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The Economic Impacts of Bt Cotton and Bt Maize in West Africa: A Sector Model Approach

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Abstract

Africa has been slow to respond to biotechnology even as its pest management grows increasingly obsolete and insects remain a major adversary of its farming. The biotechnology debate is dominated by negativity: dogmatic fears over scientific boundaries and concerns over North-South domination. This paper reports on the positive aspects of biotechnology in Africa. Results from an economic model indicate the potential economic impacts to West African consumers and producers would be significant, provided that the cotton and maize sectors received greater institutional support. Under existing institutional frameworks technology fees render the costs of bioengineered crops prohibitively high.

Key Words: Bt cotton, Bt maize, Mali, sector, technology-fee, impacts.

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INTRODUCTION

Insect pests constitute a major problem to African agriculture. Pests essentially steal from farmers' fields, reduce their profits, and make it harder for households to put enough food on their table. Left untreated insect pests typically destroy about one-third of the cotton yield and about one-fifth of the maize yield (Oerke 2002). In heavy infestations pests often eat and destroy more than they leave behind for humans; entire fields can be lost to pests. Corresponding economic losses run into the millions. In Kenya it can reach as high as $76 million per year (De Groot et al. 2003). Associated losses from pests loom even larger when concerns over food security are factored in; households typically value food at higher prices than markets would indicate (DeJanvry et al. 1991).

Existing spray-based practices are increasingly ineffective, costly, and hazardous. Pests appear to be winning the battle through resistance to conventional chemical spraying methods. Pesticides are showing signs of diminishing returns: farmers are spraying more frequently but are losing more of their crops to pests. Recommended sprayings, about six per season, will protect only about eleven percent of the cotton yield from insect pests; about 23 percent of the cotton yield will still be lost. The aerosol-based spraying methods currently used by farmers is damaging to their own health as well as the local flora and fauna. The pest problem will not go away on its own. All of the major global climate change models forecast higher temperatures and higher pest populations within the region.

Bioengineered crops offer farmers alternative pest management strategies. Bt cotton and Bt maize have been developed to allow plants to protect themselves from insect pests. Scientists have engineered these varieties to express a gene that produces bacillus thuringiensis (Bt); this is an effective agent in killing bollworms and other insect pests that afflict cotton and maize. Advantages are two-fold: (1) Bt crops are more effective in protecting the plant from insects and increase yields over conventional techniques and (2) the direct application of Bt from the plant itself eliminates the need for conventional chemical sprayings to control cotton's chief enemy, the American bollworm. Contrary to the "mad-science" rhetoric, bioengineered crops produce the same agent, Bt, that farmers currently spray on their fields using conventional methods.

The technical merits of the Bt crops are hard to argue against since so many farmers throughout the world are using them. The adoption of the Bt crops has taken place at unprecedented levels. Within just the first few years of its introduction nearly 8 out of 10 US farmers were planting Bt cotton (James 2004). Similar levels of adoption have occurred in Australia; China is quickly catching up and India is likely to follow. In 2004, less than 10 years after the introduction ob Bt technology, 28% of the world cotton acreage was planted to Bt cotton and 14% of total area planted to maize was genetically engineered (James 2004).

Ironically opposition to biotechnology has been strongest in the regions that would benefit the most from it. Africa in particular has been slow to respond to biotechnology. The biotechnology debate in Africa has been divisive and often vitriolic. Dogmatic concerns over the boundaries of science have been loudly voiced by special interest groups. The Bt debate should, however, be balanced. It needs a factual assessment of what Bt technology can do for African farmers and consumers. Only through an open debate can policy makers and its citizenry make informed decisions regarding biotechnology.

This paper documents the potential impacts of introducing bioengineered crops, Bt cotton and Bt maize, in the West African region. An entomological perspective is used to determine whether West Africa can share in the same type of Bt success story that farmers elsewhere have experienced. This paper assesses the likelihood that the known insects pests in West Africa would fall victim to the toxins produced by Bt cotton and Bt maize. The paper then uses an economic model to estimate the potential economic impacts from the introduction of Bt cotton and By maize. Estimates are primarily derived for Mali since Mali well represents cotton and maize production in West Africa.

The paper is outlined as follows. The next section provides background on the importance of maize and cotton to African agriculture. This is followed by a section on entomology that describes the nature of the insect pest problem within the West Africa region. The economic model and methodology is then presented. Model results of the potential impacts from Bt cotton and Bt maize are provided and discussed. The paper ends with conclusions on recommended policies and future areas of research.

BACKGROUND

Cotton is one of the most important cash crops in West and Central Africa. In several countries king cotton still reigns as the most important agricultural export. Cotton exports constitute major shares of export earnings in Mali (25%), Benin (38%), Burkina Faso (51%), and Chad (36%). Export earnings from selling cotton on the world markets are the primary source of hard currency in these countries; as elsewhere the cotton surplus is a vital catalyst to economic development.

Cotton has been produced in West Africa since the colonial era. Cotton production had traditionally been confined to semi-arid regions; prevalence of disease limited production in the wetter, higher potential areas. Over the past two decades frontier areas in the sub-humid tropics have been opened up (MacMillian et al. 1998). Cotton production has expanded into these areas: this has contributed to a 250 percent increase in cotton area over the recent past (Figure 1).

Cotton has been one of the major agricultural success stories since independence took hold of the region in the early 1960’s (Sanders et al. 1996). Yields have increased steadily over the past few decades; today they approach those obtained in the developed world (Figure 1). Despite the advances in technology and increased efforts to better manage soils, cotton yields have leveled off. Opportunities to raise yields in conventional ways are dwindling. Bt cotton offers an alternative approach to raising cotton yields through improved pest management that leaves more fiber in the field come harvest.

