

# Fertilizers and low emission development in sub-Saharan Africa

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## Key messages

- ▶ Greenhouse gas emissions from fertilizer usage in sub-Saharan Africa are currently low due to low application rates of nitrogen fertilizers.
- ▶ As African countries begin to implement their Nationally Determined Contributions to the Paris Agreement, there is an opportunity to improve crop productivity to meet future food needs while continuing to use N fertilizers—both organic and inorganic—efficiently.
- ▶ Efficient use of N fertilizers requires combining balanced and appropriate nutrient inputs with good agronomic practices, such as the use of improved, high-yielding varieties that are adapted to local conditions and needs, application and recycling of available organic matter, water harvesting and irrigation under drought stress conditions, and lime application on soils with acidity-related problems.
- ▶ Policies for soil fertility management in the context of climate goals may consider the need to:



Photo: G. Smith (CIAT)

- improve the availability, access and affordability of organic and inorganic nutrient inputs, along with other key inputs such as high-yielding varieties;
- build capacity in adaptive nutrient management and agronomic best practices that support crop productivity;
- ensure equitable access to inputs, particularly for women and vulnerable groups.

## Introduction

Many countries in Africa included fertilizer use, soil fertility management, and agricultural inputs as part of their contributions to the Paris Climate Agreement (see Annex 1). While nitrogen (N) fertilizers contribute substantially to nitrous oxide (N<sub>2</sub>O) emissions globally, emissions from fertilizers are still low in sub-Saharan Africa. Projections of future food needs in Africa point to the need for substantial increases in nutrient inputs on cropland. An opportunity exists in Africa to meet those future food security needs while using N fertilizers efficiently (see Annexes 3 and 4).

Since African countries will now be preparing to implement their Nationally Determined Contributions (NDCs), and further fleshing out their low emission development strategies, it is an opportune time to reflect on the role of fertilizers and soil fertility management in climate change adaptation and mitigation strategies in a holistic manner. This policy brief outlines the main issues to consider as countries develop their own specific agriculture and soil fertility management strategies with a view towards supporting food security, adapting to climate change and limiting greenhouse gas (GHG) emissions.

## Tunneling through the curve: A nutrient management strategy for Africa

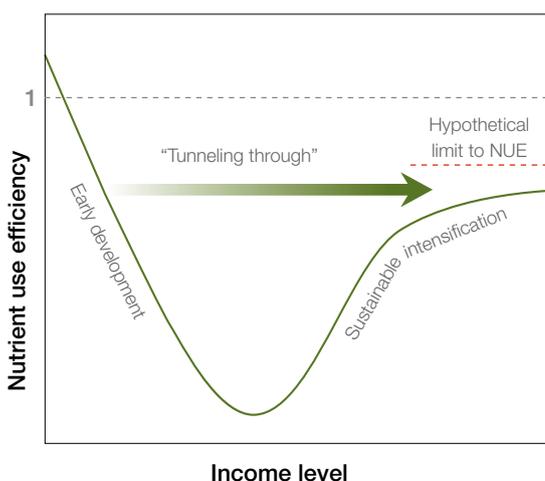
In many parts of the world, over-application of N fertilizers has led to environmental damage including contamination of ground- and surface water and emissions of nitrogen oxides, ammonia gas, and N<sub>2</sub>O, a potent GHG. Globally, agriculture is responsible for 85% of N<sub>2</sub>O emissions (Smith et al. 2007). The situation is different in sub-Saharan Africa, where fertilizer use is the lowest in the world (Chianu et al. 2012). Average N fertilizer use in 2016 was estimated at 12-15 kg N per hectare, although some countries such as Nigeria, Ethiopia, and Malawi are approaching the 50 kg mark (Sheahan and Barret 2014).

