Biotechnology Adoption in Sub-Saharan Africa

Michael Baihua Midling
Department of Economics '12
Walter A. Haas School of Business*

Abstract

The majority of Africans still live in rural areas, and an astonishing one in three Africans, or 215 million people, are malnourished. At the same time, eleven African countries use less than half the arable land within their borders. 62% of Africa's population (excluding South Africa) works in agriculture, generating 27% of these countries' GDP. Over 80% of Africans depend on subsistence agriculture to provide food for their families. An agriculture-led strategy for economic growth is one of the best ways to alleviate poverty on the continent. Not only are the direct effects powerful due to the huge number of Africans employed in agriculture, but the indirect effects of improved agricultural output and efficiency can also have a multiplier effect on the economy. Increased production can lower staple food prices, increasing purchasing power parity for consumers thereby allowing Africans to divert spending onto other products. A more reliable food system increases political stability and the welfare of the general population. In many of the faster growing African countries over the last few decades, agricultural growth rates were highly correlated with overall GDP growth. This paper will examine how technology transfers can improve agricultural productivity on the African continent, being sensitive to problems associated with each proposed solution. Through several case studies, this report will provide a comprehensive overview of the current obstacles and available solutions that shape national and international policy decisions.

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Introduction

The world's poor feel the effects of rising food prices more acutely than any other economic variable. The 21st century has seen a dramatic increase in food demand. A rising middle class in China and other developing countries puts strain on many food staples and new pressures on luxury foodstuffs like meats and fish. At the same time, there is less and less untapped arable farmland to utilize. To compound matters, a global push for renewable energy sources has picked biofuels as one of the front-runners, driving down the amount of available land even further. Rising food prices puts tremendous strain on lower-income countries that depend on commodity and food prices to maintain their economies. Food security has again become an important issue.

There has been a surge of investment in African farmland, which houses most of the world's remaining untapped agricultural land. The main drivers behind this massive land grab in the last few years are biofuel production and food security. The primary countries that have leased land to foreign countries include Sudan, Mozambique, Ethiopia, and Mali. The primary buyers of these leases are from the Middle East and Asia, with countries like UAE, China and Korea leading the way. Investments in many African countries are seen as incredibly risky, as coups and unpredictable authoritarian regimes make many resource-rich Sub-Saharan African (SSA) countries extremely volatile. African farmland has not experienced the great agricultural advancements or "Green Revolutions" that the developed world, and even many parts of the developing world, has already enjoyed. Increased utilization of fertilizers, heavy machinery, and other technologies can greatly improve crop yields. Technological productivity advancements are available, yet countries lack the funds to pursue them. The governments of African countries are trying to make their land attractive to foreigner investors; however, political instability and lack of infrastructure have proved to be major hurdles.

There is not a single solution for bringing African agriculture into the modern age. Herbicide-resistant strains of weeds have been increasing, as have pesticide-resistant insects. Increased use of fertilizers can help improve yields, but at the same time they are often overused and pollute the environment with excess nitrogen. Some areas would benefit from more basic growing practices such as crop rotation, green fertilizers, and modern horticulture techniques. There is a growing chorus of programs and organizations that decry the massive monocultures utilization methods employed in western countries. Critics malign the monoculture system, often referring to it as "outdated 20th century techniques," for destroying biodiversity and jeopardizing the future of sustainable agricultural growth.

Any solution for Africa, however, will depend on increasing its production capabilities in agriculture. Africa has a comparative advantage in agriculture: it has factor endowments relatively rich in unskilled labor and natural resources. Compared to the manufacturing sector, the African agricultural sector is also less constrained by lack of infrastructure, telecommunications, security, etc. Thus, improving agricultural output can have powerful effects on economic growth and poverty alleviation on the African continent, and represents the most important sector of investment. So far African states have failed to allocate sufficient capital to improving and building infrastructure and utilizing

foreign investments. Despite a poor track record, recent trends should make investors much more optimistic for long-term growth. Many African countries are now seriously considering biotechnology investments for long-term agricultural growth. African countries should develop higher-yielding crop varieties, attract investments to improve infrastructure, and utilize more efficient farming systems. The biotechnology revolution and the information revolution provide all the tools African countries need to accelerate growth through agriculture, while a new wave of foreign direct investment can provide access to these tools.

Background

Over the last several years Africa has seen a massive influx of investment into its farmland. As oil price shocks have led to food riots across the world, food security and access to low price food are increasingly important. At the same time, African governments are looking for foreign investment to boost productivity of their farmlands, as many governments lack the financial resources to create the infrastructure needed. World Bank FDI policies have played a major role in encouraging the transfer of land. The World Bank has encouraged the access, utilization, and the development of agricultural land through its International Finance Corporation (IFC) and Foreign Investment Advisory Service (FIAS) arms. Over the last several years the IFC/FIAS has overseen huge foreign takeovers of land, transforming underused land into more productive ventures [8]. The two big benefits are budgetary relief for poor African governments and technology transfers. Private investment is bringing infrastructure, machinery, and modern growing technology to developing countries. However, there are also conflicts with how the land deals are being created and whether or not they are mutually beneficial for participating countries.