A major co-benefit from the development of the cotton sector has been the simultaneous increase in maize production. As cotton expanded throughout West and Central Africa so did maize (Figure 2). Maize remains a subsistence-oriented crop but marketing conditions are improving. Its role as a staple food remains limited to the wetter areas where it is grown; in the drier areas the traditional cereals (sorghum and millet) remain staples. Maize arrives earlier than traditional cereals; it has helped to shorten the hungry season.

Maize and cotton are usually found in the same cropping system. They demand similar levels of rainfall and soil nutrients. Cotton requires three year rotations to maintain an adequate soil nutrient balance. Farmers usually plant maize in at least one of the two years following cotton.

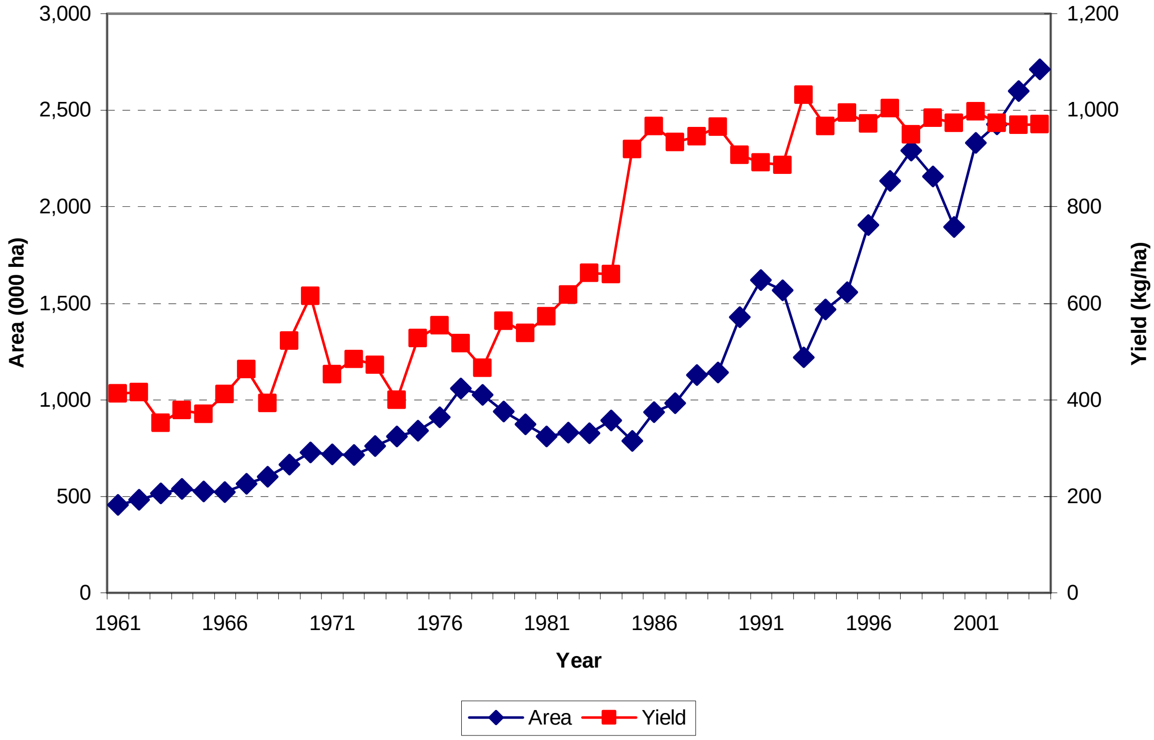

Figure 1 Cotton Area and Yield Patterns for West and Central Africa Region.
Source: FAOSTAT, 2005.

