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Impact of Bt cotton adoption on pesticide use by smallholders: A 2-year survey in Makhatini Flats (South Africa)

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Abstract

This paper explores insecticide use in fields cropped with conventional or Bt cotton varieties in a smallholder farming area (Makhathini Flats, KwaZulu Natal, South Africa). The study was carried out during the 2002–2003 and 2003–2004 growing seasons as part of a broader survey based on daily monitoring of a sample of smallholdings. The adoption of Bt cotton led to a decrease in pyrethroid use, but the level of insect resistance of this cultivar was not sufficient to completely drop this pesticide from the spraying programme. On the other hand, organophosphates were still being applied in substantial amounts, thus raising questions as to the impact of Bt cotton adoption on farmers' health. The overall economic results obtained with Bt cotton were slightly positive despite the low cotton yields obtained in the Flats during our survey. Bt cotton adoption did lead to labour savings, but the extent of this gain was not as high as expected. In conclusion, cropping Bt cotton in Makhathini Flats did not generate sufficient income to expect a tangible and sustainable socioeconomic improvement due to the way the crop is currently managed. Adoption of an innovation like Bt cotton seems to pay only in an agro-system with a sufficient level of intensification.

Keywords: Bt cotton; Insecticide use; Safety; Cost-effectiveness; Integrated crop management; Small-scale farming; South Africa

1. Introduction

Many papers have been published on the benefits of GM crops in experimental plots or on large-scale farms. Several authors (Fernandez-Cornejo and Klotz-Ingram, 1998; Gianessi and Carpenter, 1999) acknowledge that Bt cotton, genetically engineered for bollworm resistance (Perlack et al., 1990), improves farmers' revenue and reduces labour in the United States. Similar effects have been observed under small-scale farming conditions in China and especially in India (Pray et al., 2002; Quaim and Zilberman, 2003; Morse et al., 2004). Among the very few reports informing about farmers' practices in small-scale GM cropping systems in Africa, Kirsten et al. (2002) as well as Thirtle et al. (2003) concluded, after a 2-year survey in Makhathini Flats (KwaZulu Natal, South Africa), that Bt cotton had a positive impact on farmers' revenue due to increased yields and lower insecticide costs. Nevertheless, the fact that neither cotton production nor the number of cotton farmers increased these recent years in the Makhathini Flats could indicate some limitations of the impact of introducing Bt cotton in such a farming system. Climatic conditions and purchasing price of seed cotton could explain, at least partly, this situation. The study we implemented targets at clarifying what might be the limitations encountered by small cotton farmers in the area of pest management. This study is particular in consisting in a combination of on-farm survey and on-field follow-up of the pest management practices both in Bt and conventional cotton plots during two seasons. In this paper, we report the results related to the farmers' practices for cotton pest control and to the extent of the benefit deriving from using Bt-cotton.

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2. The survey

2.1. Cotton farming in Makhatini Flats

The survey was conducted in Makhathini Flats (Kwa-Zulu Natal, South Africa). Makhathini Flats host most of the small-scale cotton farming community in South Africa (Kirsten et al., 2002). This coastal plain benefits from a hot climate (mean max. T: 30.5 °C, mean min. T: 19.8 °C), with 550 mm mean annual rainfall. This area would be ideally suited for cotton production if the rains were less erratic and inter-annual variations were not as marked. Cotton is produced in areas with fertile sandy-clay soils. Cotton fields range from 1 to 10 ha in size and crops are mostly grown under rainfed conditions. Most farmers in this area do not use fertilizers. The number of cotton farmers varies from year to year, depending on the extent and frequency of early rains as well as farmers' access to financial credit (Fig. 1). Under these conditions, area under cotton and yields are erratic: the cotton cropping area ranges from 1000 to 10 000 ha, with a relatively low mean crop yield during the last 10 years (Fig. 2). In 2002–2003, rainfall ranged from 225 to 350 mm at the different field sites, far below the mean, unlike the next season when rainfall exceeded the mean with a total of 801 mm, mainly concentrated within four consecutive months (766 mm from January to April).

2.2. Data collection and analysis

For this survey, 10 farmers growing Bt cotton and 10 growing non-Bt cotton, were sampled at random in the same production area (i.e. within a 10 km radius) for two consecutive growing seasons (2002–2003 and 2003–2004). All farmers had at least seven years of cotton cropping experience. In order to avoid bias due to cultivar performance, we only considered the two near-isogenic cultivars: Bt Nuopal and non-Bt Delta Opal, while farmers growing the Bt cultivar NuCotn 37B were excluded from the sample.

