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GM Crops for Food Security in Africa – The Path Not Yet Taken

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Abstract: There is little disagreement about investing in agricultural technology – and the need to reverse the decline experienced over the 1980's and 1990s – as a priority for improving food security in Africa. Food security is not just about production or supply of food but access. In sub-Saharan Africa, increasing productivity has a particularly important role for improving food security because the majority of the hungry are in fact producers (Millennium Project 2004 p. 45-46). But there is no agreement about the role of agricultural biotechnology in the strategy for enhancing productivity. The issue is mired in controversy that has become driven by polemics, pitting multinational corporations against anti-globalization and environmental movements. Debates about agricultural biotechnology, and particularly GM crops, for food security in Sub-Saharan Africa needs to be re-centered on considering the potential of this technology in improving productivity of small scale, resource constrained farmers. But to do so cannot be based on scientific considerations alone, it must also consider the broader social, economic and political context necessary for achieving food security. While the proponents of the technology argue about the scientific merits, those who oppose its spread argue about the shift in power structures that the technology would bring about.

Keywords: Agricultural biotechnology; genetically modified foods; technology and society; economic development and agriculture; agricultural policy; technological innovation

JEL Classification: O13, Q18, O32

Introduction

There is little disagreement about the importance of investing in agricultural technology for improving food security in Africa. Food security is not just about production or supply of food but access, but in sub-Saharan Africa, increasing productivity has a particularly important role because the majority of the hungry are in fact producers[2] (Millennium Project 2004 p. 45-46). But there is no agreement about the role of agricultural biotechnology in the strategy for enhancing productivity. The issue is mired in controversy that has become driven by polemics, pitting multinational corporations against anti-globalization and environmental movements. Debates about agricultural biotechnology, and particularly GM crops, for food security in sub-Saharan Africa needs to be re-centered on considering the potential of this technology in improving productivity of small scale, resource-constrained farmers. But to do so cannot be based on scientific considerations alone, it must also consider the broader social, economic and political context necessary for achieving food security. While the proponents of the technology argue about the scientific merits, those who oppose its spread argue about the shift in power structures that the technology would bring about. This paper aims to provide an overview of issues. It starts with a brief introduction to the technology, followed by a review and analysis of the controversies. The paper then reviews the current state of GM crop technology in sub-Saharan Africa. The final section reviews institutional and policy choices for countries.

I. Brief Background on GM Crops

What are GM Crops[3]?

GM crops are developed by a process of genetic modification by which selected individual genes are inserted from one organism into another to enhance desirable characteristics ('traits') or to suppress undesirable ones. From the time that human crop cultivation began, farmers have improved the genetic makeup of plants to enhance their productivity – their yields, tolerance to pests, diseases and drought – by cross breeding. The history of these endeavors over the centuries has evolved in three stages using increasingly advanced techniques: the first stage used selection of higher performing varieties in the form of collection of landraces; Mendel's discovery of genetic principles in the 1900s made possible conventional plant breeding to obtain targeted traits through cross breeding of varieties; and the third phase began with the application of biotechnology to plant breeding and the creation of transgenics.

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[2] Task force 2 on Hunger of the UN Millennium Project analyzed the composition of the world's 846 million hungry people. Globally, 50% are in farm households, mainly in higher-risk production environments, 25% are the rural landless, mainly in higher-potential agricultural regions; 22% are urban; and 8% are directly 'resource dependent'. For Sub-Saharan Africa, the majority of the total population is rural. The rural population has high poverty rates: 55% in Eastern and Southern Africa, and 41% in Central Africa. Poverty rates are higher in rural areas than in urban areas.

[3] For a succinct description and history, see Fukuda-Parr 2006 chapter 1; FAO 2004 chapter 2.

The key advantage of genetic modification is that it makes the process of crop improvement more efficient. In comparison to conventional plant breeding methods that take years to develop or eliminate traits by selection, genetic modification techniques allow scientists to manipulate genetic material with precision, and expand the scope of breeding new varieties and achieve results in less time.

The development of GM crops requires several steps each of which requires different sets of technological expertise and institutional arrangements that present important policy choices for national governments. The first step, laboratory research, requires expertise in biotechnology to conduct scientific experiments and insert genes into plants to create an 'event'. Successful events are a scientific innovation that is patented by the innovator. The second step, development and plant breeding, involves adapting plant varieties to specific locations, and is carried out by field trials entailing plant breeding and agronomy expertise. The resulting seeds are technological innovations and patented by the innovator. These varieties need to be approved for commercialization by passing bio-safety certification. National biosafety regimes test for the environmental and health safety of the new varieties. The third step involves seed multiplication and commercialization, which is necessary to take seeds to market and to farmers. Above all, this final step requires expertise in seed marketing and technological licensing. Research and Development on GM crops started in the 1980's involving a large number of crops and traits. Only a few of these crop varieties have gone to market; they include varieties of soy, cotton, maize and canola carrying herbicide resistant (RR soy, RR canola) and insect resistant (IR) genes (Bt cotton, Bt maize). Despite the many academic and governmental researchers, and the multitude of countries involved in biotechnology research, a few multinational companies, notably Monsanto, dominate GM crop development and seed marketing. The exception to this is the public national agricultural research systems (NARS) of China, Brazil and India.

Currently two traits have gone to market: herbicide resistant 'RR' ("Roundup Ready") crops and insect resistant Bt crops. RR crops carry traits that make them resistant to the herbicide, glyphosate; and are primarily used in soy and canola. These crops can be sprayed with the herbicide for weed control without being harmed; this makes weed control more effective, primarily reducing costs. "Bt" crops, primarily cotton and maize, have been developed to include the bacterium, Bacillus thuringiensis (Bt), in the genetic makeup of a plant, making it poisonous to certain insects and therefore insect resistant. This permits a reduction in the quantity of insecticides used, which in turn reduces production costs as well as risks of crop failure, poisoning and environmental damage.

Where are the GM Crops being grown and marketed?

While experimentation with GM crop technology is widespread, the number of countries with significant levels of commercial production is limited as shown on table 1. The leading producers are the US and Brazil, followed by Argentina, India, Canada, and China.

Table 1: Global Area of Biotech Crops by Country (2009/2010) (Million Hectares)

USA	64	66.8
Brazil	21.4	25.4
Argentina	21.3	22.9
India	8.4	9.4
Canada	8.2	8.8
China	3.7	3.5
Paraguay	2.2	2.6
Pakistan	--	2.4
South Africa	2.1	2.2
Uruguay	0.8	1.1
Bolivia	0.8	0.9
Australia	0.2	0.7
Philippines	0.5	0.5
Myanmar	--	0.3
Burkina Faso	0.1	0.3
Spain	0.1	0.1
Mexico	0.1	0.1
Colombia	<0.1	<0.1
Chile	<0.1	<0.1
Honduras	<0.1	<0.1
Portugal	<0.1	<0.1
Czech Republic	<0.1	<0.1
Poland	<0.1	<0.1
Egypt	<0.1	<0.1
Slovakia	<0.1	<0.1
Costa Rica	<0.1	<0.1
Romania	<0.1	<0.1
Sweden	--	<0.1
Germany	--	<0.1

Source: (James, 2010)

The initial GM crops to go to market were developed by Monsanto and other corporations for US growers targeting global markets. Maize, soy, and cotton are globally traded crops with large export markets for US farmers. The technology then spread to other countries where adapted varieties were developed and commercialized.

An important factor in the diffusion of this technology is national policy, notably biosafety regimes. These regimes may range from permissive to precautionary, with the permissive setting lower requirements while the precautionary regimes create barriers to development and diffusion (Paarlberg, 2001). The US, Canada, South Africa, and Argentina have a relatively 'permissive' approach. India and Brazil have a more precautionary regime. China has a unique and pragmatic[4] regime. The EU initially had a more facilitating environment but policy shifted in the late 1990s towards a precautionary approach, and in 1998 enacted a moratorium on new approvals (Tiberghien, 2006). Although the moratorium was revoked in 2004, the EU continues to demand strict labeling requirements for all products containing GM crops and remains precautionary when it comes to the importation of GM crops.

The enactment of biosafety regimes has been the site of political contestation within countries. In Brazil and India, for example, the passage of biosafety law was a prolonged process involving divided opinion amongst different stakeholders within countries.

National policies and institutions

GM crops are a new technology that also comes with new institutions, actors and rules (Fukuda-Parr, 2006; FAO, 2004). The public sector and farmers themselves have historically driven technological innovation. For example, in the US, it was the land grant universities and Department of Agriculture research stations that carried out most of the research and development of new varieties. GM crop research today is dominated by the corporate sector with the exception of the national public research systems of China, Brazil and India. Unlike conventional breeding methods that require agronomy expertise, GM technology requires biotechnology expertise. GM seeds are regulated by new intellectual property rules intended to incentivize private investors. Traditional plant breeding research was in the public sector because it brings high social returns but not private profit. GM technology is regulated by biosafety rules and only those varieties that pass the biosafety tests may be commercially sold.

The institutional shifts related to the economics of GM crops differ in several critical ways from traditional agricultural innovation systems. First because GM crops are protected by intellectual property (patents) and cannot be reproduced without license, so farmers or other seed companies cannot reproduce the seeds freely. Second, they incur higher cost of innovation and certification. These high costs drive out small investors. Third, with patenting, they could generate significant profits, particularly when used for crops in high demand globally and therefore attractive to large investors. The unique challenges and opportunities associated with GM crops make institutional shifts essential in order to adapt GM crops to local environments. These issues will be explored later in this paper.

II. Global and National Debates

The history of GM crops brings us to the current debate, which has become dominated by polemics. As the FAO put it, 'supporters hail genetic engineering as essential for addressing food insecurity and malnutrition in developing countries. Opponents counter that it will wreak

[4] For example, Pray et al (2005) shows that China continuously adjusted their biosafety legislation to make it workable to give an incentive to innovators to go through the certification process rather than to market seeds that had not been tested and certified, or 'stealth seeds'.

environmental havoc, increase poverty and hunger, and lead to a corporate takeover of traditional agriculture and the global food supply' (FAONewsroom, 2004). However, while these polemics continue to politicize and dominate public debates, there is growing research that explores multiple aspects of this technology and its consequences depending on how and to what purpose it is put, rather than seeing it as and undifferentiated and homogeneous phenomenon.

To get beyond the polemics, the following section will attempt to clarify the debate by outlining the key issues that have been raised that include those of environmental and health risks, corporate control, and ethics.

Risks to the environment and to human health

One of the major controversies has been the potential risks that the GM crops pose to the environment through gene flows and to human health through ingestion of toxic substances. The controversy is not over the existence of environmental and health risks – all living organisms have an impact on the environment and all new technologies carry risks (UNDP, 2001). The debate is therefore about whether the risks are great enough to require banning this technology altogether, or to manage the risks. The Convention on Biological Diversity (CBD) and the Cartagena Protocol on Biosafety (CPB), are two international protocols intended to monitor these risks at the international level. All national governments are responsible for adopting national biosafety protocols that comply with the minimum standards set by the international regulations. By 2011, 162 countries had ratified, accepted, approved, or acceded the CPB (Cartagena Protocol on Biosafety, 2011). Before new GM crops are permitted to be commercialized, they must go through rigorous biosafety certification processes. The critical debates therefore turn on how restrictive these standards should be.

A comprehensive review of the scientific evidence by FAO (2004) finds the crops that have been approved for commercialization do not have known health and environmental risks; 'Thus far, in those countries where transgenic crops have been grown, there have been no verifiable reports of them causing any significant health or environmental harm' (p. 76). Yet they also caution that the assessment is at an early stage. Because GM crops are a relatively new technology, Greenpeace and other groups argue that there has not been enough time to be able to tell whether GM crops do not have negative impacts on human and animal health (Greenpeace, 2011). On the other hand, others point out that GM crops have been commercialized for nearly 20 years with no reported incidents of real damage, a very clean record considering that most technological innovations result in 'recalls' from the market when widespread consumption reveals risks that were not apparent in the testing process (Paarlberg, 2008).