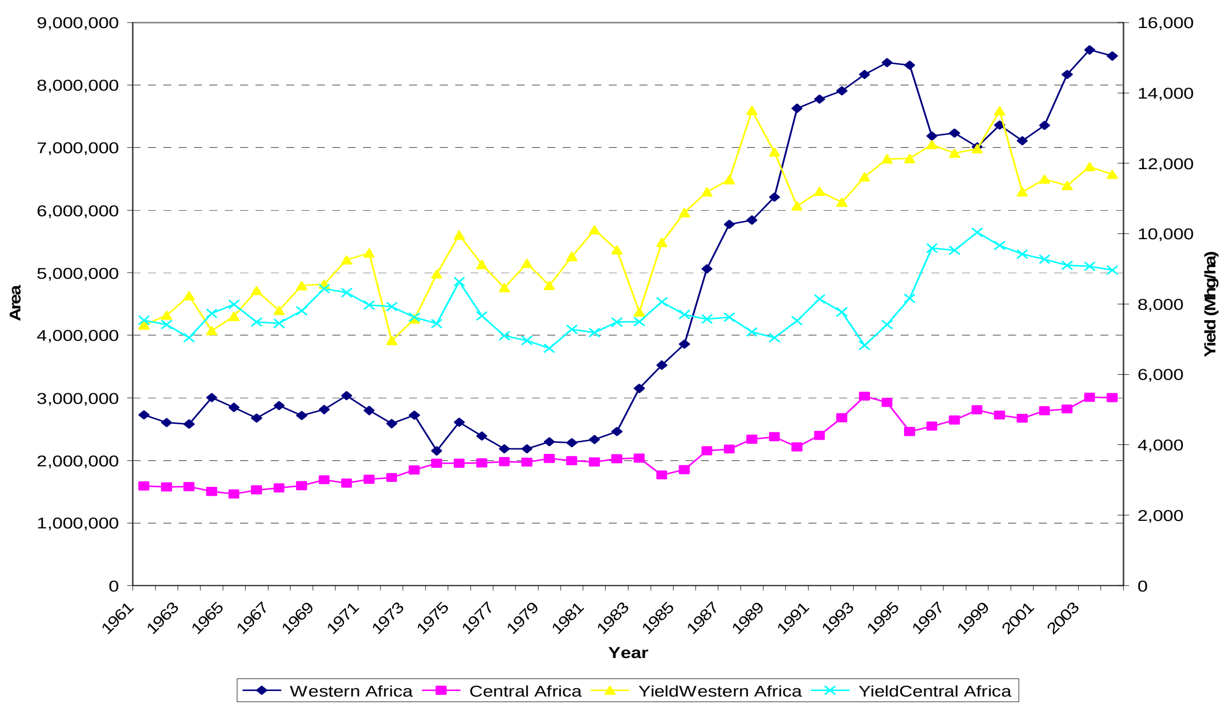

Figure 2 Maize Area and Yield Patterns for West and Central Africa Region.
Source: FAOSTAT 2005.

Bt TECHNOLOGY in WEST AFRICA

Insects are the biggest pests to cotton farmers. About 15 percent of world cotton production is lost to insects every year. In West Africa the numbers are even higher, with about 23 percent of cotton production lost to insects. Among the insects the cotton bollworm complex is the most damaging to cotton yields. In West and Central Africa the bollworm complex includes the 'old world bollworm' or 'false American bollworm' - *Helicoverpa armigera*; pink bollworm - *Pectinophora gossypiella*; spotted bollworm - and spiny bollworm - *Earias spp,* and the red bollworm (*Diparospsis spp*). The bollworm species vary throughout West Africa (Table 1).

Damage to cotton plants is characterized by feeding activity on squares (flower buds), flowers, and cotton bolls, which results in shedding of these reproductive plant parts. This may lead to a loss in cotton yield when it occurs ten weeks after plant emergence.

Chemical insecticides are used extensively on cotton crop for control of insect pests, especially bollworms. The number of sprays per crop season varies from place-to-place and from one year to the next. Typically farmers spray about 6 times a year but as many as 10 are sometimes required. 5 to 10 or more. It is estimated that insecticides worth about 10 billion CFA ($17.5 million) are used annually in Burkinabe agriculture most of which are spent for the control of cotton pests particularly against bollworms. This indicates the economic importance of cotton bollworms in general and *H. armigera* in particular.

Despite such huge efforts, bollworm control has not been generally satisfactory mainly because a pest like *H. armigera* has developed resistance to most of the currently recommended insecticides. Nevertheless, farmers continue to use insecticides repeatedly and farm in more marginal agricultural land. This had frustrated the farmers, scientists and policy makers alike. Bt-cotton came at a time when they were desperately looking for an alternative and dependable control measure.

Bt Cotton

Fortunately the most damaging pest species to West African cotton, the bollworm, is also common to the US. The same Bt cotton used by US farmers is, in principle[4], effective against West African bollworms. There is substantial evidence from farmers in the US and elsewhere that Bt cotton has complete control over the pink bollworm (*Pectinophora gossypiela)*. For other members of the bollworm species Bt provides only partial control (Table 1). Hence both Bt cotton and conventional spraying techniques are only partially effective.

Sucking insects also attack cotton plants but are less damaging than bollworms. The most common sucking pests are the jassids (*Empoasca faciali*s) and aphids (*Aphis spp*). Since Bt is not toxic to the sucking insects, Bt cotton does not control for sucking insects. Sucking pest damage is less prevalent in the US and is unlikely to be addressed by a biotechnology solution within the developed world. So at least in the short run West African farmers would need to control for sucking pests using conventional spraying techniques, even if they plant Bt cotton. African based research could be used to develop a second generation Bt cotton variety that controls for sucking pests.

Bt cotton has already been shown to be effective in Africa. South African farmers in the Makhatini Flats have been using Bt cotton since 2001. Success has been reported on both commercial and smallholder farms. Yield increases in the neighborhood of 25 percent have been achieved with Bt cotton, accompanied by reduced spraying costs. On average farmers income rose by $137/ha. Burkina Faso has been the most progressive in West Africa. Regulations still prohibit farmers from planting Bt cotton but monitored field trials have been allowed. Monsanto's Bt cotton variety, Bollgard, has been through two years of field testing. Results are so far encouraging: 20 percent yield increases, on average, have been found. The need for conventional sprayings has been reduced from six to two.

Further research is expected to achieve more impressive yield increases. African-centered research is required to expand Bt cotton's control spectrum. This includes more complete coverage over the bollworm species as well as mechanisms to control sucking insects. Another area of research is transferring the Bt gene into local cultivars. Existing

[4] Field trials in South Africa (Makathini Flats) and Burkina Faso support the effectiveness of Bt cotton in African farming.

Bt cotton varieties have been based on Monsanto's US cotton varieties. Their performances in South and West Africa have been sound, but tuning cultivars to local conditions should produce higher yields. In the long-run research along these lines is expected to increase yields by as much as 40 percent.

Insect Pests in Maize

The lepidopteran stem borer is the most damaging insect known to attack maize. The two most prominent stem borers found in Africa are the African stalk borer (*Busseola fusca)* and the spotted stem borer (*Chilo partellus)*; less important yet still damaging borers include the pink stem borer (*Sesamia calamistis)* and the sugar cane borer (*Eldana saccharina*). Maize borers vary widely throughout the African continent (Table 2). *Busseola fusca* and *Sesamia spp*. occur throughout sub-saharan Africa. Of the *Sesamia spp*., *S. calamistis* is probably the most widely distributed and economically important species. *S. botanephaga* Tams & Bowden is found in West Africa is also important. As with *E. saccharina,* the pest status of *B. fusca* varies by region.

