Transgenic cotton and crop productivity: A general equilibrium analysis for West and Central Africa

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Abstract

This study applies a multi-regional general equilibrium analysis to evaluate the economic impact of transgenic (*Bt*) cotton adoption in West and Central Africa (WCA). A special feature of the analysis was the careful estimation of productivity gains from *Bt* cotton adoption using several farm-level impact studies and a 2001 multi-country cost of production survey for cotton by the International Cotton Advisory Council. Two no-adoption scenarios for WCA (with cotton productivity loss from recent trends and without) are contrasted with a partial *Bt* cotton adoption case, under an international environment where *Bt* cotton is also adopted elsewhere. The analysis shows that under the no Bt cotton adoption and current declining productivity trends, the cotton sector in WCA shows lower output and declining export shares compared to other regions. Even without TFP loss, the pesticide-based cotton production system also results in eroding performance as other Bt adopting countries perform better and improve their world market positions. When WCA adopts Bt cotton, the cotton sector performs substantially better compared to the status quo and compares favorably with other regions.

Key words: transgenic cotton, crop productivity, Africa, general equilibrium.

Introduction

In the past two decades, cotton production has been marked by a shift from rising to stagnating yield trends in many cotton-growing regions (ICAC, 2001a). The slowdown of cotton yield growth is partly due to the reduced effectiveness of chemical pest control methods and the rising incidence of insecticide resistance. Also, unlike other major crops, cotton has not benefited to any extent from any genetic yield improvement over the years (Azfal, 1990). Instead the cotton yield improvement strategy had been to emphasize optimum nutrient management and crop protection. This led to a pesticide-centered cotton production system in much of the world which benefited from rising yields in 1970's and 1980's as pesticide use expanded, but shifted to yield stagnation and rising production costs, resulting in steady erosion of cotton productivity in many cotton-growing regions.

Beginning in 1996, the commercialization of transgenic insect-resistant cotton (*Bt* cotton) in the United States represented a technological breakthrough and the first serious alternative to insecticides. Within 3 years, *Bt* cotton occupied 20% of world cotton acreage and was grown in several countries including the US, Australia, Mexico, China, Argentina, and South Africa (James, 2001). In many cases, the adoption was rapid, driven by a pressing need for a viable alternative to chemical methods, which have become either less effective or inaccessible through regulatory actions. There is strong evidence that *Bt* cotton generates significant economic benefits to farmers, in addition to the beneficial effects on the environment, biodiversity and farmers' health (Edge et al., 2001). Moreover, many other regions not currently using *Bt* cotton such as Pakistan, and West Africa could well benefit from the technology given the serious insect problems and increasing insecticide resistance (ICAC, 2001b).

In this paper we examine the economic impact of *Bt* cotton adoption by West and Central Africa (WCA) – a region where cotton plays a critical role in the national economy, with a share of total GDP ranging from 1.3% in Cameroon up to 8.8% in Togo (Table 1). Cotton also form a significant share of total exports and contributes substantially to employment, providing a direct source of living for 2 million people in Burkina Faso (16 % of total population) and Mali (18 % of total population) (Fortucci, 2002). While WCA region produces 5% of the total world cotton, it exports 15% of world cotton trade with most cotton produced (95%) exported. This makes WCA vulnerable to world cotton price fluctuations and to global factors that depress export prices. Consequently, the long run economic performance of the cotton sector critically depends on improving the sector efficiency, through sectoral reforms, and sustained productivity through adoption of cost-effective and yield-enhancing technologies.

The objective of this analysis is to examine the economy-wide impact of Bt cotton adoption in WCA and the productivity-enhancing effects on the cotton sector. Given the significant implications on global cotton sector, we apply a multi-regional computable general equilibrium model of production and trade. A specific contribution of this paper is the careful multi-country estimation of *Bt* cotton-induced total factor productivity (TFP) using several farm-level economic impacts analyses on *Bt* cotton and 28-country survey of the cost of producing cotton including the major producers and 4 WCA countries (International Cotton Advisory Council, ICAC). In this paper, we focus solely on the productivity-induced effects on WCA under the adoption scenario. The paper does not directly address policy considerations, such as input and output subsidies-sum-taxes, which affect producers' incentives. While important, these considerations are outside the scope of the present study. We begin our analysis with a review of the recent cotton yield patterns, pesticide use, and the economic impacts of transgenic cotton in countries where it has been commercialized.