Projections of future food needs predict that Africa will need to triple food production by 2050 (see Box 1), which will require substantial increases in nutrient inputs on cropland (Mueller et al. 2012) along with good agronomic management. Most soils in Africa are highly weathered and nutrient-poor. In the past, soil fertility was traditionally managed using long fallow periods which helped restore the nutrients removed by crops, but with the increase in population and greater pressure on land, these traditional fallow systems have become shorter or even abandoned (Dreschel et al. 2001; Muyanga and Jayne 2014). As a result, soil nutrient mining is widespread, with a combined average depletion rate of N, phosphorus (P) and potassium (K) of 54 kg per hectare per year in sub-Saharan Africa (Sommer et al. 2013). While N is the most limiting nutrient for crop production, many agricultural soils in sub-Saharan Africa are deficient in P, K, sulphur (S) and micronutrients as well (Sommer et al. 2013), which makes balanced nutrient inputs critical.

Yet, as farmers increase inputs of N and other nutrients to improve productivity, African countries need *not* suffer the negative consequences of fertilizer over-use that have plagued other nations as they have industrialized. Historical patterns of agricultural development show that nutrient use efficiency (crop yield per unit N input) decreases as income grows during the early stages of national agricultural development, then increases again during more affluent stages of development before eventually leveling off at some biophysical limit of nutrient use efficiency (Figure 1) (Zhang et al. 2015). At the lowest part of this curve, agricultural application of nutrients, especially N, can greatly exceed the level needed for crop growth, and the excess is prone to loss to the air and water.

The opportunity for African countries in the context of their climate change commitments is to “tunnel through” the curve by shifting

directly from low-yield crop production with high (in many cases unsustainably high) nutrient use efficiency directly to high-yield crop production with still high nutrient use efficiency (Figure 1). This is quite similar to the sustainable intensification approach with its focus on improving efficiency of production (Campbell et al. 2014). This could also be thought of as decreasing agricultural emissions intensity (emissions per unit crop yield or unit food) by increasing yields without increasing emissions (Bellarby et al. 2014). Making such a shift would require leap-frogging over the conventional evolution of agricultural management by introducing practices and supporting policies that promote high nutrient use efficiency while maintaining soil nutrient pools at agronomically desirable levels.



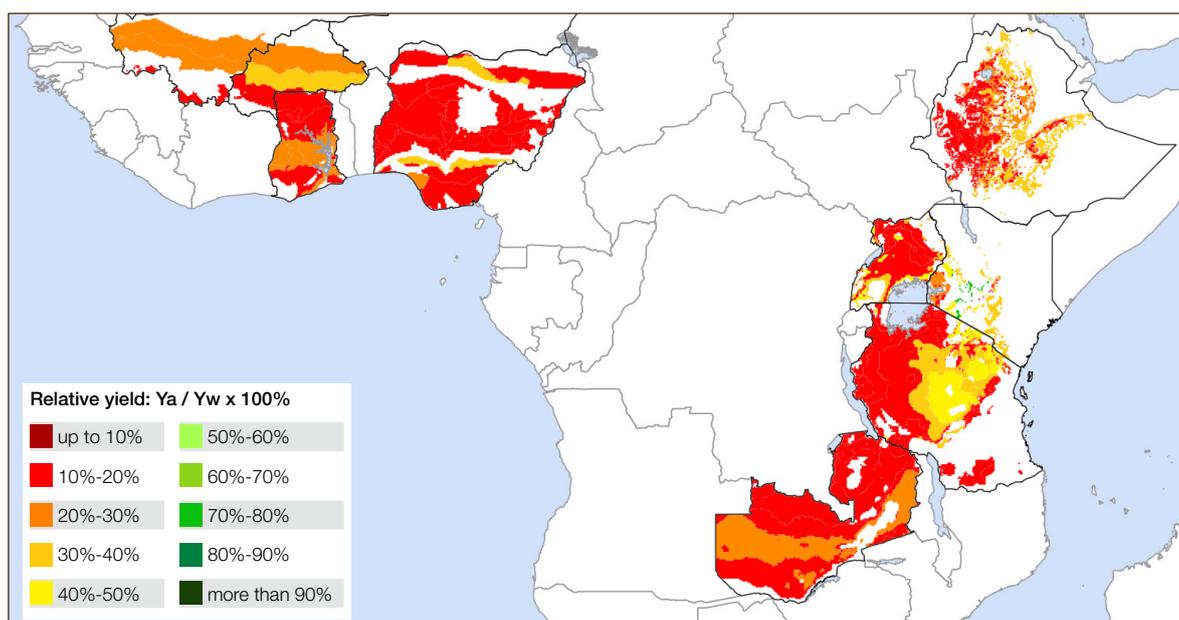
**Figure 1.** Typical curve of nutrient use efficiency (NUE) and income level evolution over time. A nutrient use efficiency value of 1 means that total nutrient inputs are perfectly balanced by nutrients harvested in crops. No biological system is 100% efficient, so the hypothetical limit for nutrient use efficiency is shown as close to but below 1 (adapted from Zhang et al. 2015).