Land lease abuses are proving to be common; similar cases are being reported in various African countries. Southern Sudan is currently the target of numerous foreign investors, buying tracts of land that add up to an area larger than Rwanda. A Norwegian aid group examined 28 land deals, and found that land ownership laws were frequently violated [29]. They reported that there is little evidence food produced at large corporate farms will be sold in local markets, essentially denying local populations access to their own resources. Local communities are rarely, if ever, consulted about the land deals, which can potentially lead to conflict over the leases down the road. One of the main problems with the land grabs is that oftentimes multinationals leave the original farming families of the lands outside of the benefits. The food produced is exported, and the infrastructure created is largely used for the company alone. As a result of the heavy land grabs in developing countries over the last several years, the UN has developed sets of principles to guide foreign investments: respecting land rights, ensuring food security, and promoting transparency. The definition for available arable land is unclear, as oftentimes the ownership rights of local farmers are disregarded entirely.

For example, in Mali over 2 million acres of farmland have been leased to Chinese, Libyan, and South African firms, many deals whose contracts have not been made public. The opposition party, the Party for National Renaissance, is claiming that thousands of acres of Malian farmland are given away practically for free. Entire families have been removed from their lands due to large

multinationals moving in, and many are not being properly compensated. Proponents of foreign private investment are citing that Mali simply doesn't have the financial resources to properly access their national resources. Despite having good, fertile land around the Niger River, the Malian government doesn't have the infrastructure built, and much of the land lacks irrigation structure. Private corporations such as Libyan Malibya, South African Illovo Group, and the Chinese project N'Sukula have been granted massive land holdings in the hope that with the land leases will come infrastructure developments needed for agricultural growth [34].

One of the primary concerns is why so few of the land deals have actually led to agricultural production. The World Bank reports that only 21% of the 115 million acres of land purchased in Africa by foreigners has actually led to active farming operations [35]. Firms are buying extensive land tracts, more than they plan to use in the near future, to lock up land at low prices for future use. Africa's agricultural land is expected to appreciate as supply dwindles so firms are staking their claims early, without explicit plans for development. Another concern is whether the companies will provide employment for the local labor force or only employ their own labor force, reducing the benefit for the host nation. Finally, the benefits of large-scale production are often lost because corporations export large percentages, if not all, of their production abroad [35]. These issues will be further explored in the *Case Studies* section of the paper.

Conventional Considerations

According to African farmers, the most important necessity for agricultural advancement isn't access to high quality seeds, rather it is access to water, equipment, credit, and, critically, remunerative prices. In 2002, UN secretary general Kofi Annan stated "African agriculture is more likely to experience numerous 'rainbow evolutions' that differ in nature and extent among the many systems, rather than one Green Revolution as in Asia" [26]. Unlike the Asian Green Revolution of the 1960s and 1970s, there is no magic bullet for developing African countries. In Asia, there were extensive areas of irrigated land with similar geographic conditions and only a few dominant crops. Additionally, good political and financial institutions were in place. All of these conditions allowed for Western agricultural technology to facilitate a production boom in Asian countries. High-yield seeds, pesticides, fertilizers, and irrigation techniques allowed for rapid expansion of production. In Africa, the setting is very different. Africa lacks the political and financial institutions for adoption or adaptation of western technologies. Lack of roads, hospitals, and basic education ties the hands of weak government institutions, making progress difficult. An overwhelming percentage of African crops depend on rainfall; only 3.5% of Sub-Saharan Africa's arable land is irrigated [12]. Additionally, Africa is a very heterogeneous continent, with many different ethnic groups and many countries, each with their own institutions. Africa's low population density increases the cost of creating basic infrastructure, and this problem is compounded by that fact that 40% of Africa's population lives in landlocked countries, greatly raising transport costs [22]. Africa thus requires a much more varied approach designed for more local problems [16].

Another limiting factor to African output is soil quality. The soils of Sahe-

lian African are too sandy and poor in nutrients while the soils of the lowland tropical areas are much too acidic [11]. Brazil managed to take low-nutrient cerrado and turn it into productive land through long-term de-acidifying the lime via limestone fertilizers and through introducing new varieties of plants that were better suited for Brazil's tropical environment. Brazilian farmers also used no-till agriculture, a method that doesn't use much water and better retains the nutrients of the soil. Africa could utilize Brazil's model, especially in areas outside the water rich region from Angola to Mozambique. Besides limestone applications and no-till agriculture, SSA countries could also consider adoption of Israel style micro-irrigation techniques that can dramatically lower the water required for crops. This method is beyond the financing capability of many Africa countries and wouldn't provide much help to the water rich central African belt.

Increasing yields through a variety of measures is appealing, but many of these potential solutions present new problems as well. A stronger government policy initiative would focus on a few promising options to devote the limited skilled manpower, finance, and institutions available. The next section will develop the most promising, yet most controversial, candidate: biotechnology.

