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Agricultural Transformation in Maize Producing Areas of Africa

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Abstract

Maize is a critical staple cereal across Sub-Saharan Africa but attempts to improve its productivity in small-scale farming systems often prove disappointing. The 12 key technologies required to overcome poor yields are mostly known, but the manner that they are mobilized, packaged, and delivered requires re-evaluation. Combinations of better varieties and their necessary accompanying inputs must become more available and affordable for an African maize revolution to succeed, and land must be managed in ways that enhance, rather than diminish, land quality over time. Adjustments to the bundling and transfer of these technologies as transferable assets pose a solvable dilemma. These interventions must be based upon specific agro-ecological and socio-economic contexts and offered within the scope of well-designed regional and national agricultural development agendas. Success in boosting maize yields and its companion field legumes form the basis for greater food security across Africa and value-adding enterprise, including the growth of blended flours and commercial animal production. This chapter describes how these technologies may be most effectively mobilized within the current thrust to transform African agriculture.

Keywords: Agricultural Transformation Agenda, Dakar 2 Feed Africa Summit, International Institute of Tropical Agriculture, Maize-based cropping systems, Rural development, Small-scale farming systems, TAAT Program, Technology packages.

1. Introduction

Maize first arrived from the New World into Africa during the 1500s. Portuguese traders supplying fortresses and coastal trading centers first introduced it. Still, the crop quickly appealed to African farmers due to its high yield, low labor requirements, and short growing season. Cultivation swiftly spread because of its higher yield than existing indigenous staples, mostly millet and sorghum, and its ability to function as a substitutable dietary staple [1]. Miracle [2] concluded that the timing when maize became important in different parts of Africa is better understood than the exact introduction sites and parties responsible. In general, maize was first introduced to West Africa, then spread inland and southward, and last reached East Africa and deeper Central Africa.

Maize offered the right combination of traits for widespread adoption. Its nutrients are concentrated and easily transported, husks protect against pests, birds, and extreme weather, and it is consumable over an extended period starting with young cobs through harvest maturity and longer given proper storage and milling [3]. The appearance of maize and its cultivation practices are like sorghum and millet, further encouraging adoption. Many New World crops were introduced to Africa following the discovery of the New World, including cassava, sweet potato, Irish potato, groundnut, and beans.

However, maize had the most rapid and greatest impact on native farming systems, and this impact continues into the present [4].

Maize is now Africa's most important crop. About 30% of energy intake across Africa comes from maize [4]. Erenstein et al. [5] provide a recent description of maize production, consumption, and trade, including its trends in different regions and countries of Africa. Maize is the second most cultivated crop worldwide after wheat. It is grown on about 197 million ha, which supplies 1,137 million tons of dry grain. Africa accounts for 21% of that land use cover but only 7.4% of production, signifying strong shortfalls in yield. Average maize grain yields in Africa are only 2.1 t ha-1 compared to 5.8 t ha-1 worldwide and 10.8 t ha-1 in North America, and closing this yield gap is critical to realize African food security and nutrition. Various agronomic and economic factors cause attainable yields not to be met by smallholder farmers, ranging from seed quality, low and variable returns on fertilizer investment, nutrient and water availability, pest control, labor, and equipment assets to gender-specific challenges, value addition, market linkage and selling prices [6, 7]. The role of technology access and adoption on production levels is evident at the level of individual farmer fields and entire regions. For instance, plots closest to the homestead typically receive most inputs and are better weeded than out-fields and therefore record higher yields. East and Southern Africa have a smaller maize growing area than West and Central Africa, yet production is higher, which is primarily ascribed to better varieties, fertilizer supply and extension support.

To safeguard the production and self-sufficiency of this staple, African governments have adopted policies like subsidizing production inputs and various price protection schemes, some benefiting producers and others designed to assure consumers. Some of these measures have been criticized by development banks as unsustainable, leading to structural adjustments, particularly those that resulted in unrealistic consumer prices and fluctuating supply [4]. Some research suggests that Africa should prioritize policies and programs centered on non-monetary incentives like advancing technology and infrastructure, investing in irrigation, precision agriculture, research services, and human development [8,9,10]. However, a growing consensus is that maize responds favorably to production inputs, particularly hybrid seeds and fertilizers. Programs encouraging investment into making these materials more available to small-scale producers are a promising pathway to rural development in maize-producing areas [11,12]. This Chapter focuses on the needed maize technologies and how they may be more effectively deployed and delivered through emergent developmental strategies to ensure maize's future in Africa.

The African agricultural development community recently consolidated around the Dakar 2 Feed Africa Summit organized by the African Development Bank and held on 22-27 January 2023. Its purpose was to unlock Africa's agricultural potential by delivering climate-smart agricultural technologies to millions of farmers and creating an enabling environment for market-driven economic development through improved value addition, rural infrastructure, and stronger policy incentives. Thirty-four (34) African Heads of State, 75 Ministers, and numerous heads of development organizations attended the Summit. They presented and discussed Country Food and Agriculture Delivery Compacts to further the Feed Africa Strategy [11] at national levels based on revised production targets for key agricultural commodities, planned improvements in enabling policies and rural infrastructure, and options for innovative financing. Following the Summit, the 36th African Union Assembly endorsed its outcomes and called for time-bound and measurable indicators for success. Within a month, the Summit mobilized more than $70 billion in investment to boost food and agriculture production across the continent. IITA's Partnership for Delivery (P4D) staff and Regional Directors are working with country planners to realize the vision of Dakar 2 African agricultural transformation. Follow-up to this event is critical for the timely modernization of agricultural technologies and services employed across Africa, including those related to maize-based cropping systems.

2. Modernizing Maize Technologies

There are twelve key technologies to modernizing production and post-harvest management of maize in Africa. These technologies include: 1) drought tolerant maize varieties to strengthen the resilience of food production, 2) imazapyr resistant maize varieties that withstand parasitic striga weeds, 3) golden maize varieties with pro-vitamin A biofortification for improved human nutrition, 4) a streamlined licensing mechanism for commercial multiplication of hybrid maize varieties, 5) information and communication technology (ICT) platforms offering ready access to digital information, 6) contracted farm mechanization services, 7) better fertilizer blends together with top dressed nitrogen for improved nutrient supply, 8) rotating and intercropping with nitrogen-fixing grain legumes to improve soil health, 9) applying herbicides for pre- and post-emergent weed control, 10) controlling the biological invasion of fall armyworm (FAW) through integrated practices, and 11) countering aflatoxin contamination through atoxic competitors, 12) improved post-harvest handling. Further details on each of these 12 technologies follow.