Cotton yields trends, impact of insecticides, and biotechnology

Much of the world's cotton yield increase during the 1970's and 1980's was due to the expansion of pesticide use, particularly insecticides. Field trial research has shown repeatedly that without insecticides a significant share of yields, up to half or more, would be lost (Yudelman, Ratta, and Nygaard, 1998). Oerke et al. (1995) estimated global cotton losses due to insects alone at 24.5% of total value of production. The heavy reliance on pesticide use made cotton the highest insecticide-consuming crop in the world. With 2.4% of total global acreage, cotton consumes over 25% of insecticides (Krattiger, 1997) and in many countries cotton's share of national pesticide use is even higher (Figure 1). In Pakistan and India, 70% and 53% of total pesticide use is consumed by cotton, respectively, while cotton's share of total crop acreage is only 5.4% and 14%. In West Africa, the cotton share of total pesticides is among the highest in the world.

During the 1990's cotton yields for many countries had been marked by either stagnation or outright decline (Figure 2) partly due to weak insecticide effectiveness (ICACS, 2001a). In addition to yield and production impacts, extensive use of chemicals is also associated with negative environmental and health effects particularly in developing countries, where farmers often use hand-spraying devices, with inadequate safety procedures (Pingali and Roger, 1995).

Direct estimates of economic costs of health impacts are few. In China, there were 100,000 poisonings in 1992 alone due to pesticide spray and 1000 deaths, with a large percentage related to cotton (Du, 2001). In Zimbabwe, Mumbe and Swinton (2002) estimated farmers' health-related costs of pesticides for 1999 equivalent to 45 to 83% of pesticides expenditures. In Mali, Ajayi et al. (2002) estimated the human health cost to pesticide use equal to 40% of the total pesticide market value. Using 1998 production survey data from ICAC, we estimate that in 52% of all world cotton acreage, insecticides are applied with hand spraying devices, a share that points to the potential magnitude of health effects from insecticide use (Figure 3).

The West and Central Africa Case

The economic implications of the prevailing pesticide-based cotton production systems are acutely felt in the WCA region[1], where cotton is of primary importance to the national economy. As in many other cotton producing countries in the World, WCA countries experienced expanded cotton production and rising yields during the 1970's and 1980's, largely due to the expansion of insecticide use. Over the last 30 years, cotton area has tripled reaching 2.4 million hectares while production jumped from 320,000 tonnes in 1970 to more than 900,000 tonnes in

1985. Yields also increased in the 1970's and 1980's. However, towards the end of the 1980's yields reached a plateau and began a downward trend affecting many of the WCA countries. Several factors account for yield decline including rising insect resistance and less effective chemical control methods (Figure 4). Also expanding cotton production into marginal lands with poor soil quality and reduced fertility-recovering follow period have also contributed to lower yields (Levin, 2000). Another contributing factor to lower yields is the increased labor shortage resulting from cotton area expansion as cotton is more labor-intensive than alternative cropping (Tefft et al. 1998).

The increasingly critical role of rising insecticide resistance has also been exacerbated by institutional structures that govern cotton production in much of WCA. The production and marketing of cotton in the WCA is vertically coordinated by state companies, which supply production inputs on credit and purchase cotton directly from farmers. With low education level among farmers and limited extension services, farmers often follow a recommended calendar spraying rather than responding to populations or damage thresholds resulting in increased resistance to certain insecticides, particularly cotton bollworm (*Helicoverpa armigera).* In some countries, farmers continuously apply pyrethroids even though those insecticides have become almost ineffective against cotton bollworm or spider mites (Martin et al., 2002). The problem has become so serious that in 1998 Burkina Faso, Ivory Coast, Mali, Benin, Guinea and Senegal started a regional insecticide resistance project (ICAC, 2001b).

Transgenic cotton: the first major alternative to insecticides

Until 1996 there were few real alternatives to insecticide use. Since the mid-1980's there has been growing interest in developing alternatives to insecticides including varietal resistance,

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[1] Ivory Coast, Mali, Benin, Burkina Faso, Guinea, Togo, Cameroon, Senegal, and Central African Republic.

biological control and integrated pest management; however their effectiveness has been relatively limited (Chaudhry, 1993). Since the advent of crop biotechnology and the commercial release in the United States of transgenic cotton variety resistant to *Lepidopteran* insects (*Bt* cotton) offered the much-awaited technological breakthrough. The new transgenic cotton released in the US and elsewhere has the ability to control a group of bollworm insects (tobacco budworm, cotton bollworm and pink bollworm) that include some of the most damaging insects worldwide. The transgenic cotton variety derives its insect resistance ability from the presence of bollworm-resistant gene (Cry1A) isolated from a soil bacterium, *Bacillus Turingiensis* (*Bt*). Between 1996 and 1998, *Bt* cotton was adopted in six countries beginning with the US, then Australia, Argentina, Mexico, China and South Africa and in 2001, *Bt* cotton coverage ranged from 5% in Argentina up to 40% in South Africa (James, 2001).