Shiva (2006) emphasizes the longer term implications of GM crops; that their introduction would shape the ecological landscape and lead to loss of diversity. This in turn would be not only harmful to the environment but also leave under-resourced communities at risk of widespread loss if something goes awry. Further controversies arise around the propensity for RR crops to create a greater dependence on herbicides. It is argued that widespread spraying of crop fields rather than just spraying harmful weeds has led to the development of weed species with herbicide resistant traits (Greenpeace, 2011). On the other hand, Bt maize and Bt cotton have positive environmental impacts as they cut the use of toxic pesticides by reducing pesticide applications.

Corporate control of the food chain

Another major concern relates to political economy; the biotechnology industry is dominated by large multinational corporations (MNCs), such as Monsanto, Snygenta, and DuPont and the spread of GM technology will ultimately lead to a corporate control of the food chain (ETC Group, 2010), leading to monocropping production systems (Altieri, 1998).

One of the most controversial issues has been the control of seed production by corporations; those who created the seed variety hold the relevant patents and prohibit farmers from reusing and propagating seeds for use in subsequent growing seasons. This fundamentally alters the farmers' involvement in technological innovation; traditionally farmers keep a part of the harvest to plant as seed the following season, and practice plant improving by selecting and exchanging seeds with others. GM varieties introduce a systemic shift from locally controlled to a global industrialized food system. Much of the opposition to GM crop technology is concerned with this systemic shift. In a political economy analysis of 'food sovereignty', communities would lose autonomy in their livelihoods, something that cannot be easily subjected to straightforward and short-term cost-benefit calculus. Thus, the profit-driven focus of GM crop technology will only serve to benefit the western industrial food chain, and conversely, impede the "peasant web's" ability to fulfill its role in feeding the vast majority of global citizens via traditional farming practices (ETC Group 2009). The high cost of GM seeds, westernized intellectual property regulations, and the inadequate ability to adapt seeds to local environments all play into this environment of corporate control, and ultimately deter any sustainable advancement towards food security for under-resourced farmers and consumers (ETC Group, 2009).

Many researchers consider agricultural biotechnology to be a technology like any other; like nuclear fission, it can be used for positive or negative social ends. Its impact depends on who uses it, for what purpose and under what conditions. Public policy choices make a significant difference to those consequences. Why do public sector research institutions, especially in developing countries, not invest in biotechnology research? Is it lack of capacity – do only corporations have biotechnology capacity? Lack of finance – do only corporations have the finance? Or is it due to political pressure from anti GM movements (Paarlberg, 2008 pp. 122-148) on governments to resist this path? Corporations have led the GM crop field, but there are exceptions; China's public agricultural research centers have developed considerable capacity, rivaling Monsanto, and small seed companies in India also produce GM crop seeds. Brazil's NARS is developing a significant program in biotechnology while its neighbor Argentina has opted to 'leave it to the private sector' (Fukuda-Parr, 2005).

The concern related to corporate control raise policy questions about alternatives to address them. Intellectual property regimes is a particular concern since it is IP that raises prices of GM seeds to farmers, but also the cost of research for scientists who must pay for a license to use some of the technology that had been developed. Studies show that where IP is not applied, such as in China, farmer prices are kept low and therefore more accessible. Efforts to overcome some of these constraints are under debate. An important global initiative, PIPRA, was founded to facilitates access to agricultural biotechnology through sharing information to reduce transaction costs for developing countries.

Moral/ethical concerns and choice for consumers and producers

For many opponents, genetic modification is tampering with nature and is an ethical concern. Others argue that genetic modification has been in progress for millennia – only without the scientific tools that we have access to in modern agricultural research.

Another dimension of the moral issue is one of choice. Opponents argue that the spread of GM crops will leave farmers with no choice but to use GM varieties that will become a dominant source of seeds, and thus introduce monoculture (Shiva, 2006). On the other hand, the Nuffield Council on Bioethics (2003) concludes that withholding GM crops from the farmers and consumers who demand it is in itself unethical, particularly when the benefits are to improve the incomes and nutrition of the poor.

Yet another issue is one of information and consumer labeling. While labeling is mandatory in some countries (e.g. in Europe), it is not in others (e.g. US). According to a poll taken by the Rutgers Food Policy Institute, 54 percent of Americans believe that GM crops "threaten the natural order" of the food supply (Paarlberg, 2008). This statistic is ironic, considering that a vast majority of Americans consume GM crops regularly. It raises a question that given a choice and adequate information, American consumers may opt not to purchase GM foods. Similarly, does the general unawareness that GM crops have been consumed regularly without side effects impact consumers' perception of the risks involved? If consumers were aware that a majority of the corn consumed was in fact genetically altered, wouldn't this mitigate the effectiveness of fear-mongering campaigns against GM crops? Moreover, it is a known fact that social scientists studying science and technology observe that there are no objections to the same technology (genetic engineering) when used in medical applications. The controversy over whether GM crops should be labeled brings to light a secondary question when considering international trade. If one government requires that GM crops are labeled and another country does not, then what are the logistical and regulatory burdens stemming from trade between countries?

NGO capture

Social scientists observing the political processes shaping ideas and debates at local and international levels argue that public opinions and public policies are being shaped by Northern NGOs who wield power over governments and international agencies. They argue that these NGOs represent the views and interests of European consumers who have little to gain or lose from banning new crop technologies because they are neither dependent on agriculture as a source of livelihood, nor spending a large proportion of their incomes on food. In contrast, the majority of the world's poor live in rural areas of developing countries and are producers. Food expenditures typically take up over half of the total expenditures of poorer households in developing countries. Moreover, economies of Europe are not dependent on agricultural production and exports in the way that Argentina, Brazil, China and others are. The opposition to GM crops leads to perverse effects, against the interests of farmers in India (Herring, 2007), and African countries, graphically expressed in the title of a 2009 book *Starved for Science: How Biotechnology is being kept out of Africa* (Paarlberg, 2008; Herring, 2007).

Alternative paths

The scientific argument for the use of GM technology is for the purpose of achieving superior results in developing crop varieties that deliver more to farmers. They may be higher yielding, more resistant to pests or disease, more robust in drought, or in other ways improve incomes for the producer. They may also be beneficial to consumers. The economic benefits of GM crops to farmers and countries where there has been significant commercial production (US, Brazil, Canada, Argentina, China, South Africa) include: higher income for farmers, reduced pest applications for Bt cotton and Bt maize leading to reduced farmer poisoning (FAO, 2004; Tripp, 2009). For national economies, GM crops have expanded exports, such as soy in Argentina and Brazil (Fukuda-Parr, 2005).

Opponents of the technology argue that alternative methods of plant improvement as well as farming systems – notably agroecology – offer similar benefits like insect resistance and herbicide control, while avoiding the potential harms of genetic modification (Uphoff, 2007).

Drivers of the controversies – stakeholders, interests, and narratives

It should be noted that these arguments are used in the context of broad discourses about food and development. To consider whether plant biotechnology and GM crops might improve food security, reduce poverty, and advance human development, we need to consider not only the strengths of the arguments but also the interests of different stakeholders. Who will be the winners and losers amongst farmers, seed companies, scientists, consumers, and national governments, and how might the experience of each stakeholder group rely on their physical location and access to institutional and regulatory support?

Controversies over GM crops take place at global and at national and sub-national levels. These debates have led to proactive or restrictive national legislation in different countries. A comparison of these national debates reveals contrasting national contexts with respect to the importance of GM crops for export, farm incomes, livelihoods and technological capacity as well as consumer preferences and eco-systems (Fukuda-Parr, 2006). In Western Europe, there is a strong public opposition that has led to the adoption of restrictive barriers to their spread, including precautionary biosafety and trade legislation, while these countries are home to some of the most important biotechnology companies. In the US and Canada, public opposition has existed but has not been strong enough to influence legislation. In India and Brazil, the controversy has been very heated at the national level, with significant opposition from environmental and anti-globalization movements. But at the same time while farmers in both countries have rapidly adopted, and spread them without authorization, developing a new market of what Herring (2007a) calls 'stealth seeds'. These controversies presented major dilemmas for government policy. But countries adopted restrictive legislation. In contrast, there has been relatively little public opposition in South Africa.

At both national and global levels, the key stakeholders include farmers, seed companies that commercialize new seeds, researchers that are creating the new technology, and consumers. Economic interests are one factor – among several – that help explain the position of different stakeholders. As Paarlberg (2008) argues, western NGOs have aggressively opposed the spread of GM crops against the economic interests of African farmers. These NGOs are essentially consumers and have not much to gain from GM crops since crop production is not an important source of income or household expenditure. It is also not surprising that the main exporting countries of cotton, maize and soy are the countries where there is a major farmer interest in adopting this new technology. The GM crops that have been commercialized are crops with large global trade markets. The top exporters are the countries that have adopted the crops: US, Argentina, Brazil for soy; US, China, India for cotton; and US, Canada for maize (Fukuda-Parr, 2006). Not only the seed companies but also the farmers who produce these crops in these countries favour the crops. It is plausible that in Brazil and India, the active opposition is in part explained by the greater risk of biodiversity loss for farmers who are not producers of cotton but who produce other crops and who rely on biodiversity for their livelihood. Economic gain is not the only interest of stakeholders. Values and attitude to risk are also important factors. They are important drivers of the opposition to this technology.

The polemicized nature of the controversy is not only a result of conflicting economic interests and values. It is also driven by divergent narratives that do not speak to one another. While activists argue that GM seeds are dangerous to farmers, there is high demand from farmers as shown by the spread of an underground market. Political scientist Ron Herring (2007) explores these processes of 'biopolitics'. One explanation he gives is that while farmers are persuaded by empirical evidence of crops on their fields, and conclude that the seeds must be beneficial, activists start from the owner of the technology – Monsanto. Because the owner is exploitative, the seeds they offer must be inherently exploitative.[5] This issue of contrasting narratives and biopolitics will be addressed later in our discussion on the nature of the debate in Africa.

Food security and social equity

Can GM crops help improve food security, especially in Africa? Two sets of issues have been raised. The first issue is whether the new varieties are beneficial to small scale farmers. This can be studied through micro-studies and short term analysis of farm incomes and productivity. There is a large body of peer-reviewed literature on the economic returns of GM crops. However, only a limited number have explicitly addressed the distributional consequences of this new technology. Those studies on GM crop use by small-scale farmers include empirical surveys, assessments of the agronomic performance, and analysis economic

[5] See Herring (2007a, 2007b) and Scoones (2009) for more background on "explaining the controversies".

and institutional factors that explain the outcomes. There are many instances of successful uptake of GM crops by small scale farmers, notably Bt Cotton in China. In India, Bt cotton has spread without authorization by popular demand. In some instances while the actual GM crop technology may be successful, the application of such technologies can fail due to the lack of underlying institutional support systems. For example, the Gouse (2006) highlights that the negative results caused by the implementation of Bt cotton in the Makhatini Flats of South Africa in 1998-1999 was not the fault of the GM crop technology itself, but it was the absence of a safety net for farmers, notably, the provision of credit and extension services to make the cost of GM seeds affordable and accessible to farmers.

But the potential value of GM technology cannot be assessed on the basis of experience of the past two decades. Led by investments in the private corporate sectors, the research and development agenda has been driven by profit-seeking objectives for the investor, quite naturally. These objectives do not align with the priorities for food security. An important concern is the research and development agenda. Developed by corporations, the initial investments were for crops with large global markets (cotton, soy, maize) and traits that would benefit large scale producers in North America (labour saving pesticide resistance and pest control). Priorities to meet food security needs of African households would include staple food crops of lower income households such as sorghum, cassava, and banana. The food insecure households are subsistence farmers who are producing in risk prone environments at low productivity levels. To address their constraints would mean development of crops with traits to increase yields and reduce risks of crop failure from drought, pests and diseases. They would also include increasing production of more nutritious food crops. Later sections of this paper will elaborate on these contrasting priorities. There is no disagreement over the fact that the varieties were developed for US farmers and crops with large export markets (cotton, maize, soy), while the food insecure farmers are concentrated in marginal areas vulnerable to drought and grow food crops such as sorghum.

