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The Commercial Application of GMO Crops in Africa: Burkina Faso's Decade of Experience with Bt Cotton

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Burkina Faso has emerged as one of the more progressive and proactive sub-Saharan African countries regarding biotechnology. In 2009, slightly more than 125,000 ha of second-generation insect-protected biotech cotton (Bollgard II from Monsanto Co.), in local varieties, were planted by Burkina Faso producers; this was the largest introduction of biotechnology on the African continent. The commercial release was made possible through a joint collaboration between Burkina Faso's national cotton companies and Monsanto that began in May 2000. This article presents empirical evidence of how Bt cotton impacted rural households in Burkina Faso following its 2009 commercial release. Based on surveys of 160 cotton producers, Bt cotton significantly increased cotton yields by an average of 18.2% over conventional cotton. There was no significant difference in production costs since the increased cost of Bt cotton seed was offset by the reduction in insecticide costs, and labor savings from growing Bt cotton were offset by slightly higher harvest costs. Hence, producers were able to capture virtually all of the benefits from higher cotton yields. Bt cotton producers earned a profit of $39.00 per ha, a $61.88 per ha increase in cotton income over conventional cotton, and also shifted producers' bottom line from a negative position to a positive one.

Key words: Bt cotton, Bollgard II, Burkina Faso, smallholder, adoption, Africa.

Introduction

Burkina Faso has emerged as one of the most progressive countries in Africa in terms of biotechnology. Last year, slightly more than 125,000 ha of Bt cotton were planted by Burkina Faso producers, marking it the largest-ever introduction of biotechnology on the African continent. Africa's overall use of biotechnology still lags far behind adoption rates throughout the world, however, as only one other country—South Africa—has commercialized bioengineered crops on a substantial scale, with Egypt growing a small amount of biotech corn (International Service for the Acquisition of Agri-Biotech Applications [ISAAA], 2009). In cotton, for instance, the adoption of Bt cotton has taken place on a global scale, yet Africa accounts for a disproportionally small percentage of global adoption. Since its 1996 debut on American cotton farms, the global adoption of Bt cotton has spread to 10 million ha in 9 countries (ISAAA, 2009). Of the 10.3 million farmers growing biotech crops in 2006, close to 90% were small, resource-poor farmers from developing countries (James, 2006). Africa accounted for less than 1% of the world's area of Bt cotton even though it produces 20% of the world's cotton (James, 2006).

Africa has been at the center of the biotechnology debate, where opposition by various public interest groups has largely succeeded in delaying the introduction of agricultural biotechnology products (Cohen & Paarlberg, 2002; Paarlberg, 2008). This African debate on biotechnology is expected to intensify and focus on Burkina Faso over the next few years as opposition groups are likely to continue arguing against biotechnology, attaching regional and global importance to Burkina Faso's on-going experiment with Bt cotton. If Bt cotton is successfully introduced in Burkina Faso, it is likely to be replicated elsewhere in Africa, particularly in neighboring countries that share similar agro-ecological zones, farming systems, and cotton industry structures. Hence, the introduction of Bt cotton in Burkina Faso could become a pivotal event that may have a substantial impact on the future use of biotechnology in Africa.

Empirical evidence will become a crucial component to the assessment of Bt cotton's performance in Burkina Faso as the debate intensifies. Success will be measured along multiple dimensions, including social, economic, and environmental scopes. To guarantee success, Bt cotton must not only generate significantly higher profits than conventional cotton, but it must do so in an equitable manner, providing benefits to all stakeholders, while maintaining favorable environmental characteristics. This article presents empirical evidence of Bt cotton benefits to producers in Burkina Faso following the first year of commercial introduction (2009) of Bollgard II® (BGII). Results are provided by recently conducted household surveys, which documented the impacts of BGII on household income and production costs.

The article begins with a brief technical description of the technology and then discusses the evolution of Bt cotton in Burkina Faso, highlighting the research and legal frameworks that were required to commercialize BGII. This is followed by a brief section on the methodology used in the household surveys. Results of the household survey are then presented and discussed. The article concludes with an examination of both the common and distinguishing features of Burkina Faso to help place the country's experience with Bt cotton in a global perspective.

What is Bt Cotton?

Genetic engineering techniques were used on the cotton plant to insert genes that encode and promote the production within the plant of proteins toxic to certain caterpillar pests common to cotton and other crops (Perlak et al., 1990). In BGII, these proteins—Cry1Ac and Cry2Ab—are encoded by genes originating from the common soil bacterium *Bacillus thuringiensis* (Bt). These Cry proteins are both highly effective in killing certain lepidopteran larvae (caterpillars) (Greenplate et al., 2003). Once ingested, the Cry proteins bind to specific molecular receptors on the lining of the caterpillar's gut, create holes in the gut, and quickly cause death (Hofte & Whiteley, 1989). Individual Bt Cry proteins are highly specific to certain caterpillars and do not target other insects (Hofte & Whiteley, 1989; MacIntosh et al., 1990; Sims et al., 1997), unlike conventional pesticides, many of which kill across a wide spectrum of both targeted and non-targeted (often beneficial) insects. Formulations of microbial Bt fermentation products (containing Cry proteins) have been used for more than 60 years as natural insecticides in spraying programs in agricultural and forestry pest control (Aronson, Beckman, & Dunn, 1986). While these Bt formulations can be quite effective under certain conditions, the products have never been widely adopted in crops such as cotton because they have short half-lives in the field (the Cry proteins are degraded by UV light); many insect larvae may escape control by these products if spray coverage is not optimal, and they are relatively expensive due to their method of production (fermentation). Interestingly, these Bt fermentation formulations are regularly used in the smaller market of organic cotton as "natural" insecticides.[1]

Commercialization of Bollgard II in Burkina Faso

Burkina Faso's experience over the past decade provides an excellent example of the processes and procedures required for a biotechnology product to be successfully introduced in a developing country. The 2009 commercial release of Bt cotton was the result of nearly a decade of coordinated efforts on behalf of various Burkina Faso cotton stakeholders to satisfy a series of technical, legal, and business requirements. With input from many sources, the Burkina Faso legislature researched, developed, and passed biosafety legislation to formalize regulatory oversight for the research and commercialization of agricultural biotech products. A large portion of the resources required for the testing and commercialization process was provided by Monsanto, who was also able to draw on past experiences from other countries in commercializing Bt cotton. Monsanto's role included assistance in transferring the Bt gene to the two regional cotton varieties—STAM 59 and STAM 103—that are grown as conventional cotton in Burkina Faso.