Biotechnology

Advantages

Biotechnology, as applied to agriculture, is the use of genetic manipulation to enhance yields or imbue other attributes to plant varieties that do not occur naturally. The greatest potential for increased food supply in SSA is increasing effective yields of crops. A survey of agricultural commodities revealed that yields in Africa have remained stagnant in the past several decades where outputs in other areas have surged. Between 1961 and 1987, world yields for sorghum and millet increased 46% and 26% respectively while African output didn't budge [11]. This discrepancy is even more apparent when looking at staple crops such as wheat, maize, and rice: African yields in 1987 are still lower than those obtained in the world in 1961 [11]. Genetic engineering and genetically modified crops (GMOs) can greatly increase the productivity of African crops. High-yield varieties are plant varieties that respond more favorably to inputs than conventional plant varieties. Drought resistant and higher yielding produce can increase the returns to the traditional factors of water, land, fertilizers, and soil, thereby reducing the dependence on water supplies and stimulate output increases.

Adopting new seed varieties can also greatly increase productivity in many countries. In Ghana, only 3% of the country's maize seed is of the hybrid variety, compared to 90% in Brazil [12]. Brazilian yields are dramatically higher despite having lower quality land available. Other technologies such as drought and freeze-resistant crops require less care and can succeed even in more marginal lands. By introducing new variations in staple crops, such as drought and pesticide resistance, Africa can mimic Brazil's successes [12]. Insect pests are another limiting factor that could greatly benefit from biotechnology. It is estimated that up to 35% of potential crops are lost to pests every year in Sub-Saharan Africa [11]. GMO crops like Bt cotton provide a significant advantage

in lessening pesticide use and increasing yields.

Countries such as Burkina Faso and South Africa have already experienced yield increases as a result of biotech adoption. In Burkina Faso, the introduction of Bt cotton has significantly increased yields, averaging 18.2% over the traditional cotton varieties. Between 2009 and 2010, over 125,000 ha of Bt cotton were planted in the country, making it one of the largest introductions of GM crops on the continent. Introduction of the Bt variety reduced spraying costs by 66%, as less insecticide use was needed. Two similar studies found comparable yield increases, with a South African study reporting increases of 18% and a Chinese study reporting increases of 15%. The farmers' cotton income increased by $138.83 per ha over traditional cotton, providing tremendous benefits for an otherwise only marginally profitable crop. However, these studies are short-term, and the longer-term effects have still not been accessed. Buildup of pest resistance to Bt could be a potential problem in the future, and one that needs to be monitored. However, Bt cotton's success in Burkina Faso is a strong indicator of the potential benefits biotechnology offers from other cotton-producing countries in the region, such as Mali and Benin [33].

Another area where biotechnology offers tremendous advantages is the nutritional enhancement of foods. A huge percentage of Africans suffer from malnutrition, more than in any other continent. Lacking required nutrients can have damaging effects on a community, leading to poor mental and physical development among children and exacerbating existing health problems. Biofortification can provide the vitamins, minerals, proteins, oils, and carbohydrates needed by large fractions of the African population [30], and has already been implanted in South Africa by law.

Biotechnology is not new. Crop cultivators have used mutagens and tissue culture techniques to modify genes in agricultural and crop plants for many years. By using recombinant DNA, modern biotechnology has simply expanded the range of results and possibilities. However, problems do exist. One of the key problems of the GMO movement is the privatization of genetic resources, as large corporations limit the food sovereignty of African farmers. This "biopiracy" is a legitimate concern, one that could cripple GMOs extension into the African continent as will be discussed in the following section [26]. There is also much public misunderstanding and distrust of GMOs, and outside of South Africa, Burkina Faso, and Egypt, there has been low penetration of GMOs into the continent [22].

Potential Problems

Biopiracy, genetic contamination, and weak support for biotechnology are legitimate problems that must be examined.

A main challenge for GMO advocates is stimulating research into technologies that would be beneficial to third world countries. Little research is conducted on African crops such as sorghum and cassava. As so-called "orphan crops," they have received little attention for varietal development because of the lack of profit incentives [24]. As the prices of these crops have risen, new research has led to better varieties of these crops. Recently introduced semi-dwarf sorghum produces 3 times the previous yield [12]. More investment into African crops is needed, and greater distribution of high-grade seed needs to be available. Alliance for a Green Revolution in Africa (AGRA) has helped

set up over 45 seed companies in Africa, and many more are needed to maximize utilization of new seed strands [20]. Investment in local research centers would also be very productive, and it would help alleviate some of the potential problems of biopiracy from foreign firms. Government investment in local research centers like Brazil's EMBRAPA agricultural research center can help focus research specifically on African crops and African needs. A joint effort from several countries with foreign support could provide a research center needed for local problems. For example, companies like Monsanto have been donating drought-resistant technology to African coalitions, such as the Water Efficient Maize for Africa. The continent lacks the financial resources to make research into African-specific plants very profitable, but importing drought resistant technologies would be a huge boost for the water-deprived countries in the Horn of Africa.