2.1 Drought-tolerant maize varieties. Recently released maize varieties allow acceptable grain yields under short-term and moderate drought (Figure 1). This technology mitigates adverse climate and lessens the risk of crop failure across many zones of Sub-Saharan Africa [13, 14]. Insufficient rainfall is a widespread reason for lost maize yield across Sub-Saharan Africa, as 90% of the land is rainfed rather than irrigated. As a result, maize yields are highly sensitive to seasonal rainfall [15]. Improved lines offered through the market include drought tolerant maize (DTMA) with an ability to withstand periods of acute soil drying and water efficient maize (WEMA) adapted to season-long reduced supply of soil moisture.

Figure 1. Drought tolerant maize variety (left) and drought sensitive variety (right).

Timely access to weather and market information and local climate adaptation measures provides a means for sound decision-making for when and where to invest in drought-tolerant maize. These same technologies allow maize to be produced in semi-arid regions with less irrigation water, allowing growers and national development planners to utilize less-traditional growing areas better. More than 200 lines of DTMA have been released in 13 African countries, and over 120 hybrids of WEMA released in seven countries. DTMA include hybrid varieties that require parent seed and licensing [16] and numerous open-pollinated varieties (OPVs). These latter varieties permit royalty-free purchase and multiplication through farmers' and community-based seed production.

These drought-tolerant varieties are introduced to farmers through on-farm demonstrations with broader coverage. This allows farmers to see the varieties in action and learn about their benefits firsthand. The main barriers to adopting DroughtTEGO® varieties are a lack of information about their productivity, unavailability of seed when needed, and the high cost compared to other locally available varieties [17, 18]. Oniang'o et al. [18] found that well-thought-out strategies to influence awareness and adoption of drought-tolerant maize include strengthening extension services, providing credit to small-scale farmers, investigating cases of discontinued use, improving access to seed through agro-dealerships, targeting age and gender, and specific agro-ecological zones.

2.2 Imazapyr-resistant maize for Striga management. Parasitic Striga invades the roots of maize and other cereals to remove water and nutrients from host plants. Maize cannot resist striga (Figure 2), causing stunting, abnormal growth, and small ears, and resulting in yield reduction of 30% to 80% [19]. About 20 million ha of farmland in sub-Saharan Africa is Striga-infested, resulting in over US $1 billion per year in yield loss and threatening the food security and livelihoods of over 100 million people [20]. Improved maize varieties that resist the herbicide imazapyr (the IR trait) are becoming available, protecting the roots against parasitic invasion [21]. Very low levels of imazapyr (e.g., 30 to 45 g per ha) are applied to maize seeds. However, the application rate is critical because too much imazapyr can harm maize germination and early growth. When used correctly, the herbicide is placed exactly where and when needed to control striga as it starts invading young maize roots.

Imazapyr herbicides are made from the active ingredient imidazoline, mixed with salt to form a stable powder. The herbicide is then coated onto maize seeds using an adhesive. An example of such seed treatment system is patented under the term StrigAway. IR maize seeds are planted following recommended soil and fertilizer management practices for a growing area. Imazapyr is non-toxic to mammals, but it is important to wear gloves or wash hands when planting the seed manually, as they may be mixed with insecticides. The spread of this technology across Africa has been slower than expected, given the scope of the problem. Where available, agro-input suppliers sell IR maize seed at about US $3 per kilogram. Yield increases of 1.0 to 3.0 tons of grain per hectare are achieved compared to comparable varieties not protected by imazapyr [22]. An additional benefit is that the Striga seed bank diminishes over time, eventually eradicating striga from croplands [23].

However, this technology is often too expensive for subsistence farmers. A more affordable option is to integrate imazapyr herbicide technology with other measures, such as planting soybean followed by striga-resistant maize varieties using nitrogen fertilizer and good agricultural practices [24, 25]. The adoption of this technology depends on several factors, including the age and education of the household head, the availability of training and support for farmers, membership in farmer group, the availability of the technology, perceptions based on the social and cultural context, and the political climate [26].

2.3 Vitamin A biofortified maize. Biofortified maize varieties higher in Vitamin A are also becoming more widely available. Maize is a staple food for over 300 million people across Sub-Saharan Africa; however, the widely grown starchy white varieties contain sub-optimal minerals and vitamins. Conventional breeding has improved the content of provitamin A in maize, offering a viable avenue to improve community nutrition. Golden maize contains beta-carotene, lending it a bright orange color (Figure 3). These compounds are converted into vitamin A after ingestion. More than 40 of these biofortified varieties have been released across Sub-Saharan Africa [27]. These varieties were originally developed from Central and South American lines naturally rich in provitamin A and then crossed with well-adapted lines holding improved agronomic traits such as disease resistance and drought tolerance.

Figure 3. Biofortified maize (center) rich in vitamin A compared to conventional yellow and white varieties (top and bottom).

Unlike biofortified lines, pro-vitamin A is often oxidized and forms off-flavors other maize varieties. Pro-vitamin A biofortified maize offers a cost-effective solution to Vitamin A deficiency in areas where people consume fresh and dried maize [28]. It provides half the daily Vitamin A requirement for adults and costs \$0.8 to \$1.2 per kg of OPV seed [29]. Golden maize contains 8 to 15 parts per million of pro-vitamin A, while conventional varieties do not have this nutrient. Biofortification of maize is a promising approach to combat micronutrient deficiencies in sub-Saharan Africa. Pro-vitamin A biofortified maize is a safe and effective way to improve vitamin A status, and it has been well-accepted by most communities compared to yellow maize, which has associated negative perceptions. With proper policy support, biofortified maize can help address the deficiency of vitamin A in this region. A study conducted by Nesamvuni et al. revealed that introducing a vitamin-fortified maize meal to the meals of African children aged one to three led to positive effects, such as better weight gain and improvements in specific aspects of their vitamin A levels [30]. Different varieties are available for cultivation in lowland and highland elevations and semi-arid and humid climates.

