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Agriculture Powering Africa’s Economic Transformation

ACET African Center for Economic Transformation
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Raising the productivity of Africa’s farms will require more intensive use of modern inputs such as fertilizers and other chemicals, irrigation, and machinery and more widespread continuous cropping. But such agricultural intensification could further damage the environment and exacerbate land degradation. In addition, the drive for greater intensification must also consider the potential impacts of climate change.

Some of the extreme environmental consequences of unsustainable intensified use of resources include irreversible soil degradation, erosion, nutrient and organic matter depletion, water contamination, and loss of biodiversity and forests. Any attempt to transform agriculture could prove counterproductive unless the potential feedback effects of these factors on productivity are taken into account.

While agricultural intensification has the potential to boost productivity, climate change may undermine—or in some cases enhance—its effectiveness. Although agriculture in Africa is expected to be adversely affected by climate change, not all agricultural subsectors will be hurt or hurt equally. One study found that climate change will reduce revenues from agricultural activities more in drylands and in the livestock sector than in irrigated agricultural production. And climate change impacts will differ across crops. For example, while tubers and root produce such as yams may see a 19%–33% productivity loss, carbon-4 (C4) plants such as maize, sugarcane, millet, and sorghum may show an increase because higher carbon dioxide in the atmosphere will improve photosynthesis. Geographic differences in climate change impacts are also likely: by 2100, agricultural gross domestic product (GDP) losses are expected to be greater in West and Central Africa (in the range of 2%–4%) than in North and Southern Africa (0.4%–1.3%).

This chapter identifies agricultural intensification practices that maximize productivity while safeguarding the environment and responding to threats posed by climate change. The chapter first discusses the determinants of agricultural productivity (or intensification) and highlights the potential negative impacts of these contributors to higher productivity on environmental sustainability. It then suggests how the potential negative (or positive) impacts may be attenuated (or scaled up).

It also reviews ways to adapt to climate change as agriculture intensifies, looking specifically at the influence of anticipated climate changes (precipitation and temperature) on the effectiveness of the various intensification practices. The chapter closes with a discussion of promising approaches that are already being implemented and of the role that policymakers and development partners can play in scaling them up.

Determinants of agricultural intensification and their impact on the environment
This section focuses on how four factors—fertilizer, irrigation water, seed variety, and machinery—that physically influence productivity might affect the environment (for good or ill), and on possible responses.

Application of fertilizers
Soil fertility management consists mainly of the application of inorganic and organic fertilizer to enhance soil fertility by increasing plant nutrients and improving the soil’s structure and water retention capacity. Countless analyses have shown the positive impact of such practices on yields. However, one key holdback to fertilizer’s impact is the initial soil fertility level, which in many smallholder farming systems in Sub-Saharan Africa differs greatly at the farm and agroecological zone level, leading to differences in the crop response to fertilizer and organic-nutrient resources.

As inorganic fertilizers are manufactured from extracted nonrenewable resources, higher fertilizer demand and use will hurt the ecology in the area where its components are extracted (as in Morocco, the world’s second-largest producer of phosphate). In addition, over-application or improper placement of fertilizer on farms can contaminate surface water and groundwater. Eutrophication—excessive quantity of nitrogen, phosphorus, and other fertilizers in a body of water—induces excessive algal and aquatic plant growth and can lead to further loss of biodiversity and fish stocks, degrade water quality, and affect the recreational value of beaches. Eutrophication was one of the drivers of the growth of water hyacinths in Lake Victoria in East Africa,
which eliminated more than half the 500-plus species of endemic cichlid fishes. Nearly half the nitrogen applied worldwide (36 million tons of 78 million) is lost annually to the environment through leaching, erosion, runoff, and gaseous emissions.

“Fertigation”—the injection of fertilizers, soil amendments (such as compost and manure), and other water-soluble products into an irrigation system (mostly drip)—is a potential solution to the inappropriate use of fertilizers that damage the environment. However, while fertigation is widely used in large-scale horticultural production in places such as Ethiopia, Kenya, and Uganda, the infrastructure is too expensive for smallholder farmers. Instead, small farmers can use microdose fertilizer application—applying small, more affordable quantities of fertilizer using a bottle cap, either during planting or as a top dressing three to four weeks after crops emerge. Microdosing technology has been developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and its partners to help subsistence farmers in the Sahel improve inorganic fertilizer application and minimize environment impacts.

