

# Sustainable intensification of agriculture in Africa

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**Abstract** Sustainable intensification is a key component of agricultural development in Africa, urgently needed to wean the continent off foreign food supply and to limit agricultural farmland expansion. It is expected that a relatively small fraction of farmers will adopt fertilizer technology, as profits in current economic settings are relatively small while risks are considerable with varying prices and uncertain yield responses. Many smallholders depend on off-farm income and local markets for food supply. Structural adjustments are therefore needed to allow management of larger units of land by trained farmers willing to take this opportunity, while recognizing land right sensitivities. There are large opportunities for African commodity crops to improve food security, including cassava and East African highland banana that strongly respond to fertilizer with limited environmental risks under good management. This requires investments in better functioning markets, local fertilizer production facilities that can produce regional crop blends and cost-efficient distribution networks, providing balanced fertilizers for African farmers.

**Keywords** Green Revolution, *Manihot esculenta*, *Musa acuminata*, sub-Saharan Africa

## 1 Introduction

Africa has a more rapidly growing population with a less developed agriculture when compared to other continents. What a missed opportunity! The rapid urbanization and growing food demand in urban centers asks for a rethink of how agriculture is organized. Are smallholders the food producers of the future? We argue here that a gradual restructuring of agriculture is needed, providing sufficient scale to support modern technology with all its benefits. It needs to be gradual to allow smallholders to transition to other work while being sensitive to land rights and the needs for biodiversity, preventing large-scale clearing of landscapes to maintain a good mix of habitats.

Agricultural development is key to wean the continent off foreign food supply<sup>[1]</sup>. Improvement of agricultural productivity brings far more than food self-sufficiency; it reduces costs of food and increases labor productivity on farms and supply of labor for off-farm economic activities, and increases demand for services<sup>[2]</sup>. As discussed by Djoumessi et al.<sup>[3]</sup>, economic growth of countries in sub-Saharan Africa (SSA) since 2000 resulted from structural changes and transition from farm labor to more productive sectors of the economy. The large labor cost differences between Asian and western economies that propelled their economic growth still exists and SSA has only a small advantage in labor costs<sup>[4]</sup>. Suitable policies are therefore needed to support transition of labor from on- to off-farm jobs in African economies<sup>[3]</sup>. The relatively low food prices on the world market are a strong disincentive for investments in agricultural productivity<sup>[2]</sup>. Yet at the same time many smallholders are net consumers and rely on purchased food for specific periods of the year. Increasing domestic food production reduces food prices but also food imports and, importantly, improves the balance of trade enabling investment in infrastructure, education and healthcare with enduring economic benefits. However, these long-term benefits from agricultural policies need visionary politicians that look far beyond price shocks and short election cycles. Good policies should therefore focus on food prices relative to income<sup>[2]</sup> at decadal timescales.

The need to boost soil fertility with fertilizers is widely recognized. Also, the required recipe of combined use of fertilizers within good agricultural practices and integrated soil fertility management is well known<sup>[5]</sup> and widely tested in a range of crops. Why is this recipe then not resonating among smallholders? One important reason is that 'bullshit

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rules<sup>[6]</sup>: promises about increased fertilizer use and supporting policies made by politicians are not met.

Agronomic research has focused on improving agronomic efficiency, which is key to reducing costs. However is this truly the bottleneck for improved productivity? Lessons from Europe<sup>[7]</sup> and elsewhere<sup>[8,9]</sup> show that on-farm effects of fertilizer are highly variable among fields and between seasons, and typically improve as soil fertility builds up. When the agronomic efficiency is high, fertilizer use gives a good return on investment for African smallholders<sup>[10]</sup>. However, is it fair and reasonable to expect African farmers to bridge the period required to build soil fertility before they are able to achieve the high agronomic efficiency required to repay their initial investments?

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## 2 Reviving the Green Revolution in sub-Saharan Africa

Africa's poor resource base, limited opportunities for irrigated agriculture, large distances to seaports and poor infrastructure made Green Revolution technologies less competitive when compared to other continents. Even now, many farmers see limited direct financial benefits from these technologies and at the same time face large financial risks, mainly due to low agronomic efficiencies of inputs, and volatile and poorly functioning markets. Recent focus has been on input subsidy schemes, which are highly politicized. In our view, protection of local markets and regulating food imports are more important as these reduce price volatility and risks. Agricultural revolutions do not start on farm but are triggered by market opportunities; African farmers will also respond to market demand.