2.4 Information communication technology (ICT) platforms: Agricultural information is vast and covers many areas of expertise, depending on the specific agro-climatic zones and socio-economic contexts. To ensure its effective use, it is crucial to have a well-organized system for sharing this information. It is equally essential to disseminate the right information to the right people at the right time. Fortunately, with information and communication technology (ICT) advancements, we can leverage these tools to provide farmers with accurate, timely, and relevant information and services. This, in turn, helps them adopt new technologies more effectively and makes their agricultural endeavors more profitable [31]. Based on an analysis conducted by Ayim et al. [32], the primary ICT technologies used in Africa to improve agriculture productivity are text and voice-based services designed for mobile phones. The rise of smartphone technology, including apps, has also led to the development of innovations in the farming industry. Radio and television are also popular tools for sharing agricultural information with rural farmers. These can be as robust and interactive as virtual workshops and webinars where call-in segments, or SMS/text interactions are included to address farmer queries in real-time during the broadcasting. Computers are a gadget primarily utilized by researchers. ICT has enabled the development of dedicated websites, social media,

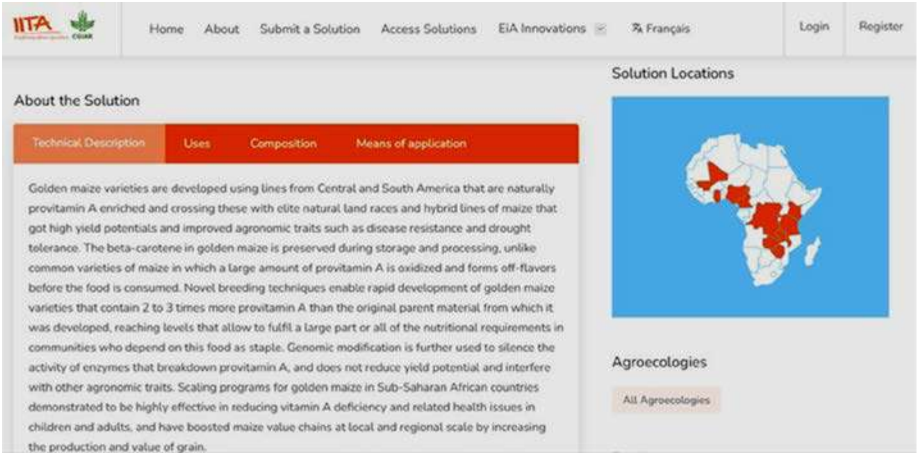

Figure 4. Output from the ProPAS website describing “golden maize”

mobile-based extension services, financial inclusion and mobile payments, and online communities to share information on agricultural technologies, including available technologies, coverage, best practices, pest and disease management, market prices, success stories, capacity-building events, and implementation guides, while also incorporating interactive features like search functions, discussion forums and chatbot for farmer engagement and query resolution by experts. Such channels include the TAAT website, https://taat-africa.org/, and the TAAT mobile app available on the App Store. Although there are many benefits to using ICT tools and systems in agriculture, most agricultural and farming communities in Africa need to adopt them to the extent necessary for significant agricultural development. Specific factors that hinder the widespread adoption and diffusion of these services include inadequate technological infrastructure, language barrier, affordability, unsuitable ICT policies, lack of awareness regarding the potential contribution of ICTs to the farm business, and a low level of user skills, particularly among farmers [33].

One such digital application relevant to maize-based systems is The Product Platform for Agricultural Solutions (ProPAS), offering open access information about innovative technologies in English or French. Each profile covers various aspects relating to the problems addressed, functional principles, geographic suitability, composition, application, customer segmentation, capital/operational costs, expected benefits, and licensing (see Figure 4). The platform has two goals; to provide technology holders with a means to disseminate their proven and promising solutions and encourage users to search through options that can assist their agricultural objectives (visit https://propas.iita.org/). The database allows filtering solutions based on multiple search fields such as relevant value chain, its form and type (i.e., genetics, input supply, management, equipment, and digital tools), location where available, and target beneficiaries. Fourteen of its solutions relate to maize, and another fourteen describe leguminous companion crops. In 2022, ProPAS received 27,207 visitors, of which 9.1% were profile views for maize technologies, and overall attracting the most attention to equipment followed by genetics, management, and input supply.

2.5 Commercial licensing systems. Limited investment by the commercial seed production sector impedes the availability of improved maize varieties to small-scale farmers across Sub-Saharan Africa. In response, The African Agricultural Technology Foundation (AATF) established a series of public-private ventures for the multiplication of high-yielding, drought tolerant TEGO® (conventional) and insect-protected TELA® (transgenic) maize hybrids. Seven African countries now produce seeds of these elite varieties, accompanied by a licensing model and agri-business training that now supplies millions of farmers through this mechanism [34]. Precautions are in place to ensure that this multiplication process ensures true-to-type seed with a high germination rate.

Hybrid maize varieties have a high market value and provide opportunities for businesses to generate investment returns from seed multiplication and developing new, improved lines. Significant increases in food and nutritional security and farm incomes are realized where TEGO® (Figure 5) [35] and TELA® seed systems are adopted because these varieties produce higher grain yield and quality than other cultivated lines under normal and lower rainfall. Royalty-free licensing results in new, improved maize varieties from public institutions becoming more rapidly available to farmers through commercial transfer rights to the private sector. This mechanism includes an agreement between the holder of intellectual properties for maize varieties and a legally eligible enterprise that intends to multiply and sell these seeds commercially.

Figure 5. TEGO® maize produced under commercial license.

Between 2013 to 2020, 7,032 tons of Drought TEGO® and 161 tons of TELA® hybrid seeds were sold and planted on an estimated 287,720 hectares of cropland to produce over 1 million tons of grain. This maize is valued at US $236 million, benefiting about 4.3 million people [34]. At the end of 2020, variety licenses were signed with 38 seed companies from seven countries to commercialize these elite TEGO® and TELA® maize hybrids and test new lines. In this way, the TEGO® and TELA® mechanism is intended to streamline the licensing process for elite, climate-smart maize and to link intellectual goods to commercial opportunities.

Stress-resilient crop varieties are often seen as inferior to regular hybrids, but this is a misconception. A multi-location evaluation study of stress-resilient maize hybrids by the International Maize and Wheat Improvement Center (CIMMYT) in Sub-Saharan Africa [36] found that stress-resilient maize hybrids produced yields that were on par with or even superior to regular hybrids under both favorable and unfavorable conditions. These hybrids are a good choice for farmers as they help to achieve more stable yields over time and to build a more resilient food system.