Burkina Faso's national agricultural research center, Institute National Environment et Agricole (INERA), has also played an important role in the commercialization of Bt cotton in Burkina Faso. Since 2003, INERA has been testing the technical efficacy of BGII by conducting environmental assessments as part of input biosafety protocols, and monitoring the socio-economic impacts of BGII. From 2003 to 2005, INERA conducted three years of confined field trials that evaluated the effectiveness of BGII within the climate and insect conditions specific to Burkina Faso (Hema et al., 2008; Vitale et al., 2008). In 2006, the Biosafety Committee approved an additional confined field trial outside of the INERA research farm environment, which also represented the first test of BGII technology in regional germplasm varieties, STAM 59 and STAM 103. In July 2007, INERA conducted field trials of these two local varietal versions of BGII on 20 testing sites within the

1. *See http://www.organicexchange.org/Documents/farmer_pest.pdf and http://www.bt.ucsd.edu/organic_farming.html.*

cotton-growing zones under the control of the three major cotton companies SOFITEX, SOCOMA, and Faso Coton. The 2007 test results were encouraging, with average yield increases of 20%. In June 2008, the National Biosafety Agency authorized the commercial planting of BGII in Burkina Faso. This was a significant milestone for Burkina Faso, marking the first commercial use of Bt cotton in the country and only the third commercial release of a bioengineered crop in Africa. In the 2008 cotton growing season, SOFITEX and its contract seed producers planted 15,000 hectares of the above mentioned two local varieties containing BGII. The modest area of 15,000 hectares was due to the limited supply of BGII seed available at that time, and represented a seed multiplication year for the anticipated broad commercial deployment in 2009. The 2008 approval and seed increase paved the way for the 2009 commercial planting of 125,000 ha of Bt cotton in Burkina Faso, the most extensive single-year biotechnology launch in Sub-Saharan Africa (SSA) to date.

The Impacts of Biotechnology: Evidence from Burkina Faso

This section presents findings from recent field surveys that documented the socio-economic and health impacts of the adoption of Bt cotton (BGII) among smallholder cotton farmers in Burkina Faso. The Burkina Faso field surveys are of particular interest since only a limited quantity of empirical evidence is available on the impacts Bt cotton in SSA. Morse, Bennett, and Ismael (2004) reported on the findings of field trials in the Makhitini Flats of South Africa, where farmers have used Bt cotton since 2001. Success was reported on both commercial and smallholder farms (Gouse, Pray, & Schimmelpfennig, 2005; Hofs, Fok, & Vaissayre, 2006; Ismael, Bennett, & Morse, 2002). Yield increases of roughly 25% were achieved with Bt cotton, accompanied by reduced spraying costs of 66%. On average, the South African farmer's income increased by $137 per ha. The previous findings provide a basis for comparison with the Burkina Faso results presented herein to better understand how biotechnology may potentially benefit producers in SSA.

Burkina Faso Producer Surveys

INERA conducted a survey of 160 rural households in 10 villages during the summer and fall of 2009 to assess the impact of BGII on various social, economic, and health impact indicators. The surveys were conducted with a representative sample from each of the three main cotton-growing zones, each controlled or administered by a separate cotton company: SOFITEX (n=80) in the west, SOCOMA (n=40) in the center, and Faso Coton (n=40) in the east. The survey villages were randomly selected and represent typical conditions in each of the cotton zones. A total of 10 villages were included in the survey, and within each village, households were selected randomly. The sample included a representative mixture of producers across farm type, with 46.2% large farms (2 or more animal draft pairs), 50.6% small farms (1 animal draft pair), and 3.1% manual farms. Nationally, using this typology, large producers comprise approximately 52% of the farms, small farms 46%, and manual farms the remaining 2%. The survey instrument was developed by INERA researchers at the Programme Coton research center in Bobo Dioulasso, Burkina Faso, and administered by local extension workers.

The household surveys had two parts. The first part included demographic and other background information to characterize households on land and livestock holdings, age and gender of occupants, household farm labor, and income. The second part of the survey collected information on production practices and other variables required to estimate the economic impacts of BGII. This included the number and type of insecticides applied on cotton fields, fertilizer applications, seeding density, labor demands, and herbicide applications. Cotton yields were measured by INERA agronomists at harvest time for each of the household's fields.

Summary statistics for the surveyed households are listed in Table 1. The area planted in BGII averaged 3.2 ha across the three zones and farm types, and varied between 1.4 ha for the smallest manually-worked farms (hand labor only, no animals) in the Faso Coton zone to 4.5 ha in the SOFITEX zone on large farms (Table 1). Across all three zones, the average households contained 14.1 persons, with 8.6 of them actively engaged in the family's farming operations, which included—but were not limited to—cotton production (Table 1). Households travel an average distance of 3.8 km to their cotton field, with manually equipped farms traveling as far as 8 km in the SOFITEX and Faso Coton zones (Table 1). The most experienced cotton producers in the survey were from the SOFITEX production zone, with an average tenure of 28 years. SOFITEX is the traditional cotton-producing zone, where the crop has been produced since the colonial era, whereas the SOCOMA and Faso Coton zones have only recently been introduced to cotton production. The longer experience with this cash crop likely explains why household incomes were found to be significantly higher in the SOFITEX

Table 1. Household and producer characteristics of the Burkina Faso cotton producers.