While many development economists argue that there has been a failure to invest in pro-poor development of GM crops for development and poverty reduction by the international community (FAO, 2004; UNDP, 2001) political scientists have blamed this on the biased influence of NGOs (Paarlberg, 2008). Much of the public relations material from corporations and funders defends the use of GM for development. Notable research agendas include the use of GM technologies to provide both consumer and producer benefits that might contribute to poverty reduction and food security goals. On the producer side, GM crop projects towards creating drought-tolerant, saline-tolerant, or nitrogen use efficiency (NUE) have been embraced by the private and public sectors alike. Seed companies, Monsanto, BASF, DuPont, and Syngenta have all made progress with drought- and saline-tolerant crop varieties (Gillam, 2011) suggesting that the profit potential for such projects is favorable. The public sector and non-profit development agencies are also generally on board with these productivity-enhancing technologies, given the importance of efficiency improvements as global resources become increasingly scarcer. Similarly, GM technologies focused on pest or disease resistance for staple food security crops are also to some extent "productivity-enhancers" and have more-or-less been welcomed by development agencies. Notable African projects include virus and disease resistance for sweet potatoes, bananas, groundnuts, and cassava as well as technologies that yield resistance to specific African pests (notably, tuber moth-resistant potatoes and maruca stem borer-resistant cowpeas). On the consumer side, GM techniques offering the possibility of biofortification have been embraced by various NARS or non-profit development agencies. Biofortification projects have been undertaken to enhance the vitamin A, iron, and/or zinc content in rice, sorghum, bananas, and cassava. Other projects have focused on ways to increase the protein content in cassava. Others yet have conducted research on high-lysine sorghum varieties (lysine being an important amino acid in mitigating viral outbreaks for those with viral diseases). The public sector has led most biofortification initiatives, but the private sector has contributed through technology donations, as was the case with the Africa Biofortified Sorghum (ABS) project. Although the project was spearheaded by Africa Harvest Biofortification, most of the research and technology was donated by Pioneer Hi-Bred. The extent to which these new agenda's for poverty reduction and social equity will be discussed in greater depth later in this paper. However, it is important to keep in mind that all of these more recent innovations (beyond the commercialized "Bt" and "RR" crops mentioned above) are still in trial stages and have not come to market.

The issues raised by those who oppose GM crops and argue for stopping them altogether concern systemic changes that this technology portends as a force that would drive systemic changes in food systems at the local and global levels. The issue is less about the financial benefits at the farm level and more about power structures, loss of autonomy, and loss of choice as discussed in the section under corporate control.

III. Agricultural Biotechnology in Africa

Critical need for investment

Sub-Saharan Africa (SSA) undoubtedly suffers from lack of agricultural investment. Figures 1, 2, and 3, provide regional comparisons of the average yields for three staple crops: cereals, pulses, and roots and tubers, respectively. This data demonstrates the stark contrast in agricultural productivity in SSA compared to the rest of the world[6]. Stagnant yields combined with increases in food prices and population growth has left sub-Saharan Africa as one of the most food insecure regions of the world (Holmén, 2011).

The 2003 Maputo Declaration on Agriculture and Food Security in Africa resulted in the development of the Comprehensive Africa Agriculture Development Programme (CAADP), as the agricultural arm of NEPAD. CAADP called upon all member governments of the African Union (AU) to commit to the goal of investing 10% of their GDP on agricultural development and to achieve at least 6% in agricultural growth by 2008. By 2009, Burkina Faso, Ethiopia, Ghana, Guinea, Malawi, Mali, Niger, Nigeria, and Senegal had successfully dedicated 10% of their GDP's towards agricultural investment. Nine countries had exceeded the 6% agricultural growth target by 2008, as demonstrated in figure 5. By 2011, twenty-six African nations had

[6] However, note the important variation Africa. While pulses and roots and tuber yields in Northern and Southern Africa have at times competed with or even surpassed global averages, the most at-risk regions of Eastern, Middle, and Western Africa have only narrowly improved crop yields since 1961.

drafted and signed a "CAADP Compact" and nineteen countries had established national investment plans (CAADP, 2011).

In 2008, the "Big Eight" countries accounted for 70% of national agricultural R&D spending in Africa (Beintema & Stads, 2011). These eight countries, including Nigeria, South Africa, Kenya, Ghana, Uganda, Tanzania, Ethiopia, and Sudan, are among Africa's top 20 GDP earners, which explains the dominant share of nominal investment dollars relative to their continental peers. However, only three of these countries, Ethiopia, Ghana, and Nigeria, have met the CAADP target of investing 10% of GDP in agriculture. Moreover, only three of the Big Eight countries – Tanzania, Uganda, and Ethiopia – met the CAADP 6% agricultural growth target by 2008. Despite the improvements in agricultural investment spurred by national and multilateral effort, it remains apparent that some countries are more focused than others on dedicating national agricultural spending specifically towards scientific improvements. For example, Ghana is one country that identifies "the use of modern technology to enhance productivity" as a priority in its CAADP Compact (Republic of Ghana, 2009), but others do not provide the same distinct emphasis. Furthermore, the aforementioned controversies of corporate control, moral/ethical concerns, and contrasting narratives over biosafety and health risks are continuously weighed against the potential benefits of GM crops, making it difficult for national agricultural research centers to dedicate investment dollars specifically to GM crops, and for external donors to support these investments.

Current State of Biotechnology in Africa

National Adopters*.* South Africa and Burkina Faso are the only two African countries to have formally approved transgenic crops for commercial production. South Africa is the forerunner for agricultural biotechnology in Africa, having first established GM crop research by allowing Delta and Pine Land (D&PL) to introduce field trials of GM cotton in 1989 (Gouse, 2007). Nearly a decade later, with the enactment of the 1997 Genetically Modified Goods Act, South Africa formally initiated commercial production of genetically modified crops. South Africa has since approved various traits of genetically modified canola, maize, cotton, and soy for commercial production, but it has relied exclusively on the major private seed developers and agrochemical companies for research and development (ISAAA, 2011). Burkina Faso took a similar approach as South Africa, approving Monsanto's insect resistant, Bt cotton, for food, feed, processing, and planting (ISAAA, 2011). Burkina Faso stands as one of the most rapid adopters of biotechnology, with 260,000 hectares of Bt cotton cultivated in 2010 accounting for 65% of the nation's total cotton production (James, 2010). Similarly, Egypt approved an insect resistant maize variety developed by Monsanto for planting in 2008; but has yet to approve any transgenic crops for commercial production (ISAAA, 2011).

Many other African countries have begun to follow the model of South Africa, and now Burkina Faso, by relying on the capabilities of international corporations to perform the laboratory work, while attempting to focus national efforts towards conducting field trials and monitoring the efficacy of GM seed varieties in local climates. Other countries have applied biotechnological research using methods such as tissue culture (TC) or marker-assisted selection (MAS), two forms of crop biotechnology that have been around for centuries, but because they are do not actually involve the alternation of genes, they are not considered to be "genetic modification" per se and therefore are less heavily regulated than full-fledged GM traits such as Bt or RR. Numerous African countries have recently become engaged in national research and development initiatives, through capacity building activities such as micro-propagation or marker identification, or genetic modification projects at national agricultural research services (NARS) or at local universities, typically in partnership with outside donors or research centers. Table 4 (Appendix) provides a list of ongoing GM R&D projects in a select list of countries, which will be discussed in greater detail in the following section.[7]

Regional Initiatives. In recent years, several multilateral organizations have begun to research GM crop technologies as part of very specific economic growth, development, poverty reduction and/or food security agendas. The following section will discuss a few of the core initiatives whose organizational foci are not exclusively centered on biotechnology, but they remain key facilitators to the sub-Saharan African agricultural development agenda and therefore, one or many of them will likely be involved in providing input regarding GM crop projects in the region. All of the organizations mentioned below span national borders and rely on both the public and private sectors for funding and sometimes for guidance on how to allocate investment dollars to research and development.

The Forum for Agricultural Research in Africa (FARA) provides an information-sharing, and networking role in sub-Saharan Africa. It was founded in 2001 by a collection of sub-regional groups including the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), the West and Central African Council for Agricultural Research and Development (CORAF/WECARD), Institut du Sahel (INSAH), Southern African Centre for Cooperation in Agricultural Research (SACCAR), and others. The purpose of FARA was to expand the dialogue between NARS and sub-regional organizations in sub-Saharan Africa. FARA is also charged with the oversight of CAADP Pillar IV: "Agricultural Research and Technology Dissemination" (FARA, 2007). FARA plays a major role in facilitating the information exchange across national, sub-regional, and private entities. Among other projects, FARA is currently working closely with the Nairobi-based Biosciences for East and Central Africa (BecA), the African Biosciences Network of Expertise (ABNE), based out of Burkina Faso, and various African universities to help build both conventional and biotechnological agricultural education programs with the hope that agricultural knowledge capital can be grown and maintained in Africa (FARA, 2010). In 2009 FARA initiated a partnership with the Syngenta Foundation for Sustainable Development (SFSA) to form the joint project called Strengthening Capacity for Safe Biotechnology Management in sub-Saharan Africa (SABIMA). This project was geared towards sharing of biotechnology information, and as of November 2011, gathered information about all ongoing biotechnology projects in various African countries, as shown in Table 4 (FARA Africa Biotechnology Database, 2011).

[7] The data provided in Table 6 is mostly taken from the FARA Biotechnology database, but has been adapted by the authors. The available data only includes those countries that have submitted to the database, so some country projects are missing, including Nigeria and Kenya.

The African Agricultural Technology Foundation (AATF) and the International Institute for Tropical Agriculture (IITA) are two organizations that are both more directly and outwardly involved in biotechnology-related agricultural development projects.

The AATF has a central goal of providing affordable technologies and encouraging partnerships to facilitate the transfer of such technologies to African countries. Current AATF projects include work on genetically modified cowpeas, cassava, and bananas, all of which are staple African crops, and the traits are predominantly focused on risk mitigation (pest or disease resistance), with a goal of contributing towards Africa's food security agenda. AATF is also a core contributor, in partnership with African NARS, Gates, Monsanto, and others, to the water efficient maize (WEMA) project. Because maize is traded as a global commodity, the WEMA project does not have a pure food-security agenda. However, the trait and technology could be redirected towards a food security agenda if applied to staple food products. Lastly, the striga control project, which is led AATF and includes various partners listed in Table 4, has a goal if introducing varieties of maize, sorghum, millet, and rice that are resistant to the "StrigAway" herbicide, developed by BASF and commonly used in Africa. The striga project is notable in that it is one of few initiatives that have worked in conjunction with various African seed companies (Kenya Seed, Tanseed International, and Zum Seed (Malawi)), thereby confirming AATF's proposed commitment to local resourcing and capacity building in Africa. However, it should be noted that the striga resistant varieties created thus far do not rely on transgenics (and instead, were developed through "mutagenesis") (GRAIN, 2006). Because of the different level of biotechnology used, the striga-resistant crops are likely to have lower biosafety standards, which could explain the greater local participation from African seed companies. Despite the striga project's widespread local participation, its distinct goal of developing varieties with resistance to an externally produced and controlled herbicide ("StrigAway") will likely yield fewer direct benefits on the local food security agenda, especially when compared to some of the other projects such as biofortification.

The IITA is a CGIAR institution and serves as CGIAR's primary African agricultural-focused research center. In 2010, nearly one-third of the IITA's total expenditures were allocated to "genetic improvements" suggesting its distinct focus on GM crops in its core initiatives. The IITA has engaged in projects focusing specifically on other African staples, including cassava, cowpeas and bananas, as well as the globally marketed crops, such as soybean and maize (IITA, 2011). Three IITA-supported initiatives are currently underway in Africa, including "Strengthening Capacity for Yam Research-for-development in Central and Western Africa" (SCYReC), "The Great Lakes Cassava Initiative", and "Management of Millet Head Borer to Increase Pearl Millet Production in the Sahel". Each of these initiatives rely on partnerships with African NARS, local and international research centers, seed companies public not-for-profit donors shown in Table 4.

Africa Harvest Foundation International ("Africa Harvest") started in 2002 with a founding goal of improving agricultural productivity through the promotion of science and technology. Today, the Africa Harvest is involved with two primary biotechnology projects involving African staple crops, banana and sorghum. Both projects, listed on Table 4, have specific goals of making improved crop varieties available and affordable to small farmers and are focused on keeping African institutions involved in all aspects of the value chain.