2.6 Contract mechanization services and applications. An increasing amount and variety of mechanized agricultural services are offered to farmers across Sub-Saharan Africa. Unfortunately, this contracted and rented use of mechanization services remains limited because contracting businesses experience difficulties in informing and convincing lower-income farmers of their value. Ironically, these contracted services provide labor-reducing operations through equipment beyond small-scale farmers' purchasing power [37]. African countries must develop favorable arrangements to make agricultural mechanization accessible to small and medium-scale farmers. This could be done by incentivizing the private sector to scale up agricultural mechanization initiatives and targeting and engaging women farmers and youth by investing in supportive infrastructure and training [38]. ICT applications can help farmers to access contract mechanization services by matching farmers with mechanization service providers, providing information about mechanization services, and tracking the progress of mechanization activities. For instance, data on the extent of land cultivated or harvested can be utilized to verify the fulfilment of mechanization services and ascertain whether farmers receive the expected benefits for their investments.

Nevertheless, there is a lot of debate about the role of mechanization and digitalization in African agricultural transformation. A study by Daum et al. [39] documented these concerns by national stakeholders in several African countries. Some argue that mechanization is essential for reducing drudgery, increasing productivity, and reducing poverty, while others say that it can lead to the displacement of rural labor and environmental degradation. Furthermore, there is a continued appeal for state-led mechanization in some countries, even though this approach has been criticized for being inefficient and corrupt. This has resulted in yet another debate about how governments should best promote mechanization in Africa. Some people believe that governments should provide subsidized tractors and run public hire centers, while others believe that the state should focus on creating an enabling environment for private actors.

On the other hand, digitalization is seen as a promising tool, but there are concerns about data sovereignty and the digital divide. Moreover, gender and age can influence how people view digitalization, with younger people and women being more likely to be optimistic about its potential. Therefore, policymakers and development institutions must consider local stakeholders' viewpoints to aid in selecting and designing the most promising policies/programs and ensure their effective implementation at the grassroots level.

Hello Tractor (Figure 6) is a success in this area, an award-winning equipment-sharing application that connects tractor operators to African smallholder farmers. This digital platform results in the collaborative use of mechanized field operations by creating a common marketplace between machine owners and

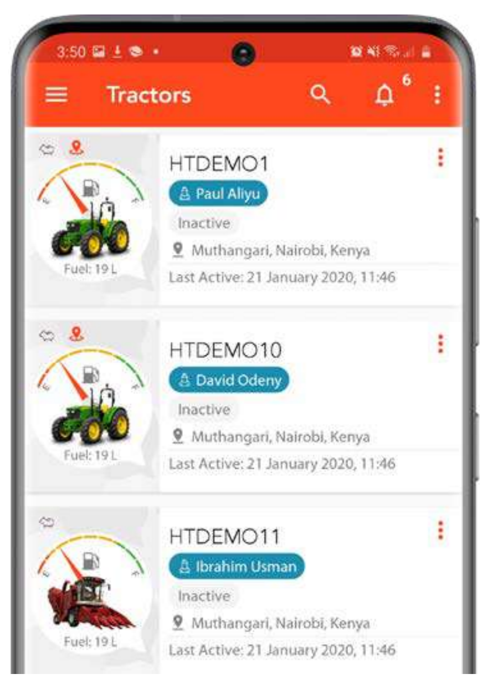

Figure 6. The Hello Tractor application accessible to farmers via a smart phone

farmers who request and pay for services via messaging. The smartphone application also supports credit scoring and provides market intelligence for risk management and loan repayment. This approach allows service providers to match seasonal demand for mechanization services and linked cash flows. Digital information and communication technology enable equipment owners to track the movement and use of their assets, expand their serviceable areas, and manage payment quickly and transparently. Reliable information and communication channels via smartphones allow clients equitable access to agricultural mechanization in ways that improve land productivity, reduce labor costs, and improve their incomes [40].

2.7 Pre-plant blended fertilizers and nitrogen topdressing. The right fertilizers must be applied at the right rate and at the right time, following best agronomic practices before smallholder maize producers across Africa can optimize grain yields. Shortages of soil nitrogen (N), phosphorus (P) and potassium (K) result in weak roots, stunted growth, greater vulnerability to pests and disease, reduced photosynthetic efficiency, fewer and smaller ears, and incomplete grain fill. Sub-Saharan Africa is facing food security challenges due, in part, to decades of soil fertility depletion. Applying mineral fertilizer, in conjunction with better management of organic resources and increasing Biological Nitrogen Fixation (BNF) can increase crop yields, replenish soil nutrients, and increases soil organic carbon sequestration, and reduces N and C losses. [41, 42]. Too few farmers in Sub-Saharan Africa use appropriate fertilizer formulations, dosages, and schedules, leading to lower yields, reduced profits, and nutrient-depleted soils [43].

Specialized blends of common fertilizers that contain N, P, K, and other nutrients such as sulfur, magnesium and zinc are developed for basal application to maize crops. Applying blended fertilizers before planting can help to ensure a more balanced availability of nutrients for maize crops. This is important because nitrogen fertilizer is one of the largest investments maize farmers make, and it can be lost due to drought or excessive rainfall. To overcome this inefficiency, it is widely recommended that nitrogen fertilizer be applied in two or more split applications throughout the growth cycle. This practice ensures that crops have a continuous supply of nitrogen, which can help to mitigate financial risks to farmers and improve yields [46].

Figure 7. Dry rotary system used in small-scale fertilizer blending.

Many agro-dealers and manufacturers offer specially designed pre-plant fertilizer blends for maize. These formulations are adjusted to local growing conditions and soils and promote early crop development, stress resilience and grain production by effectively delivering nutrients throughout the growing season. Top dressing N fertilizer later in the season better matches soil availability to the demand pattern of maize crops (Figure 7). The optimum time for top-dressing N fertilizer is when maize crops have eight to ten fully developed leaves. In this way, African farmers can obtain higher maize yields with lower rates of nutrient inputs when using blended fertilizers at planting instead of single fertilizers and splitting their nitrogen applications instead of a one-time input.

2.8 Maize-legume rotation and intercropping. Growing maize and grain legumes together as intercrops or in rotation offers many advantages compared to growing maize continuously as a monocrop [47]. Legumes increase nitrogen (N) in soils through biological nitrogen fixation and subsequent mineralization and can be used to offset the N requirements of the maize crop. Rotation and intercropping legumes with maize (Figure 8) improve the efficiency of land, nutrient and water use due to synergistic effects between the crops [48]. Mixing maize and legumes also reduces the infestation of weeds, pests and diseases in farmers' fields. Intercropping is crucial for small and marginal farmers in numerous countries as it diversifies and mitigates risks, improves the efficiency of land utilization, enhances soil fertility, and boosts economic returns, particularly in unpredictable weather conditions [49].