Pest management practices were followed daily from plant emergence until harvest on each farm. Labour input for insecticide spraying and pest control-related tasks were recorded (e.g. date, area treated, duration of spraying and

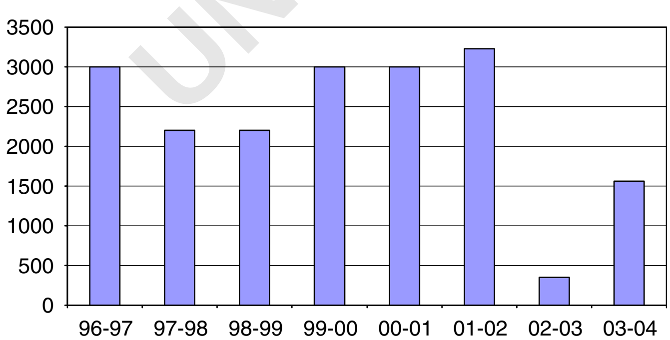

Fig. 1. Variations in cotton farmer numbers in Makhathini Flats.

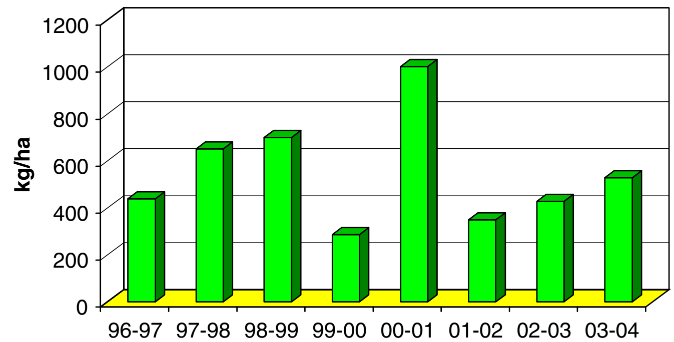

Fig. 2. Yield (seed-cotton) obtained by smallholders in Makhathini Flats from 1997 to 2004. *Source*: Cotton SA.

number of workers involved). Spraying frequency as well as dosage of insecticide used were recorded. A Student's t-test for independent samples was applied to each dataset at $\alpha = 0.05$ probability level.

2.3. Limits of the survey

Two years of data is too short, especially with only a small number of farms and such a contrast in climatic conditions between first and second year, to achieve reliable conclusions. Data for the two years is thus presented separately. The samples differed somewhat between years with only 90% of the Bt farmers and 80% of the non-Bt farmers followed during the first year could be retained for the second year survey. Despite these minor differences, we decided to compare data between years under the assumption that climatic factors have more influence on insecticide management than farmers' individual practices.

3. Results

No significant difference has been established between Bt and non-Bt cotton yields (respectively, 760 ± 301 kg/ha and 671 ± 209 kg/ha of seed cotton), due to high between-farm variability (Table 1).

3.1. Pest management practices

The decision to spray should be set up on the basis of insect scouting (Tunstall et al., 1962; Silvie et al., 2001). However, with a poor extension network, the practices often differ on smallholdings where farmers generally implement more haphazard methods. The introduction of Bt cotton as an "insect resistant" cotton has increased confusion amongst farmers as they might incline to believe that they no longer needed to use insecticides with such a cultivar.

The organophosphate monocrotophos and pyrethroid cypermethrin were used. Some farmer also occasionally sprayed deltamethrin. Makhathini Flats farmers do not use

Table 1
Yields frequencies among Bt and non-Bt farmers in Makhathini during both seasons 2002–2003 and 2003–2004 (sample of 20 farmers)

Yield rank (kg of seed cotton)	2002–2003		2003–2004	
	Bt farmers	Non-Bt farmers	Bt farmers	Non-Bt farmers
300–500	2	1	1	0
501–700	3	7	3	7
701–900	3	1	3	1
901–1300	2	1	3	2

Table 2
Inter-annual comparison of insecticide use in Bt and non-Bt cotton fields

Season	Bt					Non-Bt				
	Spray numbers			Total amount (ml/ha)		Spray numbers			Total amount (ml/ha)	
	Total	OP	Py	OP	Py	Total	OP	Py	OP	Py
2002–2003	2.3±0.9	2.3±0.9	0	2140±849		2.9±0.3	2.5±0.9	2.1±0.7	1405±522	430±178
2003–2004	3.5±1.2	3.0±1.2	0.5	2995±1240	265	6.7±2.2	5.4±1.5	3.4±1.9	3471±2298	978±940
Difference	*	ns	—	ns	—	***	***	ns	*	ns

$n = 20$, df = 18.
Total amount: cumulated volume of product used within a season.
OP: organophosphates; Py: pyrethroids; ns: non-significant; *significant at $P \leqslant 0.05$; ***significant at $P \leqslant 0.001$.