Item	SOFITEX[a] Large[b] n=48	SOFITEX Small n=29	SOFITEX Man. n=3	SOFITEX Ave n=80	SOCOMA Large n=15	SOCOMA Small n=25	SOCOMA Ave n=40	Faso Coton Large n=11	Faso Coton Small n=27	Faso Coton Man. n=2	Faso Coton Ave n=40	All Ave n=160
Household size (persons)	16.7	11.0	11	13.9	24.1	10.0	18.7	11.5	9.5	11	10.1	14.1
Household farm labor (persons)	10.1	6.4	3.8	8.3	21.6	6.1	14.3	5.5	4.4	3.5	4.6	8.6
Area in Bt cotton (ha)	4.5	2.4	1.8	3.6	4.1	1.5	2.9	2.9	1.9	1.4	2.2	3.2
Distance to cotton field (km)	3.7	3.7	8	3.6	2.9	2.8	2.8	5.8	5.0	8	5.4	3.8
Experience growing cotton (yrs)	31.9	25.5	13	28.0	9.1	11.1	9.8	8.5	10.8	13.0	10.2	20.4
Household income ($ per year)	924	513	-	780	575	280	455	691	471	-	520	655

[a] Cotton production zone refers to the areas of operation of the three national cotton companies: SOFITEX, SOCOMA, and Faso Cotton.

[b] Farm types are defined as follows: Large are farms with 2 or more animals for assistance in field operations, Small are farms with 1 animal for assistance in field operations, and Man. are farms where everything is done manually (no assistance of animals).

zone, with an average household income of $780 per year. In the Faso Coton zone, household incomes were found to be $520 per year and in the SOCOMA zone household incomes averaged $455 per year.

Bollgard II Yield Advantage

One of the most important and widely reported measures of agronomic performance is the generation of higher yields (Gouse et al., 2005; Hofs et al., 2006; Ismael et al., 2002; Morse et al., 2005). Since cotton yields are influenced by effects other than the presence of the Bt genes, an analysis of variance (ANOVA) was conducted on the observed yield data. The ANOVA approach accounts for cotton yield variability due to the presence of the Bt genes, but in addition includes other factors which can also influence yield. Without including these other factors, the causes for yield differences could be misinterpreted due to bias from missing variables (Greene, 2007). Using the ANOVA approach, the significance of the Bt genes on cotton yield can be rigorously tested from the observed data. An ANOVA model of cotton yield was estimated that explained cotton yields, *Y*, using gene type (*GENE*), location (*ZONE*), farm size (*TYPE*), and the number of late season insecticide sprays (*SPRAYS*) using the following equation.

$$Y_i = \alpha + GENE_{ij} + ZONE_{ik} + TYPE_{il} + SPRAYS_{im} + \varepsilon_i \quad (1)$$

In Equation 1, the subscript i denotes the i^{th} producer in the survey, while the other subscripts (j, k, l, and m) represent the levels included for the other factors; α is an intercept term; and ε_i is the error term for the i^{th} producer. Gene type (*GENE*) had two effects levels, one for Bt cotton (BGII) and the other for conventional cotton. The farm size (*TYPE*) effect had three levels for large, small, and manual (hand-hoe) farms. The location (*ZONE*) effect included three survey sites, one in each of the cotton company zones of operation: SOFITEX, SOCOMA, and Faso Coton. The number of late-season pest sprays (*SPRAYS*) was included as a treatment effect with three levels (0, 1, and 2). Many BGII producers did not follow the recommended regimen of two late-season sprays (2), and instead either did not spray (0) or sprayed only once (1). The ANOVA yield model also included interaction terms to test, for instance, whether the *GENE* effect varied significantly across *ZONE* and *TYPE*. The ANOVA yield model was solved using the PROC GLM statement in the SAS statistical software package (2009).

Bollgard II Economic Impact

The economic impact of BGII was assessed by measuring the change in cotton profit ($\Delta\Pi$) from producing BGII relative to conventional cotton using partial budget analysis (Kay, Edwards, & Duffy, 2006). This is a farm accounting statement that reports only the revenues and costs that vary as a result of a change in the production environment and has been used in previous impact studies on Bt cotton (Gouse, Kirsten, & Jenkins, 2003; Ismael et al., 2002; Pemsl, Waibel, & Orphal, 2004). Hence, in this study the partial budget includes only the changes that occur from introducing Bt cotton, namely cotton yield and production costs for insecticide treatment, labor, seed, fertilizer, and herbicide costs. Remaining costs, including fixed costs from animal traction and other variables costs such as plowing and weeding, were presumed constant and were not used in the partial budget analysis.

Using partial budgeting, the economic impact from growing BGII for a producer is obtained from

$$\Delta\Pi_i = P_c{*}A_i{*}\Delta Y_i - (\Delta INSECT_i + \Delta LABOR_i + \Delta SEED_i + \Delta OTHER_i\,), \qquad (2)$$

where $\Delta\Pi_i$ is the change in profit for the i^{th} producer, P_c is the price for harvested cotton paid to producers, A_i is the area of BGII cotton planted by the i^{th} producer, ΔY_i is the yield difference between BGII and conventional cotton, $\Delta INSECT_i$ is the difference in insecticide treatment costs, $\Delta LABOR_i$ is the difference in labor costs, $\Delta SEED_i$ is the difference in seed costs, and $\Delta OTHER_i$ is the difference in other costs such as fertilizer that could vary between BGII and conventional cotton. Equation 2 states that the economic impact is given by the change in revenue, the first term on the right hand side of the equation, less the incremental changes in production costs from growing BGII.