## BOX 1 – The challenge for food production in Africa

On September 25, 2015, United Nations member countries adopted a set of Sustainable Development Goals (SDGs) to end poverty and protect the planet. While climate action and responsible consumption and production are among the goals, and critical to future well-being, the goals of no poverty and zero hunger (SDGs 1 and 2) arguably must be the priority. Strategies to reduce the contribution of food systems to climate change should reinforce these goals.

Sub-Saharan Africa needs to produce three times more cereals by 2050 relative to 2005-2007 in order to maintain the present level of self-sufficiency (approximately 80%), due to projected population growth and dietary change (Alexandratos and Bruinsma 2012). The alternative to some degree of self-sufficiency is massive food imports, which would require economic growth. Economic growth, in turn, is unlikely without agricultural development (Van Ittersum et al. in press).

Tripling grain production would require that yield gaps—the difference between potential and actual yields—be almost entirely closed. Agronomists use the term “water-limited potential” to describe maximum attainable crop yields with ideal management, limited only by water availability. Currently, actual average yields in sub-Saharan Africa are 20-25% of water-limited potential (Figure 2); maintaining the current self-sufficiency level in production would mean increasing yields to 70% of water-limited potential. Maintaining self-sufficiency without closing yield gaps would require large-scale conversion of natural lands, with undesirable outcomes for GHG emissions, biodiversity, and loss of forest-based livelihoods. While African forests have historically suffered low rates of agriculturally-driven deforestation (Galford 2015; Rudel 2013), meeting regional food needs in 2050 without increasing yields would mean converting approximately 80 million ha of additional land to agriculture (Phalan et al. 2014)—nearly the size of Kenya and Uganda combined.



**Figure 2.** Relative yield gap closure of maize (actual maize yields,  $Y_a$ , as a percentage of their water-limited yield potential,  $Y_w$ ) for countries in West and East sub-Saharan Africa (data from [www.yieldgap.org](http://www.yieldgap.org)).

### Practices for high nutrient use efficiency

At application rates below soil and crop requirements, N losses as  $N_2O$  are minimal. In much of sub-Saharan Africa, substantial increases in N inputs could be absorbed and greatly increase crop yields with little immediate risk of significantly increased  $N_2O$  emissions. A study of this phenomenon in Kenya concluded that nutrient inputs for increasing yields have little impact on  $N_2O$  emissions if application rates remain at or below 100 kg N per hectare (Bellarby et al. 2014; Hickman et al. 2015).

However, few would suggest a continent-wide recommendation of 100 kg N per hectare; appropriate nutrient input rates differ widely with soil types and crop requirements. Moreover, N by itself will not bring about high yields in the absence of good agronomic practices. Flexible approaches to soil fertility management, rather than blanket fertilizer recommendations, can help farmers make efficient use of balanced nutrient inputs and improve return on investment. The principles of efficient and effective use of nutrient inputs are often described as the “4Rs”:

1. use the **right** source of nutrients (the right composition of nutrients, including other than NPK),
2. applied at the **right** rate (based on economic criteria and soil fertility status),
3. at the **right** time (relative to crop needs and weather),
4. and at the **right** place (targeting plant roots and minimizing losses) (see Annex 2).

Achieving high nutrient use efficiency also requires combining efficient use of nutrient inputs with good agronomic practices in order to support crop productivity, such as the use of improved, high-yielding varieties that are adapted to local conditions and needs, application and recycling of available organic matter (crop residues and farmyard manure), water harvesting and irrigation under drought stress conditions, and lime application on soils with acidity-related problems. One way of thinking about this integrated approach is the integrated soil fertility management paradigm (Figure 3) (Vanlauwe et al. 2010; Roobroeck et al. 2015; Zhang et al. 2015).