There are a number of benefits for adopting transgenic cotton, including environmentally safer pest control of major *Lepidopterous* insects, improved safety and health conditions for farmers, enhanced use of beneficial insects as biological control agents, and lower cost of production and higher yields (Edge et al, 2001). These benefits explain the rapid adoption rates of *Bt* cotton in regions where the technology was made available. In the US, farmers quickly embraced *Bt* cotton varieties in response to the pressing problem of reduced efficacy of chemical controls and the loss of some of insecticides from regulatory actions (Kazmierczak and Paxton, 1997). In China, *Bt* cotton was also adopted rapidly in regions with severe cotton bollworm outbreak beginning in 1992 and causing extensive economic losses, leading to a shift in cotton from the Yellow River Valley to the Northwest (Du, 2001). By 2001, 40 percent of China's cotton area outside the Northwest was grown with *Bt* cotton. In South Africa, *Bt* cotton was also rapidly adopted with a four-fold increase in acreage in three years reaching a total of 40% in 2001 (Ismail et al, 2001).

Evidence of economic benefits from *Bt* cotton can be gleaned from several studies that used farm surveys to analyze the yield, cost and revenue impact from the new technology. Table 2 summarizes several impact study findings from five countries: USA, China, South Africa, Mexico and Argentina. Table 2 reports the extend of insecticide and labor cost savings, seed cost increases including technology fee as well as yield advantages due to *Bt* cotton technology. For example, in China, plot comparison between transgenic and conventional cotton showed pesticide cost reductions of over 80% but seed cost is higher. Transgenic cotton also results in labor saving costs and higher value of output ranging from 6 to 20% based on three-year data. In the case of South Africa, Ismail et al. (2001) for one year insecticide cost reduction of 39%, seed cost increased by 109% for transgenic cotton and value of output increase by 33%. In the case of Mexico and Argentina, similar farm level cost-benefit surveys reported significant savings in costs for pesticides and labor and overall value of output, even when seed cost was also higher for transgenic cotton. Moreover, these estimated economic gains offer only a partial picture and may well underestimate the full benefits as they do not fully account for labor and water savings, and any positive spillover on farmers' health.

Overall, the evidence is strongly suggestive of economic benefits to cotton growers in those regions that have adopted the *Bt* cotton technology. To the question of whether the benefits of *Bt* technology can be extended to other cotton producing regions, the answer is clearly yes in regions with significant economic impact from heavy pest problems (particularly bollworms and the Spodoptera complex) and where both yields and effectiveness of insecticides are declining. This is clearly the case in many other cotton growing regions in the world such as India, Pakistan, parts of Latin America (Brazil and Columbia) as well as much of west and central Africa.

Assessing Bt cotton impact for west and central Africa: A CGE Analysis

Economic assessments of benefits of new technologies can use several approaches. Several studies have used the partial-equilibrium model of Alston, Norton and Pardey (1995) which examines the market consequences of new technologies and calculates changes in producer and consumer welfare (Pray et al., 2001). An alternative approach uses applied general equilibrium (AGE) models. These models focus on the unit-cost reduction and output expansion from the new technology and derive general equilibrium price, production, trade, and welfare impacts resulting from total factor productivity (TFP) or factor-biased technical change (Nielson et al., 2001; Stone et al., 2002; Huang et al., 2003). Except the study by Huang et al. (2003) on China, most of the AGE studies to date on crop biotechnology have used arbitrary levels of TFP with little empirical backing.

Model and data: In this analysis, we apply an AGE model to *Bt* cotton adoption in WCA by paying particular attention to the estimation of productivity change from the *Bt* cotton technology. We apply the standard GTAP applied general equilibrium model (Hertel, 1997) to quantify the impact of *Bt* cotton adoption on regional production, consumption, trade and welfare. This is a relatively standard, multi-regional model built on a complete set of economic accounts and detailed inter-industry linkages. The 66 economies in the version 5 of GTAP database are aggregated into 15 regions including the major cotton producers in the world[2].

[2] The 15 regions in the model are: Australia, Japan, China, rest of Asia, India, rest of south Asia, USA, rest of NAFTA, Latin America, European Union, Ex-soviet countries, Middle East and North Africa, Southern African region, West and Central Africa. In the model, WCA region is represented by the Sub-Saharan Africa while Southern African region include: Botswana, Namibia, Malawi, Mozambique, Tanzania, Zambia, Zimbabwe, Other Southern Africa.