Finally, the Alliance for a Green Revolution in Africa (AGRA) was formed in partnership with international donors (Gates and Rockefeller) and under the leadership of Kofi Annan. AGRA's organizational mission is geared towards assisting small-scale farmers increase productivity and farmer incomes. AGRA has historically communicated mixed messages about the extent to which it will utilize biotechnology research as part of this program until 2007, when AGRA issued a statement confirming its support for "the use of science and technology – including genetic modification (GM) technology – to aid Africa's smallholder farmers in their urgent efforts to end widespread poverty and hunger" (ISAAA, 2007). AGRA's seed program, "PASS", and its four sub-programs: Education for African Crop Improvement (EACI); Fund for the Improvement and Adoption of African Crops (FIAAC); Seed Production for Africa (SEPA), and the Agro-dealer Development Program (ADP), combined, have dominated AGRA's initiatives to date. According to publicly available information, the organization does not appear to be directly involved in any GM crop projects, but is indirectly involved through partnering with African seed companies who are themselves undertaking GM crop projects. For instance, AGRA works in partnership with Tanseed International and forty other African seed companies as part of the SEPA program (AGRA, 2012). Tanseed, in particular, has been involved in GM crop research, notably through the striga resistant maize project listed in Table 4.Most of AGRA's current projects, like the partnership with Tanseed, are focused on fostering locally based and owned development projects.

Although all of the aforementioned organizations are considered non-profit multilateral organizations, they have very different organizational objectives and underlying incentive structures. For example, although IITA is committed to African agriculture, it is a global institution looking specifically at tropical agriculture and although it does have a specific African development agenda, and it is essentially a public sector, inter-governmental organization funded by developed and developing country governments, multilateral organizations, and foundations and is a member of the Consultative Group on International Agricultural Research (CGIAR). Conversely, AGRA, Africa Harvest, and FARA are all focused, first and foremost, on fostering locally driven agricultural development in Africa. Although AATF is distinctly committed to making technologies accessible to African farmers, it is more closely tied to some of the major international seed companies. Notably, representatives from Monsanto, Emergent Genetics, Pioneer HiBred, and DowAgroSciences are involved in the AATF's "Design Advisory Committee" (DAC) which was the working group charged with developing AATF's core organizational focus upon its 2002 inception (AATF, 2011).

There are a number of other international, national, and regional organizations that have made a significant contribution towards agricultural biotechnology in Africa but tend to focus more on specific projects and are not listed here because most of these organizations are often tied, at some level, to one or more of the regional or multilateral initiatives listed above. Given the great need of many African governments to prioritize agricultural biotechnology with other more immediate development needs, the multi-layered and multi-party approach towards agricultural development is almost universally supported. However, it is the extent to which these partnerships and processes are conducted with profit-driven intentions or for the achievement of food security is subject of ongoing debate in the field, a topic that will be expanded upon in greater detail in subsequent sections.

The Nature of the Debate in Africa

The nature of the debate in Africa reflects many of the core positions and themes that dominate the controversies at the global level discussed in the earlier section and are not repeated here. This section focuses on particular issues that have been raised.

As elsewhere, the debate has been polarized in Africa over the last decade. Initiatives have been launched to steer the historically polarized debate towards a more evidence based and constructive analysis of the issues. Notably, the AU and NEPAD established the African Platform on Biotechnology (APB) and the African Ministerial Conference on Science and Technology's with the goal of developing an "African consensus" on the debate regarding biotechnology and to "facilitate open and informed regional multi-stakeholder dialogues… associated with or raised by rapid developments in modern biotechnology" (NEPAD, 2011). However, the anti-biotechnology NGOs such as La Via Campesina, Greenpeace, Vandana Shiva, and the ETC Group, remain skeptical about the motives behind biotechnology research agenda in Africa and remain opposed to GM crop development in general. As elsewhere, most of the African views opposed to GM crops are centered on two primary concerns: (i) that the industry is controlled by corporate profit interests and associated research agendas, and (ii) that biosafety and health regulations are becoming increasingly permissive, leaving African citizens and the environment subject to the unknown negative impacts of GM crops.

The heavy involvement of the dominant seed companies in the actions of multilateral organizations such as AATF and IITA has fostered much criticism by anti-globalization NGOs. The fact that AATF's "Design Advisory Committee" (DAC) includes representatives from various international seed companies in addition to African NARS representatives (AATF, 2011) is often highlighted as problematic due to the competing and conflicting interests between the profit motives of the international seed companies and poverty reduction goals of NARS. Similarly, the IITA has been criticized for having disproportionate investments in research projects that will benefit corporate interests – as one-third of 2010 expenditures were invested in "genetic improvements" and nearly a third of the organization's funding came from USAID (IITA, 2011). Even FARA, which is uniquely public in origin and is entirely focused on agricultural development for food security in Africa, has also relied on partnerships with private seed companies. The aforementioned information-sharing partnership with Syngenta Foundation is one of such partnerships. AGRA and Africa Harvest, despite their explicit development philosophies of being "African-led" organizations, also have ties to corporate interests through its international donors and/or research centers.

Recognizing the clear evidence of the involvement of multinational seed companies in promoting biotechnology research in Africa, we must ask whether the involvement of the private sector is intrinsically negative or if, alternatively, the private sector could indeed be utilized to encourage knowledge transfer and adaptation of technologies to achieve greater food security. This question elicits a wide range of responses.

La Via Campesina, a well-known opponent of GM crops, believes that any development effort tied to the corporate interests of private seed companies will undoubtedly inhibit the ability of under-resourced African farmers to achieve sustainable progress toward food security. On December 5th 2011, La Villa Campesina organized an "International Food Sovereignty Day to Cool Down the Earth", calling upon citizens to mobilize "actions against multinational corporations like Monsanto undermining our seed sovereignty" (La Villa Campesina, 2011). The event took place in Durban, South Africa, at the University of KwaZulu-Natal. Speakers from Mozambique, Zimbabwe and Mexico came to educate citizens about the wrongs of the corporate control of African agricultural systems.

Claims of the potential risks of corporate control, made by La Via Campesina and other organizations, are often supported by references to past instances of failed intellectual property regimes making it impossible for smallholder farmers to benefit from GM crops. For example, in 2010, a group of NGOs sent an open letter to Oxfam, criticizing the Oxfam decision to commission the publication: *Biotechnology and Agricultural Development: Transgenic Cotton, Rural Institutions and Resource-Poor Farmers,* edited by Robert Tripp. The open letter attacked Tripp's conclusion that GM crops could be used as a tool to help resource-poor farmers increase productivity and reduce poverty, highlighting the case of the Makhatini Flats in South Africa, where the use of GM crops actually led to the subsequent indebtedness of farmers (An open letter to Oxfam America, 2010).

On the other hand, many researchers and policy-makers argue that corporate participation argue that the multinational seed companies have the necessary technology, especially the upstream biotechnology research capacity, that is otherwise difficult to develop. Such capacity could be developed in the CGIAR system, or in large public NARS such as of China, India and Brazil. Thus, multinational seed companies could be critical in allowing African research centers to benefit and improve upon past research without having to reinvent the wheel. As mentioned in the outset of this paper, the private sector has been involved in many national efforts to develop capacity for GM crop technology, including in Brazil, and India. However, it must not be ignored that profit-driven interests must be joined by effective policy measures (such as royalty-free licensing agreements, provision of farmers with access to credit, etc) intended to benefit local smallholder farmers rather than profit interests of multinational companies (Nwalozie, et al, 2007; Juma, 2011; Paarlberg, 2008). For example, when taking a closer look at the aforementioned Makhatini Flats experience in South Africa, the failure to introduce GM crops was not due to GM crop technology itself, but it was the fault of the absence of safety nets to protect small-scale farmers from the risk of indebtedness from more expensive seeds. This repercussion could have been mitigated or eliminated if the South African government would have implemented more accessible credit provision systems simultaneously with the introduction of Bt cotton (Tripp, 2010).

A particular concern debated in Africa has been the impact on exports. Governments have been fearful that the adoption of GM crops would reduce potential for their exports to the

European Union where consumers are anti-GM. This fear is not founded on evidence in as much as none of the principal African agricultural exports, such as coffee, cocoa, groundnuts etc., have GM varieties except cotton. However there is fear of creating a perception amongst the consumers that African countries are pro-GM and that their products are likely to be genetically engineered.

Biosafety legislation. Controversies over environmental and health risks parallel those elsewhere, with emphasis on why this technology would not contribute to food security objectives. No doubt as a result of these controversies, African governments have opted for highly precautionary. This has in turn, as elsewhere, discouraged investment since stricter legislation leads to high costs of certification (Paarlberg, 2008).

Although a majority of African countries have ratified and signed the CPB, only handful have written specific laws specific to GM crops (Cartagena Protocol on Biosafety, 2011). Understanding the difficulty of administering such labor-intensive regulatory controls, many regional economic communities (REC's) such as the Economic Community of West African States (ECOWAS) and the Common Market for Eastern and Southern Africa (COMESA) have made attempts to "harmonize" biosafety laws among their constituent countries (FARA, 2010). FARA's African Biotechnology Biosafety Policy Platform (ABBPP) has assumed an oversight role in regulation some of these regional regulatory efforts. The African High-Level African Panel on Modern Biotechnology (APB) argues that African countries should adopt the "co-evolutionary" approach to biosafety regulation. This approach encourages African countries to continue developing biotechnology research capacities while keeping biosafety regulation open and flexible (Juma & Serageldin, 2007). Moreover, the APB maintains that biosafety policies must distinguish from different types and uses of biotechnology in agriculture rather than taking a "broad-based" precautionary approach to regulation without assessing the specific cases at hand (Juma & Serageldin, 2007). However, the debate continues over how and to what extent biosafety setbacks should be allowed to inhibit potential progress towards food security in Africa.

The issues of biosafety regulation and corporate control are important and unavoidable topics that that have undoubtedly been addressed by all of the multilateral organizations involved. The narratives offered by Greenpeace, La Via Campesina, and Vandana Shiva, the ETC Group, contrast with the message of some of the main African development organizations looking at GM crops for its potential to yield solutions for food security goals. The contrasting dialogues in Africa have been a source of contention that has undoubtedly inhibited the ability of national agricultural research systems and sub-regional groups to get past the polemics and merely consider GM crops as a tool for potentially achieving greater food security in Africa.

IV. Institutional and Policy Choices

The application of biotechnology requires new institutional and policy challenges. This new technology is not only new science requiring new types of human and laboratory capacity in the biotechnology and life sciences. They require institutional shifts including regulation for biosafety, intellectual property, and new roles for NARS, international research organizations, local and international seed companies, and new types of partnership arrangements amongst them.

Research and development priorities for food security and poverty

Governments in sub-Saharan Africa face critical choices with respect to biotechnology for food security. As we noted at the outset of this paper, food security does not depend on production but on the access that people have to food. Accessibility depends in turn not only on the availability in the country but also on both food prices and household incomes. In this context, agricultural biotechnology has potential to increase national production and increase availability. It also has the potential to improve accessibility in increasing producer incomes and reducing local food prices for consumers. But this potential can only be realized if the food insecure households benefit and resource poor producers benefit. That in turn would depend on the multitude of direct and indirect consequences of technological change. But in the first instance, it would require a research agenda that gives priority to staple food crops and to the productivity constraints faced by poor producers. As we review institutional and policy choices faced by African governments, a critical issue that must be kept in mind is not only the potential of the technology for enhancing productivity and production, but also its distributional and indirect impacts.

In 1999, the seminal report on prospects for GM crops in developing countries by the UK Nuffield Council on Bioethics warned "*As GM crop research is organized at present, the following worst-case scenario is all too likely; slow progress in those GM crops that enable poor countries to be self-sufficient in food; advances directed at crop quality or management rather than drought tolerance or yield enhancement; emphasis on innovations that save labour costs (for example herbicide tolerance), rather than those that create employment; major yield-enhancing progress in developed countries to produce, or substitute for GM crops now imported in conventional (non-GM) form from poor countries'.*

The story of the first generation of commercialized GM crops closely resembles the worst-case scenario. The main crops developed – maize, cotton, and soy – were aimed at North American producers, and are all crops with large and profitable world markets. This is clearly the product of the incentive structures of the corporate business model that supplies products that do not target and can bypass pro-poor priorities. As the 2004 FAO State of Food and Agriculture report 'Agricultural Biotechnology: Meeting the Needs of the Poor' concluded, this technology has the potential to meet the needs of the poor but for the potential to be realized requires considerable investment.