Table 3
Insect control: number of applications, dosage and amount of insecticide used

	Season 2002–2003							Season 2003–2004						
	Spray number			Dosage (ml/ha)		Total amount (ml/ha)		Spray number			Dosage (ml/ha)		Total amount (ml/ha)	
	Total	OP	Py	OP	Py	OP	Py	Total	OP	Py	OP	Py	OP	Py
Bt	2.3	2.3	0	935	0	2140	0	3.5	3.0	0.5	1000	265	2995	265
Non-Bt	2.9	2.5	2.1	575	205	1405	430	6.7	5.4	3.4	603	233	3471	978
SD Bt	1.0	1.0	0	116	0	523	0	1.2	1.2	0.5	24	401	1240	401
SD non-Bt	0.3	0.9	0.7	142	35	849	178	2.2	1.5	1.9	307	143	2298	940
Sig.	ns	ns	—	***	—	*	—	***	***	***	***	ns	ns	*

$n = 20$, df = 18.
OP: organophosphates; Py: pyrethroids; dosage: volume of product mixed in 200 l of water used for 1 ha; total amount: cumulated volume of product used within a season; ns: non-significant; *significant at $P \leqslant 0.05$; ***significant at $P \leqslant 0.001$.

endosulfan or thiamethoxam because they are too expensive (Broodryk et al., 2003).

Cotton farmers usually combined insecticides of different classes in a single spray, but those who had adopted Bt cotton used each insecticide separately, pyrethroids being used quite marginally or for a specific purpose. The number of sprays varied according to climatic conditions (year), cotton cultivar and class of insecticide. During the 2003–2004 cropping season, the number of insecticide applications increased significantly compared with the previous season (Table 2): organophosphate treatments increased in non-Bt cotton. In dry conditions, Bt and non-Bt cotton farmers applied a similar number of sprays (Table 3), although Bt farmers did not apply pyrethroids. In 2003–2004, Bt-cotton farmers applied significantly fewer sprays than non-Bt farmers, but half of them had to undertake one pyrethroid spray to control a late *Helicoverpa armigera* infestation.

3.2. Insecticide use

Non-Bt cotton was sprayed more, mainly against aphids and bollworms (Table 4), but Bt cotton farmers used significantly higher doses (+60% OP dosage) than non-Bt cotton farmers. Bt cotton did result in a significant decrease in pyrethroid use.

Dosage of insecticide remained relatively stable between cropping seasons, with an average of 8.8 knapsack loads per hectare applied for both cultivars. There were no significant differences between means (Bt = 8.7 ± 0.260,

Table 4
Number of sprays targeting specific pests during the 2003–2004 cropping season

Cultivar	*Aphididae*	*Typhlocybinae*	*H. armigera*	*Dysdercus* sp.	*Acrididae*
Bt	2.1 ± 0.9	1.3 ± 1.1	0.5 ± 0.5	0.1 ± 0.3	0.6 ± 0.7
Non-Bt	4.0 ± 1.3	1.0 ± 0.8	3.0 ± 1.5	0.7 ± 1.1	1.4 ± 0.7
Significance	**	ns	***	ns	*

ns: non-significant.; *significant at $P \leqslant 0.05$; **significant at $P \leqslant 0.01$; ***significant at $P \leqslant 0.001$.

Table 5
Bt license fees and mean prices of insecticides in the Makhathini Flats

Product	Price unit	2002–2003	2003–2004
Bt (license)	ZAR/25 kg seed bags	350.0	350.0
Pyrethroids (Polytrin)	ZAR/l	100.0	125.0
OP (Monostem)	ZAR/l	88.8	122.0
Seed-cotton	ZAR/kg	4.0	3.1

(1) 1 South African Rand (ZAR) = 0.1540 USD.

