (UNCCD). PSNP is one element of this policy. Grassroots mobilization of labor for soil and water conservation investment, establishment of area exclosures[4] for rehabilitation of degraded lands, restricting grazing by animals, and intensification on rehabilitated communal lands by allocation to landless and unemployed youth in formalized youth business groups, are other elements of the policy that has contributed to massive investments in environmental restoration (World Future Council 2017). Elements of this policy are similar to Payment for Environmental Services (PES)[5] as a policy to internalize environmental externalities based on a combination of beneficiary-pays and a polluter-pays principle (Engel et al. 2008). This approach is more relevant in settings where environmental service (ES) providers are poor, marginalized landholders or powerful groups of actors who also have to contribute themselves. PES programs may be financed by users of the ES or by governments acting on behalf of users. In

[4] "Exclosures" are degraded communal lands that the community has agreed to protect from further degradation by prohibiting further extraction by humans and livestock such that the area is regenerated.

[5] Wunder (2005) defines PES as (a) a voluntary transaction where (b) a well-defined environmental service (or a land use likely to secure that service) (c) is being 'bought' by a (minimum one) service buyer (d) from a (minimum one) service provider (e) if and only if the service provider secures service provision (conditionality).

the case of Tigray beneficiaries include current and future users. Current users contribute unpaid as well as compensated labor. The costs of the compensations have been paid by the government and international organizations like the World Food Program and The World Bank Trust Fund. The program may be an interesting case for a "tunneling through" ECK analysis.

8. Conclusions

SSA faces massive challenges to meet the food needs of its rapidly growing population and the broader Sustainable Development Goals towards 2050. Sustainable intensification of agriculture and rapid economic transformation while also reducing population growth rates will be necessary to protect remaining forest areas.

No silver bullet policies exist to achieve this but promising new policies need to be pilot tested in heterogeneous environments before scaled up in SSA, drawing on the improved toolbox of researchers in concerted action with SDG oriented policy-makers. The challenge is to create incentives for sustainable intensification to reduce area expansion and deforestation by stimulating nutrient demand while retaining nutrient use efficiency. This is easier said than done but may not be impossible.

References

Agricultural Transformation Agency, 2014. Soil Fertility Status and Fertilizer Recommendation Atlas for Tigray Regional State, Ethiopia. Ministry of Agriculture and Ethiopian Agricultural Transformation Agency, Addis Ababa.

Arslan, A., McCarthy, N., Lipper, L., Asfaw, S., Cattaneo, A., & Kokwe, M., 2015. Climate smart agriculture? Assessing the adaptation implications in Zambia. *Journal of Agricultural Economics*, 66(3), 753-780.

Barbier, E. B., 2010. Poverty, development, and environment. *Environment and Development Economics*, 15(6), 635-660.

Bezu, S., & Holden, S., 2008. Can food-for-work encourage agricultural production? *Food Policy*, *33*(6), 541-549.

Binswanger-Mkhize, H. P., 2012. Is there too much hype about index-based agricultural insurance?. *Journal of Development studies*, 48(2), 187-200.

Carter, M. R., & Barrett, C. B., 2006. The economics of poverty traps and persistent poverty: An asset-based approach. *The Journal of Development Studies*, *42*(2), 178-199.

Carter, M. R., Laajaj, R., & Yang, D., 2014. *Subsidies and the persistence of technology adoption: Field experimental evidence from Mozambique* (No. w20465). National Bureau of Economic Research.

Collier, P., 2008. *The bottom billion: Why the poorest countries are failing and what can be done about it*. Oxford University Press, USA.

Crawford, E. W., Jayne, T. S., & Kelly, V. A., 2006. *Alternative approaches for promoting fertilizer use in Africa*. Agriculture & Rural Development Department, World Bank.

Duflo, E., Kremer, M., & Robinson, J., 2011. Nudging farmers to use fertilizer: Theory and experimental evidence from Kenya. *The American Economic Review*, 101(6), 2350-2390.