Table 2 highlights the potentially contrasting priorities between food security, national economic growth, and financial return.

Table 2: Contrasting Policy Objectives – Food Security, National Economic Growth and Financial Return

	Food Security	National Economy	Financial Return to Investor
Crop	**Staple food crops** Examples: cassava, sorghum	**Major crops by output** Examples: cassava, sorghum	**Large global markets** Examples: cotton, maize, soy
	Nutritious Food Examples: cowpea	**Major export earners** Examples: cotton, groundnuts, coffee, cocoa	**Profit/growth potential** Examples: Luxury goods (strawberries, grapes, guava, flowers) or growth markets (use of cassava, jatropha for industrial products and/or biofuels)
Trait	**Yield increase** Examples: higher yielding varieties, nitrogen use efficiency, fertilizer response, water use, tolerance to salinity, resistance to disease and pests	**Yield increase** Examples: higher yielding varieties, nitrogen use efficiency, fertilizer response, water use, tolerance to salinity, resistance to disease and pests	**Leverage global technology** Examples: Bt, RR
	Risk reduction Examples: resistance to drought, pests, disease	**Cost reduction** Examples: using herbicide tolerant traits for purpose of enabling mass-application of herbicides without damaging crop	**Cost reduction** Examples: using herbicide tolerant traits for purpose of enabling mass-application of herbicides without damaging crop
	Environmental management Examples: more efficient use of resources or reduced need for chemicals (note that pest resistant traits are considered a form of environmental management, but NOT herbicide tolerance)	**Risk reduction** Examples: resistance to drought, pests, disease	**Risk Reduction** Examples: Ease of transport/packaging/prolonged ripening (bananas)
	Nutrition enhancement Examples: biofortification of seeds with vitamin A, iron, zinc, protein (rice, cassava, sorghum, potato)	**Environmental management** Examples: Preservation/expansion of biodiversity, efficient use of resources or reduced need for chemicals (note that pest resistant traits are considered a form of environmental management, but NOT herbicide tolerance)	

Historically, the dominant role of corporate players in GM crop research has meant an overwhelming focus on the right side of this matrix, financial return to the investor. The objectives listed here are focused only on ways to increase profitability of their investments, as should be expected from corporate participants, by identifying large scale markets, leveraging existing technologies, and reducing costs. The crops developed – maize, soy and cotton are all crops with large global markets. Herbicide tolerant maize and soy are good examples of GM crops that earned a very healthy financial return for seed companies, given the crop's ability to reduce farmer production costs by allowing for the widespread application of herbicides and limiting labor requirements. From a food security perspective, reduction in labour demand in developing country agriculture has adverse consequences since it reduces employment and incomes of the poorest households.

If we turn to the left side of Table 2, we are provided a list of objectives that are focused specifically on improving food security by increasing availability of food consumed by the most food insecure households many of whom are in rural areas and in marginal ecological environments. For instance, a GM project geared towards creating pest-resistant cowpeas, a nutritious staple crop in Africa, has the potential to contribute positively towards Africa's food security and poverty reduction agendas. The cowpea project is unlikely to attract a large amount of private investors, given that it is not have any potential for large market demand. Alternatively, development of a GM cassava variety for potential industrial use in biofuels and building materials might attract interest from multinational seed companies, and it could also have a positive impact on both food security and national economic growth since it is a staple food crop that is readily gown in harsh African climates. Alternatively, if industrial cassava production is focused solely on export profits, it could make this staple food inaccessible to under-resourced communities and in turn, driven a people further into poverty and food insecurity.

The most important takeaway from Table 2 is that not all GM crop research agendas are necessarily driven by corporate interest and financial gain. However, all projects are faced with the constant interplay of competing interests given the current reliance on the multinational private sector for technological expertise. Therefore, the matrix serves to reiterate an important point made throughout this paper, the essential role of African governments in managing these contrasting priorities and driving the research agenda so it works towards bettering social equity and poverty reduction at home. To date, more African countries are starting to take a more active approach in biotechnology research. Table 3 demonstrates the extent to which a national agenda is driving research priorities in seven African countries that are involved in biotechnology research activities (FARA Database, 2011).

Table 3: Biotech Activities and Food Security Objectives[8]

Country	Total Number of Biotech Activities	Activities with Food Security Objectives	Activities with National Public Involvement (NARS, Higher Education)
Burkina Faso	17	9	17
Ghana	26	12	24
South Africa	25	7	25
Tanzania	7	3	7
Togo	17	13	17
Uganda	22	19	18
Zambia	3	1	3

Many of the biotechnology research activities do have representation from NARS or local universities. Food security tends to be more of a focus in Uganda, Togo, Ghana, and Burkina Faso, where approximately half of the biotechnology research activities are focused on food security objectives such (risk mitigation, yield increases, or nutritional enhancement for staple foods). Interestingly, despite the presence of South Africa's public sector in all of the biotechnology activities, food security objectives tend to be less of a focus there than most other African countries engaging in biotechnology research.

Research and development capacity and institutional arrangements

One of the critical challenges in the use of agricultural biotechnology to meet food security priorities is the national research capacity. Capacity constraints have long raised questions about whether developing countries could access modern biotechnololgy (Byerlee and Fisher, 2001; UNDP, 2001). However, the spread of research and seeds around the world indicates that the obstacles to developing country access may not be as overwhelming as has been anticipated. First, African countries may benefit from spillover effects of international research. Second, biotechnology capacity can be built up.

Nwalozie and others (2006, based on Byerlee and Fischer, 2002) use three-tiered model to categorize the capacity level of national agricultural research systems (NARS) Type I: "having molecular biology and plant breeding capacity", Type II: "with limited molecular biology but solid plant breeding capacity", and Type III: "having limited capacity overall". Although African NARS vary significantly in capacity, most fall into the lowest level, Type III. But these capacity limitations are not insurmountable and the more important question is how these limitations may be overcome. There are different institutional approaches through which countries can access and benefit from agricultural biotechnology: relying more or less on their own national capacities or drawing from global R & D; and relying more or less on public institutions or on

[8] This chart is constructed from FARA's biotechnology database of "biotechnology activities". This database includes many tissue culture projects or other biotechnology activities beyond what is listed in Table 4.

private investment. Juma (2011) emphasizes the importance of "Regional Innovation Communities" which focus on creating physical centers, or "Local Innovation Areas", hosted by appropriate institutions that would vary in focus, from universities, research centers, or private companies. He states the importance that these local and regional communities utilize resources provided by international partners, but he also stresses that these international tools should be channeled to regional innovation communities remain focused on the "core biotechnology mission" for each of the five AU regions (Juma, 2011). By creating regional centers for innovation, it might serve to alleviate pressure from national NARS and also foster collaboration within regional communities.

As explained in the earlier sections of this paper, the scientific process of developing a commercially viable GM variety involves two distinct steps: a biotechnology step leading to a successful 'transformation event;' and a plant breeding step leading to a variety adapted to a particular location. These two steps do not need to be carried out in the same country and a country can take advantage of the spillover benefits of the biotechnology stage R & D by licensing the technology. Countries do not need to develop their own upstream biotechnology research capacity to benefit from global technology. Indeed, most countries across the world that have engaged with commercial production of GM crops (including Brazil, India, Argentina, South Africa) have benefited from spillover benefits of internationally developed technology. Only the US and EU countries have developed capacity in both these processes. The capacity has been located in the private corporate sector, and in academic research institutions for the upstream biotechnology research. China has developed extensive capacity that rivals Monsanto, though they initially benefited from Bt Cotton developed in the US.

Strategic choices for agricultural biotechnology capacity development for African countries concern the appropriate role of private and public sectors, at national, regional and international levels. Some developing countries have successfully adopted GM crop varieties by relying on private sector innovation in the seed sector without necessarily developing their own biotechnology capacity in NARS. Argentina and South Africa are relying on this 'leave it to the private sector' approach to access the benefits of agricultural biotechnology. At the other extreme, China has developed both biotechnology and plant breeding capacities in its public sector. In between, Brazil and India are starting later, with fewer resources than China, to develop both biotechnology and plant breeding capacities in the public sector, and plant breeding capacity in the seed companies. India has released a variety using its own event. Brazil has released varieties through joint ventures.

Two countries in Africa that have commercialized GM crops, South Africa and Burkina Faso, are following the private sector-led model. As Table 4 shows, the primary research is being conducted by multinationals in South Africa: Bayer, Pioneer, Syngenta and Monsanto; and in Burkina Faso, by Monsanto and Arcadia Biosciences but also with the involvement of the country's NARS, INERA. While this is a shortcut to benefiting from the spillover effects of global technology development, this approach does not make full use of the potential of biotechnology to address R&D priorities of food security and poverty in Africa. Alternatives sources of meeting these priorities include greater regional collaboration and international research. These include: (i) public international agricultural research institutions, such as of the

Consultative Group on Agricultural Research; (ii) cooperation with China, Brazil and India with public capacity in biotechnology research; (iii) regional cooperation; (iv) public-private partnerships between a national research institution and international public or private organizations. The initiatives supported by AATF, IITA, AGRA, and FARA outlined in the previous section involves some of these regional collaborations, notably regional cooperation and public-private partnerships. However, each of these initiatives remains limited in scope and potential to make headway in the relatively new, complex and controversial field of agricultural biotechnology.

Creating a regulated seed market: biosafety controls, intellectual property and seed marketing

While much attention has gone into developing biosafety legislation in Africa, the experience of countries that have commercialized GM crops so far has shown that the bigger challenge is in the implementation of the legislation because both biosafety and IP rules are difficult to enforce, and lead to unintended consequences. The ultimate objective is to create a regulated seed market in which biosafety controls and intellectual property are effectively enforced, and one where seed markets deliver quality seed at an affordable price to farmers. The persistent problem in Argentina (Chudnovsky, 2006), Brazil (da Silva, 2006), India (Ramaswami, 2006), China (Huang, 2006) has been the rapid spread of seeds - 'stealth seeds' - that have not gone through certification and do not respect intellectual property regulations (Herring, 2007a). These seeds are spreading in countries where either the authorized seeds are not available, or to supply seeds at a lower price than the certified seeds. In addition to the potential environmental risks that they pose, they do a disservice to farmers who buy them who cannot be assured of their quality. The broader impact of this phenomenon is little known and studied.

Developing a regulated seed market for GM seeds requires a major institutional shift in developing countries where commercial and informal seed markets exist side by side. In most countries, hybrids are supplied by organized commercial seed companies (alongside many small companies) and by farmers themselves. These seed supply systems are intrinsically connected to plant improvement and breeding activities, which take place primarily in NARS and to a more limited extent in seed companies, as well as by farmers themselves, who select and multiply seeds for their own and neighbours' use. In the US, as in the commercial sectors of many developing countries, farmers have a more consistent tradition of buying seed from seed companies. GM seeds are patent protected and the companies require farmers to sign a contract agreeing not to save their own seeds and invest in enforcing these contracts through the courts. Yet such agreements are inherently difficult to enforce. There is little incentive for farmers not to keep their seeds and share them with neighbours. It is not surprising that the spread of 'stealth seeds' has been extensive in India, Argentina, Brazil and elsewhere (Herring, 2006; Scoones, 2006).

Many African countries have adopted precautionary biosafety legislation. While the objective of this policy choice is to minimize environmental risk, it is also associated with high cost and slow process. This acts as a disincentive to seed companies, particularly for the smaller ones.

High cost of the approval process may be contributing to the concentration in the seed industry globally with a handful of companies leading the field. Comparison of China and India also suggests that at the national level, restrictive legislation encourages evasion and the spread of unauthorized seeds (Pray et al, 2006). Pray and others found obtaining approval much more costly, lengthy and unpredictable in India than in China. As the case study in this volume argues, the result in India is that those varieties that the official market in GM seeds offers is less competitive because only one variety was approved between 2002 and 2006. China encourages seed companies selling unauthorized varieties to go through the approval process. This approach effectively gives incentives for all seed entrepreneurs to integrate into the regulated market rather than to stay out in the informal sector. The result is a system more capable of providing farmers with a greater choice of varieties.

China's experience has taken a pragmatic approach of revising their legislation repeatedly so that seed companies – most of them small – would comply. The model of a regulated seed market with strict legal enforcement does not fit the realities of developing countries. In India, when Bt cotton varieties were found growing before they were authorized, courts ordered them to be burned. But this was not a politically enforceable verdict.