Table 6
Calculation of the differential profit for a 1 ha Bt field (in South African Rands)

Cost and income	2002–2003		2003–2004	
	Bt cotton	Non-Bt cotton	Bt cotton	Non-Bt cotton
(A) License fee(2)	186.2	0.0	186.2	0.0
(B) Pyrethroid cost	0.0	43.0	33.1	122.3
(C) OP cost(3)	190.0	124.8	365.4	423.5
Protection cost (A + B + C)	**376.2** ± 23.8 **a**	**167.8** ± 18.3 **b**	584.7 ± 43.0	545.8 ± 118.8
Yield income(4)	2932.0 ± 369.2	2516.0 ± 177.8	2442.8 ± 237.6	2213.4 ± 193.4
(D)Protection differential	+ 208.4 ± 32.1		+ 39.0 ± 116.8	
(E) Income differential	+ 420.0 ± 446.8		+ 226.3 ± 320.8	
Bt profit margin (E−D)	+ 211.5 ± 351.6		+ 187.3 ± 350.5	

Significant difference among treatments for $\alpha = 0.05$ is noted by different letters (a,b).
(1): 1 South African Rand (ZAR) = 0.1540 USD;
(2): Bt license fee calculated on the basis of 13.3 kg/ha of planted seeds;
(3): Insecticide costs were calculated from Tables 3 and 5;
(4): Yield income was calculated from Tables 1 and 5.

non-Bt = 8.9 ± 0.233, $t = -0.572$). As the knapsacks were not completely filled, we assumed that an average of 165–170 l/ha was sprayed.

3.3. *Cost-effectiveness of Bt cotton management versus conventional insect control*

Insecticide prices are substantially higher in Makhathini Flats than in other parts of the province (Table 5). Assuming that agricultural practices did not markedly differ for Bt cotton and non-Bt cotton, except for pest control and insecticide management, we estimated the comparative cost-effectiveness of Bt cotton through pest control, excluding other production costs (Table 6). The effect of the better yields obtained during a more favourable year was thus offset by the unfavourable price trends!

4. Discussion and conclusion

The impact of Bt cotton will vary between years, due to effects of climate, pest pressure, input costs and output price. Adoption of Bt cotton reduced chemical inputs as proportion of production costs but did not alter overall pest control costs. In particular relatively high quantities of organophosphates were still required in Bt cotton to control pests (aphids, jassids, thrips and true bugs) not affected by the Bt toxin. In China a reduction in pesticide use for bollworm (*H. armigera*) control could increase populations of sucking insects (Men et al., 2005). More money was invested in insect management for Bt cotton than for non-Bt cotton crops, probably because farmers feeling being more secure against bollworm damage upgraded their seed-cotton yield objectives and adjusted their investment accordingly. Under Bt cotton cropping conditions, the decline in pyrethroid use, was similar to that reported by Udikeri et al. (2003), but was less than savings of 7.4 sprays per season reported in a previous survey conducted in the same area (Bennett et al., 2002). Bt cotton generally did not enable farmers to implement a cleaner and less hazardous pest management as a reduction of two sprays will only slightly improve the ecosystem health and diminish the probability of poisoning, especially with continued OP use (Brown, 2000; Phipps and Park, 2002; Shelton et al., 2002). In our financial assessment, and contrary to some studies (Thirtle et al., 2003; Bennett et al., 2002), the Bt cotton license fee was an additional pest management cost. Kirsten et al. (2002) did recognize that the advantage of applying less insecticide is erased when the cost of Bt technology is taken into account. In this study specific to Makhatini Flats, pest management costs were slightly higher for Bt cotton but the investment return was slightly superior. The number of sprays was not sufficiently reduced and the yield was usually too low to offset the Bt technology fees. Despite positive returns in favour of Bt cotton, farmers' mean net revenues were still low, and could be improved by rational agricultural practices such as fertilization and weed control. Makhathini Flats farming systems are characterized by recurrent low crop yields and broad variations due to climatic and environmental factors. In this setting, the adoption of Bt cotton increases the financial risk for farmers. It could be misguiding to focus on the impact of Bt cotton without considering the entire range of technical inputs and interactions of these factors with transgenic technology. Farmers could enhance their income through the combination of insect resistance conferred by Bt technology and integrated crop management practices, but this is not yet the case in Makhathini Flats.

5. Uncited reference

A.R.C., 1996.

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