The change in yield, ΔY_i, is calculated as the difference between BGII and conventional cotton yields, Y_{BGII} and Y_{CONV}:

$$\Delta Y_i = Y_{BGII} - Y_{CONV}\,. \qquad (3)$$

The changes in revenue and production costs were structured using standard farm-management accounting relationships (Kay et al., 2006). The change in insecticide costs is given by the difference between the number of insecticide treatments applied on BGII cotton plots by the i^{th} producer, N_{BGII}, and the number of treatments applied on conventional cotton, N_{CONV}, multiplied by the price of each insecticide treatment, P_{INS}. This equation for the change in insecticide costs for the i^{th} producer is given by

$$\Delta INSECT_i = (N_{BGII} - N_{CONV}){*}P_{INS}. \qquad (4)$$

The change in labor costs was calculated using two components. The first was the time savings from applying insecticide, including the travel time to the field, calculated as speed of travel, *SPEED*, multiplied by distance traveled to field, *DIST*. The rural wage rate (*WAGE*) was used to value the producer's time. Our field surveys found a rural wage rate of $1.50 per day and travel speed to the field 5 km per hour. The second component was from the increased labor required to harvest cotton on the BGII plots. The increased harvest labor was calculated as the difference between BGII and conventional cotton production multiplied by the harvest efficiency coefficient, HRV_{EFF}, which was determined as 18.9 kg of cotton per day based on field survey data. Based on those two components, the change in labor costs is given by

$$\Delta LABOR_i = -WAGE{*}DIST_i{*}SPEED + A_i{*}\Delta Y_i{*}HRV_{EFF}\,. \qquad (5)$$

The change in seed costs is calculated as the difference between BGII and conventional seed costs. Since seeding density, *DNS*, could vary between BGII and conventional cotton, the change in seed costs is calculated as

$$\Delta SEED_i = A_i{*}(P_{BGII}{*}DNS_{BGII} - P_{CONV}{*}DNS_{CONV}). \qquad (6)$$

Equations 2 through 6 were calculated using data from the household surveys and also data obtained from the cotton companies and the cotton-producing cooperative Union Nationale de Producteurs de Cotton Burkina Faso (National Union of Cotton Producers of Burkina Faso; UNPCB), which provided input prices and the cotton price paid to producers. For instance, the price paid to producers in 2009 for harvested cotton was $0.35 per kg of raw seed cotton (harvested lint plus seed). The price of BGII seed for planting was $5 per kg in 2009, which corresponds to a cost of $69.5 per ha for an average typical seeding density of 13.9 kg per ha. Conventional cotton seed for planting, sold to producers from the national cotton company, was $0.89 per kg in 2009, and corresponded to a cost of $8.88 per ha based

Table 2. ANOVA model results for cotton yield and economic returns.

	Yield model (R^2 = 0.617)		Economic model (R^2 = 0.501)	
Factor	**F-value**	**P-value**	**F-value**	**P-value**
Gene	23.36	<0.0001	13.30	0.0004
Zone	26.80	<0.0001	22.78	<0.0001
Type	0.24	0.7881	0.18	0.8319
Insecticide sprays	2.64	0.0746	2.32	0.1017
Gene × Zone	2.07	0.0391	4.34	0.0146
Gene × Type	4.09	0.0184	4.07	0.0188
Zone × Sprays	16.92	<0.0001	17.57	<0.0001
Type × Sprays	3.49	0.0092	3.45	0.0098
Type × Zone	6.68	<0.0001	6.51	<0.0001

Table 3. Bollgard II yield advantage and corresponding increase in cotton revenue relative to conventional cotton.

	Cotton production zone [a]											
	SOFITEX (n=80)				SOCOMA (n=40)			Faso Coton (n=40)				
Yield item (kg ha^{-1})	Large[b] n=48	Small n=29	Man. n=3	Ave n=80	Large n=15	Small n=25	Ave n=40	Large n=11	Small n=27	Man. n=2	Ave n=40	All zones n=160
GENE												
BGII	1,300	1,059	997	1,201	1,234	1,420	1,350	988	939	1,065	959	1,178
Conventional	1,118	1,088	888	1,031	1,088	1,215	1,222	903	724	480	702	997
Average yield	1,209	1,074	943	1,116	1,161	1,318	1,286	946	832	773	831	1,087
BGII yield advantage (%)	16.3	-2.7	12.3	16.5	13.4	16.9	14.3	9.4	29.7	121.9	36.6	18.2

[a] Cotton production zone refers to the areas of operation of the three national cotton companies: SOFITEX, SOCOMA, and Faso Cotton.

[b] Farm types are defined as follows: Large are farms with 2 or more animals for assistance in field operations, Small are farms with 1 animal for assistance in field operations, and Man. are farms where everything is done manually (no assistance of animals).

on a typical seeding density of 10 kg per ha. Data for yields, insecticide use, seeding density, fertilizer use, distance to cotton field were collected from the producer surveys.

The economic impacts are estimated using an ANOVA model to avoid biasing the effect of the Bt genes on economic profits (see above). An ANOVA economic model was constructed that explains the economic impacts from Equation 2 using gene type (*GENE*), location (*ZONE*), farm type (*TYPE*), and the number of late season sprays (*SPRAYS*).

$$\Delta\Pi_i = \beta + GENE_{ij} + ZONE_{ik} + TYPE_{il} + SPRAYS_{im} + \eta_i , \quad (7)$$

where β is an intercept term and η_i is the error term for the i^{th} producer. The ANOVA economic impact model in Equation 7 was solved using the PROC GLM statement in the SAS statistical software package (2009).

Results

The ANOVA model provided a good fit to the observed yield data with an R^2 of 0.617 (Table 2). Five out of the nine factors were highly significant (P<0.01), and only the factor *TYPE* was not significant (P=0.7881) in the model (Table 2). Bollgard II generated significantly higher yields (P<0.01) than conventional cotton, with an average yield that was 18.2% higher than conventional cotton among surveyed producers (Table 3). The average seedcotton yield was 1,178 kg ha^{-1} for BGII, which was 181 kg ha^{-1} higher than conventional cotton's average yield of 997 kg ha^{-1}.

Interaction terms between the *GENE* and the *ZONE* and *TYPE* variables were added to the ANOVA model to investigate whether the *GENE* effect varied across *ZONE* or TYPE, i.e. whether BGII provided significantly different yield performances among company zones (or farm types). The ANOVA model found that the *GENE* × *ZONE* interaction term had a significant effect (P<0.05) on cotton yield and corresponding yield advantage, with Faso Coton generating the highest yield advantage (36.6%), followed by SOFITEX with an average yield advantage of 16.5%, and SOCOMA with a 14.3% yield advantage (Table 3). The yield differences across zones may be explained by the influences of some combination of factors including environmental characteristics, pest pressure, and secondary pest spray differences. The *GENE* × *TYPE* interaction term was also significant (P<0.05) in the ANOVA model. This was largely due to the manual producers achieving the largest yield increase of 41.3%, compared to smaller yield increases of 14.8% and 12.4% in the SOFITEX and SOCOMA zones, respectively.