Another issue with GMOs is simply whether or not they are effective. Utilizing herbicide resistant plants can lead to development of herbicide-resistant super-weeds. Roundup Ready crops (herbicide resistant) are shown to increase the level of plants with herbicide resistance, increasing herbicide requirements beyond what would be required without the genetic modification. Bt crops face similar criticism [31]. Bt genes give plants a built-in insecticide, *bacillus thuringiensis*, effective at pest-control. However, recently Bt resistant varieties of insects have been emerging, actually increasing the required dosages of pesticides required. Similar to the case made against improper use of antibiotics, usage of herbicides and pesticides can lead to the evolution of resistant strains of plants and insects as the organisms develop "field evolved resistance." Field evolved resistance occurs when exposure to a toxin increases the frequency of resistance alleles in the subsequent generations of a population, giving it immunity [23]. In 2000, there were several reported cases of herbicide-tolerant canola plants cross-pollinating with related weeds, giving the weeds resistance [31].

However, although cases of resistances exist, studies show that they form a small minority. There are also several strategies that researchers have identified to limit and manage insect resistance. One strategy, known as the refuge strategy, can slow the evolution of resistance traits by increasing the chances that non-mutated insects will mate with the resistance-mutated insects, leading to non-resistant offspring. Bt crops are grown next to non-Bt crops to maximize crossbreeding of surviving insects. Another strategy is known as "pyramiding," where several Bt toxins are used in a crop, making it more difficult for insects to develop immunity [23]. A comprehensive study examined 41 cases of Bt crops in several countries over a decade and found that despite a few documented cases of resistance, the vast majority of insect populations still remain susceptible [23]. Incorporating the previously mentioned strategies can significantly limit the frequency of field-evolved resistance in future crops.

There are claims that AGRA's primary goal is biopiracy: giving global corporations access to the genetic wealth of African crops in order to patent and privatize. 41% of US agricultural biotech patents are owned by a small group of corporations: Monsanto (14%), Pioneer-DuPont (13%), Syngenta (7%), Bayer CropScience (4%), and Dow AgroScience (3%). Once privatized, there are fears that the corporations will have access to the genetic code of these species without sharing the benefits with the cultivators of these species, the African farmers. A recent example is the Tuli breed of cattle from Zimbabwe. The Tuli breed is an exceptionally hardy breed of cattle, requiring little water while providing

substantial meat. In the 1990s, the genetic code of the Tuli cattle was exported to North America, and the US Department of Agriculture quickly noticed its value. Soon, all the useful genes of the Tuli cattle will be patented, with no benefits given to the breeders of the cattle. Currently, the WTO promotes the intellectual propery rights of laboratory breeders while giving minimal consideration for the farmers. The International Treaty on Plant Genetic Resource for Food and Agriculture (ITPGRFA) on the other hand does consider the farmers and the local communities. They realize that biopiracy is a real threat and genetic resources need to be protected [26].

Critics also often cite the issue of genetic contamination of local varieties. GMO monocultures face significant problems in being adopted by Sub-Saharan Africa. Currently, one of the only African countries to use GMOs is South Africa. Other neighboring countries staunchly oppose wide-scale adoption of GMOs, many citing the fear of contamination. GMOs can breed with local plant varieties, changing the genetic composition of the plant varieties with unintended effects. For example, in 2001 UC Berkeley professors Ignacio Chapela and David Quist found that traditional varieties of Mexican corn had been contaminated by genetically modified genes. Maize openly pollinates and thus easily allows for gene flow between varieties. Starlink was a genetically modified variety of corn determined unfit for consumption by the FDA and was only allowed be used for animal feed. But in 2000, traces of Starlink were found in hundreds of supermarkets products, and led to widespread recall of the GMO. Some people suffered from allergic reactions after consuming Starlink-contaminated food products [31].

One of the main ways to combat genetic contamination is to utilize the "terminator" technology, where the plants essentially fail to reproduce. This introduces another problem: food security. Without the ability to store homegrown seed, farmers will become dependent on the seed provided by the large seed companies. The seed saving system has been integral to African farming methods. The Oakland Institute argues that large seed companies, like Syngenta and Monsanto, are using AGRA as a corporate entryway into the African continent [8]. Recent news reports look at attempted takeovers of African seed companies as further proof that corporations are trying to muscle their way into the African market.

The problems raised by various NGOs and government watch groups extend beyond the aforementioned list. Health concerns from consumption of GMOs, company monopolies, unfair pricing strategies, the organic movement etc. all raise issues beyond the immediate scope of this paper. However, while some of the concerns are legitimate, with strong government institutions, good biotechnology safety regulations, and greater government funding, a careful cost-benefit would show that biotechnology could be an effective way to proceed.

Discussion

Norman Borlaug, father of the Green Revolution, recently argued in favor of GM crops, saying that many of the supposed risks are overhyped and that the benefits are much greater than the costs. He argues that the health risks to consuming GM food crops are overplayed, saying "allergies caused by natural foods have been with us for a long time, so why wouldn't they happen with GM crops?" [6] Critics often point to the environment damage caused by GMO

crops, saying that the toxin release and high input requirements of some varieties are detrimental to the crops' surroundings. However, Borlaug argues that without GMOs, the massive increase in output over the last several decades wouldn't have been possible without additional land inputs, which would have resulted in widespread deforestation and habitat destruction. Lastly, he mentions the dangers of applying a "western" mentality to judging the morality and validity of GMOs: "Most people in the 'western' world are urbanites and they don't know what it takes to feed the world. These people can afford to buy expensive 'organic' food and to criticize genetically modified food. They pressure governments to ban genetically modified foods and that could be disastrous for developing nations" [6].

