Tripling crop yields in tropical Africa

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Between 1960 and 2000, Asian and Latin American food production tripled, thanks to the use of high-yielding varieties of crops. Africa can follow suit, but only if depletion of soil nutrients is addressed.

Nearly one sixth of the global population is malnourished. The problem is particularly acute in tropical Africa, where constant or recurrent food shortages affect over 30% of the population — over 260 million people. Low levels of agricultural productivity are a key cause of hunger in this part of the world. Decades of farming without adequate fertilizer and manure have stripped the soils of the vital nutrients needed to support plant growth. Replenishing soil fertility, by using mineral and organic fertilizers, is therefore the primary biophysical requirement for increasing food production in tropical Africa. Many studies have shown that, once this fundamental deficiency has been addressed, the road to food security is open.

Nutrient-limited yields

The development of high-yielding varieties of rice, maize and wheat between the 1960s and 2000 boosted crop production by 66–88% in Asia and Latin America[1], and cereal crop yields rose from around one to three tons per hectare in these regions[2]. But the benefits of the improved seeds did not spread to the nutrient-deficient soils of tropical Africa, where the average staple crop yield has remained stagnant — hovering around one ton per hectare — since the 1960s. Without soil replenishment, even the best crop varieties and the most enlightened policies cannot stave off hunger.

Unfortunately, donor agencies such as the World Bank ignored the advice of soil scientists for decades, focusing instead on the use of improved crop varieties, governance and macroeconomic policies. The need to tackle soil fertility in Africa was first raised in 1981[3]. The case was supported with evidence-based results in the nineties; large-scale studies revealed that African crop yields could be increased two- to four-fold by replenishing soil fertility, and caught the attention of the international research community[4–7]. But it was not until the start of the twenty-first century that the advice of soil scientists was placed squarely in the policy arena.

From one to three tons per hectare

The United Nations (UN) Hunger Task Force was established in 2002, to help achieve the first Millennium Development Goal of halving world hunger by 2015[8,9]. Comprising scientists, policymakers, civil society leaders and private sector representatives, the task force set forth a series of recommendations for improving agricultural productivity in tropical Africa. The replenishment of nutrient-depleted soils, the management of soil moisture and the use of high-yielding crop varieties and hybrids were key. Two years later, former UN Secretary General Kofi Annan called for a uniquely African green revolution[10], to be fuelled by more fertile soils.

Today, the goal of an African green revolution can be quantified as increasing cereal grain yields from one to three tons per hectare by 2020, primarily through the use of mineral and organic fertilizers and high-yielding crop cultivars, and by empowering farmers with the latest agronomic knowledge and enabling them to sell their produce profitably. Proof that a green revolution can be achieved in Africa is evident on two scales: in the 80 Millennium Villages spread throughout tropical Africa, and in one entire country.

The Millennium Villages project was set up in 2005 to help some of the most deprived African communities lift themselves out of hunger, poverty and disease[11]. Public-sector investments and science-based interventions are used to improve access to fertilizers and improved seeds, and to provide basic health care, school meals, safe water and sanitation, together with better roads, and electricity and internet access in these villages. Eighty Millennium Villages, comprising about 500,000 people, now operate in hunger hotspots in 10 African countries. As a result of fertilizer applications, improved cultivars and up-to-date agronomic knowledge, maize yields have surpassed the three-tons-per-hectare mark (or equivalent yields in other crops) in 78% of the Millennium Village households. Food production in these villages now meets, or indeed exceeds, the annual calorie requirements of the villagers[12,13].

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Figure 1 | Maize field near Zomba, Malawi, likely to reach three tons per hectare. Fertilizers and improved maize hybrids have tripled maize production in Malawi in recent years.

There is also evidence that the application of fertilizers, together with the use of improved cultivars, works at a country-wide scale. A landlocked country with a population of 13 million, a GDP per capita of US$600, and a history of recurring famines, Malawi was the first country in tropical Africa to implement a green revolution strategy on a national scale. Maize is Malawi's staple food crop, grown by nearly all of the 2.4 million farm families. But even in years of high rainfall, the nitrogen-depleted soils could not produce sufficient maize to feed the country. In 2005, Malawi's maize harvest reached only 57% of the country's requirement, with approximately five million Malawians requiring food aid. In the same year, the government introduced a scheme that enabled farmers to buy 100 kg of fertilizer and 3–5 kg of improved maize seed at 37% of the market price.