Organic materials play an important role in supporting productivity and nutrient use efficiency by providing plant nutrients and maintaining soil organic matter. However, the debate that has pitted organic inputs and inorganic fertilizers against each other as alternative ways to support crop growth represents a false dichotomy. Inorganic fertilizers and organic inputs—such as livestock manure, crop biological N fixation, crop residues, and leguminous green manures—play complementary roles in agroecosystems. Inorganic fertilizers provide high amounts of readily available nutrients required for plant growth, while organic resources also provide carbon—an essential ingredient of healthy soils—along with some nutrients. Organic inputs play an important role in improving inorganic fertilizer use efficiency and when combined with agronomic best practices, they can help improve soil structure and fertility. Applying these in combination often creates added benefits. For instance, in drought situations, leaving crop residues as mulch can alleviate water scarcity and high temperature stress and enable crops to take up the nutrients from inorganic fertilizers more easily (Zougmoré et al. 2003; Thierfelder et al. 2013).

However, organic inputs are not always available in sufficient quantity or quality to support—let alone boost—crop productivity in sub-Saharan

Africa (Vanlauwe and Giller 2006). The production of organic inputs itself relies on sufficient nutrient inputs (otherwise, mining of soil reserves occurs), and inorganic fertilizers are often necessary to kick-start soil restoration by restoring biomass productivity and carbon inputs to the soil (Tittonell et al. 2008). Increased crop productivity also results in an increased availability of crop residues that can then be recycled directly or as manure to increase soil carbon stocks, another important mitigation strategy and the main focus of the recently-initiated '4 pour mille' initiative led by the French Government (Koch et al. 2015). A rational nutrient management strategy should therefore make optimal use of locally available organic material together with judicious and balanced use of inorganic fertilizers (Vanlauwe et al. 2010; Roobroeck et al. 2015).

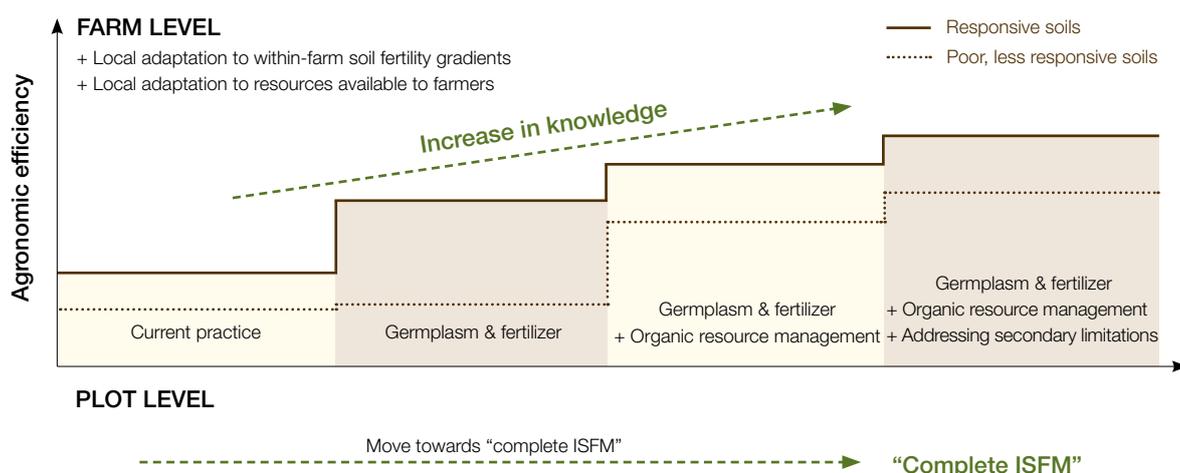
A number of advanced fertilizer technologies can also reduce nutrient losses and support high efficiency, such as slow- and controlled-release fertilizers, fertigation (use of water-soluble fertilizers applied with irrigation water), and biofertilizers (seed treatments with living organisms that fix nitrogen or otherwise improve nutrient availability to the plant). Such technologies may become relevant as African agriculture develops and inorganic fertilizer use becomes more widespread, but they are currently too expensive to be attractive to African farmers, with the possible exception of biofertilizers.