Government policy approaches for agricultural biotechnology

While conventional crop improvement research has been primarily a public sector activity throughout world, including in the developed countries until recently, the private sector has come to play the principal role in relation to agricultural biotechnology. Government policy tools therefore include not only direct investment in public sector research by NARS and other public institutions but also through the way that the private sector is incentivized and regulated. The principal policy tools therefore include: (i) public financing for research and development; (ii) biosafety process including seed certification and quality control; (iii) IPR; and (iv) public communication with consumers and other civil society stakeholders.

The global biotechnology research has been led by the US and Europe where there has been a strong public financing and support for upstream R&D in universities, strong IPR that recognizes genes and plants that facilitated corporate research. Commercialization in US and Canada was facilitated on a model of a permissive biosafety policy, string implementation of IP and public opposition that did not influence policy. In Europe, the biosafety process has been precautionary and public debates have been more active with NGO opposition having a stronger influence on public opinion and government policy. These models of government policy approaches are not likely to be applicable to African countries. As we have pointed out, strict IP is unlikely to be enforceable. Strict biosafety legislation is also likely to undermine enforcement. Government capacity for financial support to research is limited. African countries might draw more lessons from other developing countries that have used or are developing alternative policy approaches.

1. Support to R & D: other than South Africa, most countries are severely resource constrained and unlikely to have adequate financial resources to support R & D. Nonetheless, countries do have an important choice with respect to: (i) research

priorities - whether to undertake R & D, and what priorities should be defined. The association of agricultural research institutes of West and Central African countries (CORAF-WECARD) had adopted a policy to give priority to agricultural biotechnology research, and developed priorities aiming at food security and defined a number of priorities; (ii) research partnerships - research partnerships are needed to acquire necessary know how and expertise in biotechnology. This can range from scientific collaboration with corporations, international research institutions, or foreign public research centers. The list of GM crop R&D projects by country in Table 4 (Appendix) shows an interesting range. South Africa is heavily engaged with global corporations with little involvement of the NARS, a model that could be termed 'leave it to the private sector'. Ghana and Burkina Faso has developed partnership between the NARS and global corporations as well as other international non-governmental initiatives. Tanzania and Uganda are collaborating with international universities and other publicly supported international initiatives. (iii) research financing – research financing primarily comes with the partnerships which in turn can range from private to public sources.

An important choice is the extent to which African countries are able to finance priorities for national food security rather than for global export markets. Other developing countries have followed different models: from entirely public sector financed and executed research in China with minimum external partnerships to South Africa and Argentina where R & D is almost entirely in the hands of the global corporations. India and Brazil fall in between.

2. Biosafety process – the impact of biosafety legislation has had less to do with direct risk management than with controlling the flow of approved varieties. In African countries (with the exception of South Africa's commercial farming sector) where enforcement is the major challenge and the spread of 'stealth seeds' is difficult to contain, the choice of biosafety legislation would need to take account of these realities. Precautionary legislation has had an effect of encouraging uncertified seeds that is ultimately counterproductive to farmers.

3. IP – As with biosafety legislation, the biggest challenge is in the enforcement while a major concern is with the distributional impact of policy choices. Strong IP recognizing plants and gene patents favours corporate investment, and arguably monopolistic tendencies while discouraging small enterprises and diversity of supply. Moreover, strong IP leads to higher prices for longer periods of time. China would appear to have no IP protection for its GM. Has weak intellectual property protection been a constraint to innovation? Huang and Pray note that this is a major challenge that policy makers face in China.

   Developing country considerations for balancing incentives to breeders and incentives for diffusion are quite different from the US context. Multinationals based in the US and elsewhere who are investing large sums in biotechnology and plant breeding would need large markets for their products and strong patent protection on genes as well as on tools and varieties to protect their R & D investments. Developing countries can license these technologies. Can revenues from patent licenses finance R & D for small markets of developing country research?

As we know from the pharmaceutical sector, strong patents can be an incentive to develop high price products for high income consumers, but can do little to encourage investment in high need products for low income consumers. In the pharmaceuticals sector, this has led to large investments in diseases of the wealthy and neglect of diseases of the poor – or 'orphan diseases'. Naylor et al (2004) have argued that a similar process could be at work with private investments in agriculture. In this situation, developing country priorities for R & D will not likely be financed from the private sector, even taking account of initiatives for public-private partnerships and philanthropy. (Osgood, 2006; Chan, 2006). Will the public sector be the only source of financing – and in that case, what kind of patent protection would work best to stimulate research in public sector institutions for varieties with high social and low financial returns. Much more research is needed to explore the implications for developing countries. In this context, the practical difficulties of enforcing patents, especially for crops like soy, and the positive impacts of weak patents on seed prices as well as on entrepreneurial response to develop adapted seed varieties for farmers cannot be ignored.

Conclusions: Biotechnology for Food Security - The Path Not Taken

Africa has been slow to engage with agricultural biotechnology. Commercial production is taking place in any significant scale in only South Africa, and starting in Burkina Faso. Several other countries have on-going research programs. While still very limited, these activities are spreading fast. Given both the potential of the technology, the powerful interests of global corporations to invest in Africa, governments need to adopt a clear strategy. The strategy may be less about whether to use agricultural biotechnology but how and for what purpose.

The focus of attention amongst policy makers has so far been on putting in place biosafety legislation and system which has been stressed by donors as a necessary precondition for any engagement with agricultural biotechnology. We argue in this paper that the critical choices go beyond adopting strong biosafety legislation. For food security and national development, there are other important policy choices. There are choices that center around the type of partnership governments would develop with private and public actors, and with international or regional bodies. Another critical area is to consider policy tools in a perspective of development – IP and biosafety systems not only as tools intended as incentives for investment and environmental risk management. In the developing country context, implementation of these systems is particularly difficult and strong systems could lead to perverse consequences that encourage the proliferation of unregulated seeds.

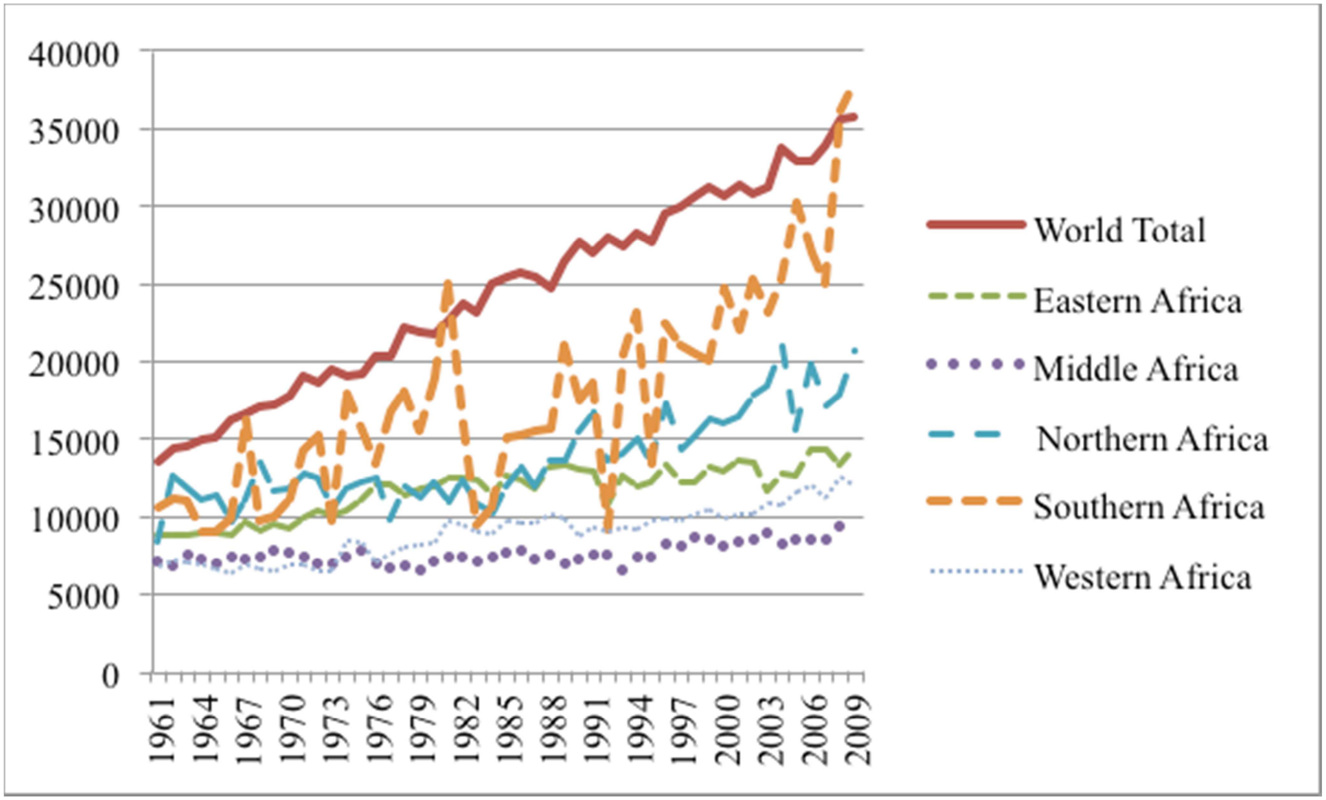
This paper has stressed food security – food crops, increasing yields, and improving incomes of small-scale farmers as important objectives. But governments have other development objectives to which engagement with this technology can contribute. These include: accelerating GDP growth, expanding export growth, building technological capabilities, in addition to reducing hunger and improving household incomes. For the several countries that rely on cotton for a significant part of their export earnings, using Bt cotton may be important to compete for world markets. The current global trend in GM crop development has been to develop export crops and the corporations have found incentive to invest worldwide where production of these crops takes place. The trajectory of GM crops in South Africa and Burkina Faso is clearly driven by that corporate model. By default, agricultural biotechnology is available for meeting economic growth objectives but has not been addressing food security goals.

The distributional consequences of this pattern of GM crop development may not be favourable to food security and poverty reduction. For that purpose, African countries will need to define their own priorities. Several years ago, the association NARS of West and Central African countries, CORAF-WECARD, undertook to design such a strategy. They identified food security as the primary objective and defined a research agenda centered around staple food crops including sorghum, maize, cassava, rice, as well as export crops including ground nut, cotton, cacao, and on traits focusing on disease and insect resistance that would increase yield and farmer incomes. The agricultural development motives of recently established organizations such as AGRA and FARA have also attempted to define specific priorities towards food security goals. These agendas, driven first and foremost by food security goals, do not overlap much with the research agenda and commercial priorities of private corporations.

While no doubt agricultural potential in Africa will attract private sector biotechnology investors. But this is unlikely to overlap with the priorities for food security and the related poverty reduction and human development agendas. African countries will therefore need to attract support and partnership of public and non-profit sectors. What is missing in the GM technology development story so far is proactive pro-poor support from the international public sector (World Bank, 2004); a global public support for a pro-poor R & D agenda, a political alliance of pro-poor civil society advocacy for mobilizing new technology for human development, and public financing for developing country access. Without such an alliance, a new R & D agenda focused not on export crops but on staple crops considered most important for poor farmers and poor consumers is not likely to emerge. But for that kind of alliance to emerge, a new social dialogue is needed that can break the gridlock driven by opposition that cannot be by-passed or ignored. The opposition is driven by a mistrust of science and fundamental questions about the nature of agriculture in society – what food, what farming, what society? These questions call for a new approach to democratic debates about biotechnology in the 21st century, and to forge new policies that would combat technological divides between developed and developing countries, between large, resource rich and small, resource poor developing countries, and between poor farmers and agribusiness in within countries.