Figure 8. An innovative, staggered maize-soybean intercrop

Large numbers of farmers in major maize production areas across Sub-Saharan Africa practice maize and legume rotation and intercropping, substantially increasing maize and legume yields and total harvests from a given land area. Growing a high-energy crop such as maize with high-protein legume results in improved diets among small-scale farmers and mitigates the risk of a hunger season when one of the two crops may fail because of drought or pest attacks. Biological nitrogen fixation in the root nodules of legumes benefits the productivity of maize crops rotated in the same field because part of the assimilated nitrogen is transferred between the crops through the decomposition of legume residues [50]. Mineral fertilizer application in mixed cropping systems is used very efficiently since either of the crops can benefit from residual nutrients that might have otherwise been lost due to the different root depths and distribution of maize and legumes [51]. Maize and legume intercropping is beneficial by reducing weed infestation, soil erosion, and run-off. This plant arrangement increases crop coverage and protection throughout the growing season.

Legumes can offer other advantages to maize crops. For example, soybeans and cowpea can help to reduce parasitic striga weed infestations. This is because these legumes induce the germination of Striga seeds, but the weed does not infect them. Taller-statured maize benefits the legumes by better-regulating soil temperature soil through shading. However, understory legumes compete with maize for light, water, and nutrients. Intercropping can be a good way to increase maize yields and generate larger returns to labor. However, some challenges are associated with intercropping, such as careful crop selection and spacing. Additionally, some field operations, such as mechanization and chemical weeding, can be more difficult with intercropping systems [52].

2.9 Pre-emergent herbicides for weed management. Weeds can compromise maize croplands by competing for limited soil water and nutrients. Uncontrolled weeds can reduce yields and limit returns on agro-input investments. Controlling weeds in maize is critical, particularly during its early establishment and vegetative growth phases that extend to 10 weeks or so after planting. Without effective weed control, maize yields can be reduced by up to 50% on average [53], and losses can reach 80% if no measures are taken. In Africa, most smallholder farmers weed their maize crops by hand, a labor-intensive practice that must be repeated 2 or 3 times to be effective. This is because shallow hoeing can agitate the soil and promote the germination of weed seeds. Pre-emergent herbicides can help to reduce labor requirements by eliminating the need for hand weeding and help to improve soil quality by reducing the need for tillage, which can damage soil structure.

Figure 9. Weedy (left) and weed-free maize understory.

Pre-emergence herbicides prevent weeds from developing and allow fields to remain weed–free through the critical stages of crop establishment (Figure 9). This is important because it prevents weeds from competing with the maize crop for water, nutrients, and sunlight, which can help to reduce crop losses. This effect continues until the maize canopy shades the ground and weeds become suppressed [54]. This class of herbicides is applied shortly before or when planting maize and after the soil has been tilled. This technology prevents weed seedlings from establishing but requires that the proper chemicals are affordable, and that application equipment and safety gear are available. Some weeds emerge in most maize fields after crop establishment during the latter vegetative stage. These late-season weeds are effectively controlled by spraying recommended post-emergence herbicides to keep the fields clean until harvest, further enhancing maize productivity. Maize is very sensitive to competition from weeds between the emergence up to the unfurling of six leaves. During this time, maize's fibrous root system is under development, and its shoots may become outcompeted by faster-growing plants. Maize gains the upper hand against weeds with pre-emergent herbicides. These herbicides remove the competition for light, nutrients, and moisture during maize's vulnerable initial growth phase. This, in turn, speeds up the growth of both roots and shoots.

2.10 New and emerging pest control practices. Fall Armyworm (FAW) invaded Africa in 2016 and continues to damage maize and many other crops (Figure 10). FAW is an aggressively damaging invader that afflicts the entire continent and affects numerous African crops [55]. Approximately US $13 billion worth of crops are at risk throughout Sub-Saharan Africa, threatening the livelihoods of many millions of smallholders [56]. FAW are the caterpillars of the invasive species Spodoptera frugiperda, and this destructive insect continues to spread across Sub-Saharan Africa [57]. Infestations of farmlands by the pest are caused by eggs deposited in soil and on the plants coming from adult moths that can fly and cover large distances. FAW larvae inflict extensive damage to maize crops at all life cycle stages by eating the whorl (apex), leaves and ears, resulting in 50% yield loss or complete crop failure. Effective chemical control agents for FAW are known, but the pest has nonetheless spread across the continent and is threatening millions of farmers in major production zones.

Figure 10. Severe damage to maize inflicted by the Fall Armyworm that has recently invaded Africa.

A range of insecticide products are marketed on the continent by agro-input suppliers that kill larvae of FAW inside the soil and on the plant [58]. Coating maize seeds with insecticides protects the young maize plant from pest attack by enhancing seed survival, germination rates and initial growth stages after planting [59]. Using insecticide as a seed treatment offers several advantages compared to foliar applications. The approach makes it possible to apply smaller amounts of the control agent and is positioned into the soil where eggs of FAW are deposited and hatched. FORTENZA® Duo seed coating technology from Syngenta has been demonstrated to be a powerful control agent for FAW and has been used to treat more than 3,000 tons of maize seed in Zambia. Coating maize seeds is simple: mixing insecticide with a binding agent like gum Arabic, vaporizing it over the material, and letting it mix and dry in a rotary blending system. After treatment, the seed retains protective properties and provides a sufficient defence to the young seedling against FAW and other pests below and above the soil surface. Insecticides recommended for use as foliar spray later in the growing season are Ampligo® (chlorantraniliprole + lamba cyhalothrin), DenimFit® (emamectin benzoate+lufenuron) or Neconeem® (neem). It is vital to detect FAW infestations early so that control measures can be implemented before the pest causes too much damage.

2.11 Aflatoxin management. Common species of the soil-dwelling fungus Aspergillus flavus infest farmers' crops and foods, producing a highly toxic, cancer-causing poison called "aflatoxin" [60]. Widespread and severe contamination of several key staple crops, animal feeds and processed foods occurs across Africa as a combined result of conducive weather conditions, extremely potent fungal strains, and substandard post-harvest handling and storage practices. In Africa, aflatoxin occurs not only in maize (Figure 11) and groundnut, where it poses a serious public health challenge, but also in cassava, sorghum, rice, and cashews, among others. When contaminated food is consumed by humans or livestock, aflatoxin accumulates inside the body and causes major damage to internal organs and blood. This toxin causes liver cancer, weakens people against other diseases and stunts growth of children. Animals such as cows, pigs and chickens are also affected by this toxin, and their milk, meat and eggs become contaminated and unsafe for consumption. The aflatoxin pandemic in Africa has massive economic impacts by making food unfit to eat or trade, robbing humans of their health, and stunting and killing farm animals.