Biotechnology would not be a cure-all. The effectiveness of technology introductions depends greatly on the institutional capacities and the level of infrastructure available in the countries. When inequality is widespread, the benefits of biotechnology may not be uniform. Additionally, at present, there are no intellectual property (IP) protection laws for either farmers or seed companies, dissuading investments. Having a governing body for IP protection would encourage investments in many countries while also protecting farmers from being cheated. By examining some of the most populous countries in Africa at different stages of agricultural development, we can identify the potential biotechnology benefits and implementation strategies.

Case Studies

This section will overview 3 different case countries: Ethiopia, South Africa, and Nigeria. Each one of these countries has had different experiences with biotechnology, FDI flows, and agricultural output in recent decades.

South Africa

South Africa has the eighth highest acreage of GM crops in the world and is currently the only significant cultivator of GM crops in Sub-Saharan Africa [36]. Following the GMO Act of 1997, the country approved the use of GM seeds and the institutions required for biotechnology oversight and evaluation. GM maize area in 2009 was recorded at over 1.8 million hectares and has continued to increase [17]. By 2006, GM cotton consisted of 90% of the cotton acreage and GM soybeans constituted nearly 60% of the soybean acreage, and these numbers have continued to increase [36]. South Africa became just the second country (after the United States) to adopt Roundup Ready maize [36]. As the continent's most economically robust country, South Africa plays a pivotal role in the adoption of GM crops in the future.

GM crops have already had a major impact on South Africa's agriculture. A national biofortification program has aimed to address the 50% of South African children between ages 1 and 9 who receive less than half of the recommended daily intake of Vitamin A, Vitamin C, riboflavin, niacin, Vitamin B, folic acid, calcium, iron, and zinc. Starting in October 2003 with the introduction of "Regulation Relating to the Fortification of Certain Foodstuffs" Notice to Act No. 54, the regulations mandated fortification of maize meal and bread flour with a variety of nutrients and vitamins. Maize meal and bread, as the two most

common food items, were selected because of their high consumption among low-income demographics [36].

An illustration of the benefits of biotechnology can be seen by a well documented Bt cotton adoption in KwaZulu-Natal. Small-scale farmers in the plains of Makhathini Flats in KwaZulu-Natal rapidly adopted Bt cotton, and the introduction of the crops was the first major attempt to spread GM planting to resource poor farmers [36]. By 2002 over 90% of the approximately 3500 farmers were using Bt cotton varieties [14]. A study that focused on interview responses found that 88% of the respondents reported higher incomes from Bt varieties. This additional income was spent for greater education investment in children, more investment in growing cotton and other crops, and repaying debt. Vunisa Cotton, the primary provider of credit, pesticides, and seeds, was a major facilitator of the adoption process. Two-thirds of the farmers cited lack of credit as the primary constraint to biotech adoption, and 41% of these farmers were non-adopters. While farmers complained credit lines were insufficient, over 67% of farmers depended on Vunisa for seed and pesticide payment credit [25]. After initial success, however, the support of the company, Vunisa Cotton, was withdrawn. Credit subsequently dried up and the GM program faltered. This case illustrates the value of biotechnology but also how it is limited by governmental and institutional problems. Institutional failures are common in SSA, and are some of the major hurdles that need to be addressed for the adoption of valuable technologies.

One of the larger concerns about the economic viability of GM crops is consumer acceptance. Surveys show that among several countries, South Africans were the least likely to believe that GM food consumption was harmful. Indeed, nearly 80% of South African respondents knew close to nothing of biotechnologies in a separate survey [36]. These studies showed the South African consumers were likely to choose GM foods if they were offered at lower prices. The general lack of knowledge of GM crops can prove to either be a boon or a bust, depending on the reaction of consumers once greater information is available to the public. Regulatory constraints might also limit the introduction of new varieties of GM crops. In 2006, an attempt to test laboratory and greenhouse trials on biofortified sorghum was turned down, despite being submitted by the Gates Foundation-backed Africa Biofortified Sorghum Project. The issue of contamination was raised, as contamination of wild varieties of sorghum was a major concern. This ruling under the GMO Act might limit future entry of crop varieties in the near future [36].

South Africa is endowed with the continent's best research universities, such as the University of Cape Town, allowing for cutting-edge research activities. University departments and national agricultural research bodies are the driving forces behind biotechnology R&D projects. In 1997, UCT collaborated with the Agricultural Research Council (ARC) and developed the first transgenic potato in the country. South Africa also has the benefit of a well-established biosafety regulatory framework that sets it apart from other SSA countries.