### 2.1 Tunneling through: green solutions or murky waters?

Cheap inputs, such as fertilizer in China and feed imports in Europe, led to overuse and overload of nutrients in the system that sooner or later leach through, causing pollution of ground- and drinking water, eutrophication of surface water and toxic green tides. Excess N not only leaches but also results in gaseous losses, responsible for eutrophication and acidification of nature reserves and loss of biodiversity. Legislation to reduce the environmental burden can increase nutrient use efficiency (NUE) to near theoretical levels. This is what happened in Europe with a turnaround in the 1980s and is happening now in China<sup>[11–13]</sup>. Tunneling through the Kutznets curve shortcuts this process of rise and decline in fertilizer rates<sup>[14]</sup> with a focus on high NUE being of key importance.

African agriculture is, with some exceptions, based on soil mining; large amounts of nutrients are extracted from the farming system without adequate replacement. This erodes soil fertility with enduring negative consequences. This process has been happening for nearly a century, fueled by population growth and expansion of agriculture. Theoretically, the highest efficiencies are observed when all other production factors are optimal. In Africa, efficiencies are very low, even at the very low application rates that are commonly used, reflecting a combination of limiting factors. Fertilizing crops on a soil with a poor resource base therefore results in much smaller yield gains than on richer soils. For example, maximum yield gains for N applications of 50 kg grain kg<sup>-1</sup> N are observed in the new polders of the Netherlands, with vast soil reserves of nutrients. Farmers in SSA are also aware of this and will preferably focus fertilizers on their better fields which can also reach these high efficiencies<sup>[15]</sup>, while nutrients are most needed on poor fields these must be supplied in a more balanced composition. One of the reasons for the low agronomic efficiencies in African agriculture is inappropriate blends of nutrients in fertilizers. The variability of soil fertility is well known and reflects large differences in parent material and weathering, over which the impacts of management history are superimposed. Proper accounting for these differences is almost impossible. In addition, experimental results are highly variable, even more so when conducted on farm. Large experiments including replicates are not always possible; they might not fit in a single smallholder field or might violate the *ceteris paribus* assumptions. Alternatively, experimental results from a range of locations are pooled adding spatial variability. Then, the effect of locally-deficient nutrients will be masked by spatial variability and overall effects become insignificant. Typically, only nutrient limitations that occur everywhere are identified as significant, notably N + P. Although wide ranges in responses can mask differences between treatments when statistically analyzed, they reflect a risk for the farmer<sup>[16]</sup> and indicate that a complete and balanced mix of nutrients should be applied. A well balanced fertilizer with optimum N:P:K ratios that compensates for nutrient offtake will reduce the risk of poor NUE<sup>[17]</sup>. This strongly argues for providing balanced nutrient mixtures in fertilizer blends that are regionally tailored to crop offtakes at competitive prices to prevent use of unbalanced fertilizer with long-term negative impacts on soil fertility.

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## 3 Structural adjustments

African agriculture is dominated by smallholders. Many smallholders are net consumers, producing much of their

own food but relying on off-farm income to meet the full household dietary needs, while at the same time more than 95% of smallholders sell produce to markets<sup>[18]</sup>. Although intensification produces more, financial gains are marginal and will not help lift smallholders out of poverty. Many smallholders will opt for opportunities to invest away from the farm with larger potential income gains<sup>[19]</sup>. This also means that not all smallholder land will be available for intensification, adding pressure on other areas. A first estimate is that only 11% to 14% of farmers in Africa will take this opportunity to step up and adopt technology when price incentives are right with food secure farmers are more likely to adopt than food insecure farmers<sup>[20]</sup>.