The number of late-season pest sprays (*SPRAYS*) also had a significant effect (P<0.10) on BGII yield (Table 2). Conventionally treated cotton requires a regimen of six sprays: the initial four targeting lepidoptera (the primary pests), and the last two targeting secondary pests, which include the piercing-sucking aphids and jassids. Bollgard II reduces the need for the first four sprays since it is effective in controlling Lepidoptera. However, a majority of producers surveyed (78%) did not spray the recommended late-season sprays, leaving fields unprotected from secondary pests and vulnerable to damage. Producers holding to the prescribed regimen of two late-season sprays had higher yields than those who sprayed only once or not at all, but the difference in means was not significant (P>0.10; Table 4). Overall, producers who sprayed twice obtained BGII yields that

Table 4. ANOVA model results for Bollgard II yields and corresponding cotton income across the main factor of the number of late season insecticide treatments applied by cotton producers.

	Cotton production zone [a]									
	SOFITEX (n=80)			SOCOMA (n=40)			Faso Coton (n=40)			
Insecticide treatments[b]	Large[c] n=48	Small n=29	Ave n=80	Large n=15	Small n=25	Ave n=40	Large n=11	Small n=27	Ave n=38	All zones n=160
					Bollgard II					
0	1,036[c]	759[c]	940[c]	1,485[a]	1,595[a]	1,540 [a]	-	-	0	1,064 [a]
1	1,263[b]	1,095[b]	1,187[b]	1,275[b]	1,237 [b]	1,247 [b]	779 [b]	886 [a]	855 [b]	1,100 [a]
2	1,569[a]	1,303[a]	1,493[a]	970[c]	1,127 [b]	1,060 [b]	1,108 [a]	972 [a]	1,012 [a]	1,213 [a]
Ave.	1,300	1,059	1,201	1,234	1,420	1,350	988	939	959	1,178
					Conventional cotton yields (kg ha^{-1})					
6	1,118	1,088	1,031	1,088	1,215	1,222	903	724	702	997
					Bollgard II income ($ ha^{-1})					
0	-10.36[c]	-75.64[c]	-33.07[b]	97.24[a]	125.64 [a]	111.44 [a]	-	-	-	-3.17 [c]
1	57.10[b]	21.80[b]	41.05[b]	12.61[b]	38.13 [b]	31.75 [b]	-64.43 [b]	-42.40 [a]	-48.69 [b]	15.69 [b]
2	156.46[a]	94.74[a]	138.83[a]	-90.46[c]	-9.63 [c]	-44.27 [c]	47.32 [a]	-17.17 [a]	1.64 [a]	50.86 [a]
Ave.	66.28	7.08	41.30	15.89	104.69	71.39	6.52	-26.85	-13.11	39.00
					Conventional cotton profit ($ ha^{-1})					
6	4.00	7.33	-17.84	-25.16	54.17	25.61	-44.36	-103.1	-108.4	-22.89

[a] Cotton production zone refers to the areas of operation of the three national cotton companies: SOFITEX, SOCOMA, and Faso Cotton.
[b] Farm types are defined as follows: Large are farms with 2 or more animals for assistance in field operations, Small are farms with 1 animal for assistance in field operations, and Man. are farms where everything is performed by hand.
[c] Letters represent significant differences in mean values within each column.

averaged 1,213 kg ha^{-1} across all three zones, which was 10.3% higher than the yields of producers who sprayed once, 1,100 kg ha^{-1}, and 14.0% higher than those who didn't spray at all (1,064 kg ha^{-1}; Table 4). The effect of late-season sprays on cotton yield was not uniform, however, as evident by the significance (P<0.01) of the interaction factor, *ZONE* × *SPAYS* (Table 2). The SOFITEX and Faso Coton zones showed the effect of not spraying fields late in the season, but the SOCOMA zone was found to have excellent BGII yields over conventional cotton at all spray levels (Table 4). The largest effect of not spraying was in SOFITEX, where producers who sprayed twice obtained BGII yields that averaged 1,493 kg ha^{-1} across all three farm types, which was 25.8% higher than the yields of producers who sprayed once (1,187 kg ha^{-1}) and 37.0% higher than those who didn't spray at all (940 kg ha^{-1}; Table 4). These yield differences may reflect regional variation in secondary pest densities, which influence the relative value of targeted sprays in protecting yield.

One other factor, *ZONE*, was significant in the ANOVA model (P<0.01), indicating that cotton yields were significantly different across the three cotton company production zones (Table 2). The highest cotton yields were found in the SOCOMA zone, where total yields (Bt and conventional) averaged 1,286 kg ha^{-1}. The SOCOMA yields were 455 kg ha^{-1} higher than cotton yields in Faso Coton (which had total yields of 831 kg ha^{-1}) and 170 kg ha^{-1} higher than cotton yields in SOFITEX (which had total yields of 1,116 kg ha^{-1}; Table 3). Although the *TYPE* factor did not have a significant effect (P=0.7881) on cotton yield, the interaction term *TYPE* × *ZONE* was significant (P<0.01), indicating that the effect of farm size on yields varied across zone (Table 2). Across farm types, cotton yields were significantly different in the Faso Coton zone, where manually equipped farmers had much lower conventional cotton yields than the large and small farms. The manually equipped farmers in Faso Coton had conventional yields of 480 kg ha^{-1}, only about one-half (53.1%) of the conventional yields obtained by large producers. It may be important to consider that these manual farms represented only two of the 40 surveys completed in the Faso Coton zone, and therefore may not be truly representative of yield performance throughout the larger cotton farm population.

Table 5. Production cost comparison between Bollgard II and conventional cotton based on purchased inputs: Insecticide use, labor effort, and seed cost.