Figure 11. Infestation by *Aspergillus flavus* causing maize to be unfit for consumption.

Biocontrol technologies for aflatoxin exist that rely upon natural competitors rather than industrial chemicals. These agents were safely and effectively adopted on increasingly large farmland areas over the past decade [61]. Aflasafe® is a product made in Africa that substantially reduces aflatoxin levels in food and is inexpensive and cost-effective to purchase and apply (Figure 12). The active ingredients of Aflasafe® are atoxic strains of Aspergillus flavus that do not produce the toxin. Combinations of four different strains are combined for each country by screening thousands of candidate strains recovered from local environments. Aflasafe® products are broadcast across crops two to three weeks before the onset of flowering. Alternatively, the product may be applied onto the soil using a tractor-mounted spinner [62]. Different Aflasafe® products are produced and marketed in Burkina Faso, Ghana, Kenya, Malawi, Mozambique, Nigeria, Senegal, Tanzania, The Gambia, Uganda, and Zambia. Additional countries are in the process of identifying and registering biocontrol agents and constructing production facilities. Manufacturers of biological control technologies for aflatoxin must gain approval to use certified strains of atoxic fungi and comply with national regulations concerning the production, distribution, and release of microbial agents. Farmers do not require permits to apply Aflasafe® to their fields. The atoxic strains of A. flavus used in biocontrol are never copyrighted. However, they remain the genetic resources and property of the countries where they are developed for use as a public good. The IITA Business Incubation Platform is responsible for further developing and extending Aflasafe® across Sub-Saharan Africa.

Figure 12. Packaged Aflasafe, a product able to reduce the threat of mycotoxins.

2.12 Post harvest management technologies: In Africa, post-harvest management technologies for maize focus on reducing losses and maintaining grain quality. These technologies include drying methods such as solar and mechanical dryers and improved traditional drying techniques. Storage precautions such as hermetic bags, metal silos, and plastic drums are utilized to protect maize from pests and moisture. Grain cleaning using mechanical grain cleaners or sieves helps remove impurities. Maize processing technologies, such as milling machines and dehullers, are employed to transform maize into different products. Integrated pest management techniques and quality testing tools ensure pest control and quality assurance. These technologies minimize post-harvest losses and improve the value of maize crops.

Hermetic bags are a type of storage technology with a three-layered design. The outer layer is made of woven polypropylene and provides the necessary strength to support the weight of the stored grain (Figure 13). Inside, there are two inner bags made of high-density polythene. These inner bags are specifically designed to have extremely low gas permeability and are water-resistant. The production process of hermetic bags involves converting melted polypropylene into string form, which is then wound to create the polypropylene woven outer bag. A knitting machine weaves the string into the desired bag shape. For the polyethylene inner liners, recycled or raw plastic is melted and shaped into a thin layer, which is then cooled. The plastic is then combined into rolls and cut into the appropriate sizes for the inner bags. The purpose of hermetic bags is to create a barrier that prevents air and moisture from entering the stored grain. By cutting off the supply of oxygen, these bags effectively eliminate insects and microbial organisms, thus preserving the quality of the grain and reducing stored grain losses. They can provide storage for up to two years. Additionally, hermetic bags have gained cultural acceptance and are widely adopted by African farmers [63, 64].

Promoting hermetic bags prevents food loss and offers economic benefits to farmers and improved health outcomes due to reduced pesticide use and potential aflatoxin intake reduction. A study by Ndengwa et al. [65] found that compared to conventional methods, hermetic bags significantly curbed insect-related damage and weight loss with only 4% grain damage and 0.4% weight loss compared to the traditional practices group's 14% damage and 1.7% loss, over a crucial four-month storage period. The study also highlighted the potential profitability of hermetic bags with at least four months' seasonal usage across four seasons. Similarly, when produce quality is less crucial for a farmer's consumption, Dijkink et al. [66] reported that utilizing hermetic bags becomes economically advantageous compared to alternative storage methods for produce stored for more than 100 days.

Figure 13. Many different brands of hermetic grain storage bags are now available through agrodealers.

3. Delivery of Modernizing Technologies

Developmental importance is attached to how proven, accompanying maize technologies are packaged for deployment and then managed as transferable assets within large programs and institutions [12, 67]. These technologies exist as production inputs, crop and land management options, and opportunities for contracted services. Combining these technologies into packages that result in improved yields offering reliable, profitable returns, and then scaling these packages to increasingly larger adopters may be viewed as central to agricultural transformation strategies, and major programs and institutional innovations are forming around this goal [11, 67, 68, 69]. In some cases, farmers are committed to older and traditional varieties for reasons other than their productive capacity or marketability, and efforts may be directed to convincing them of a need for change [70].

3.1. Follow Up to the Dakar 2 Summit. The agricultural development community must mobilize and sustain country and development partners' commitment to agricultural transformation. To do so, Regional Member Countries of the African Development Bank first presented individual Country Food and Agriculture Delivery Compacts at the Dakar 2 Summit [71]. These planning documents are being formalized into standardized Agricultural Transformation Agendas through assistance from international development partners. Presidential Advisory Councils supervise each of the Country Compacts (see Box 1) led by the Head of State or their directly appointed representative and then report to the AfDB President through a Special Envoy. This mechanism is intended to provide high-level policy guidance toward the Feed Africa priorities. Several policies are associated with successful efforts toward agricultural transformation, including progressive regulation of seed systems, duty-free entry of agricultural inputs and equipment, ready movement of production inputs across borders, special incentives and provisions for agricultural loans, and others. Tracking the establishment and operations of the Country Compacts ensures that the necessary ingredients and actors needed for agricultural transformation are in place. The Dakar 2 process also involves working with key funding partners and the private sector to mobilize additional resources. The first challenge is to ensure that funds pledged for agricultural transformation materialize, and this is best accomplished by building confidence among different potential contributors that timely and significant progress is being made. In some cases, the Country Compacts represent a means to consolidate and more efficiently organize various, and sometimes underperforming, agricultural development projects. Notably, underspending of past loans and grants because of disruption by the COVID-19 pandemic still occurs, and it is important to see these projects incorporated into and revitalized by the Country Compacts.