To keep pace with population growth, yield gains of 100–200 kg·ha<sup>-1</sup>·yr<sup>-1</sup> cereal grain are needed<sup>[21]</sup>, depending on the expansion of land under agricultural use. These are staggering numbers, far larger than the yield increases that were achieved in the past in developed countries, especially when considering that not all farmland is available for intensification. Effective use of fertilizer combined with good agronomic practices is labor intensive, but for smallholders labor is a serious constraint at the peak of season<sup>[22]</sup> depending on local conditions<sup>[23]</sup>. Manual land-preparation, seeding and weeding is backbreaking work<sup>[24]</sup>, sowing 50000 seeds h<sup>-1</sup> and fertilizer requires bending over up to 50–100 thousand times ha<sup>-1</sup>. Even simple, locally manufactured mechanized seeders can place both seeds and fertilizer in rows at the required depth, providing direct yield benefits<sup>[24]</sup>. The yield benefits resulting from more accurately placing seeds in a row also reduce the need for thinning compared to the common practice of two seeds per planting and reduces the risk of ammonium toxicity to the germinating seeds from basal fertilizers. This example shows that the benefits of scale are much larger for intensified systems, but also go far beyond economics alone.

Therefore, sustainable intensification of agriculture must be done concurrently with consolidation of farms to reap the benefits of mechanization and technology, fueled by a gradual transition to a more urbanized life for workers. Another major advantage of land consolidation is that a much smaller number of farmers need to be trained. Land is not only an asset for producing food, it is also the rural home, a place of belonging where ancestors are buried, and provides a safety net and insurance for families with urban workers to retreat to. Land use and land ownership are very sensitive issues but need to be addressed to allow short- or long-term land rent contracts that can provide the required scale for mechanized intensification.

## 4 Large opportunities for crops in sub-Saharan Africa

To revitalize the Green Revolution, African commodity crops provide excellent opportunities to boost productivity of land and labor, and initialize local processing industries proving work in rural areas. Recent work on cassava (*Manihot esculenta*) has shown that balanced nutrient ratios, applied in split applications aligned to crop demand, can result in highly-efficient crop uptake with high yields, for the commonly used cultivar TME 419, approaching theoretical maximum yields<sup>[25]</sup>. Cassava is a widely grown food crop in SSA that also can be used for chips and starch processing, and is well-adapted to periods of drought. Also, cassava strongly responds to fertilizer and uses nutrients very efficiently (Table 1), strongly limiting environmental risks.

East African highland banana (*Musa acuminata* genome group AAA-EA) is another example; it is a highly productive crop, requiring little N fertilization<sup>[30]</sup> and well suited to local conditions. Bananas demand large amounts of potassium<sup>[29]</sup>, but when properly fertilized with K, they provide high yields. Highland bananas are also labor intensive, providing job opportunities in rural areas with a good economic yield for sale in urban areas. In addition, the continuous soil cover provided helps to limit erosion of hillsides.

## 5 Conclusions

**Table 1** Optimum yields, agronomic efficiency and nutrient recovery of fertilizer (expressed kg<sup>-1</sup> N applied) under balanced NPK nutrition for major food staple crops in sub-Saharan Africa

Plant	Agronomic efficiency (kg DM kg <sup>-1</sup> N applied)	N recovery (kg N uptake kg <sup>-1</sup> N applied)	Water-limited yields under optimum management (t·ha <sup>-1</sup> DM)	Reference
Maize	18–19	0.5–0.6	6–13 (grain)	[26,27]
Cassava	27–60	0.5–0.7	22–35 (roots)	[25]
Highland banana	–	–	6–8 (fingers)	[28–30]

Investing in sustainable intensification in SSA is urgently required to prevent further nutrient mining of soils. Investments in agricultural development have wide-reaching benefits in the long-term. Fertilizer is a key component to increase land and labor productivity, that may free-up labor, and kick-start services and exporting industries when combined with broader economic investments. Low NUE may need to be accepted in the short-term to build up soil resources. Along with sustainable intensification, policies that address land rights are critical, enabling long-term investments in soil fertility and land exchange to provide the much-needed increase in the size of land management units to support improved management practices. In our view, investing in agriculture is an essential development pathway for African countries to boost economies and protect biodiversity from further expansion of agricultural use of land. International donors should invest in facilitating balanced fertilizer production facilities and reduction of transaction costs of fertilizer use through providing better services (e.g., roads, market access, storage services and agricultural supplier networks) in SSA to support intensification. Support for locally processed tropical root and tuber crops provide excellent opportunities to produce food locally and kick-start competitive industries that may produce for both domestic and international markets.

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