	Cotton production zone [a]											
	SOFITEX (n=80)				SOCOMA (n=40)			Faso Coton (n=40)				All
Item ($ ha^{-1})	Large[b] n=48	Small n=29	Man. n=3	Ave n=80	Large n=15	Small n=25	Ave n=40	Large n=11	Small n=27	Man. n=2	Ave n=40	zones n=160
Bollgard II												
Insecticide	2.35	4.37	1.07	3.03	2.41	8.93	6.49	6.55	9.96	12.40	9.14	5.42
Seed cost	63.83	60.57	66.33	62.74	74.82	76.66	75.97	43.10	53.53	78.57	47.99	62.36
Labor	151.64	138.79	135.48	146.3	147.43	157.35	153.63	133.6	131.01	137.73	132.0	143.75
Fert & herb	178.12	165.72	155.92	173.6	198.21	157.26	172.62	161.4	166.22	134.73	164.8	168.29
Total cost	395.94	369.45	358.80	385.8	422.87	400.20	408.70	344.7	360.72	363.43	354.0	379.83
Conventional cotton												
Insecticide	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00
Seed cost	8.88	8.88	8.88	8.88	8.88	8.88	8.88	8.88	8.88	8.88	8.88	8.88
Labor	148.52	146.92	136.25	143.8	146.92	153.69	154.07	137.0	127.50	114.49	126.3	142.04
Fert & herb	178.12	165.72	155.92	173.6	198.21	157.26	187.97	161.4	134.73	166.22	164.8	168.29
Total cost	393.51	379.52	359.05	384.4	412.00	377.83	408.92	365.4	316.10	360.60	358.0	377.21
Cost comparison: Bollgard II – Conventional cotton												
BGII - Conv.	2.43	-10.07	-0.25	1.40	10.87	22.37	-0.22	-20.6	47.33	0.12	-4.00	2.62

a Cotton production zone refers to the areas of operation of the three national cotton companies: SOFITEX, SOCOMA, and Faso Cotton.

b Farm types are defined as follows: Large are farms with 2 or more animals for assistance in field operations, Small are farms with 1 animal for assistance in field operations, and Man. are farms where everything is done manually (no assistance of animals).

Economic Benefits

The ANOVA model provided a good fit to the observed economic data with an R^2 of 0.501 (Table 2). Five out of the nine factors were highly significant (P<0.01), and only factor *TYPE* was not significant (P=0.8319) in the model (Table 2). Cotton incomes were significantly higher for producers who grew BGII (Table 4). Compared to conventional cotton, BGII increased cotton income by an average of $61.88 per ha compared to conventional cotton (Table 6). Among the surveyed producers, BGII had a substantial effect by enabling them to earn a positive return of $39.00 per ha rather than the negative return of -$22.89 per ha generated by conventional cotton.[2] In relative terms, BGII's economic impact in 2009 corresponded to more than a doubling of the income that would have been earned by conventional cotton, a 270% increase in cotton income[3] (Table 4). For an average household with 3.2 ha of cotton, BGII would increase farm income by $124.79, which would have a substantial impact on household income. The INERA surveys found an average household cash income of $655, which increased by an average of 19.1% from the introduction of BGII among surveyed households.

Production costs had no significant effect (P>0.10) on cotton income since costs were found to be nearly identical between BGII and conventional cotton (Table 5). Bollgard II cotton had an average production cost of $379.83 per ha, which was $2.62 per ha higher than the production cost of conventional cotton, $377.21, but the difference was not significant (P>0.10). This is an important finding since critics of biotechnology some-

2. *The negative return of $33.50 per ha with conventional cotton reflects valuing the opportunity cost of household labor at $1.67 per day (750 Fcfa per day). The negative return does not imply that households growing conventional cotton incurred a financial loss, since household labor is not always paid in cash. Rather, the head of the household compensates family members with in-kind gifts (food, clothes, shelter, etc.) for their labor and often labor is considered obligatory. The negative return indicates that the returns to labor from conventional cotton is less than the $1.66 per day wage rate used in the economic analysis shown in Table 3.*
3. *The percent increase in cotton income was calculated using the following formula: % Diff = 100*(I_{BG} – I_{conv})/I_{conv} , where I_{BG} is the cotton income from Bollgard II and I_{conv} is the income from conventional cotton. Since I_{conv} is negative, we report the absolute value of the percent increase in cotton income.*

Table 6. Cotton income comparison between Bollgard II and conventional cotton.

	Cotton production zone [a]											
	SOFITEX (n=80)				SOCOMA (n=40)			Faso Coton (n=40)				All
Item ($ ha^{-1})	Large[b] n=48	Small n=29	Man. n=3	Ave n=80	Large n=15	Small n=25	Ave n=40	Large n=11	Small n=27	Man. n=2	Ave n=40	zones n=160
	Bollgard II											
Revenue	462.22	376.53	354.49	427.12	438.76	504.89	480.09	351.29	333.87	378.67	340.98	418.83
Prod cost	395.94	369.45	358.80	385.82	422.87	400.20	408.70	344.77	360.72	363.43	354.09	379.83
Cott. income	66.28	7.08	-4.31	41.30	15.89	104.69	71.39	6.52	-26.85	15.24	-13.11	39.00
	Conventional cotton											
Revenue	397.51	386.84	315.73	366.58	386.84	432.00	434.53	321.07	257.42	170.67	249.60	354.32
Prod cost	393.51	379.52	359.05	384.42	412.00	377.83	408.92	365.42	360.60	316.10	358.09	377.21
Cott. income	4.00	7.33	-43.32	-17.84	-25.16	54.17	25.61	-44.36	-103.1	-145.4	-108.4	-22.89
	Cotton income comparison: Bollgard II – Conventional cotton											
Δ income	62.28	-0.24	39.00	59.14	41.04	50.52	45.77	50.88	76.33	160.67	95.38	61.88

[a] Cotton production zone refers to the areas of operation of the three national cotton companies: SOFITEX, SOCOMA, and Faso Cotton.