Stem borers first attack the plant's leaves. Later on in the growing season they bore into plant's stems and its stalk. Once they have bored-in they interfere with the movement of water and metabolites through the plant's vascular system. Further damage can result from stalk breakage and ear drop. The early attacks disrupt the plant's reproductive stage. Fertility is significantly decreased and farmers are left with less grain to harvest. Once inside the ear the borers often damage maize tissue that allows fungi, particularly *Fusarium* species, to colonize. This rots the stalk and ear and accumulates harmful mycotoxins. This creates phytosanitary concerns within the human food and animal fee chains and the risk of spreading disease in storage.

Maize corn borers are difficult to control with insecticides anywhere in the world. Only modest amounts of insecticides are used to control for maize stem borers, even in developed countries. In North America and Europe insecticides cover less than 10 percent of total maize area; insecticide control is limited to the European maize borer (*Ostrinia nubilalis*).

Bt Maize

Bt maize has been bioengineered to produce Bt with cry protein variants known to be effective against lepidopterean maize borers (Table 3). The IRMA project had identified three cry proteins that are very effective against *C. Partellus.* Other stem borers are controlled only by a selected cry protein, and are resistant to the others. None of the cry genes were completely effective against *B. fusca* (Groote et al., 2003).

Concerns over potential risks of Bt maize within the food and feed chains have lead to more opposition to Bt maize introduction throughout Africa. Bt maize is being grown only by small scale farmers in South Africa; in West Africa regulations prohibit even field trials. Yield gains from Bt maize in South Africa and elsewhere have been more mixed than with Bt cotton. On average farmers have been reported to increase yields by about 20 percent. As with Bt cotton, long-run research could increase yields through introducing the Bt gene into local cultivars as well as expanding the control spectrum. The long-run research is expected to produce more modest results with potential yield increases reaching 30 percent.

Table 1 Principal bollworms in certain countries of West Africa and their susceptibility to Bt cotton

Country	Early season pests (In order of importance)	Control by Bt cotton[a]	Late season pests (In order of importance)	Control by Bt cotton[a]
Benin	*Helicoverpa armigera*	¢	*Helicoverpa armigera*	¢
			Pectinophora gossypiela	l
Ivory Cost	-		*Pectinophora gossypiela*	l
			Earias spp.	¢
			Helicoverpa armigera	¢
Mali	-		*Helicoverpa armigera*	¢
			Diparopsis castanea	¢
			Earias spp.	¢
Senegal	-		*Helicoverpa armigera*	¢
			Earias spp.	¢
			Diparopsis watersi	¢
Togo	*Diparopsis watersi*	¢	*Diparopsis watersi*	¢
			Helicoverpa armigera	¢
			Pectinophora gossypiela	l
			Earias spp.	l

[a] l = complete control and ¢ = partial control.
Source: Modified from Secretariat for the 61st Plenary Meeting of the International Cotton Advisory Committee, Report on Production Practices, Cairo, Egypt, October 2002).

Table 2 Major Stem Borers Insect Species Causing Economic Losses in Maize in Africa

Common Name	Scientific Name	Distribution
Spotted stem borer	*Chilo partlelus*	East, South, and Central Africa
Pink stem borer	*Sesamia cretica*	Africa, Indian Ocean islands
African pink stem borer	*Sesamia calamistis*	Africa, Indian Ocean islands
African maize stalk borer	*Busseola fusca*	Sub-Saharan Africa
African sugarcane borer	*Eldana saccharina*	West, Central Africa

Sources: Compiled from various sources.

Table 3 Resistance to Different Maize Borers by Different Bt Constructs

	Lepidopteran Maize Borer			
Bt Construct	*C. partellus*	*B. fusca*	*S. calamistis*	*E. sacharina*
Cry1B	Yes	No	No	No
Cry1Ab	Yes	No	Yes	Yes
Cry1Ab-1B	Yes	No	Yes	Yes

Source: deGrassi 2003.

METHODOLOGY: ECONOMIC IMPACT MODEL

Impacts of Bt cotton and Bt maize are measured using the economic surplus method (Alston et al. 1995). Economic surplus is generated through new technology introduction; farmers increase market supply and/or produce at lower costs. The economic surplus method places a monetary value on the increased supply/reduced production costs. A supply-demand framework is used to detail how markets respond to downward price pressure. Consumers obtain a surplus from purchasing at lower prices; producers obtain a surplus from selling greater quantities in the market, and perhaps, by reducing production costs. The consumer surplus measure represents “freed resources” that can be transferred to other parts of the economy. The producer surplus, PS, is the sum of the additional rents that accrue to farmers’ internal resources, as given by the model’s shadow prices; PS is not a pure economic rent in the Ricardian sense.

Empirical estimates of the impacts are obtained using an agricultural sector model. This is an equilibrium model that details how markets would respond to the introduction of Bt crops. It determines the new equilibrium following the introduction of Bt technology. Equilibrium is governed by well-established economic theory: it achieves the best outcomes for society under perfect competition (Samuelson 1952). Consumer and producers are made as well-off as possible; consumers maximize utility at minimum cost and producers maximize profits. The model determines the long-run outcomes following technology introduction; it does not detail the dynamics of how equilibrium was established. Typically early adopters will achieve large benefits that will taper off as more producers adopt.