Agricultural water management
Agricultural water management involves the application of water resources to increase agricultural productivity and prevent reductions in productivity caused by droughts and high temperatures. Instruments for agricultural water management include irrigation, drainage, water harvesting, soil and water conservation, agronomy, and integrated watershed management. Managing agricultural water use is especially important in drylands (lands with an aridity index of 0.65 or lower), which cover three-quarters of Sub-Saharan Africa’s agricultural land area. The drylands include arid, semi-arid, and dry subhumid areas; they experience severe water stress that increases the need for irrigation and other water management practices. The drylands are home to more than half of Africa’s population of 1.2 billion and to a substantial share of the region’s population living below the international poverty line (US$1.90 a day). The arid lands support more than 80% of Sub-Saharan Africa’s livestock population. These conditions underscore the importance of enhancing agricultural water management as part of Africa’s agricultural transformation strategy.

Despite the important benefits to agricultural productivity from irrigation, only 4% of Sub-Saharan Africa’s total cropland area is irrigated, with the highest share in Southern Africa. Across Africa, only 20% of irrigable area in the drylands is equipped for irrigation, and the rate of expansion of new irrigation is only about 1% a year (chapter 3).

Although returns to irrigation are high, irrigation infrastructure usually damages natural ecosystems by disrupting water flows and increasing erosion. Excessive irrigation increases the rate of mineral weathering of the soil and can transport and leach soluble and colloidal material. Irrigation using groundwater may cause soil and water degradation through water logging and salinization and may accelerate other types of groundwater pollution.

Small irrigation systems linked to reservoirs for harvesting surface water have been introduced in places such as Mount Kilimanjaro in Tanzania, where smallholder farmers face increasing risks of uncertain rainfall. These systems reduce evaporation by using closed underground irrigation pipes in place of the traditional open-furrow systems used in most rural areas. In Tanzania, training accompanied the introduction of the new infrastructure, to strengthen the ability of the local water users association to maintain the infrastructure through user fees and to manage their members’ contributions. The increased revenues expected from the closed pipe system would pay for the cost of building the system within 8–10 years, according to a cost-benefit analysis (using a 5% discount rate). The positive environmental impacts of the closed-pipe system are also important. The underground pipes dramatically reduce water evaporation from ambient air temperatures. Water user associations also ensure that farms are watered when the temperature is low, which further reduces evaporation. In addition, the water harvested in these reservoirs minimally affects the ecology that used to depend on it because of the reservoirs’ relatively small size.

Adoption of improved seeds
The productivity-enhancing potential of improved seeds depends not only on the development of appropriate varieties but also on programs that multiply and market the seeds to ensure quality, availability, and affordability (chapter 3).

The adoption of disease- and pest-resistant seeds lowers the need for pesticide use, as with genetically modified cotton (Bt-cotton), and reduces the pressure to expand agricultural land since farmers can get more from the land they are already planting. On the negative side, adopting improved varieties can lead to environmental disruption, as the use of hybrids and other improved crop varieties contribute to a loss of agricultural biodiversity in native varieties (landraces). This has caused genetic drift (change in the frequency of different genotypes in a small population) and disturbed natural selection, increasing crop vulnerability to stresses.
Because farmers know which varieties are economically and socially important in their community, plant breeders should consult with them on their evaluations of new varieties based on local knowledge and preferences. Such a participatory arrangement will reduce unintended disruption to the local ecological food chain. It will also enable public research systems to fine-tune new seeds to existing conditions and farmers’ preferences, which will increase adoption rates while minimizing environmental impacts. This approach differs from the current system, which creates commercial networks to ensure that farmers must buy seeds rather than multiply and distribute them on their own, with few environmental protection measures.

**Mechanized agriculture**

Mechanization is a key component of the technology that allows agricultural production to be intensified. When more land has to be brought under cultivation to meet increased market demand, or when existing land has to be more intensively cultivated (requiring more labor per unit of land), mechanized plowing and harvesting are more likely to be adopted. For this reason, the dynamic relationship between land and labor (changes in the land–labor ratio, in particular) that is part of the intensification process is another key factor influencing mechanization.