[b] Farm types are defined as follows: Large are farms with 2 or more animals for assistance in field operations, Small are farms with 1 animal for assistance in field operations, and Man. are farms where everything is done manually (no assistance of animals).

times argue that seed costs for Bt crops are extreme. In this case, we find that although Bt seed is significantly more expensive than its conventional counterpart ($62.36 per ha *vs.* $8.88 per ha), the cost is offset by the savings on insecticide input costs of $52.58 per ha (Table 5). Hence, BGII is able to recoup its cost through an equivalent savings in insecticide and conventional seed costs. When the additional yield realized in BGII is considered, the Bt seed cost is a better investment than the purchase of additional insecticide sprays and conventional cotton. Likewise, labor costs also had components that both increased and decreased cotton production costs. Fewer insecticide sprayings reduced labor costs, but the higher yields obtained by growing BGII resulted in higher harvest costs and no significant reduction in labor costs. While labor cost savings are often cited in the biotechnology adoption literature, they have been reported primarily in the developed-country context, where opportunity cost of operator time and machinery running costs are greater. For instance, in South Africa, both Kirsten and Gouse (2003) and Shankar and Thirtle (2005) report no significant labor cost savings from Bt cotton due to higher harvest costs that offset the effects of reduced labor in pesticide application.

The ANOVA model of economic returns found *ZONE* as a significant factor (P<0.01), with the highest returns in SOCOMA, where BGII earned an average of $71.39 per ha (Table 6). In the SOFITEX zone, economic returns averaged $41.30 per ha for BGII, which were $59.14 per ha greater than conventional cotton's return of $-17.84 per ha (Table 6). Faso Coton was the only zone that had a negative return for BGII, -$13.11 per ha. There was no significant difference (P>0.10) in economic returns among farm types, although the interaction term *ZONE* × *TYPE* was significant (Table 2). The broader lack of significance of farm size as a source of variation is an expected finding and is consistent with results from South Africa, where large-scale (mechanized) farms benefitted in the same proportion as smallholder farmers, although they benefitted in different ways (Gouse et al., 2003; Ismael et al., 2002). Large-scale producers benefitted primarily from labor and operating cost savings (fuel), whereas smallholder producers in South Africa benefitted more from yield advantage.

Production costs in SOCOMA were calculated as the highest among the three zones—$408.70 per ha for BGII and $408.92 per ha for conventional cotton—but the difference in production costs among the zones was not significant (P>0.10; Table 5). Likewise, although the large farms had the highest production costs on average within each production zone, there were no significant difference among farm types (P>0.10). The household surveys also found no significant differences (P>0.10) in fertilizer or herbicide costs (Table 5). Those production costs are similar since producers generally adhere to the recommended fertilizer and crop management practices established by the Burkina Faso cotton companies.

The economic benefits of BGII can be illustrated in other ways as well. The average cost of producing a pound of cotton lint was significantly lower with BGII than conventional cotton. According to the survey, producers growing BGII had an average cost of $0.338 per kg of seedcotton—$0.115 less per kg (17%) than the conventional cotton production cost of $0.453 per kg. Returns to labor were also substantially higher with BGII than conventional cotton. In Burkina Faso, where cotton production is labor intensive, households allocate approximately 58 days of labor to each hectare of cotton produced, according to our household surveys. Households planting BGII were found to have average returns to labor of $3.00 per day—62% higher than conventional cotton producers, whose labor returned an average of $1.84 per day.

Discussion and Implications

The 18.2% BGII yield advantage is consistent with the findings of the broad Burkina Faso field trials conducted in 2007, where yield advantages from BGII averaged around 20% (Hemi et al., 2008). The results of the 2009 field survey indicate that Burkina Faso producers, on average, would obtain yield advantages consistent with those reported in previous studies from different parts of the developing world (Elberhi & MacDonald, 2004). Two previous studies found similar Bt cotton yield increases among smallholders; these include Ismael et al. (2002), who report an average yield increase of 18% from a survey of South African smallholder farmers, and a Chinese study by Huang, Hu, Fan, Pray, and Rozelle (2002), who report a 15% increase in cotton yields. These are similar to the values seen herein for the SOFITEX and SOCOMA cotton zones, which were found to have yield increases of 16.5% and 14.3% (Table 3). Higher yield increases from Bt cotton have also been reported. In India, where results have been mixed, Qaim (2003) reports yield increases of 58% and Qaim and De Janvry (2005) cite yield increases of up to 42% among smallholder farmers in Argentina. These previously reported higher yields are close to those reported herein for the Faso Coton zone (36.6%; Table 3). Several studies found significantly lower yield advantages from Bt than the ones reported in this article. In the United States, Marra (2001) found only a 3-5% increase in US cotton yields, and elsewhere no significant yield increases have been reported, including in South Africa (Gouse et al., 2003) and India (Orphal, 2005). In Burkina Faso, pest pressure is greater, and existing pest-control strategies are less effective than in the United States.

The positive economic returns found in this study also compare favorably with findings from previous studies. Ismael et al. (2002) reported returns of 11% and 77% on gross margins among smallholder producers in South Africa in two successive growing seasons, 1998/99 and 1999/2000. They also explained the higher returns from Bt cotton as a combination of higher cotton yields and lower pesticide costs that offset increased seed costs, as found in this study. In a more recent study in South Africa, Bennett, Morse, and Ismael (2006) also reported positive economic returns from growing Bt cotton among smallholder producers. In China, the study by Huang et al. (2002) found—based on the first year of Bt cotton use (1999)—that adopters earned a positive net income, whereas non-adopters had negative net incomes. Likewise, the findings of Huang, Hu, Pray, Qiao, and Rozelle (2003) are similar to the results reported in this article, showing that Bt cotton enabled producers to earn a positive net income. In India results have been mixed, but higher returns from Bt cotton have been reported. Perhaps the most substantial studies were those by Bennett, Ismael, Kambhampati, and Morse (2004) and Morse et al. (2005), which were based on a large survey of 9,000 India cotton producers. While both studies found higher returns on Bt cotton plots, results varied significantly from one year to the other and among subregions. This study also found significant variation in Bt cotton performance across production zones, and future surveys will need to be conducted to assess Bt cotton performance over time.