A distinguishing feature of the approach is the use of farm-level models. This allows farmers' decision making and socio-economic constraints to be included in analysis that is aggregate in nature. Farm level effects are ignored in more standard approaches and remain hidden. In regions where income literally changes with the weather risk is an important issue. Risk is modeled using lexicographic preferences consistent with observed farmer behavior. Farmers secure income and staple food requirements before pursuing profit maximizing objectives. This captures the subsistence-oriented nature of production; household's value of food and fiber are determined endogenously (DeJanvry 1991). Household resource endowments on land, labor, and capital are modeled using constraint inequalities. Cotton places a strong demand on soil nutrients; nutrient balances are typically negative on cotton fields. Farmers rotate cotton with cereals in three-year rotations. This rotational constraint is included in the model.

Model Empirical Structure

Markets are modeled using supply and demand equations. Markets are included for the major standing crops and legumes: sorghum, millet, maize, cotton, rice, peanuts, and cowpeas. There are twelve regional markets in the model, one for each of the major urban areas throughout Mali. Trade-flows between regional markets are included within the model; they are governed by the transportation costs required to ship commodities from one market to another.

The model's empirical structure of the cotton and maize markets is worth noting. Nearly all of the cotton produced in the region (98 %) is sold in the world market. Mali is a "small country" and does not have market power; the introduction of Bt cotton is not expected to change world cotton prices. Cotton demand is perfectly price elastic: cotton prices paid to farmers remain constant under the Bt cotton scenario. Maize markets are much the opposite of cotton. There are limited export opportunities. Nearly all of the maize produced is traded in domestic markets within Malian borders; maize imports are infrequent. Maize demand is largely price inelastic: prices can fall quickly with the introduction of Bt maize. Maize demand includes a storage component; farmers let prices fall only so far before grain is held back in silos. Maize impacts are likely to accrue more to consumers; producers' impacts will be governed more by cost reductions.

Adoption profiles are determined endogenously within the model. Adoption of Bt cotton and Bt maize is determined based on farm profits. Bt cotton and Bt maize are introduced into the model under the biotech scenarios. To be adopted Bt cotton and Bt maize must pass over the "profit hurdle" established by the embedded farm models: they must be more profitable than the conventional cotton and maize technology. The extent of adoption, hence, is dictated by how "high" this hurdle is. Adoption is influenced by farmers' decision making preferences, resource constraints, yield increases, costs, and prices. The model presumes farmers have complete information.

Model Data

Bt cotton yield data is taken from recent field trials conducted by Monsanto in Burkina Faso study (Table 4). Cotton yields were increased by an average of 20 percent using Bollgard®, Monsanto's Bt cotton variety. Further research is expected to introduce the Bt gene into local cotton cultivars. This could bring long-run cotton yield increases up to as much as 40 percent. For sensitivity model runs also included cotton yield increases of 10 and 15 percent. Field trials on Bt maize have not yet started in West Africa. In its place Bt maize data was obtained from other regions in Sub-Saharan Africa. Bt maize was presumed to increase yields by an average of 20 percent, with additional model runs of ± 10 percent for sensitivity. Other data is documented elsewhere (Vitale and Sanders 2005).

Table 4 Bt cotton yield increase and cost reduction data used in model scenarios

Variety	Pest Sprayings (Number/year)	Spraying Cost ($/ha)	Cotton Yield: (kg/ha)	Bt Cotton Yield Increase
Conventional	6	60	1,200	-
Bollgard® II	2	20	1,440	+ 20 %
Bt Cotton: Long-run	2	20	1,680	+ 40 %

Source: Monsanto Field Trials, Burkina Faso, 2005.

RESULTS

With the introduction of existing Bt cotton varieties, 20 percent yield increases are expected. Under this scenario the aggregate impacts on social welfare would reach as high as US$ 30.7 million per year (Figure 3). Since nearly all of the cotton produced is exported, the change in social welfare accrues primarily to producers. As the technology fee charged to farmers is increased, the aggregate impacts fall off. The Bt technology fee's effect on aggregate impacts is fairly marginal up to the $30/ha level. Throughout this range farmers' adoption of Bt cotton remains constant; impacts decline mainly due to the technology fee's transfer to the seed company. Adoption of Bt cotton begins to weaken just beyond the $30/ha level. Farmers in the more marginal production areas would be the first to find the technology fee prohibitively expensive. The model indicates that the fall in Bt adoption would be fairly constant. For technology fees greater than $US 50/ha none of the Malian cotton farmers would adopt Bt cotton. This is much lower than the technology fee charged by Monsanto to farmers in developed countries. In 2004 Bt cotton technology fees averaged about $US 92/ha in the United States.

More cautious projections place Bt cotton yield increases at 10 percent. Even with yield increases cut in half the impacts from the introduction of Bt cotton on social welfare would remain substantial at US$ 23.1 million per year (Figure 3). This points out that farmers benefit from both yield increases and unit costs reductions. From comparing the two scenarios it can be inferred that about US$ 8 million in unit production costs are saved by farmers each year. With the more modest 10 percent yield increases the potential for Bt cotton adoption is weakened and adoption falls off more quickly. Adoption begins to fall off at $ 20/ha technology fee in the more marginal areas. The $ 30/ha technology fee is a point of interest. Under the cautious yield projections of 10 percent, Bt cotton adoption rates have fallen practically to zero; yet under the expected yield increase essentially all of the farmers would remain in Bt cotton.