While improper use of plows and other farm equipment could further disturb soil structure and cause waterlogging, erosion, and soil degradation, proper use can reduce greenhouse gas emissions and improve the efficiency of nutrient use. By properly covering manure, farm machinery can reduce methane emissions, and by properly placing and covering inorganic fertilizer, farm machinery can reduce nitrous oxide emissions. Two-wheeled tractors are ideal tillage tools that meet the plowing demands of farmers while promoting soil conservation. They are relatively affordable and, with a little government support, can be assembled, if not manufactured, locally.

**Climate change and agricultural productivity in Africa**

Climate change will bring opportunities and challenges to African agriculture through its effects on precipitation and average temperatures, and its influence on the effectiveness of agricultural intensification measures.

**Effects of climate change impacts on precipitation and temperature**

As the effects of climate change build, humid and subhumid areas in Sub-Saharan Africa are expected to receive higher rainfall, while the drier areas are likely to experience less—and more erratic—rainfall. A simulation using a set of 21 global models showed that East Africa will experience a 7% increase in precipitation in 2080–2099 relative to 1980–1999. The increase will be more evident around the Lake Victoria basin. West Africa’s humid and subhumid zones will see a 2% increase in precipitation, while the Sahara subregion will see a 6% drop (figure 9.1). New opportunities could open up for farmers in the areas experiencing an increase in precipitation, allowing them to produce crops that would otherwise be impossible to grow.

Temperature is expected to increase across Africa, which could undermine the positive effects of increased precipitation by accelerating evaporation in East Africa and parts of West Africa. While higher temperatures are generally expected to lower productivity by reducing soil water content, they may benefit farming at higher altitudes by prolonging the growing season, reducing the amount of time needed for crops to mature, increasing the survival rate of young animals, and generally raising livestock productivity.

Cereal crops are a key to adapting to climate change because the increased carbon in the atmosphere will improve their productivity (enhanced photosynthesis due to higher levels of carbon in the atmosphere, known as carbon fertilization), although higher temperatures and greater variation in rainfall are expected to outweigh the positive impact of carbon fertilization in some parts of the world. By 2080, a consensus estimate of six climate
models and two crop modeling methods—assuming a 4.4°C increase in temperature and a 2.9% increase in precipitation—finds that global agricultural output potential is likely to fall by about 6%, or by about 16% without factoring in the positive effect of improved photosynthesis from increased carbon in the atmosphere.²⁴

The potential agricultural output decline ranges from 10% to 25% among the world’s regions.

By 2080 across Africa, as climate change progresses, cereal output potential could fall by 16%–27% on average and by up to 60% in some countries, depending on the effect of carbon fertilization (map 9.1). These effects are in addition to general water scarcity and changes in rainfall patterns.

**The influence of climate change on the effectiveness of agricultural intensification**

The following assessment considers mainly the direct impacts of climate change on the four determinants of productivity just discussed, not the indirect effects such as disturbance of natural selection, which require more sophisticated modeling that is beyond the scope of this chapter.

**Application of fertilizer.** If water shortages intensify, that could undermine the effectiveness of fertilizer application. An experiment on maize in Niger found that the grain yield response to nitrogen differed with the level of the water deficit and with the level of nitrogen application.²⁵ Under conditions of water shortage (low rainfall), yield reductions were much more severe at high nitrogen rates. This implies that areas where climate change causes a decline in precipitation will experience a greater reduction in fertilizer effectiveness, holding everything else constant. In addition, if fertilizer is not applied at the right time, increases in rainfall could also reduce the effectiveness of fertilizers by washing them off the soil before they have a chance to nourish plants.²⁶ And because fertilizer requires the correct amount of water at the right time to work effectively, temperature increases will also reduce the effectiveness of fertilizers by increasing the evaporation rate. For carbon-4 crops, however, which will be affected by countervailing forces, it is difficult to draw any conclusions about the impact of temperature change on fertilizer effectiveness.²⁷