Late Season Sprays. The findings suggest that yield comparisons between BGII and conventional cotton based on the average number of pest sprays understate and bias the potential impacts that could be achieved when producers follow the recommended pest sprayings. The results also have significance for cotton producers who, according to the ANOVA results, would stand to lose income from not spraying for late-season pests. If SOFITEX producers had followed the recommended spray regimen, not only would yield advantages have been significantly higher (as discussed above), but cotton income would have been $97.52 per ha higher than the average income and $171.89 per ha higher than producers who did not spray at all (Table 4).

The results highlight the need for national extension services to work with the cotton companies and the seed companies to provide information to producers on how Bt cotton affects their pest management. While future survey work will seek to determine why producers did not spray for late-season pests, there are two lines of reasoning that can potentially explain the lack of late-season sprays. One is that producers had false expectations of BGII, believing it capable of controlling late-season pests. This is plausible since BGII is a high-technology product that is unlikely to be fully understood by smallholder producers, which could lead to overly optimistic expectations of performance. A second reason is that producers may have found an alternative use for the late-season sprays, applying them on other crops such as maize or vegetable crops.[4] In this case, further analysis would be required to determine whether the alternative use of insecticide on other crops would be more profitable than using it on cotton.

Benefit Distribution

National-level impact of BGII adoption would reach upwards of $30.94 million per year based on an 80% adoption (500,000 ha) and an extrapolation of the $61.88 per ha increase in cotton income (Table 6) throughout each cotton growing zone. Producers would capture a slightly larger share of the benefits than the seed industry, which would obtain increased revenue of $31.18 million per year from BGII sales based on a seed price of $62.36 per ha (Table 5). With this benefit sharing, 53.0% of the economic impact would remain on-farm. Additional benefits would be captured by the three Burkina Faso cotton companies from increased cotton processing and marketing opportunities. Estimates of how the three Burkina Faso cotton companies would benefit are not currently available.

Discussion and Implications

External factors also can affect the adoption and returns from Bt cotton. One of the distinguishing features of the Burkina Faso cotton industry is the vertical integration in the input and output supply chains. While international donors have pushed for liberalization and the shift from parastatal to private ownership to improve efficiency, the vertical control of the Burkina Faso cotton industry by the cotton companies appears to make it better suited to introduce Bt cotton than a privately owned sector. In the case of Burkina Faso, the technology provider was able to introduce Bt seed through existing input channels in each of the three cotton companies that directly connected to the vast network of smallholder producers. This reasoning is consistent with Gouse et al. (2003), who proposed that in South Africa the adoption of Bt cotton was stronger and more sustainable in situations where a single cotton company provided inputs to producers and was the sole buyer of cotton. In contrast, the adoption of Bt cotton broke down when producers defaulted on loans to the Vunisa Cotton Company and sold their cotton to a rival gin. Smale, Zambrano, and Cartel (2006) pointed out that the strong government control over the cotton sector in China may also be a contributing factor to the success that China has had in commercializing Bt cotton.

Burkina Faso is taking shape as a working example of how a business model can be successfully implemented in an industry heavily influenced by the public sector, wherein credit is provided for seed, and in return, producers are obligated to buy their seed and inputs from and sell their cotton to a single entity. In Burkina Faso, recent reform has granted more power to UNPCB. Cotton prices are now negotiated prior to planting and producers have had success in obtaining a greater share of the world price. UNPCB also has the same type of bargaining power in negotiating the price of BGII as explained above. Moreover, the legal framework has been greatly streamlined in the Burkina Faso cotton industry since contracting and legal responsibility has been achieved through the national cotton companies and Monsanto. This bypasses the need to develop individual contracts with smallholder producers, which would be a daunting task in Burkina Faso given the large number of cotton producers—more than 300,000.

Conclusion

Based on the empirical evidence collected for this study, BGII outperformed conventional cotton in its first year of commercial release in Burkina Faso. Producer surveys of 160 Burkina Faso households found that BGII increased cotton yields by 18.2% over conventional cotton, which reached as high as 36.6% in one of the cotton production zones. Since the higher seed costs from adopting BGII were offset by equivalent savings in insecticide costs, producers were able to capture virtually all of the yield increase in their bottom line. Boll-

4. *Insecticides are provided on credit and distributed by the cotton companies to producers but are supplied only in proportion to the cotton area. This rationing provides a potential incentive to divert inputs, such as insecticides, from cotton to other crops.*

gard II increased cotton income by $61.88 per ha compared to conventional cotton. Both yield and economic performance were hindered in the SOFITEX production zone by producers who did not perform the recommended two late-season sprayings targeting secondary pests. For producers who followed the recommended late season sprayings, cotton income increased by $138.83 per ha over conventional cotton.

Continued monitoring will be required to determine the technical and economic viability of Bt cotton over the short and long term. Experience from other parts of the world suggest that benefits can change significantly from one year to another due to differences in weather, pest density, and economic conditions. The government of Burkina Faso requires an annual assessment of the technical and socioeconomic outcomes of BGII and is recommended that this policy continue. Such monitoring should include not only the types of outcomes included in this study, but also farmer compliance with biosfety protocols (e.g., refugia) and environmental impacts. Since the buildup of pest resistance and secondary pest pressure is a potential problem, monitoring efforts will also need to focus on these issues.

The Burkina Faso experience may serve as a watershed event in biotechnology in Africa, potentially opening the door to many exciting opportunities. The next 3-5 years is likely to have a large effect of the long-term viability of biotechnology in SSA. The Burkina Faso story is emerging as a working model of how biotechnology can be successfully introduced in Africa. If it continues to be successful, Burkina Faso's experience will show that biotechnology can overcome challenges in legal frameworks, technocratic bureaucracy, and can be supported and sustained by business models that link the private sector to small- and medium-sized producers in developing countries. In Burkina Faso, the demand for Bt cotton is driven by the high lepidoptera pest densities and the growing cost of conventional pest-control methods, and cotton export markets that strengthen producers' willingness to pay for Bt products. Other cotton-producing countries in the region, such as Mali and Benin, would likely benefit as much as Burkina Faso and could be next in line to introduce Bt cotton once legal frameworks are established.

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