3.2. Emergence of the African Agricultural Leadership Institute (AALI). AALI was formed shortly after the Dakar 2 event, led by the departure of the IITA Director General after 11 years of service. AALI's Strategy is embedded in a vision of establishing a new paradigm in the leadership of African agricultural development, resulting in accelerated agricultural sector modernization. AALI's agenda consists of three Primary Objectives:1) Provides advisory services to African governments seeking to modernize their agriculture and better implement their rural development agendas; 2) Empowers youth as agricultural producers, service providers and processors and restores agriculture as an attractive career path; and 3) Transforms agriculture through private sector growth resulting in the introduction of new technologies, needed production inputs and a next generation of service providers and agro-processors [72]. Achieving this agenda requires an enabling environment that helps countries expand agricultural growth through higher productivity on existing farmland, encourages strategic alliances within the continent and revives the capacity for agricultural research and development through innovative problem-solving. Success requires that AALI operate an efficient internal organizational structure that guides the emergent Country Food and Agriculture Delivery Compacts emerging from the Dakar 2 Feed Africa Summit to establish precedents that guide agricultural transformation. Two of its foremost Objectives related to propelling the Dakar 2 Summit process forward relate to supporting African governments to develop innovative delivery mechanisms that translate vision and intent into concrete actions and benefits and guide current and future African political leaders and civil servants to acquire the leadership

Box 1. Declaration summary extracted from the Dakar 2 Feed Africa Summit

ACKNOWLEDGE that the Country Food and Agriculture Delivery Compacts developed at this Summit, were prepared and are owned by African countries, which convey the vision, challenges, and opportunities in agricultural productivity, infrastructure, processing and value addition, markets and financing that will accelerate the implementation of the African Union's Comprehensive Africa Agriculture Development Program (CAADP);

AGREE that it is time for Africa to feed itself and fully unlock its agriculture potential to help feed the world;

HEREBY RESOLVE to undertake the following:

Finalize the development of the Country Food and Agriculture Delivery Compact endorsed at the Dakar 2 Summit in collaboration with country stakeholders, development partners and the private sector to achieve food security and self-sufficiency;

Establish Presidential Delivery Councils to oversee the implementation of the Country Food and Agriculture Delivery Compacts;

Support the implementation of the Country Food and Agriculture Delivery Compacts with time-bound and clearly measurable indicators for success, including concrete national policies, incentives, and regulations to establish an enabling environment for wider and accelerated investments across the agriculture sector;

Mobilize internal and external financing for the Country Food and Agriculture Delivery Compacts from a broad range of bilateral and multilateral partners and the private sector;

Increase financing from national budgets to support the Country Food and Agriculture Delivery Compacts in line with the Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods by allocating at least 10% of public expenditure to agriculture; and

Request that the African Union Commission and the African Development Bank follow up with various development partners to finalize their planned financial support to complement the $30 billion of financing announced at this Summit (now $70 billion) and to report on the overall investment of development partners; and ensure that the Dakar 2 Summit's Declaration is submitted to the February 2023 African Union Summit for consideration.

skills required to mobilize rural communities and to achieve pressing rural development agendas more successfully.

3.3. IITA's Partnerships for Delivery Directorate. The Partnerships for Delivery (P4D) Directorate aims to establish sustainable impact at scale and continues to expand rapidly in size and complexity. The Directorate operates under the authority of the IITA Board of Trustees and the supervision of the IITA Director General under the leadership of its Deputy Director General. It includes project and administrative support mechanisms provided to six Delivery Units: Development and Delivery, Youth in Agribusiness, Business Incubation Platform, Mechanization, Capacity Development and Communications. Each of these Units supports customized programs, projects, activities and networks. P4D responded to two major opportunities: the unfolding of the One CGIAR agenda and the Dakar 2 Feed Africa Summit. The design of P4D is proving itself very strategic. Its Development and Delivery Unit is no longer a catchall for miscellaneous projects but has become a leader in Agricultural Transformation through its linkages to sovereign country loans and significant rural development efforts. The Youth in Agribusiness Unit [73] is no longer an exploratory curiosity but rather a platform for investment in the critical empowerment of young women and men through various approaches attractive to donors and national systems. With private partners, the P4D has proven to be a driving vehicle for increasing agricultural productivity by scaling technologies, promoting value chain development, and building economically sustainable seed systems. The Business Incubation Platform [74] has become the conveyor of proven technologies to the private sector while at the same time pivoting its orientation toward social enterprise in keeping with IITA's humanitarian principles. Maize is one of the focus commodities across all these efforts.

3.4. Technologies for African Agricultural Transformation (TAAT). TAAT was launched in 2018 and renewed in 2022 through awards from the African Development Bank and the Bill and Melinda Gates Foundation. IITA is the executing agency of TAAT. [12]. It is an integral component of AfDB's Feed Africa Strategy [11] and was well represented at the Dakar 2 Summit. TAAT ensures agricultural sector growth, improving food security and encouraging inclusive growth by involving more women and youth in profitable agricultural production and processing. Its larger goal is to improve agriculture as a business across Africa by deploying productivity-increasing agricultural technologies within nine priority food commodities: maize, cassava, wheat, rice, sorghum and millet, orange-fleshed sweet potato, high iron beans, aquaculture, and small livestock [12, 75]. By focusing efforts on these value chains, TAAT impacts agricultural productivity and diversification, leading to improved food and nutrition security, job creation, and agro-industrialization. Other benefits are reduced vulnerabilities to market price fluctuations due to more reliable supplies leading to better organized and accessible markets, improved soil, land and water management practices, and increased resilience to climate variability and stress. TAAT's technologies are described through a series of Technology Toolkit Catalogues, including one devoted to modernized maize production [52].

TAAT's Maize Technology Delivery Compact is mainly active in the savanna agro-ecosystems of East and Southern Africa. TAAT delivered water-efficient maize to 5.6 million households in Eastern Africa, an area hit by severe droughts. In Zambia, Zimbabwe, and Malawi, a TAAT-led collaboration with 15 private-sector seed companies reached 600,000 farmers with 6,000 MT of drought-tolerant maize varieties (see Section 2.1) treated with specialized dual-purpose pesticides with demonstrated capabilities to control Fall Armyworm (see Section 2.10). TAAT promotes seed treatment with Fortenza Duo (FD) to combat invasive Fall Armyworm (FAW). In Zambia and Zimbabwe, TAAT deployed 6,598 metric tons of certified maize seed treated with Fortenza Duo through government programs and reached 660,000 beneficiaries. An internal report of an impact study commissioned by TAAT found a 1.5 MT/ha yield improvement among farmers that used the FD-treated seeds compared to those that did not.