South Africa is often viewed as the main testing ground for GM crops in SSA. South Africa possesses the great university research advantage, relatively wealthier government funding, as well as the accepting consumer population required for successful implantation. Success could lead to much wider adoption across the continent; lack of sustained success could dim future prospects.

Ethiopia

Ethiopia's economy is directly tied to the performance of its agricultural sector; 47% of Ethiopia's GDP is derived from agriculture, and farmland consists of nearly 94% of the water use [13]. Agricultural production is becoming increasingly important as a result of rapid population growth. Advances in output and food security are a key component of economic development in the nation; however, significant obstacles still exist before biotechnology can be adopted.

There is currently considerable capacity in Ethiopia. There are 7 institutions with total of 24 centers currently engaged in biotech research. The major obstacles are the lack of intra-institutional linkages and skilled manpower. Many of the biotechnology laboratories, such as the Ethiopian Institute of Agricultural Research and Holetta Agricultural Research Center, have been focusing on achieving their own objectives with their limited capacities. Only a total of 105 staff members are involved with biotech research, out of which only 29% are PhD holders. The capacities of the Ethiopian research centers are still at their early stages. Government attention needs to be focused on creating a better environment for research collaboration, such as sharing equipment, information, and knowledge across different institutions. As one of Africa's poorest countries, Ethiopia requires greater external financial resources to effectively develop. This includes developing joint projects with international organizations [10].

Ethiopia is now at the center of the African land rush. Thousands of square kilometers are being leased out at a few hundred dollars a week for multinationals. Ethiopia has offered 7.4 million acres of virgin land to foreign corporations. Increasing oil prices led to food riots in many countries, encouraging investment abroad to grow food. Indian, Chinese, Pakistani, and Saudi Arabian companies, among others, have been the leaders on a massive farmland rush. Gambella, one of the most fertile regions of Ethiopia, has been the heart of the land grab, offering over 1 million hectares of its best farmland to over 800 companies. Heavy machinery and infrastructure are being introduced to the region at high speed. Recently, Saudi Star Agricultural Development Plc announced plans to invest $2.5 billion by 2020 in a rice-farming project in the country. However, far from providing Ethiopia with food security, the company will export two-thirds of the food produced, Saudi Arabia being the primary recipient. Saudi Star plans to make the farming labor-intensive, hoping to provide over 250,000 jobs. The company claims that their development will make Ethiopia more self-sufficient in food while also producing jobs for the local population [9].

Beyond the obvious environmental concerns that this invokes for the country, another major concern is the displaced people. Ethiopia claims that villagers have all left voluntarily in a large-scale relocation effort separate from the private investments in agriculture. In the "villagisation" program, villages are being moved from the Gambella region closer to roads and other services. Villagers are criticizing the program, however, citing that the government has not followed through with its promises of support services such as schools, healthcare, and fresh water, while also claiming to be undercompensated for their land [32]. The problem is two-fold: not only do the deals made under-compensate African farmers, but also the food being produced doesn't benefit the local population. Investors are using Ethiopian land to produce high-value crops such as soya beans and palm oils, instead of cereal produce for consumption. This higher rate of return can have negative consequences for the Ethiopian populace, which

already is one of the most undernourished in the word [15]. Additionally, while foreign bodies see Ethiopian land as under- or even un-utilized, studies show that competition for land and access to water are the most common sources for communal conflict. While the IFC and FIAS have encouraged accessing Ethiopian land, it is clear that the appearance of abundant arable land is overplayed. Also, the utilization of uncultivated land can be disastrous for pastoralists and small farmers who depend on the land but have limited legal rights.

Biotechnology has already had a positive impact on Ethiopian agriculture. *Eragrostis tef*, Ethiopia's main cereal crop, covers more than 2.6 million hectares. The crop has high weather tolerance, drought and flood resistance, as well as having good pest and disease resistance. Additionally, tef seeds are high in fiber, iron, and protein. However this crop has seen very low yields, as the stems of tef are very prone to falling. Stem destruction has led to considerable harvest losses, and attempts at using nitrogen fertilizers only further weakens the stem. Mechanized harvesting isn't currently feasible. As an underutilized species, the scientific community hasn't studied tef extensively. However, a recent research partnership of the University of Bern and the Syngenta Foundation has used biotechnology to improve tef stems. Using state-of-the-art targeting induced local lesions in genomes (TILLING) methods, the researchers created a new variety of semi-dwarf tef plants that have a stronger architecture and don't collapse. The researchers are planning to release these new seeds through local and national organizations, and the seeds offer promise of increased yields for smallholder farmers. Another example of the benefits of biotechnology would be *Lathryus sativus*, a drought tolerant grass pea, which has been both a blessing and a curse for the country. Although it is a vital resource during times of drought, long-term overconsumption can be cripplingly toxic. Biotechnology research to create a more nutritiously safe food could yield tremendous benefits for Ethiopian consumers [10]. Some of the genetic material that provided tef with drought and pest resistance have now been coded and might offer advantages to solve problems for other plant species [1].