Photo: N. Palmer, CIAT

## **BOX 2 – Is switching to organic fertilizers a climate change mitigation option?**

Organic N inputs do not have lower emissions than inorganic fertilizers. Legume-derived N, for example, once converted into inorganic form in the soil, is indistinguishable from inorganic fertilizer-derived N (Rosenstock et al. 2014) and subject to the same mechanisms for loss as  $N_2O$ . The same applies to manure, which may have additional emissions (methane, for example, but also  $N_2O$ ) associated with storage and application. Substituting inorganic fertilizers with organic ones is therefore not necessarily an opportunity for mitigation of  $N_2O$  emissions (Bos et al. in press). Using a life-cycle approach, however, organic N inputs produced on-farm may have lower emissions from production and transportation than inorganic fertilizers.



**Figure 3.** Conceptual relationship between the agronomic efficiency of fertilizers and organic resources and the implementation of various components of integrated soil fertility management (ISFM), culminating in complete ISFM towards the right side of the graph. Soils that are responsive to NPK-based fertilizer (generally, those that already have sufficient soil organic matter) and those that are poor and less responsive (due to other constraints besides the nutrients contained in the fertilizer) are distinguished. The ‘current practice’ step assumes the use of the current average fertilizer application rate in sub-Saharan Africa (Vanlauwe et al. 2010).

### Policy options for nutrient management in the context of NDC goals

Individual country pledges need to prioritize sustainable agricultural practices that balance the need for more food with a reduction in GHG emissions, with the aim of tunneling to a high-yielding agricultural system that uses fertilizers efficiently. In view of this, policies for soil fertility management in the context of NDC goals may consider the need for the following:

- ▶ **Build capacity in adaptive nutrient management.** Working towards higher crop yield while maintaining high nutrient use efficiency requires building capacity that goes beyond blanket fertilizer recommendations. Training can equip extension staff and farmers with skills in good soil fertility practices based around integrated soil fertility management and the “4Rs” and support effective local practices. The basis of effective nutrient management is understanding the fertility status of a given soil; where soil testing is not available, simple

visual indicators (e.g. leaf colour charts) can be useful. Awareness raising amongst value chain actors can also help prevent pollution and soil fertility degradation due to inappropriate fertilizer handling or use.

- ▶ **Support balanced nutrient inputs.** To improve the response to fertilizer and efficiency of use, fertilizer recommendations need to account for imbalances not just in N, P and K but also in other nutrients such as sulfur (S) and micronutrients, whose deficiencies are increasingly widespread in Africa. The application of balanced fertilizer use should form part of an overall integrated soil fertility management strategy including organic inputs to complement inorganic fertilizer use and liming.
- ▶ **Strengthened and equitable access to nutrient inputs.** Targeted, well-designed policies and structural support are needed to improve the availability, access and affordability of nutrient inputs—both organic and inorganic. For organic inputs,

countries would do well to examine a range of potential sources, from nitrogen fixing trees to manure composting, while considering the availability of land and labour for producing and using these inputs. These must go hand-in-hand with increased access to markets and other farm inputs including inorganic fertilizers and seed.

- ▶ **Emphasize institutional links and social equity.** Women play a significant role in agriculture but often have few decision-making powers and limited access to and use of fertilizers. Policies and programs need to be designed to ensure that women have more opportunities to benefit from training, trade, and use of inputs and technologies to improve yields and nutrient use efficiency. This may involve, for example, working with input suppliers to help them develop market strategies tailored to women's needs (Farnworth et al. 2015) or ensuring that female-headed households have equal access to input subsidy coupons (Chirwa et al. 2011).
- ▶ **Monitor GHG emissions intensities along with emissions.** To be meaningful, monitoring and targets should consider GHG emission intensity of fertilizer use along with absolute emissions to accommodate the need for raised production whilst ensuring that growth occurs efficiently and more sustainably. Emission intensity is calculated by dividing emissions from fertilizer use on a given crop by the yield of the crop.

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