Engel, S., Pagiola, S., & Wunder, S., 2008. Designing payments for environmental services in theory and practice: An overview of the issues. *Ecological Economics*, 65(4), 663-674.

Fisher, M., Holden, S. T., & Katengeza, S. P., 2017. *Adoption of CA technologies among Followers of Lead Farmers: How Strong is the Influence from Lead Farmers?* (No. 7/17). Centre for Land Tenure Studies, Norwegian University of Life Sciences.

Fisher, M., Holden, S. T., & Katengeza, S. P., 2017. *The adoption potential of Conservation Agriculture technologies in Malawi: A lead farmer promoter-adopter approach and assessment* (No. 1/17). Centre for Land Tenure Studies, Norwegian University of Life Sciences.

Henrich, J., Heine, S. J. & Norenzayan, A., 2010. The weirdest people in the world. *Behavioral and Brain Sciences* 33 (2-3): 61-83.

Hess, U., & Hazell, P., 2009. *Sustainability and scalability of index-based insurance for agriculture and rural livelihoods*. International Food Policy Research Institute (IFPRI).

Holden, S., Barrett, C. B., & Hagos, F., 2006. Food-for-work for poverty reduction and the promotion of sustainable land use: can it work? *Environment and Development Economics*, 11(1), 15-38.

Holden, S. T. & Binswanger, H. P., 1998. Small farmers, market imperfections, and natural resource management. In E. Lutz, H. P. Binswanger, P. Hazell, and A. McCalla, eds., *Agriculture and the Environment. Perspectives on Sustainable Rural Development*. Washington, D.C.: The World Bank.

Holden, S., Lofgren, H., & Shiferaw, B., 2005. Economic reforms and soil degradation in the Ethiopian highlands: a micro CGE model with transaction costs. In International Conference on Policy Modeling, Istanbul (EcoMod2005) June 2005.

Holden, S. T., & Lunduka, R. W., 2013a. Who benefit from Malawi's targeted farm input subsidy program? *Forum for Development Studies* 40(1), 1-25.

Holden, S. T., & Lunduka, R. W., 2013b. Input subsidies, cash constraints, and timing of input supply. *American Journal of Agricultural Economics*, 96(1), 290-307.

Holden, S. T., & Quiggin, J., 2017a. Climate risk and state-contingent technology adoption: shocks, drought tolerance and preferences. *European Review of Agricultural Economics,* 44(2), 285-308.

Holden, S. T., & Quiggin, J., 2017b. *Probability Weighting and Input Use Intensity in a State-Contingent Framework* (No. 8/17). Centre for Land Tenure Studies, Norwegian University of Life Sciences, Ås, Norway.

Holden, S. T., Shiferaw, B. A., & Pender, J., 2005b. *Policy analysis for sustainable land management and food security in Ethiopia: A bioeconomic model with market imperfections*. Research Report 140, International Food Policy Research Institute, Washington DC.

Holden, S. T., Shiferaw, B., & Wik, M., 1998. Poverty, market imperfections and time preferences: of relevance for environmental policy?. *Environment and Development Economics*, 3(1), 105-130.

Jayne, T. S., Mather, D., Mason, N., & Ricker-Gilbert, J., 2013. How do fertilizer subsidy programs affect total fertilizer use in sub-Saharan Africa? Crowding out, diversion, and benefit/cost assessments. *Agricultural Economics*, 44(6), 687-703.

Lesschen, J. P., Stoorvogel, J. J., Smaling, E. M. A., Heuvelink, G. B. M., & Veldkamp, A., 2007. A spatially explicit methodology to quantify soil nutrient balances and their uncertainties at the national level. *Nutrient Cycling in Agroecosystems*, 78(2), 111-131.

Malthus, T. R., 1798. *An Essay on the Principle of Population, as it Affects the Future Improvement of Society, with Remarks on the Speculations of Mr. Godwin, M. Condorcet, and Other Writers*. The Lawbook Exchange, Ltd.

Marenya, P. P., & Barrett, C. B., 2009. State-conditional fertilizer yield response on western Kenyan farms. *American Journal of Agricultural Economics,* 91(4), 991-1006.