A key parameterization in this analysis is the estimation of productivity gains due to transgenic technology (table 3 and 4). We derived these using several data sources. We estimated percent output increase, percent insecticide, seed and labor cost changes due to Bt technology using farm-level studies for USA, China, South Africa, Mexico and Argentina (table 2). These studies report farm-level costs and returns comparing directly *Bt* and non-*Bt* cotton. To extrapolate these cost and returns data to the sector level, we used cost shares of pesticides and seed (relative to total variable costs) from the 2001 ICAC survey of cost production which covers 28 of the major cotton producing regions of the world (Table 3). For example, in the case of China, *Bt* cotton reduce pesticide cost by 80%; and from the ICAC cost of production survey, the calculated share of pesticide to total variable cost is 12.58%. Therefore, *Bt* cotton lowers variable cost by 10% in the case of China. Similar calculations are also performed for seed and the value of output changes due to Bt cotton. In the case of labor, we use the GTAP database primary factor cost shares to derive the overall impact of labor to total cost change. Adding up all these changes on the input and output side and adjusting for the rate of Bt cotton adoption at the country level yields the overall sectoral TFP (table 4). We assumed 25% adoption rate of *Bt* cotton for the WCA region (would be adopter) and India (recent adopter) while for current adopters, we assume that the *Bt* cotton adoption rates for 2001 are unchanged during the model simulation. For other regions in the model considered non-adopters, no TFP change was used.

We considered three scenarios. In scenarios 1 and 2, WCA does not adopt *Bt* cotton, while in scenario 3 WCA adopts *Bt* cotton to the extent of 25% of total cotton acreage. Under all three scenarios, the other cotton-producing regions in the model that are Bt adopters (plus India) are assumed to benefit from the biotech-related TFP gains (table 4).

Under scenario 1, with no Bt cotton adoption, WCA continue along the recent trend of eroding productivity in the cotton sector. The corresponding TFP shock was derived taking into account both declining yield trends and increased per unit production costs. Region-wide average yield trends show an annual loss of 2.5% per year over the last decade (Figure 2). However, several factors account for these declining yield trends including less effective chemical control due to rising insect resistance, expanding cotton production into marginal lands with lower soil quality, and increased labor shortage (Tefft et al. 1998). Under scenario 1, it is assumed that only 50% of yield decline are due to lower chemical control effectiveness. For cost of production trends, we use time series data for Mali (Ajayi et al., 2002) as a proxy for WCA and calculate the long term cost increase due to insecticide at 1.1% of output value and arrive at the total annual decline of cotton productivity for WCA estimated at – 2.3%. This is the TFP shock used in scenario 1. In scenario 2, there is no productivity loss, so that TFP shock is zero. We can think of this scenario as the medium term outcome of sectoral reforms in WCA which remove some of the inefficiencies in the cotton sector (Badian et al., 2002) and therefore undo the recent negative productivity trends. Under scenario 3, the positive TFP shock for WCA as reported in table 4 represent the productivity gain to the cotton sector starting from zero productivity base.

Results: Given our focus on WCA, and the space constraints in the paper, we focus here on the changes in the volume of cotton output, trade and welfare for WCA. Under scenario 1 (no adoption, and negative TFP), WCA region shows an annual decline in cotton output by 6.9 percent (or $161.7 million constant 1997) compared to the base (table 5). Exports for WCA also suffer under this scenario (-13.3%) resulting in over $US 156.5 million of lower exports annually. The increased exports in other commodities (due to inter-sectoral factor reallocations) do not fully compensate for the cotton export reductions. Even when WCA doesn't experience TFP loss (scenario 2) but without the benefit of Bt technology while other regions do, WCA also experience a loss in output and exports. In this scenario, WCA cotton export share drop from 12.4 to 11.5 of world exports (table 6). When WCA adopt transgenic cotton (scenario 3), the region's cotton production rise by over 5.9 percent ($US 144.2 M) while exports increase by 11.1 percent or $US 137.2 M more compared to the base (Table 5). The performance of the cotton sector under scenario 3 represent significant positive turn around as the cotton performance in WCA compare favorably with other regions showing a slight increase in cotton export shares compared to the base (table 6).

In terms of welfare changes, the no adoption scenarios for WCA results in an annual welfare loss of $US 83.1 million (under negative TFP) and -$US 30.6 M (under no TFP change) (table 7). Under the Bt adoption scenario 3, regional welfare for WCA is now positive ($US 87.6 million) driven mostly by technical efficiency gain ($US 115.7 million). Allocative efficiency is also positive ($10.1 million) but terms of trade effects on welfare are negative (-$US38.3 million) as would be expected given the price reducing effect of technical change improvement. Overall, between scenario 1 and 3 the net welfare gain for WCA is $US 170.65 million higher under *Bt* cotton technology.

Given the uncertainty associated with some of the components underlying the TFP estimation for WCA (actual seed cost change, percent Bt cotton adoption, and level of yield change), we have conducted a sensitivity analysis with respect to the level of TFP shock. We employ a Gaussian Quadrature procedure (DeVuyst and Preckel 1997; Arndt and Pearson, 1996) to obtain estimates of the standard deviations of model results, thereby allowing determining the degree of robustness of model results to the productivity shocks. We applied a symmetric, triangular distribution around the calculated the sectoral cotton TFP change ranging from 0.5 to 1.5 times the initial shock level used in all scenarios. The results of sensitivity analysis for total welfare are reported in table 7 and show that the differences in welfare outcomes between all three scenarios are quite robust to this variation in cotton-sector productivity with or without Bt cotton adoption. For example, in scenario 3, the mean and standard deviation of total welfare gain for WCA is $US 87.5 M and $US23.9 M, respectively.