**Irrigation infrastructure.** Official records for irrigated areas in Sub-Saharan Africa show that full-control surface water irrigation accounts for more than half of the total irrigated area of 71 million hectares (figure 9.2), including mainly publicly funded irrigation schemes.²⁸ Performance of these irrigation systems is poor, as 20% of the developed area is no longer cultivated.²⁹ Irrigation’s contribution to raising productivity in Sub-Saharan Africa is expected to decline with the anticipated reduction in annual rainfall.³⁰

The effectiveness of irrigation under climate change is likely to vary across African subregions. Irrigation effectiveness is expected to be enhanced in East Africa and parts of Central Africa and in the humid and subhumid zones of West Africa, but reduced in Southern Africa because of diminished rainfall. However, the overall effectiveness of irrigation may be weakened by a higher rate of water evaporation, especially for open furrow irrigation, as a result of expected higher temperatures across the continent.

**Adoption of improved seeds.** The impact of climate change on improved seeds is ambiguous. Seeds are constantly being improved to increase crop resilience to shocks associated with climate change, such as water stress and temperature change. Nonetheless, if climate change effects are severe enough, they may undermine the effectiveness of drought-resistant seeds. Improved seeds that strengthen crop tolerance to flooding appear to be less needed. While such tolerance could be useful in places where flooding is likely, it would be useless everywhere else, as this type of seed would not be suitable for areas that do not flood or are far from water.

**Mechanization.** Dry conditions caused by both water shortages and higher temperatures (evaporation) can make plowing more difficult. Plowing may therefore require more machine effort, which would raise the cost of mechanization. For farmers who can already barely afford to mechanize, higher costs would mean forgoing or limiting the use of machinery for plowing and increasing the use of hand hoes. A hand hoe does not lead to the land-degrading soil disturbance and compaction experienced in highly mechanized farming,³¹ but by increasing the drudgery and the need for labor, it could constrain farmers’ adoption of some land management practices that lead to higher yields and adaptation to climate change.

**Making agricultural intensification environment-friendly and climate-smart**

African countries and countries with conditions that are comparable to those in Africa have adopted solutions that can sustainably increase productivity while adjusting to the effects of climate change and preserving the
MAP 9.1 Projected impact of climate change on cereal output in Africa in 2080

Change in potential cereal output, 2080
- Decrease: -50% or more
- Decrease: 25-50%
- Decrease: 5-25%
- No change: ±5%
- Increase: 5-25%
- Increase: 25% or more
- Not suitable

Source: Fischer 2009.
Identifying scalable solutions

Coordinating crop and livestock production to reduce need for inorganic fertilizers. Complementing the use of inorganic fertilizers with organic fertilizer should be encouraged to mitigate the greater adverse environmental impact of inorganic fertilizers and the potential impacts of climate change on the effectiveness of fertilizers in general. However, the use of organic fertilizers, especially farm produced, requires strict coordination of crop-production and livestock-raising activities that can be a deterrent to most farmers.

The details of such coordination will necessarily vary by country, subregion, and even community. More research is recommended on the appropriate coordination model for crop production (cash crops and food crops) relative to livestock raising (large or small ruminants and poultry). One study, however, presents some ideas from a new maize-based farming system in the highlands of Kenya:32

• Use stall-fed cows (not grazed cows), so all dung and urine can be collected. Intercrop feed crops for stall feeding with maize, to which manure or compost from stall-fed cows is applied.

TABLE 9.1 Increasing agricultural productivity while protecting the environment and mitigating climate change—an overview