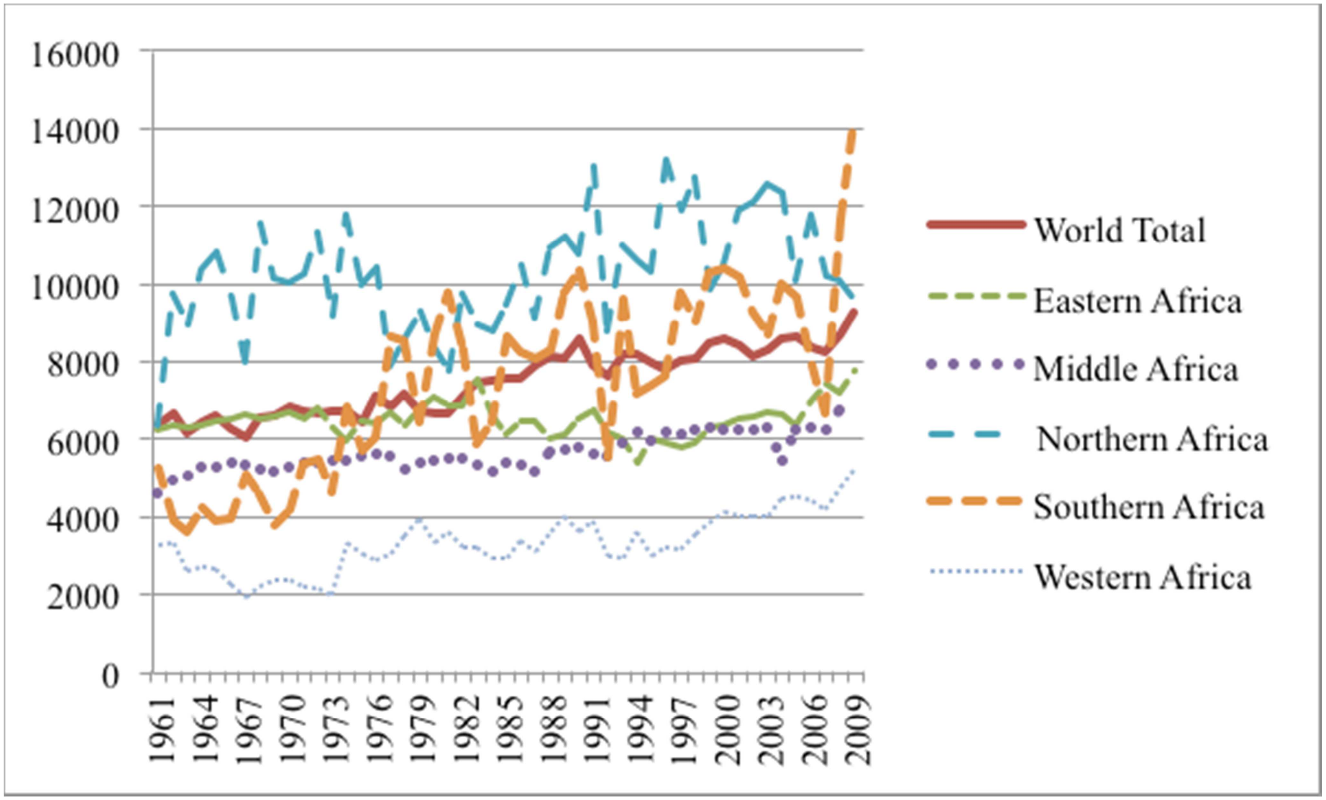
Appendix:

Figure 1: Cereals Yield (Hg/Ha)



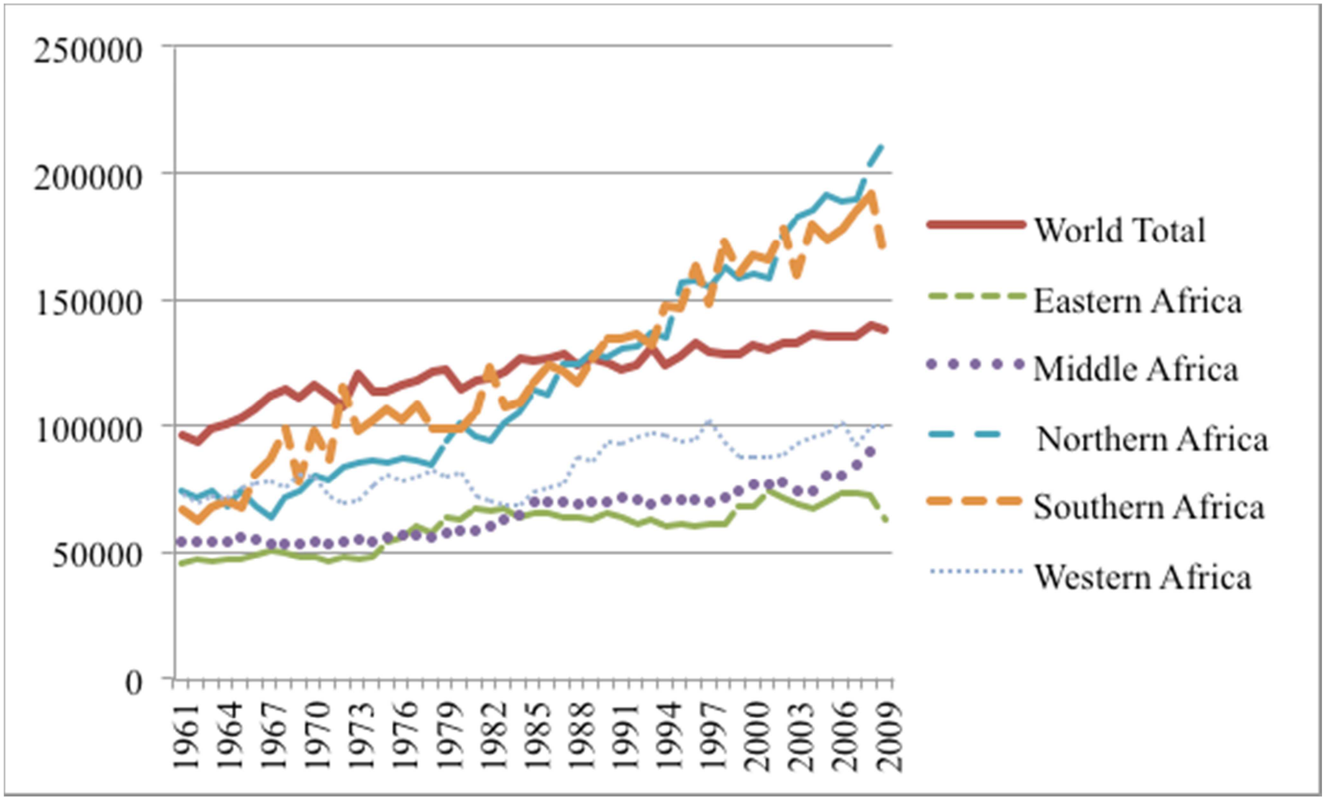
Source: FAOSTAT, 2011

Figure 2: Pulses Yield (Hg/Ha) (1961-2009)



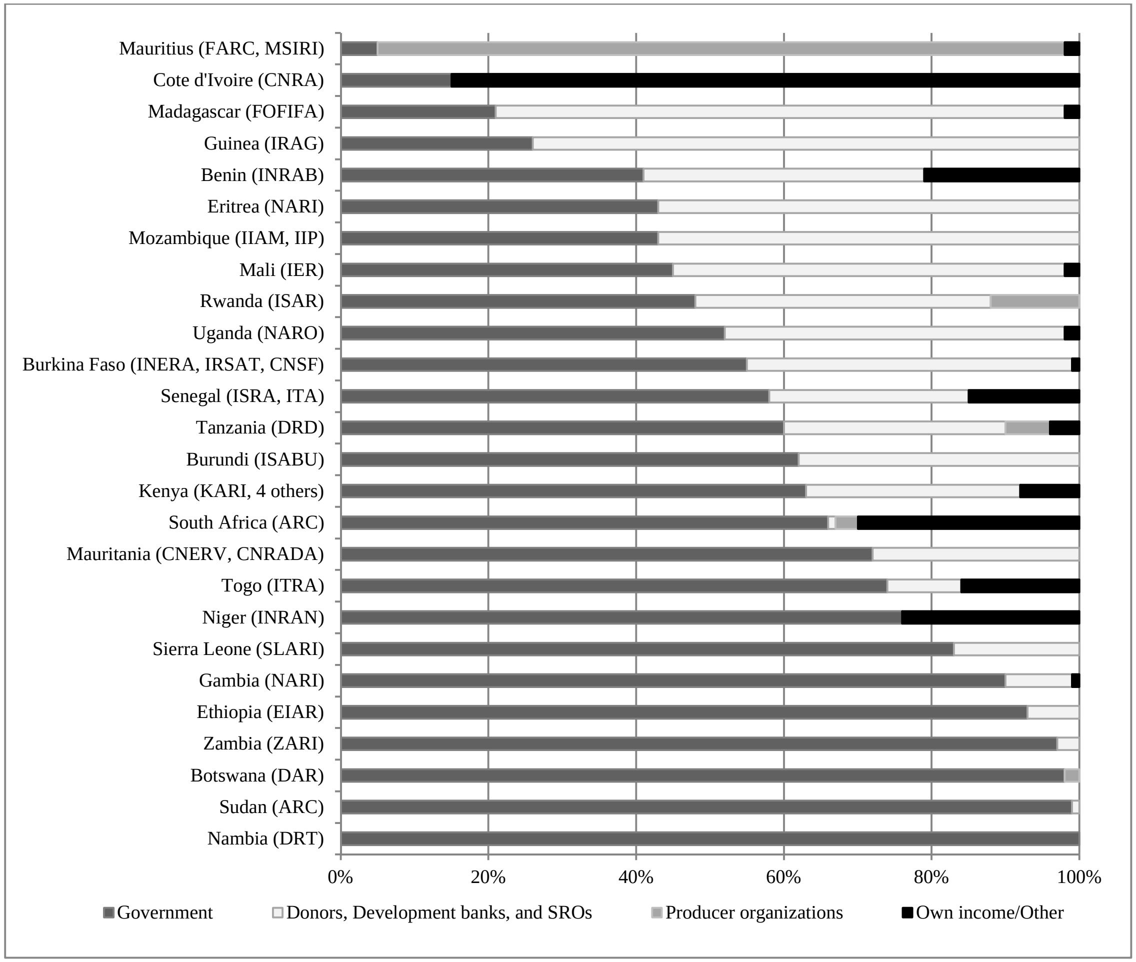
Source: FAOSTAT, 2011

Figure 3: Roots and Tubers Yield (Hg/Ha) (1961-2009)



Source: FAOSTAT, 2011

Figure 4: Funding Sources of Main Agricultural R&D Centers (2008)*



Source: Beintema & Stads, 2011

*The following countries were not included due to incomplete data: Gabon, Ghana, Malawi, Nigeria, the Republic of Congo, and Zimbabwe.