Conclusions

This study sought to evaluate the potential gains from adoption of transgenic cotton technology in West and Central Africa (WCA). Using a multi-regional general equilibrium analysis, and careful estimation of productivity gains due to *Bt* cotton technology, the analysis show that under no Bt cotton adoption and current declining productivity trends, the cotton sector in WCA shows lower output and declining export shares compared to other regions. Even without TFP loss, the pesticide-based cotton production system also result in eroding performance as other Bt adopting countries perform better and improve their world market positions. When WCA adopts Bt cotton, the cotton sector performs substantially better compared to the status quo and compares favorably with other regions. Overall, these results suggest that WCA can greatly benefit from transgenic cotton technology, which raises the important question of whether the necessary conditions ("technology infrastructure") are met in the WCA case to access and harness biotechnology to benefit its agriculture.

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Figure 1. National cotton share of crops and pesticide use

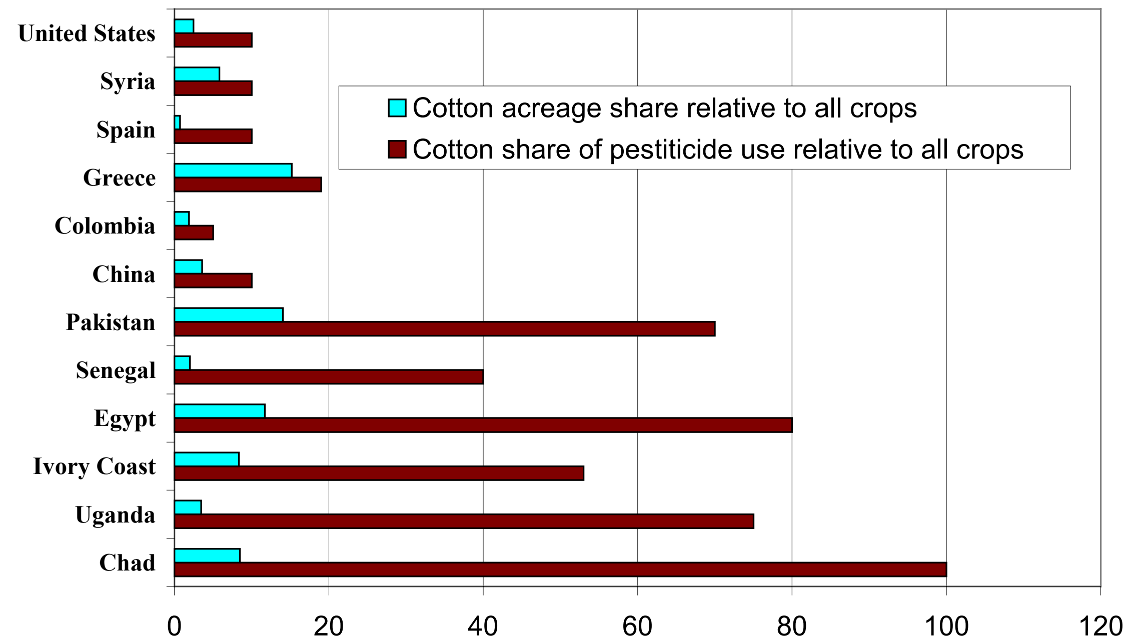
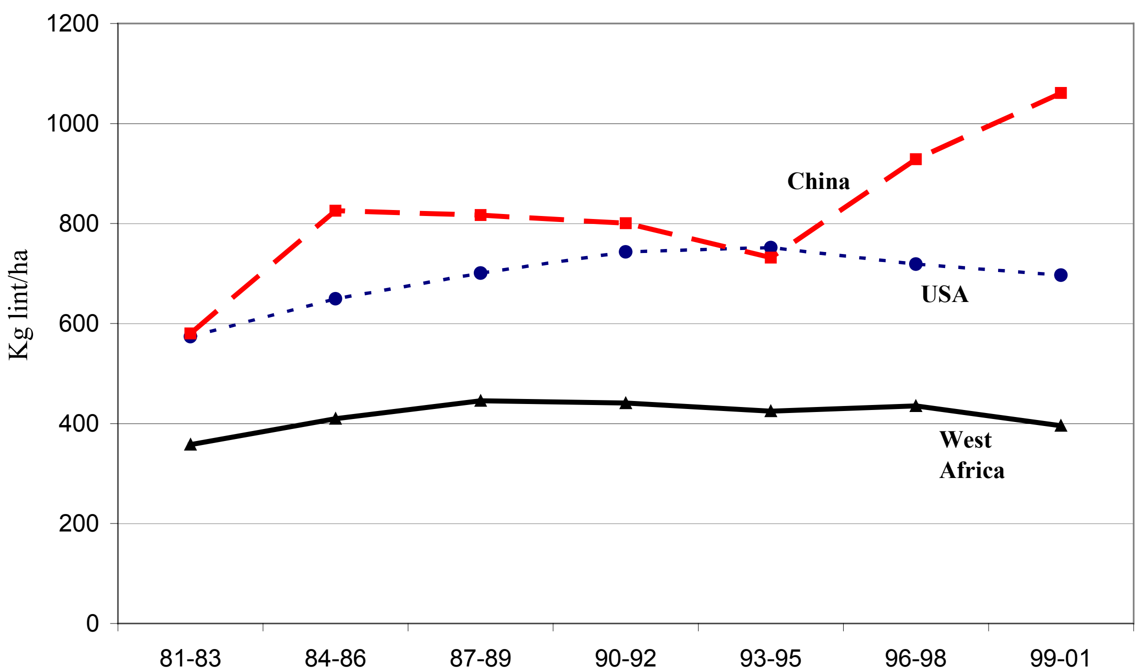
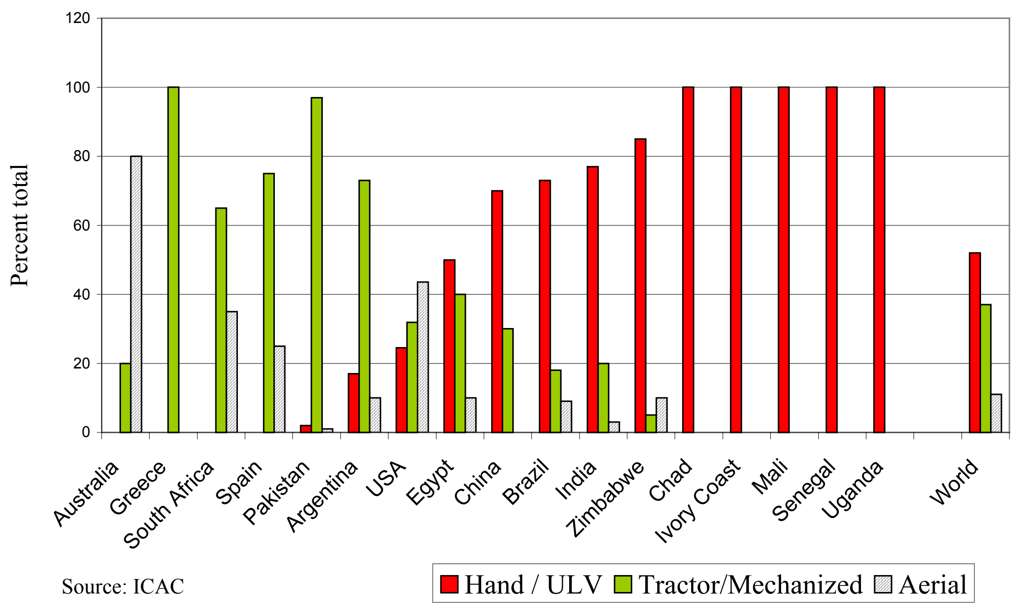


