Can Genetically-Modified Cotton Contribute to Sustainable Development in Africa?

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ABSTRACT

Genetically modified (GM) crops and sustainable development remain the foci of much media attention, especially given current concerns about a global food crisis. However, whilst the latter is embraced with enthusiasm by almost all groups GM crops generate very mixed views. Some countries have welcomed GM, but others, notably those in Europe, adopt a cautious stance. This paper aims to review the contribution that GM crops can make to agricultural sustainability in the developing world. Following brief reviews of both issues and their linkages, notably the pros and cons of GM cotton as a contributory factor in sustainability, a number of case studies from resource-poor cotton farmers in Makhathini Flats, South Africa, is presented for a six year period. Data on expenditure, productivity and income indicate that Bt cotton is advantageous because it reduces costs, e.g. of pesticides, and increases income, and the indications are that those benefits continued over at least the six years cover by the studies. There are repercussions of the additional income in the households; debts are reduced and money is invested in children's education and in the farms. However, in the general GM debate, the results show that GM crops are not miracle products which alleviate poverty at a stroke, but nor is there evidence that they will cause the scale of environmental damage associated with indiscriminate pesticide use. Indeed for some GM antagonists, perhaps even the majority, such debates are irrelevant; the transfer of genes between species is unnatural and unethical. For them GM crops will never be acceptable despite pressure to increase world food production.

Keywords: Bt cotton, genetic modification, pesticides, sustainable development, South Africa

INTRODUCTION

The concept of sustainable development and issues surrounding the genetic modification (GM) of organisms, especially those for agriculture, have generated much interest in the popular and academic media in recent years (Charles, 2001; Chrispeels, 2003; Curtis, 2004; Mannion, 2007; Pringle, 2003; Pua and Davey 2007; Sanderson, 2007; Slater *et al*, 2007; Thomson, 2006). Sustainable development is “*Development that meets the needs of the present without compromising the ability of future generations to meet their own needs*” (WCED, 1987), and requires that actions to improve the quality of life should not be at the expense of future generations and neither should there be an increase in inequality within the present generation. Sustainable development has been widely embraced, and if there is a controversial aspect it relates to achievement and the ‘trade offs’ which can occur (Dresner, 2008; Bell and Morse, 2008; Purvis and Grainger, 2004; Rogers *et al* 2007). Some argue that the environment cannot be compromised, while less stringent approaches accept that a certain degree of environmental degradation is inevitable as a price to pay for economic growth.

By way of contrast, the use of GM technology in agriculture has met with opinions polarised between vehement opposition and enthusiastic acceptance. Some claimed advantages and disadvantages for GM are summarised in Figure 1. The backdrop to

the debate is the unavoidable fact that world population is increasing by c.81 million people per year and is set to increase from the current 6.6 billion to at least 9 billion by 2050 (various estimates are reviewed by O'Neil and Balk for the Population Reference Bureau, 2001; see also Department of Economic and Social Affairs, 2007). This increase plus enhanced demands for meat and meat products is already intensifying pressure on existing agricultural systems and provides impetus to create agricultural land from natural ecosystems, especially in the tropics and sub-tropics. Neither prospect is welcome and adequate food production in ensuing years will be a challenge; sustainable food production will be an even greater challenge. A further important element in this debate, especially in the context of global warming, is the maintenance of carbon storage in forest, savanna and grassland ecosystems, and their protection against further destruction because of their vital role in biogeochemical cycling and carbon storage (Mannion, 2002, 2007).

<Figure 1 near here>

In 2006 22 countries grew biotech crops, comprising 11 developing countries and 11 industrial countries (Table 1). The relative lack of adoption in Europe is noteworthy and is primarily due to a strong anti-GM lobby. Yet the capacity to enhance beneficial traits which can be transmitted to the progeny appears at first glance to be ideal for sustainability. For example, yields (i.e. amount of product harvested per area of land) can be substantially reduced by insects and diseases. Farmers may have little choice but to limit this damage by using pesticides, and for small farmers in the tropics this typically involves the use of knapsack sprayers and no protective clothing. Consequently, farmers not only have to absorb the economic costs of spraying but

they also have to cope with the damage that pesticides can cause to their own health and that of their families as well as the environment. Genes which confer inherent resistance to pests or diseases would effectively diminish or even eliminate the need for pesticides. GM offers a real possibility of improved productivity on land already cultivated, thereby reducing the need for the conversion of natural ecosystems to agriculture.

<Table 1 near here>

However, multinational GM seed producing companies have a monopoly over seeds via patents and thus control prices. Other concerns include the role of the state in the regulation of GM crops and the control of GM seed, and problems of technology transfer between developed and developing nations and how such exchange should be financed. Far from encouraging sustainable development GM could exacerbate the gap between those who have and those who have not. Indeed GM crops have the potential to cause further loss of natural ecosystems just as they might contribute to conservation (Mannion, 1998, 2006).

GM crops have been cultivated since 1996 and new developments are rapidly occurring. Given that GM companies are primarily in business for profit, their main focus is the richer markets. However, it can be difficult to determine the benefits for resource-poor subsistence farmers in the global South. This is a grey area of the GM debate for which there is growing but still limited evidence. This paper will address this question by reviewing the economic impact of a specific GM technology, insect resistance in cotton, in the developing world. The paper reviews the evidence to date,

and provides specific examples within the context of sustainability for resource-poor cotton farmers in the Republic of South Africa; the first African country with commercial release of GM crops. Although the case study involved only one form of GM trait it provides valuable insights into the impact of a GM crop for resource-limited farmers.