Biotechnology offers ways to overcome longstanding agricultural problems of Ethiopia. Ethiopia is already making progress toward biosafety regulations, having ratified the Cartagena Protocol on Biosafety in 2004 [10]. Problems with leasing out tracts of land are being made clear by the abuses of incoming foreign entities, and should be better monitored and controlled by the federal government. Further investment from government institutions could provide a way for Ethiopia to achieve food sovereignty and security.

Nigeria

With a population of over 140 million and an annual growth rate of 2.9%, Nigeria has a strong demand for increased agricultural production to ensure food security in the coming years. Nigeria has enormous amounts of land available for cultivation, over 71 million hectares [21]. To accommodate the huge increases in population, Nigeria will need to adopt modern agricultural techniques to increase agriculture production beyond the current 6% annual output increase, and into double digits [28]. As a net importer of food, 3 billion dollars annually, Nigeria is particularly susceptible to shocks in worldwide food prices.

Low levels of investment in research have been the major roadblocks for Nigerian scientists towards the development of biotechnology [7]. Nigeria lacks

regular energy, effective information and communication technology, and adequate water supply. An investigation in 2001 reported that of the seventeen biotech research institutions in Nigeria, at least 40% were hampered by lack of electricity and inadequate facilities [18]. Other problems include lack of infrastructure and skilled manpower, and insufficient backing by the national government. Finally, the country lacks the teaching and learning frameworks to generate the necessary domestic labor force for growing needs in the biotechnology sector. Despite these issues, Nigeria GM cultivation outlook is beginning to look very positive.

Nigeria has dramatically increased its regional spending share of R&D expenditures on agriculture. Between 1991 and 2008, Nigeria increased its share from 9.8% to 23.2% of Sub-Saharan investment. In 2000, Nigeria passed a major hurdle by ratifying the 2000 Cartagena Protocol on Biosafety. Just recently, the IITA set up a modern biotech laboratory, a multimillion-dollar project that illustrates Nigeria's growing commitment to GM crops. Nigeria would benefit tremendously from genetic improvements in sorghum, cassava, gum Arabic, and cowpea, crops which constitute a large fraction of Nigeria's output but have been relatively neglected. Having high output growth in the past decade so far has only served to offset years of underinvestment in the 1990s, and Nigeria looks to make larger advancements in the coming decade [4]. Nigeria has also begun to make the required institutional arrangements, creating the National Biotechnology Development Agency to coordinate R&D and biotech entrepreneurship development.

Academic research of problems often doesn't provide the solutions that farmers require. The adoption of improved cassava varieties in Nigeria is an example: the high-yield plant varieties developed often don't meet all the needs of farmers. In the Anambra State, farmers have the choice between several improved cassava varieties and their own cultivated varieties. The improved variety, TMS 30572, offers many benefits, such as higher yield, lower cassava poison levels, greater pest and disease resistance, and greater drought resistance citeagwu. However, the local Udukanani variety can stay 2–3 years in the soil without rotting, acting as a famine reserve, and also has a greater perceived color (ranked 4th in terms of farmers' importance). As a result, despite research efforts into high-yield varieties, 77.1% farmers choose Udukanani and 78.8% choose TMS 30572 (64% of farmers use both) [2]. Technological options often ignore some of the more specific needs of farmers besides yield and pest resistance; these needs must be addressed for a more comprehensive solution to Nigerian farmers' problems.

Evaluation

In the shorter-term, GMOs offer an effective way to increase crop yields within existing infrastructural confines. Contamination, resistance-development, and genetic privatization, the problems associated with biotechnology are not insignificant. However, there are ways to limit the issues associated with GMOs and highlight their benefits. There are major hurdles to implemented biotechnology effectively in SSA: low levels of financing, biosafety regulations, and insufficient intellectual property protection.

A hurdle that needs to be addressed is biosafety regulation and protection laws. Countries need to develop regulations to not only protect local farmers

but also to attract foreign companies looking for a safe country to in which to invest. While 23 countries in Africa have biosafety laws, currently many of these are restrictive and lack coherent liability clauses, making investors wary [17]. Many countries have already ratified the Cartagena Protocol on Biosafety—all countries considering biotechnology need to have regulations guiding the use and handling of GM seed and crops.

The creation of national or even an international intellectual property "clearinghouse" is important for the flow of technologies between developing and developed countries. An international IP body can reduce the transaction costs of innovations, reduce uncertainty about terms of access, increase transparency, and increase flow of knowledge into orphaned research on crop development [30]. While public sector institutions comprise 24% of total patents, no individual public institution controls more than 2% of the agricultural biotech patents; diffuse ownership raises transaction costs dramatically [30]. The African Agricultural Technology Foundation (AATF) in Kenya is an important example, as it tries to facilitate research and adoption of new crop varieties in SSA. It emphasizes the negotiation of licenses and sublicenses for technology throughout SSA. Having coherent patent and IP laws gives institutions and firms greater incentives to invest in research and technology, and is a vital component of future development.