3.5. DR Congo Agricultural Transformation Agenda. The Agenda for the Transformation of Agriculture in the Democratic Republic of Congo (ATA-DRC) is fulfilling a Presidential promise to modernize agriculture [69]. The Government appointed IITA to lead this Agenda in early 2022. While it has a nationwide mandate, its first phase commenced in five carefully selected locations, focusing on maize, beans, soybeans, cassava, rice, banana, and aquaculture, the first three of which are particularly important within maize-based systems. It increases agricultural production by using improved crop varieties and building a solid seed system in close collaboration with the national agriculture research system and regulatory bodies. In addition, ATA-DRC provides other production inputs and good agricultural practices and adds value at the community level by engaging private sector operators in ways that build agro-industrial capacity and reduce food imports. Its goal is to create wealth and jobs through modernized agriculture by consolidating and building upon IITA expertise and several ongoing and planned future development projects. IITA works closely with Bio Agronomic Business (BAB), appointed as a national counterpart by the Ministry of Agriculture, with initial attention focused on realizing the potential of large state farms in different parts of the country.

In its short lifespan, ATA-DRC has produced some remarkable results. Starting with the 2022-2023 growing season, this program established 1,518 ha into modernized crop production, including 547 ha of maize, 864 ha of cassava, and 81 ha of soybean. Most of this area is on previously underperforming state farms (83%) but with increasing attention on establishing vibrant out-grower networks. Seed production occurs on an additional 434 ha, including 188 ha of IITA's improved cassava varieties, soon destined to provide about 38 million cuttings. To date, 979 tons of improved maize, soybean, bean, and rice seed were produced for distribution to national partners. IITA's Semi Autotrophic Hydroponics (SAH) Technology is producing improved, disease-free cassava plantlets in two locations and is drawing investors to expand the SAH technology to other sites. IITA expertise is applied to existing cassava processing facilities, increasing production of High-Quality Cassava Flour from negligible to 4 tons per hour. This engineering expertise is also used in the milling of grains and will be applied to the production of animal feeds and biogas. Organizing the "Brigade du Pain" allows cassava flour to substitute for imported wheat flour across hundreds of bakeries partially. Over 100,000 fish fingerlings were produced in Kinshasa to promote aquaculture, and 10 tons of Aflasafe were made at the IITA Kalambo factory to spearhead food safety (see Section 2.11). DRC-ATA has put in place the essential building blocks to create impact at scale in the short run, including improvements in the maize value chain.

The agenda is charting a proven pathway to modernized agriculture across DRC in close collaboration with its national counterparts and private sector operators. It works with a Special Advisor to the President and even consults directly with H.E. Felix Antoine Tshisekedi. Seed systems gains are moving toward private and community-based seed producers. The production and processing facilities at the state farms are unlocking great potential to serve as the models for public–private partnerships, demonstrating the profitability of agro-processing to lure further private sector investment. Out-grower networks are forming around these facilities to ensure an adequate and reliable supply of raw materials and access to steady markets. IITA also partners with the African Agricultural Leadership Institute at the national level to engage in promoting a conducive policy environment and, at the field level, has been instrumental in establishing a nationwide "Brigade des Jeunes" (Youth Brigade) based in part upon many of the approaches of the IITA Youth Agripreneurs [73]. Farm mechanization is essential for scaling up operations, and the Brigadiers have introduced small-scale fields and processing equipment to help achieve this. Most importantly, DRC-ATA serves as an example for scaling operations to be replicated by the Dakar 2 process and its Country Compacts, starting with efforts in DR Congo.

4. Conclusions

This Chapter provides a short history of maize in Africa, including its importance as a staple food, and identifies various accompanying technologies for modernizing maize production. It then describes some unfolding mechanisms to deploy these technologies within larger development thrusts. The Chapter features high-yielding varieties that resist drought and pests and those that improve their nutritional value. It provides opportunities for supplying improved maize seed through recent mechanisms for commercial licensing and access to mechanized agricultural equipment and contracted services through digital agriculture platforms. It highlights fertilizer and soil nutrient management advances in maize-based systems, including pre-plant and top-dress fertilizers and legumes, to increase soil nitrogen stocks. Advances in weed management include the use of speciality and pre-emergent herbicides. It also provides insights into the control of invasive Fall Armyworm. It further features biotechnology that prevents aflatoxin contaminants from entering food systems. Maize grain is an important human food, but it can also be processed into high-quality flour and starches from which various products are manufactured. In addition, maize stover is widely used as fodder for livestock and important for practices like mulching and the maintenance of soil organic matter. Technologies featured in this Chapter offer the means for farming communities in Africa to access the high-end of the maize value chain and its global marketplace, improving returns to both small-scale farmers and commercial agribusinesses. The Feed Africa Strategy of the African Development Bank, the partnership galvanized around that

Strategy and the momentum achieved through the recent Dakar 2 Summit are viewed as a promising means to deploy these technologies.

The authors note with concern that The Democratic Republic of Congo (DRC) is currently experiencing a maize crisis because national demand now far exceeds domestic supplies. Its government seeks a combined federal, international, and private sector response. Maize production for the DRC has grown from 306,000 MT in 1971 to 2 million MT in 2020, increasing at a rate of 4.5% per year. This growth was caused more by expanding land under cultivation rather than improving maize productivity. Land area under maize cultivation increased from 1.5 million ha in 2001 to 2.9 million ha in 2021, but maize yields remain low, averaging only 0.8 MT per ha. As a result, maize deficits of about 2.8 million MT developed, a shortage that was largely addressed through importation from Zambia. But Zambia recently halted maize exports to cope with its own domestic shortages. As a result, the cost of maize flour on RDC has skyrocketed, increasing in some parts of the country from US $0.45 per kg a few months previously to $1.61 per kg in May 2023. A recent communication from the Deputy Prime Minister in charge of the economy stated, "The causes of this situation include the shortfall in local production in line with demand, restrictions on Zambian exports and high import costs, as well as the deterioration of climatic conditions, which affects agricultural production in the sub-region". Recent outreach efforts by ATA-DRC providing farming communities in Kasai and Lualaba with improved maize management practices resulted in yields of 1.7 MT per ha, a readily achieved increase of 112%. More concentrated efforts relying upon improved varieties, judiciously applied pre-plant and top-dressed fertilizer, better weed control, and other technologies described in this Chapter readily achieve 3 MT per ha yields. In this way, maize production in DRC may be improved by 2.6 to 6.4 million tons per year provided technologies described in this Chapter are scaled through increasingly available agricultural transformation processes.

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