With the introduction of existing Bt maize varieties, farmers are expected to increase yields by 20 percent over conventional varieties. Under this scenario the aggregate impacts on social welfare would reach as high as US$ 40.4 million per year (Figure 4). Since nearly all of the maize produced is consumed in domestic markets, the change in social welfare accrues to both consumers and producers. Existing markets for maize are weak[5]; nearly three-fourths of the social welfare accrues to consumers. The model results indicate that Bt maize would provide larger aggregate impacts than Bt cotton, about $ 10.3 million more per year. Maize is cultivated over a larger area than cotton. Farmers typically rotate cotton with cereals in three year rotations. This appears in aggregate land use data, where cotton areas occupy only about one-third of the area occupied by cereals.

With weaker demand, Bt maize is much more sensitive to technology fees than Bt cotton. The decline in Bt maize adoption begins immediately; even at a modest charge of $10/ha nearly all of the Malian farmers would find the technology fee too excessive. This falls far short of the technology fee paid by US farmers, which is about $ 67/ha. With a more cautious projection of 15 percent yield increases, the potential for Bt maize adoption is further weakened. At even a $ 5/ha technology fee nearly all of the maize farmers would not be able to enter the Bt seed market; the $ 10/ha fee would make the cost prohibitive for all maize farmers.

With further research focused on the African setting Bt cotton yields could be increased by 40 percent. This corresponds to aggregate impacts that would reach as high as $US 45.7 million per year (Figure 3). Malian farmers' demand for Bt cotton would increase; adoption would not begin to fall off until technology fees of $ 60/ha are reached. Even with these higher yields the model results indicate that Malian adoption would still not rival that of farmers in other parts of the world. The 2004 technology fee levels charged to US farmers, $ 92/ha, would drive out all of the Malian farmers from the Bt cotton market.

Further research in Bt maize is expected to increase yields by as much as 30 percent (Figure 4). Under this scenario aggregate impacts would reach $88.6 million per year. Malian farmers' demand for Bt maize would increase somewhat. A larger number of farmers would remain in Bt maize as the large drop-off in adoption wouldn't occur until technology fees reached about $10/ha. Malian farmers' willingness-to- pay for Bt maize would still remain, however, much lower than farmers elsewhere in the world.

[5] Efforts are underway to provide cereal farmers with better markets. With expanded market opportunities from processed foods and feeds cereal demand becomes more price elastic. Prices fall less when new technology is introduced. In practical terms farmers are able to earn higher profits with less of the surplus transferred to consumers (Vitale and Sanders 2005).

West African extrapolations of Bt cotton impacts show similar impacts throughout the region for the “Big Four” cotton producing countries of Mali, Burkina Faso, Benin, and Cote D’Ivoire (Figure 5). Impacts would be largest in Mali, $ 31 million per year, followed by Benin, where Bt cotton would have the potential to generate $ 24.2 million per year in economic impacts. Cote D’Ivoire and Burkina Faso would have similar impacts from Bt cotton introduction, $ 20.4 million per year and $ 18.8 million per year, respectively. The smaller producing countries would still have the potential to generate economic gains from Bt cotton. The analysis indicates that Nigeria would have impacts of $ 13.7 million per year and Togo $ 9.8 million per year, with the remaining producer all under $ 5 million per year.

DISCUSSION

The potential impacts from Bt cotton and Bt maize are both significant. Because of greater areas Bt maize would provide the greatest benefits. With weaker marketing opportunities, however, demand for Bt maize falls off much more quickly than for Bt cotton. The Bt maize adoption profile responds poorly to even modest technology fees. Falling maize prices reduce its profitability; the perfectly elastic nature of cotton demand keeps prices fixed. Such differences in marketing should not be over looked.

Bt crops have a distinct cost-cutting advantage that can only be viewed as “farmer-friendly”; concerns over falling prices are reduced. Introducing Bt crops compare favorably to potential gains from conventional crops. Previous research estimated impacts from introducing new technology based on conventional maize and sorghum varieties; it used the same impact model and assumptions. The potential impacts from introducing conventional new technology in maize were found to be only $ 8.7 million per year (Vitale and Sanders 2005). Bt maize could provide more than three times the potential impacts as conventional maize varieties. Introducing new sorghum technology, using conventional varieties, would come closer to Bt maize. The potential impacts of new sorghum technology were found to be $ US 14.4 million, about one-half of the impacts obtainable from Bt maize.

Potential impacts are large but technology fees could take the bulk of the benefits, leaving little for farmers to put in their pocket. Bt is a proprietary technology: farmers throughout the world are required to pay an annual fee. The property rights remain in the hands of a few large seed companies. With little competition seed companies will be able to extract monopolistic profits. African farmers' bargaining power is weak; in the end very little of the potential gains from Bt crops may end up staying in the region.

The demand for Bt cotton and maize from West African farmers is much weaker than in developed countries. West African farmers would not adopt Bt technology at the same level of technology fees paid in developing countries. Demand is weakened by the poor institutional structure in West African cotton sector and the limited commercial uses of maize. Additional model runs could be used to investigate the effects of alternative policies. The runs could include institutional changes in the cotton sector that gives farmers a higher share of world price, as well as policies to increase the commercial uses of maize to strengthen its demand. From the other perspective, future modeling could provide estimates of what the optimal technology fee would be under monopoly conditions in the Bt seed industry. For instance, this could investigate whether Monsanto and other seed companies would have incentives to establish country or regionally specific technology fees.

Expanding Bt crops effectiveness against a wider spectrum of insect pests would double impacts. Such second generation Bt crops would target aphids and jacids, insects that are not susceptible to existing Bt cotton and Bt maize varieties. Research along these lines would need to be African-driven. These are pests indigenous to Africa; they are unlikely to be addressed by research at institutions within the developed world.