Lack of sufficient levels of investment is a common issue in SSA. Research institutions and universities face low levels of investment from the federal government. 41.2% of institutes report that their primary source of funding is from the federal government, compared to 47.1% from various donor agencies. For universities, the percentages are 61.5% and 57.7% respectively [3]. As previously mentioned, foreign and domestic capital constraints restrict the ability for countries to develop comprehensive agricultural strategies. Countries need to develop national strategies for biotech investments. As shown by South Africa, creating national goals can have a catalytic effect on the ability for biotechnology to be implemented. Since resources in many SSA countries are very limited, countries cannot afford to thinly spread their research and human capital. Most African countries have not identified clear trajectories or goals—having articulated priorities helps countries make informed long-term policies.

The potential benefits from development of important staple crops such as cassava are huge. Cassava is a staple crop that is low in nutritious content but very high in calories, and provides a high percentage of daily caloric intake in many countries: 56% in DR Congo, 36% in Mozambique, 31% in Angola etc. Cassava consumption alone represents 11% of the daily calories of Sub-Saharan Africans [24]. Root quality, diseases, pests, and low yields are all problems that plague this crop. Biotechnology research could help overcome many of cassava's problems, and increase output across SSA. Developing virus-resistant cassava and adopting biofortified nutrients could greatly expand cassava's appeal on the continent.

The transformation is already beginning to happen. An increasingly number of countries in Africa are turning to GM crops to boost output. Until recently, South Africa had been the continent's only grower of GM maize, cotton, and soybeans. In 2008, Egypt and Burkina Faso began growing GM crops, and now Kenya, Tanzania, Uganda, Malawi, Mali, Zimbabwe, Nigeria, and Ghana are all conducting studies and field trials of GM crops. Kenya seems the most likely candidate to begin cultivating GM crops. After recently passing biosafety

regulations, Kenya looks to become the fourth cultivator on the continent [17].

Conclusions

Due to the deep and nuanced nature of the issue, academic opinions have not converged on a single solution to the African agriculture problem. Africa would derive the greatest benefit from a multi-pronged approach: sustainable soil and water management, stronger institutions, greater investment in infrastructure, and improved seed technology. Unfortunately, the region doesn't seem likely to reach all of these goals in the short-term. While by no means comprehensive, utilizing existing biotechnology and developing new strains focused on African crop varieties would be the first step toward developing a more viable agricultural enterprise in Africa. Biotechnology offers one clear strategy to increase output within the immediate confines of irrigation, unfair foreign competition, and limited transportation infrastructure. Much of the academic literature and studies presented show that there are tangible increases to productivity with limited input increases when utilizing technologies such as drought-resistant and high-yielding plants.

Educating the public about the pros and cons of GM crops remains a vital concern. Abisai Mafa, the chief executive of the National Biotechnology Authority in Zimbabwe, stated "Polarization and lack of awareness are still the biggest challenge" to the adoption of GM crops. The general populations of SSA countries are not informed, and polarization has increasingly become a large and "dangerous" constraint [27]. Bickering over GMO issues has prolonged and even sidetracked productive developments of national biosafety regulations and guidelines in SSA countries. Countries like Zimbabwe still have little to no capacity to monitor or regulate the flow of GM crops into their borders [27]. As illustrated by the case of South Africa, public acceptance of GM crops can stimulate the economic viability of utilizing GM seed, and is a key component for many SSA countries moving forward.

The case studies of the disadvantaged worker show that problems exist in the institutions of African countries and the structure of land takeovers. The land grab in particular is leading to unequal results, as major corporations and foreign interests are collaborating with government entities, with no consideration for farmers. To truly provide a more comprehensive growth strategy, African farmers need to be included in the structuring of land deals, and employment opportunities need to be present. Greater IP and land protection laws are needed to protect both international business interests and local farmers from land grabbing and biopiracy.

Finally, emerging advancements in mobile technology offer smaller, but important ways to eliminate the information gap between suppliers and buyers. Increased mobile-phone penetration into Africa has made such services much more valuable as an agricultural pricing tool; a farmer sends an SMS text message to a number, which then responds with current wholesale and retail prices of crops. Access to agricultural insurance products for farmers via mobile phones has also increased [19]. Farmers that have access to insurance problems are more comfortable in investing in production. The recent increase in use of cell phones has coincided with mobile insurance; farmers promise to sell their produce at a discount, but are partially compensated if their crop is wiped out.

By giving farmers greater control over prices of their crops as well as access to reliable insurance, farmers can improve their confidence, investments, and ultimately profits without relying on massive infrastructure enhancements in the short-term.

The adoption of biotechnology will not provide immediate benefits; rather, it must be part of a larger framework of infrastructure investments, government institutional improvements, and biotechnology research. Many problems, such as international economic conditions, regional trade restrictions (EU), and global climate change are factors outside any one country's immediate control. What would be most beneficial in the short-term for agricultural productivity increases is a variety of measures: high-seed quality and access, more international oversight of equitable land deals, and availability of beneficial mobile technologies. The most valuable and immediate of these suggestions would be improving yields through biotechnology and utilizing the penetration of mobile technology to strengthen the pricing muscle of local farmers. The larger issues are generally outside the shorter-term scope of this paper, and prove even more problematic and intricate.

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