Figure 2. Cotton yield trends: selected regions



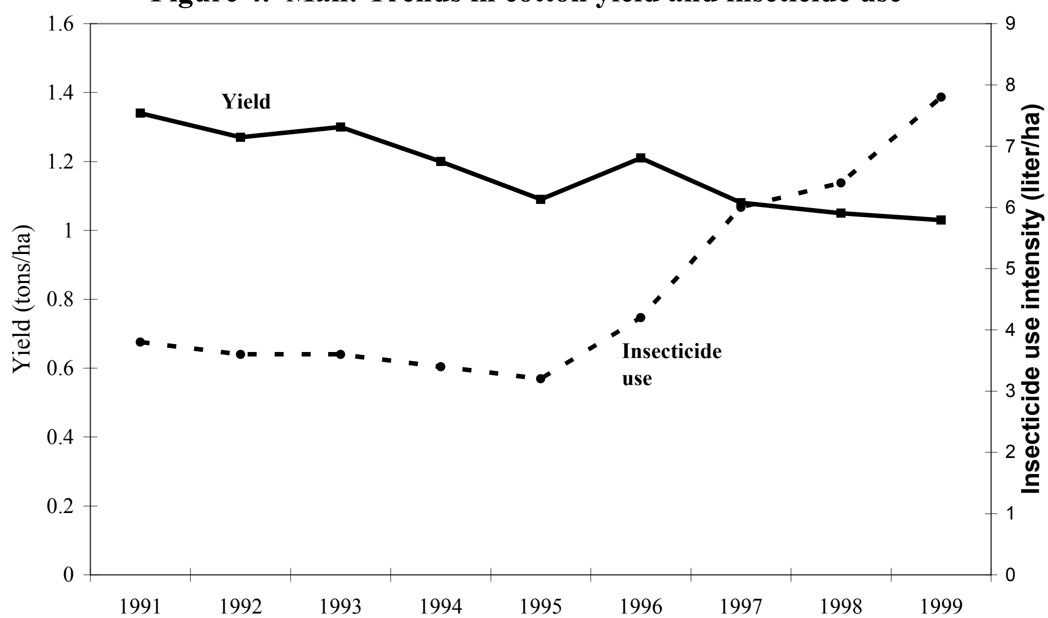
Source: Cotton world statistics, ICAC

Figure 3. Cottn insecticide spray methods



Source: ICAC

Figure 4. Mali: Trends in cotton yield and inseticide use



Source: Ajayi et al. (2002)

Table 1 - Importance of cotton in the economies of of West and Center Africa

	value of cotton output ($ M)	*GDP in 2000 ($ M)*	*Share of cotton to total GDP*	*Cotton to total export share*	*2000 value of cotton exports*	*Ratio of otton exports to food imports*
Benin	192	2168	8.8	44	106	88
Burkina Faso	151	2192	6.9	58	85	99.5
Chad	72	1407	5.1	46	46	143.8
Mali	114	2298	5	41	156	160.9
Togo	60	1219	4.9	19	55	169.6
Ivory Coast	163	9370	1.7	5	148	45.3
Cameroon	116	8879	1.3	4	97	78.2
C. African Rep.	12	963	1.3	7	13	62.5

Sources: Fortucci, 2002; FAOSTAT; USDA; IMF Statistics

Table 2. Estimates of Bt cotton impact on input cost and yield changes in cotton

		Input cost changes from Bt cotton				
Country	Source	savings in insecticides (percent)	Seed cost increase[1] (percent)	Labor saving (percent)	Output advantage due to *Bt* cotton (percent)	Net return per hectare due to *Bt* cotton (percent)
USA	Benedict and Altman (2001)				14.00	
	Deville, Mullins and Mills (2002)					8.98
	Kerby (2001)				9.00	
	Bosch et al. (2001)					5.90
	Miller et al. (2001)					6.20
China	Du (2001): Heibei, 1999	-82.00	673.00		14.60	
	Du (2001): Shongdon, 1999	-84.00	50.00		20.00	
	Huang et al. (2002)	-83.30	120.00	-15.00	5.80	
South Africa	Ismail et al. (2001)	-34.00	109.00		33.00	
Mexico	Traxler et al., 2001	-77.00	500.00		8.50	
	Gonzales-Garcia et al. (2001)					23.20
Argentina	Qaim and de Janvry, 2002	-46.00	166.00	-17.00	33.00	

[1]: inclusive of technology fees

Table 3. Cotton sector cost structure and insecticides and seed cost shares for Bt cotton adopting regions

Model regions	*Cotton sector cost structure1* *Land*	*Labor*	*Capital*	*Intermediate Inputs*	*Share of total variable cost due to*[2]*:* *Insecticides*	*Seed*
Australia	8.2	20.0	11.0	60.8	17.1	1.4
China	9.8	20.0	4.1	66.1	12.6	6.0
India	31.8	27.4	13.0	27.8	17.0	4.2
USA	12.5	16.9	15.2	55.4	12.0	3.4
Rest of NAFTA	9.0	15.1	8.0	67.9	6.4	6.8
Latin America	6.9	11.5	8.6	73.0	6.4	3.1
Southern Africa	7.9	30.5	14.1	47.6	10.7	2.3
West & Center Africa	6.9	41.1	9.1	42.9	13.8	3.2

Footnotes:

1 From GTAP database version 5

2 Authors calculations based on 2001 cost of production survey by the International Cotton Advisory Council.

Table 4. Calculated Bt-cotton induced total factor productivity for Bt cotton adopting regions

Model regions	*Input cost and yield changes with Bt cotton compared to non-Bt cotton (percent)* [1] *Insecticide*	*Seed* [2]	*Labor*	*Yield*	*Bt cotton adoption rate (Percent)* [3]	*Bt cotton-induced TFP* [4]
Australia	-80	80	-2	0	30	3.89
China	-82	220	-15	15	25	3.80
India	-82	220	-15	15	25	3.67
USA	-80	80	-2	0	37	1.74
Rest of NAFTA	-77	166	-15	8.5	30	4.17
Latin America	-46	166	-15	33	5	1.62
Southern Africa	-25	110	-8	18	40	8.21
West & Center Africa	-25	110	-8	18	25	5.29

Footnotes:

1 Authors calculated shares based on farm level studies for Mexico (Traxler et al. 2001); China (Du, 2001, Huang et al., 2002); South Africa (Ismail et al., 2001); Argentina (Qaim and de Janvry, 2002) and Burkina Faso (Savadogo et al., 1994).