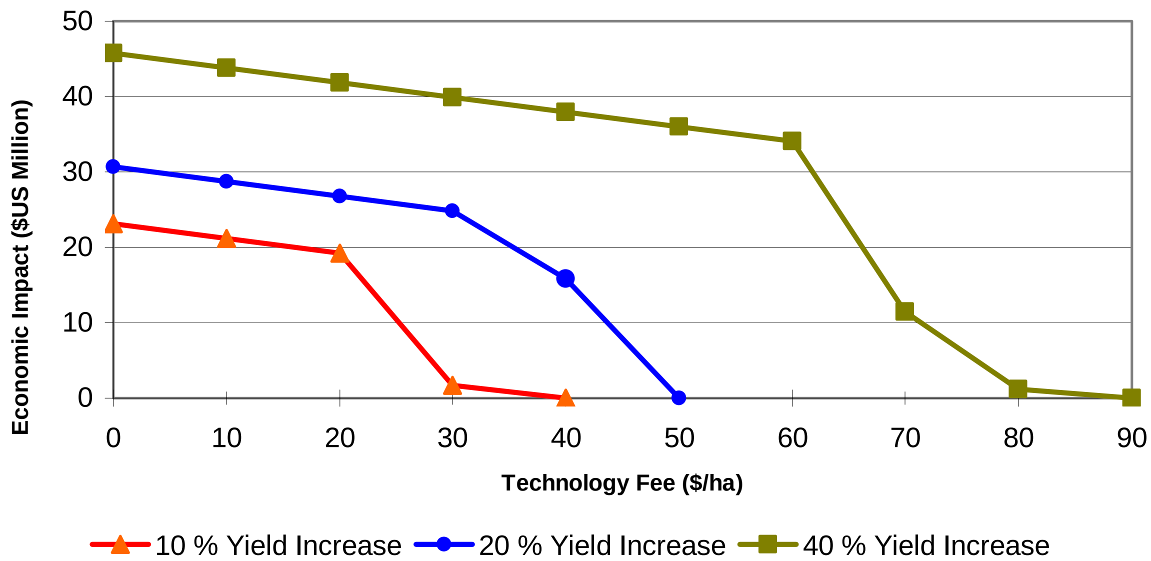

Figure 3 Economic Impacts of Bt Cotton Introduction in Mali.
Source: Authors' economic model.

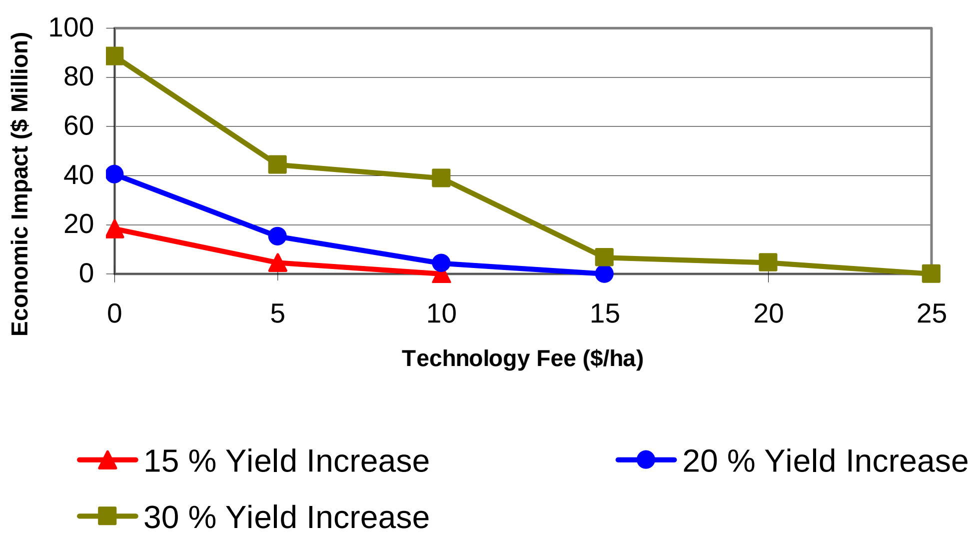

Figure 4 Economic Impacts of Bt Maize Introduction in Mali.
Source: Authors' economic model.