<table>
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<tr>
<th>Determinants of intensification</th>
<th>Environmental impact</th>
<th>Potential climate change impact</th>
<th>Solutions used elsewhere</th>
<th>Enabling environment factors</th>
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| Fertilizers                    | Nonrenewable resource mining to manufacture fertilizers | Heavy rain will wash away applied fertilizers | Appropriate mixed crop production–livestock raising model to maximize home organic fertilizer production; greater access to weather information | Research to identify the appropriate model
|                                | Eutrophication        | Drought will reduce fertilizer effectiveness |                          | Extension officers equipped to disseminate knowledge |
| Irrigation                     | Rise in water table   | Drought will reduce availability of irrigation water | Small, closed underground pipe irrigation infrastructure managed by a multifunctional water users association | With the irrigation infrastructure identified, the most important enabler is a well-functioning water user association |
|                                | Water logging         | Higher temperatures will increase water evaporation, especially for open-furrow irrigation |                          | |
|                                | Alteration of soil structure |                          |                          | |
|                                | Soil erosion          |                          |                          | |
| Improved seeds                 | Lowered use of pesticides and less pressure on land expansion | Ambiguous, but higher incidence of drought may reduce the effectiveness of drought-resistant seeds, while higher incidence of floods may make improved seeds irrelevant | Seed multiplication and distribution models that include a public–private partnership with a development partner or private seed company can reduce the commercial risks faced by seed companies | Flexible agricultural seed policy that provides the necessary guidance for engaging private actors |
|                                | Loss of agricultural biodiversity |                          | Public partner also provides extension services, including sustainable agricultural practices | Work groups for addressing inefficiencies not foreseen by the policy |
| Mechanization                  | Inappropriate tillage intensity releases more carbon into the atmosphere | Dry conditions caused by water shortage and higher temperatures will make plowing harder, requiring more machinery and increasing cost of mechanization | Small, multipurpose, and inexpensive power sources, such as two-wheeled tractors; Promotion of energy saving/ environmental conservation/climate-resilient approaches such as conservation agriculture | A commercially oriented agriculture sector |
|                                | Mechanization can be used to properly place and cover synthetic fertilizer, reducing nitrous oxide emissions and increasing nutrient use efficiency |                          |                          | Development of repair services of machinery |
|                                |                       |                          |                          | Removal of tariffs on imported spare parts |

Source: Authors’ analysis.
• Use dairy cows that are cross-breeds between European and indigenous cows, as they produce more milk and manure than indigenous varieties.
• Plant high-yielding hybrid seeds on most of the maize fields.

This system helps build farm resilience to extreme weather events caused by climate change. Beyond enabling the use of less inorganic fertilizer, using organic fertilizers, with their rich soil-nutrient content, will increase the soil’s water retention capabilities.

Introducing more environment-friendly irrigation infrastructure and improving irrigation system governance. Irrigation is important to transforming Africa’s agriculture, but irrigation infrastructure usually damages natural ecosystems. To minimize these adverse impacts, environment-friendly structures have been introduced (see the example above from Mount Kilimanjaro in Tanzania in the section on agricultural water management). These and other irrigation systems also need proper governance of the infrastructure, often through strong local water user associations, to reduce market failures, including the need to raise irrigation user fees to reflect higher costs resulting from changing weather patterns.

Coupling conservation agriculture with two-wheeled tractor use. Conservation agriculture entails land management practices that reduce soil disturbance, maintain permanent soil cover of at least 30%, and diversify crop species in a given area over time. It covers practices adopted to sustainably intensify agriculture in light of climate change risks, including combinations of tillage intensity, cover crop, manure application, crop rotation patterns, and residue application. Applied successfully, conservation agriculture practices can bolster a community’s resilience to risks today and ensure its food security in the future. Further, by improving the organic content of the soil, conservation agriculture increases the soil’s water-retention capacity, thus easing the water constraint that many smallholder farmers face.

Based on information from 15 Sub-Saharan countries that reported conservation agriculture adoption rates, only about 1.5% of cropland area is under conservation agriculture. Lack of appropriate implements to seed to the right depth with minimum soil disturbance is one of the major constraints for African smallholders, especially as labor-intensive drudgery leads African youth to favor nonfarm activities. For these reasons, tying the promotion of technologies in energy saving, environmental conservation, and climate resilience such as
conservation agriculture to the promotion of small, multipurpose, and inexpensive power sources such as two-wheeled tractors could be the most appropriate model for mechanizing agriculture and promoting conservation agriculture in Africa.

**Creating an enabling environment for scaling up**

In light of the effectiveness of the scalable solutions described above, policymakers might consider the following actions to foster the appropriate enabling environment for scaling up.