Table 4: GM Crop R&D Projects by Country and Regional Initiative (FARA Database, 2011)

	Crop				Trait**						Locus of Research and Development (* = Originator of Trait)			Funding source
	Name	**Staple food**	**Large. global mkt.**	**Global GM tech-nology**	**Description of Trait/Target Pest****	**Risk mitig-ation**	**Yield incr-ease**	**Environ. Mgmt.**	**Cost reduc-tion**	**Nutrition enhance-ement**	**Corporate (seed companies or research centers)**	**National Public (NARS or local higher edu)**	**Int'l non-profit (multilateral, research inst, or govn't agency)**	
R&D Projects By Country														
Burkina Faso	Cowpea	x			*Maruca* stem borer resistant	x					*Monsanto	INERA	-	USAID
	Cotton		x	x	Boll worm control	x	x	x			*Monsanto	INERA	-	-
	Rice		x		Nitrogen use efficiency		x	x			*Arcadia Biosciences	-	-	USAID
	Sorghum	x			Biofortified sorghum with iron and zinc					x	*Dupont/ Pioneer	INERA	-	Gates
Ghana	Cowpea	x			*Maruca* stem borer resistant	x					*Monsanto	CSIR-SARI (Savanna Agricultural Research Institute - Ghana)	CSIRO Australia	AATF, Rockefeller, USAID
	Rice		x		Nitrogen use efficient		x	x			*Arcadia Biosciences	CSIR-CRI (Crops Research Institute - Ghana)	AATF	-
					Salt tolerance		x							
	Sweet potato	x			Sweet potato virus disease (SPVD) and weevils	x					-	CSIR-CRI (Crops Research Institute - Ghana)	*Tuskegee University	USDA, Foreign Agricultural Service (FAS)
	Cotton		x	x	Insect resistant/Herbicide tolerance	x	x	x	x		*Bayer	-	-	-

South Africa					Insect resistant	x	x	x			*Monsanto	-	-	-
					Glyphosate				x		*Monsanto	-	-	-
					Herbicide tolerance				x					
					Glyphosate				x		*Monsanto	-	-	-
					Herbicide tolerance				x					
					Insect Resistant	x	x	x			*Monsanto	-	-	-
	Maize		x	x	Insect resistant/Herbicide tolerance	x	x	x	x		*Pioneer	-	-	-
					Insect resistant	x	x	x			*Syngenta	-	-	-
					Insect resistant/Herbicide tolerance	x	x	x	x		*Syngenta	-	-	-
					Insect resistant/Herbicide tolerance	x	x	x	x		*Syngenta	-	-	-
					Herbicide tolerance				x		*Syngenta	-	-	-
					Insect control	x	x	x			*Syngenta	-	-	-
	Ornithogalum dubium x thyrsoides (Flower)		x		*Ornithogalum* mosaic virus resistance	x	x				-	ARC - Vegetable and Ornamental Plant Institute (VOPI), *Gauteng Department of Agriculture and Rural Development (GDARD)	Agricultural Research Organization (Israel)	-
	Potato	x			tuber moth resistant	x	x				-	*ARC	*USAID, *Michigan State University	-

South Africa (cont'd)					tuber moth resistant	x	x				-	*ARC	Michigan State University	-
					Resistance to "potato virus Y" (PVY)	x	x				-	ARC - Vegetable and Ornamental Plant Institute (VOPI), *National Research Foundation (NRF)	-	-
	Strawberry				Herbicide tolerance, Fungal resistance	x	x		x		-	-	-	-
	Sorghum	x			High lysine, biofortified					x	*Pioneer	The Council for Scientific and Industrial Research (CSIR) of South Africa	Africa Harvest Biofortification, Gates	-
	Soybean		x	x	Gyphosate herbicide tolerance				x		*Monsanto	-	-	-
	Sugarcane		x		Insect resistant/Herbicide tolerance	x	x	x	x		-	University of Natal (South Africa)	-	-
					Alternative sugar, growth rate/yield and altered sucrose content.		x			x	-	South African Sugarcane Research Institute (SASRI)	-	-
	Wheat		x		Herbicide tolerance				x		*Monsanto	-	-	-
Tanzania	Cotton		x	x	Insect resistant	x	x	x			-	-	-	-
	Maize		x	x	Water efficient maize for Africa (WEMA)	x	x	x			*Monsanto	Mikocheni Agricultural Research Institute (MARI)/Tanzania Commission for Science and Technology (COSTECH)	-	Gates, AATF
					Striga resistant via Imazapyr-resistant	x	x				Tanseed International	Agricultural Research Institute (Ukiriguru, Mwanza) Tanzania Ministry of Agriculture	-	AATF

Tanzania (cont'd)	Cassava	x			Resistance to brown streak and cassava mosaic disease	x	x				-	Mikocheni Agricultural Research Institute (MARI)	*IITA	Gates
Uganda	Banana	x			Bacterial Xanthomonas wilt	x	x				*Academia Sinica, Taiwan	National Agricultural Research Laboratories (NARL), National Crops Resources Research Institute (NaCRRI), Kawanda	-	IITA, AATF, Gatsby, USAID
					Black sigatoka	x	x				-	National Agricultural Research Organization (NARO), NARL, NaCCRI, Kawanda	*Univ Leuven (Belgium), *Cornell Univ (US)	USAID
					Sigatoka disease	x	x				-	NaCCRI/NARL	*Katholieke Universiteit Leuven (KUL) (Belgium)	NARO, USAID
					Fusarium wilt	x	x				*Academia Sinica (Taiwan)	NaCCRI/NARL	-	IITA, Gatsby, USAID
					Weevils and nematodes	x	x				-	NARO NaCCRI/NARL	*U. Leeds, *U. Pretoria, *U. California, San Diego	NARO, Rockefeller, Bioversity Intl, USAID
					Nematodes	x	x				*Rahan Meristem (Israel)	NaCCRI/NARL	-	Rockefeller
					Improved micro-nutrients (Vitamin A+Iron)					x	-	NaCRRI/NARL	*Queensland Univ. of Technology (Australia)	Gates
					Growth parameters: early maturity, early flowering	x	x				-	NARO NaCCRI/NARL	*University of Ghent (Belgium)	Rockefeller
	Banana (cont'd)				Delayed ripening	x	x				*Rahan Meristem (Israel)	*NARO, NaCCRI/NARL	-	Rockefeller

Uganda (cont'd)	Cassava	x			Cassava mosaic virus, brown streak disease	x	x				*Danforth Centre, US	NaCCRI	-	NARO, Virus Resistant Cassava for Africa (VIRCA) Project, Danforth Centre
	Cotton		x	x	Cotton bollworm resistance + herbicide tolerance	x	x	x	x		*Monsanto	NARO –NaSARRI, Mubuku Prison's Farm, Kasese	-	USAID, NARO
	Maize		x	x	Water efficient maize (WEMA)	x	x	x			*Monsanto	NaCCRI	-	Gates, AATF, NARO
	Rice		x	x	Nitrogen use efficiency and drought resistance		x	x			-	NaCCRI	-	-
	Sweet Potato	x			Sweet potato virus disease (SPVD)	x	x				-	NARO, NaCRRI,	International Potato Center (CIP)	CIP, NARO
					Sweet potato weevils Cylas pucnticollis C. Brunneus	x	x				-	NARO, NaCRRI	International Potato Center (CIP)	CIP, NARO
	Ground-nut	x	x		Groundnut rosette disease (GRD)	x	x				-	NARL,National Semi-Arid Resources Research Institute (NaSARRI) - Serere	*University of Georgia	NARO, University of Georgia, USAID
Zambia	Cassava	x			Cassava micro propagation	x	x				-	University of Zambia	-	-
	Jatropha				Jatropha micro propagation		x				-	University of Zambia	-	-
	Groundn ut	x	x		Groundnut improvement programme (molecular markers)	x	x				-	University of Zambia	-	-

Togo	Cassava	x			Cassava micro propagation: cleaning of varieties by thermotherapy & in vitro culture; using of cleaning planting material by famers; *in vitro* preservation of varieties	x		x			-	Togolese Agricultural Research Institute (ITRA)	-	-
	Sweet Potato	x			Sweet potato micro propagation: *in vitro* preservation, exchange of germplasm with other countries	x		x			-	Togolese Agricultural Research Institute (ITRA)	-	-
	Yam	x			Yams micro propagation : cleaning of varieties by thermotherapy, meristem *in vitro* culture; using of cleaning planting material by famers; *in vitro* preservation of varieties			x			-	Togolese Agricultural Research Institute (ITRA)	-	-
	Cassava	x			Cassava micro propagation (goal: free of disease)	x	x				-	Togolese Agricultural Research Institute (ITRA)	CSRI (Ghana)	-
	Banana & Plantain	x			Banana and plantain micro propagation (goal: free of disease)	x	x				-	ITRA	Centre African de Recherches sur Bananiers et Plantains (CARBAP)	-

Togo (cont'd)	Cassava	x			Cassava micro propagation (goal: free of disease)	x	x				-	ITRA	CSRI (Ghana)	-
	Cotton		x	x	Evaluation of preconditions of the introduction of GM cotton	x	x	x			-	ITRA - CRASH Station	-	-
	Sweet Potato	x			Sweet potato micro propagation: *in vitro* preservation of local ecotypes free of disease, genetic characterization	x	x				-	University of Lomé, Faculty of Sciences (FDS)	-	-
	Yam	x			Yams micro propagation: *in vitro* preservation of local cultivars free of disease	x	x	x			-	University of Lomé, Faculty of Sciences (FDS)	-	-
	Okra				Abelmoschus esculentus (Okra) *Capsicum* sp. micro propagation		x				-	University of Lomé, Faculty of Sciences (FDS)	-	-
	Medicinal Plants				Aromatic and medicinal plants micro propagation, tissue and cell culture, endangered species preservation and biomolecules production			x		x	-	FDS, Ecole Supérieure des Affaires (ESA-Togo)	University of Tours (France)	-

Togo (cont'd)	Potato	x			Potato micro propagation	x	x				-	University of Lomé, Faculty of Sciences (FDS)	-	-
	Forestry Prods.		x		Nauclea diderichi micro propagation: plants production for forestry		x				-	University of Lomé, Faculty of Sciences (FDS)	-	-

	Crop				**Trait****						**Locus of Research and Development (* = Originator of Trait)**			**Funding source**
	Name	**Staple food**	**Large global mkt.**	**Global GM tech-nology**	**Description of Trait/Target Pest****	**Risk mitig-ation**	**Yield incr-ease**	**Environ. Mgmt.**	**Cost reduc-tion**	**Nutrition enhance-ement**	**Corporate (seed companies or research centers)**	**African Public (NARS or African higher edu)**	**Int'l non-profit (multilateral, research inst, or govn't agency)**	
Projects by Regional Initiative														
African Agricultural Technology Foundation (AATF)	Maize		x	x	Striga control	x	x				BASF, Western Seed, Lagrotech, Kenya Seed, Tanseed International, Farm Inputs Care Centre (Uganda), Zum Seed (Malawi)	KARI, WeRATE (Kenya), NARO, NAADS (Uganda), Ministry of Ag, ARI–Mwanz (Tanzania), University of Malawi, Bunda College, Ministry of Ag, Chitedze Research Station (Malawi)	Africa 2000 Network (Uganda - NGO), IITA, CIMMYT, Weizmann Inst of Science (Israel), TSBF-CIAT	-
	Sorghum	x												
	Millet	x												
	Rice		x											
	Maize		x	x	Water Efficient Maize for Africa (WEMA)		x	x			*Monsanto, BASF	ARC (South Africa), IIAM (Mozambique), KARI (Kenya), NARO (Uganda), COSTECH (Tanzania)	-	Gates, Buffett Foundation
	Cowpea	x			Pest and disease resistance	x	x				*Monsanto	INERA (Burkina Faso), IAR (Nigeria), other NARS in West Africa.	Network for the Genetic Improvement of Cowpea for Africa (NGICA), CSIRO Australia, IITA	The Kirkhouse Trust (Scottish charity)

AATF (cont'd)	Banana	x	x		Disease, virus resistance	x	x				*Academia Sinica (Taiwan)	NARO (Uganda), IRAZ (Burundi)	IITA	-
International Institute for Tropical Agriculture (IITA)	Millet	x			Pest management	x	x				-	INRAN (Niger), IER (Mali), INERA (Burkina Faso)	-	McKnight Foundation (US)
	Cassava	x			Resistance to cassava mosaic disease/cassava brown streak disease	x	x				-	ISAR (Rwanda), IRAZ (Burundi), MARI (Tanzania) Tanzania Root and Tuber Crops Research Program, INERA (Burkina Faso), KARI (Kenya),	The University of Arizona	Catholic Relief Service (Kenya)
	Yam	x			Preservation of local Yam varieties			x			-	Representatives from Togo, the Republic of Benin, Nigeria, Ghana	Representatives from Japan, Thailand, Colombia	-
Africa Harvest Foundation International ("Africa Harvest")	Banana	x			Tissue culture of banana and plantain for disease/virus resistance	x	x				-	KARI (Kenya)	AGRA, FARA	-
	Sorghum	x			Biofortified sorghum					x	Dupont/Pioneer Hi-Bred	ARC, CSIR (South Africa), INERA (Burkina Faso)	CORAF/WECARD, University of Pretoria, University of California Berkeley, AATF, ICRISAT, AGRA	-

Source: FARA Africa Biotechnology Database, 2011
Note: FARA databases provided all crop and trait data by country. Regional initiatives were added by authors. Authors are responsible for categorization of crops and traits.
**Trait classification guide:
Risk mitigation: pest tolerance, disease or virus resistance, drought tolerance, protection against post harvest losses
Yield increase: pest tolerance, increased durability (saline tolerance/drought tolerance, disease/virus resistance)
Environmental management: resource efficiency, reducing need for chemical applications (i.e. Bt), biodiversity management
Cost reduction: reduced need for labor (i.e. herbicide tolerance to allow for large-scale application of herbicides without damaging plants)
Nutritional enhancement: biofortification

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