McIntosh, C., Sarris, A., & Papadopoulos, F., 2013. Productivity, credit, risk, and the demand for weather index insurance in smallholder agriculture in Ethiopia. *Agricultural Economics*, 44(4-5), 399-417.

Mueller, N. D., Gerber, J. S., Johnston, M., Ray, D. K., Ramankutty, N., & Foley, J. A., 2012. Closing yield gaps through nutrient and water management. *Nature*, 490(7419), 254.

Ray, D. K., Mueller, N. D., West, P. C., & Foley, J. A., 2013. Yield trends are insufficient to double global crop production by 2050. *PloS one*, 8(6), e66428.

Ricker-Gilbert, J., Jayne, T. S., & Chirwa, E., 2011. Subsidies and crowding out: A double-hurdle model of fertilizer demand in Malawi. *American Journal of Agricultural Economics*, 93(1), 26-42.

Sachs, J., 2008. The end of poverty: economic possibilities for our time. *European Journal of Dental Education*, 12(s1), 17-21.

Sachs, J., McArthur, J. W., Schmidt-Traub, G., Kruk, M., Bahadur, C., Faye, M., & McCord, G., 2004. Ending Africa's poverty trap. *Brookings Papers on Economic Activity*, 1, 117-240.

Sheahan, M., & Barrett, C. B., 2014. Understanding the agricultural input landscape in sub-Saharan Africa: Recent plot, household, and community-level evidence. Policy Research Working Paper 7014, Africa Region, The World Bank.

Sheahan, M., & Barrett, C. B., 2017. Ten striking facts about agricultural input use in Sub-Saharan Africa. *Food Policy*, 67, 12-25.

Shiferaw, B., & Holden, S. T. (1998). Resource degradation and adoption of land conservation technologies in the Ethiopian highlands: a case study in Andit Tid, North Shewa. *Agricultural Economics*, 18(3), 233-247.

Stoorvogel, J. J., Smaling, E. A., & Janssen, B. H., 1993. Calculating soil nutrient balances in Africa at different scales. *Nutrient Cycling in Agroecosystems*, 35(3), 227-235.

Suri, T., 2011. Selection and comparative advantage in technology adoption. *Econometrica*, 79(1), 159-209.

Takeshima, H., & Nkonya, E., 2014. Government fertilizer subsidy and commercial sector fertilizer demand: Evidence from the Federal Market Stabilization Program (FMSP) in Nigeria. *Food Policy*, 47, 1-12.

Tilman, D., Balzer, C., Hill, J., & Befort, B. L., 2011. Global food demand and the sustainable intensification of agriculture. *Proceedings of the National Academy of Sciences*, *108*(50), 20260-20264.

Vanlauwe, B., J. Kihara, P. Chivenge, P. Pypers, R. Coe, J., 2011. Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility management. *Plant Soil*, 339, 35-50.

Villegas, L., Smith, V., Atwood, J., & Belasco, E., 2016. Does participation in public works programs encourage fertilizer use in rural Ethiopia?. *International Journal of Food and Agricultural Economics*, 4(2), 101.

World Future Council (2017). Tigray's Conservation-Based Agricultural Development-Led Industrialization. Downloaded from:

http://www.futurepolicy.org/healthy-ecosystems/biodiversity-and-soil/tigrays-conservation-based-adli/.

Wunder, S. (2005). *Payments for environmental services: some nuts and bolts.* CIFOR Occasional Paper no. 42, Center for International Forestry Research, Bogor, Indonesia. 24pp.

Xu, Z., Burke, W. J., Jayne, T. S., & Govereh, J., 2009. Do input subsidy programs "crowd in" or "crowd out" commercial market development? Modeling fertilizer demand in a two-channel marketing system. *Agricultural Economics*, 40(1), 79-94.

Zhang, X., Davidson, E. A., Mauzerall, D. L., Searchinger, T. D., Dumas, P., Shen, Y., 2015. Managing nitrogen for sustainable development. *Nature*, 528(7580): 51-59.