*Increasing access to agricultural extension and other advisory services.* Farmers’ access to agricultural advisory services on the cost and benefits of intensification tools is key, yet extension services are not well equipped to inform farmers about appropriate farm management practices. Conventional extension services in Sub-Saharan Africa have weak capacity to provide advisory services on climate change, organic soil fertility management practices, and other environment-friendly land management practices. Not surprising then, according to a study in Kenya, Niger, Nigeria, and Uganda, is that one reason farmers fail to adapt to climate change even after noticing its effects is a lack of knowledge of adaptation strategies. Receiving timely and accurate information alleviates some of the uncertainty about the outcome of farm management practices and may influence farmers to adopt them.

Short training in climate change adaptation, conservation agriculture practices, and environmental protection are required to increase the capacity of advisory services on these fairly recent knowledge sets. As governments may lack the resources to fully fund such training, they could consider establishing a public–private partnership with an active input provider that has a network of dealers. That could leverage the existing network to deliver extension services for a fiscal incentive, such as reducing custom duties paid by input companies on imported inputs. Given the gender imbalance in access to the information needed to adopt appropriate farm management practices, it is important that extension services also use female extension officers to enhance women’s access to information.

**Building the capacity of water user associations to address tensions between social and commercial roles.** The example in Tanzania shows that proper training of members of a water user association is key to the success of a small irrigation system. Many irrigation systems face recurring problems with poor management partly due to tensions (often from conflicting goals and functions) that may jeopardize the association’s performance, especially in the long run. The most common tensions are between the social activities and the business functions of the water user association. While the social activities boost membership, they are often achieved at the expense of economic performance.

Dealing with such tensions is a major managerial and organizational challenge for each water user association. The right way to address them depends on individual circumstances. A core requirement is to improve the business management capabilities of the association’s leadership. That task could be assumed by a donor or government body that equips the association to manage the infrastructure and revenue, introduce sanctions, and link the irrigation system to service providers and markets.

**Designing seed policy and working groups for addressing frictions in implementing policies.** The success of seed multiplication initiatives in Kenya and Zimbabwe was due to having a national framework to guide the seed system. That approach ties in with experiences around the world indicating that addressing the infrastructure and other hardware needs of the seed industry in isolation may not be enough to ensure success in developing the industry. Also needed are good policies that guide the actions of government agencies and foster partnerships between the public and private sectors.

Although policies may be well written, frictions often arise when implementing them, especially in the context of environmental protection rules. Policymakers must be alert to such frictions and work to diffuse them through regular dialogue in small working groups with all stakeholders to agree on ways to address policy challenges, especially those that cut across government agencies.

**Removing import duties and custom clearance burdens on environment-friendly imported spare parts.** Import policies should provide incentives to import environment-friendly machinery and parts. Raw materials for farm machinery and mechanical tools and for completely knocked down and semi–knocked down tractor parts are still subject to full tariffs in many African countries. If there is potential for locally manufactured implements or locally assembled environment-friendly tractors to compete with imports of tractors and parts, governments could encourage the sector by removing or lowering duties on imports of raw materials needed to manufacture such parts.
Notes
3. C4 plants follow a carbon pathway that allows them to mini-
mimize photorespiration. This process is sometimes referred as
5. The chapter focuses less on the determinants, which are
discussed in chapter 3, and more on their impacts on the
environment.
10. Drylands are also defined as areas with an
aridity index (AI) of 0.65 or less, where 0 is very dry and 1 is very
wet. Drylands fall into four subgroups: hyper-arid (AI 0–0.05),
arid (AI 0.05–0.20), semi-arid (AI 0.20–0.50), and dry subhumid
(AI 0.50–0.65).
14. A domesticated regional ecotype: a locally adapted, traditional
variety of a domesticated species of animal or plant that has
developed over time through adaptation to its natural and cul-
tural environment of agriculture and pastoralism and due to
isolation from other populations of the species.
16. Mechanization is a very broad term but here refers mainly to
machinery for plowing the soil, with a few references to com-
bine harvesters.
17. Diao, Silver, and Takeshima 2016 (chapter 3).
27. Xie et al. 2015.
31. FAO 2014.
32. Kassam et al. 2015.
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Agricultural transformation incorporates two main processes. The first is transforming or modernizing farming by boosting productivity and running farms as modern businesses. The second is strengthening the links between farms and other economic sectors in a mutually beneficial process, whereby farm output supports manufacturing (through agroprocessing), and other sectors support farming by providing modern manufactured inputs and services.