2 Inclusive of technology fees

3 2001 levels of adoption for all regions that have adopted Bt cotton; *: assumed rates for West africa and India

4 For an explanation of how these TFP rates are calculated, see text page 7.

Table 5. Output and export effects of transgenic cotton adoption in West and Central Africa (WCA)

	Scenario 1: No adoption/(negative) TFP trends				**Scenario 2:** No Bt cotton adoption/No TFP change			
	Output change		*Export change*		*Output change*		*Export change*	
Sectors	*(%)*	*($US M)*	*(%)*	*($US M)*	*(%)*	*($US M)*	*(%)*	*($US M)*
Cotton	-7.0	-161.7	-13.3	-156.5	-3.2	-75.1	-6.2	-73.4
Other Crops	0.1	36.3	0.6	28.9	0.1	19.5	0.3	15.2
Fruit & Vegetables	0.0	3.9	0.7	4.5	0.0	2.9	0.4	2.4
Other Agriculture	0.0	-2.7	0.9	1.0	0.0	-0.9	0.5	0.6
Processed Food	0.0	12.8	0.6	12.1	0.0	9.6	0.3	6.2
Textile	-0.3	-20.3	-1.0	-2.9	0.0	0.0	0.1	0.4
Apparel	-0.1	-1.9	-0.1	-0.3	0.2	3.4	0.5	2.2
Other manufacturing	0.3	56.4	0.5	27.7	0.1	29.3	0.3	13.8

	Scenario 3: Bt cotton adoption/positive cotton TFP			
	Output change		*Export change*	
	(%)	*($US M)*	*(%)*	*($US M)*
Cotton	5.9	144.2	11.1	137.2
Other Crops	-0.1	-16.7	-0.4	-18.0
Fruit & Vegetables	0.0	0.0	-0.4	-2.6
Other Agriculture	0.0	1.8	-0.4	-0.5
Processed Food	0.0	-2.9	-0.3	-7.3
Textile	0.6	45.3	2.6	7.3
Apparel	0.7	14.0	1.6	7.3
Other manufacturing	-0.1	-30.1	-0.3	-16.9

Source: Authors' simulation results

Table 6. Output and export effects of transgenic cotton adoption in selected countries

(all numbers are in percent)	**Initial export shares**	**Scenario 1:** No adoption/(negative) TFP trends			**Scenario 2:** No Bt cotton/adoption/No TFP change		
		Output	*Export*		*Output*	*Exports*	
			change	share		change	share
Australia	9.8	9.7	15.5	10.7	9.1	14.7	10.6
China	0.0	1.0	5.1	0.0	1.0	4.7	0.0
India	4.0	1.0	11.3	4.2	0.9	10.2	4.1
USA	28.7	-0.2	-0.4	75.5	-0.5	-1.1	36.1
Southern African region	3.5	14.7	25.2	6.6	13.9	23.8	6.8
West and Central Africa	12.4	-7.0	-13.3	11.5	-3.2	-6.2	12.7

	Scenario 3: Bt cotton adoption/positive cotton TFP for all regiosn		
	Output	*Exports*	
		change	share
Australia	7.8	13.1	10.6
China	0.9	3.6	0.0
India	0.8	7.7	4.1
USA	-1.2	-2.8	28.6
Southern African region	11.9	20.5	7.6
West and Central Africa	5.9	11.1	11.4

Source: Authors' simulation results

Table 7. Impact of Bt cotton adoption on WCA's welfare (Constant 1997 $US Million)

	Scenario 1: No adoption/ (negative) TFP trends	**Scenario 2:** No Bt cotton adoption/ No TFP change	**Scenario 3:** Bt cotton adoption/positive cotton TFP
Total Welfare (EV; $US M)	-83.1	-30.61	87.55
Welfare components:			
Allocative efficieciency	-16.91	-8.96	10.1
Technical change	-50.7	0	115.71
Terms of trade	-15.49	-21.65	-38.26
Factor returns:			
Land	-0.65	-0.46	0.03
Unskilled labor	-0.08	-0.03	0.08
Capital	-0.03	0	0.07
Sensitivity analysis- Total welfare($USM)[1]			
Mean	-83.13	-30.62	87.47
Standard deviation	11.09	2.69	23.96

Source: authors's simulations

1 Sensitivity analysis (SSA) with respect to productivity shocks was carried out using a Gaussian Quadrature procedure (DeVuyst and Preckel 1997; Arndt and Pearson, 1996) which generates estimates of both the mean and standard deviations of model results. See text page 11-12 for description of how SSA is implemented.