The 2006 harvest greatly surpassed previous years. Maize production more than doubled nationwide, resulting in an 18% surplus. In 2007, maize yields almost tripled at the national scale (increasing from 0.8 tons per hectare in 2005 to 2.2 in 2007), transforming the country into a food-exporting nation that also became a food aid donor to its neighbours (Fig. 1)[14]. Ten other African countries are following suit, adapting the Malawi model to their circumstances. Persistent advocacy over three years finally resulted in a US$20 billion commitment — made at the G8 meeting in L'Aquila in 2009 — to support smallholder agriculture in tropical Africa, primarily with fertilizers and improved seeds[15]. The key now is the delivery of these promises on the ground.

The initial gains seen in the Millennium Villages and Malawi are similar to those seen in India and the Philippines at the start of the Asian green revolution[16]. Now they have to be consolidated with improved agronomic practices, strategies for adapting to climate change and sustained policy support.

Introducing organics

To build on the initial success achieved by applying mineral fertilizers, it is important to start adding organic fertilizers to African soils. Few, if any, sustainable agricultural systems rely on mineral fertilizers alone. Although plants do not distinguish between nitrate and phosphate ions derived from mineral fertilizers, manure or decomposing leaves, only organic fertilizers add carbon, feed soil microbes and help to retain soil moisture.

Organic materials contain low levels of nutrients. Thus the best way to apply them — and to avoid onerous transportation costs — is to grow leguminous trees and cover crops in the same field as the cereal crops[7]. Here they can fix nitrogen from the air, recycle nutrients from the subsoil, control weeds and add carbon. This approach works well in humid and sub-humid Africa, where nitrogen-fixing plants capture 50–100 kg of nitrogen per hectare per year — similar to the amount added by fertilizers. The nitrogen-fixing trees also supply fuel wood for farm families to cook with[17]. Other organic fertilizers, such as cattle manure and compost, are rarely produced in sufficient quantities on African farms to meet the nutritional needs of crops[6], but they are useful supplements to mineral fertilizers and nitrogen-fixing plants.

Yet despite these advantages, most farmers abandon nitrogen-fixing practices after initial adoption of the techniques[18]. The main reason is the time delay needed to get the nitrogen-fixing system established, which means that farmers have to forgo one crop. The solution may be to subsidize nitrogen-fixing trees and crops grown *in situ* to compensate for the crop lost at the start. This would also level the playing field between mineral and organic inputs, as mineral fertilizers are now widely subsidized. But both are needed.

Tailored fertilization

Other nutrient deficiencies — primarily in phosphorus, potassium, sulphur, zinc and iron — are region and soil specific. Phosphorus is spectacularly deficient in parts of East Africa and the Sahel. The ongoing development of a high-resolution digital soil map of Africa[19] will enable farmers to pinpoint exactly which forms of mineral and organic fertilizers are needed in each field, helping to replace the current blanket recommendations that are often used in tropical Africa. The digital soil map will also provide information on which leguminous trees or nitrogen-fixing crops to use. Once cereal crop yields have surpassed the three-tons-per-hectare mark — which would more than satisfy basic food demands — part of the land can be used to grow high-value crops such as vegetables, fruits and timber, or to provide forage for dairy production[12].

The green revolution bonus

Luckily, with higher yields comes a more efficient use of soil moisture. At current African yields, about two-thirds of soil moisture is lost via soil evaporation, leaving only one-third of the captured rainfall available for plants. But when cereal yields rise from one to three tons per hectare, the crop canopy closes and the balance flips over: only about a third is lost by soil evaporation, and two-thirds is funnelled through the plants as transpiration[20]. So even where climate change brings reduced rainfall, the green revolution can carry on.

Beyond staple food

An increase in staple crop production is only a first step towards reducing hunger in tropical Africa. The provision of wider nutritional needs, such as more protein and adequate vitamins and trace elements, coupled with a reduction in disease, is also necessary. Poor health and hunger are directly related: people with diseases such as malaria or HIV/AIDS are less likely to farm efficiently. Furthermore, the ability to enter market-based economies is hampered by a lack of education about banking and commerce.

Agriculture and health need to be tackled together, and immediately. Education, water, sanitation, infrastructure, environment, gender inequalities and information technology should follow closely, as seen in the Millennium Villages[11,12]. Clearly, soil science alone cannot solve food shortages in tropical Africa. But in combination with other agricultural, health and environmental disciplines, it is beginning to have a positive impact on development policy and on the ground. A scientific look at Africa's soils can help the continent to meet the basic needs of its people. ❐

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