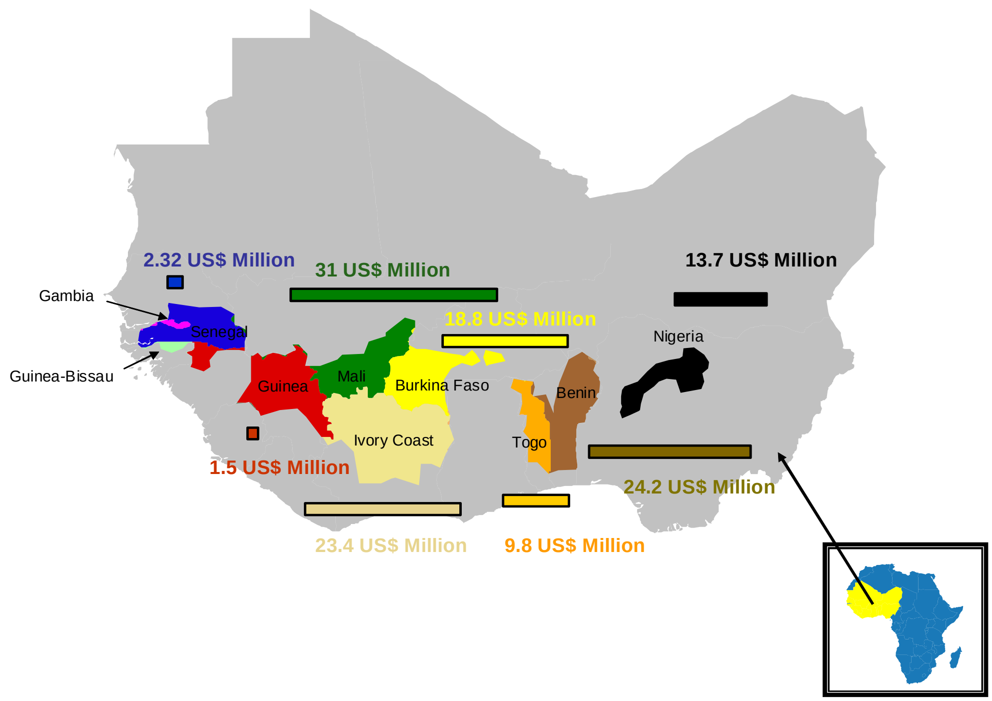

Figure 5 West Africa Regional Impacts of Bt Cotton.
Sources: Authors' model and Foreign Agricultural Service.

CONCLUSIONS

The technical and economic barriers will be the easiest ones to overcome. South African and Burkina Faso field trials have already demonstrated the technical merits of Bt crops in the African setting. The potential economic gains of Bt engineered crops have been shown to be substantial in this paper and others. Yet experience has shown reluctance, often strongly voiced, to bioengineered crops in developing countries. This has been politicized into regulatory hurdles that often far surpass those established within the political landscapes of developed countries[6]. Getting Bt engineered crops into the hands of African farmers will require progressively-minded policy makers. History has, moreover, shown a propensity towards politically based decisions that favor urban elites over the interests of farmers and low income peoples. Until prevailing attitudes are

[6] Even in situations where technical merits have been demonstrated policy makers have been hesitant to move forward with biotechnology. The Bt cotton trials in Burkina Faso are being delayed due to increased regulatory guidelines. These appear to be based more on fears than fact.

changed, African agricultural sectors will find it difficult to maintain any sort of competitive stance with the bioengineered-equipped farmers in the developed world.

Similar resistance is likely to come from within the cotton sector. Bt modified crops will produce positive gains to society but there will be winners and losers. The French have dominated nearly all input and output marketing channels. Fortunately the cotton sector is undergoing an era of institutional change: this is an avenue of hope and provides a window of opportunity free-up input markets. With progressive input markets Bt crops are more likely to be made available to farmers and should ease the introduction of Bt pest management. Cotton sector reform would also increase farmers' share of the world price. Demand for Bt cotton would be strengthened. Likewise, in areas where hybrid maize has been widely adopted, Bt maize will pose a threat to existing suppliers. Barriers to entry are likely to be erected.

Regulatory issues are particularly important with Bt maize. Being a staple food Bt maize is directly consumed by humans. Concerns over bio-safety are more salient with Bt maize than with Bt cotton. Consumer preferences could render bioengineered foods as imperfect substitutes for conventionally grown foods; demand for Bt maize would be weakened. This would be particularly so in the short run, before consumers have had time to gain confidence in them. With weaker marketing conditions the potential impacts from Bt maize introduction are reduced.

On the producer compliance with seed company contracts will be key issues. This primarily includes setting aside buffer zones to reduce the spread of pollen to adjacent fields. The atomistic nature of smallholder farming could complicate these matters; the role of extension services and village based farmer organizations will be critical. Further up the supply chain contamination issues and segregation will be important. Efforts to combine Bt cotton and Bt maize seed distribution networks should be encouraged. In many areas cotton and maize are found as part of the same cropping system; rotational concerns typically mandate farmers to have both crops planted on a yearly basis. Adopting farmers are likely to plant both cotton and maize.

Long-term impacts can only be sustained if effective and responsible deployment strategies are adopted to maintain the durability of the Bt genes. Deployment strategies must be aimed at reducing the possibility of negative long-term impacts. Insect resistance needs to be mitigated by preventing resistant insects from mating with other resistant insects[7]. This is likely to require continual monitoring to assure proper buffer zones and to detect changes in insect populations.

Gene stacking would provide additional impacts. This is a newer aspect of the biotechnology suite that puts the Bt gene into the plant along with other genes that benefit farmers' weed management practices. Roundup ready varieties allow farmers to apply herbicides during the critical period of seedling growth. Genes introduced into the plant's DNA protect itself from the toxic effects of herbicide applications. Herbicides kill the weeds yet leave the seedlings unharmed.

The introduction of Bt cotton and Bt maize could impact about one-third of the cultivated land in West Africa. Future research will need to address insect pest management in areas outside of the cotton-maize belt to reach the remaining farmers. The introduction of existing Bt varieties in cotton and maize make significant headways in controlling pests; with complete adoption about 30 percent of all cropped areas would be under Bt protection. But there is still more work to be done. Other important food crops, such as rice, sorghum, and millet are also susceptible to pests.

Future prospects for bioengineered crops hold even greater promises. Bt technology has been designed to protect plants from pests; it does little in the way of pushing yield frontiers to higher levels. The marginal benefits to Bt research will decline as existing yield frontiers are approached. Future bioengineering will be required to identify and express genes that can push out yield frontiers.

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[7] Insect populations typically contain small numbers that are resistant to Bt. If they are allowed to reproduce with one another the population can quickly become dominated by resistant types. Leaving an adequate buffer zone increases the mating between resistant and non-resistant insects.

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