GENETIC MODIFICATION

GM can be employed in a variety of fields, but arguably the greatest advances have been made in agriculture (Heaf, 2005; Singh and Jauhar, 2006; Monsanto, 2001). Research has focussed on the identification of genes and gene components which control various characteristics such as drought tolerance, flavour, colour, resistance to pests etc (Slater *et al*, 2007). Foreign genes or their components, may be introduced into crop plants from related or entirely different species. It is also possible to introduce more than one GM characteristic. Such crops are described as having stacked genes (Syngenta, 2007). Examples include GM crops having both engineered herbicide and insect resistance. The financial value of GM crops is considerable. According to James (2006) the total value for all GM crops in 2006 was \$6.15 billion or 16 % of the global crop protection market and 21% of the global commercial seed market. Of the \$6.15 billion, GM cotton accounted for \$0.87 million or 14%. Three examples of GM-derived characteristics important today are herbicide resistance, insect resistance and nutritional enhancement.

Herbicide resistance has been engineered by introducing genes which confer the ability to degrade specific herbicides. Two groups of crops are available: *Roundup Ready* crops which can degrade the broad-spectrum herbicide glyphosate and *Liberty Link* crops which can degrade glufosinate. The former group carry the gene coding for a glyphosate-insensitive form of the enzyme 5-enolpyruvylshikimate 3-phosphate (EPSP) synthase which derives from the bacterium *Agrobacterium* sp. strain CP4 (Funke *et al.*, 2006). Glyphosate normally works by blocking this important enzyme in plants which results in death. If a crop plant has a form of the enzyme which is insensitive to the herbicide then it will be unaffected while the weeds die. The tolerance of *Liberty Link* crops is due to introduced genetic material from another bacterial group, the *Streptomyces* (Block *et al.*, 1987; Thompson *et al.*, 1987). The advantage of herbicide resistance is that crops can be sprayed to eliminate weeds without impairment of the crop itself.

A second example involves the insertion of genes from the bacterium *Bacillus thuringiensis* (Bt) into crops to enable the production of a crystal protein with insecticidal properties (Metz, 2003). The rod-shaped aerobic bacterium was first discovered by Shigetane Ishiwatari, a Japanese biologist, in 1901 when he was investigating causes of death in silkworms. Ernst Berliner rediscovered it in 1911 and named it *Bacillus thuringiensis* (after the town of Thuringia). Berliner also discovered a crystal protein in Bt though it was to be another 50 years before the significance of the crystal protein was realised (Knowles, 1994). The capacity of Bt to kill insects was quickly exploited. French farmers began to use it as an insecticide in 1920 and the first commercial preparations, known as Sporine, were produced as sprays in 1938. It was available in the USA by 1958, two years after the active

component of Bt was determined to be the crystal protein. Originally considered to be toxic only to lepidopteran pests, in the 1970s it was found that there were various strains of Bt, each being toxic to particular insects. For example, the subspecies *israelensis* is toxic to mosquitoes and black flies, and the subspecies *tenebrionis* is toxic to several beetle species. By the 1980s Bt sprays had become a significant tool in crop protection, especially as insects were becoming increasingly resistant to chemical pesticides and because Bt sprays do not cause environmental contamination or residue accumulation.

Bt maize, the first genetically engineered crop plant, was registered in the USA in 1995. Bt cotton, with engineered protection against tobacco budworm, bollworm and pink bollworm, was produced in the late 1980s by Monsanto. Cultivation of Bollgard[®], the commercial name for Bt cotton, began in 1996 in the USA and in 1997 in China. Soon after a further 13 countries approved Bollgard[®], including South Africa and India. Bollgard II[®] is an improved version of the original Bollgard[®] cotton; it contains two genes from *B. thuringiensis* which confer resistance to a wider range of insect pests including budworms, bollworms, armyworms and loopers, plus saltmarsh caterpillars and cotton leaf perforators. It was approved in the USA in 2002 and first planted in 2003. Subsequently stacked-gene varieties of GM cotton have been developed, e.g. varieties with Bollgard[®] plus RoundupReady and Bollgard II[®] plus RoundupReady[®] Flex with both insect resistance and herbicide tolerance.

A third example of GM is that of Golden Rice, a bio-fortified rice engineered to produce a high level of vitamin A. Vitamin A deficiency occurs in millions of people, especially children, in parts of Africa and Asia, who are thus vulnerable to blindness.

Golden Rice is one solution to this problem, especially as rice is the staple diet of at least 1.6 billion people. The production of Golden Rice involves genetic modification of the indigenous rice gene which codes for beta-carotene (the precursor of vitamin A) in rice leaves to produce it in the grain. A second step involves the addition of gene components from other species including the daffodil and the soil bacterium *Erwinia uredovora* to further enhance beta-carotene production (Golden Rice Project, 2007; Potrykus, 2001; Sakakibara and Saito, 2006). However, the adoption of Golden Rice has been painfully slow due to anti-GM lobbies and the introduction of regulatory hurdles (Enserink, 2008). Nevertheless nutrition improvement remains the goal of many GM programmes focussed on crop attributes which range from productivity improvement to vitamin and micro-nutrient availability (Sauter *et al.*, 2006).

Since 1996 the area planted with transgenic crops in general (Figure 2) and Bt crops in particular (Figure 3) has increased markedly. Today Bt maize and cotton are widely grown, and concerns that such crops would have short commercial lives due to the rapid spread of insect resistance (Ferry *et al.*, 2006) have not materialised. Apart from China, which has produced its own transgenic seeds and where 70% of the cotton crop is Bt GM (Kong-Ming, 2007), Monsanto controls the world seed market for transgenic cotton. In relation to the global area planted with GM crops, cotton occupies third position after soybean and maize. In 2006 GM cotton was grown on 13.4 million ha i.e. 13% of the total area planted with GM crops as compared with 58.6 million ha (57% of the GM crop area) for soybean and 25.2 million ha (25% of the GM crop area (James, 2006).

<Figures 2 and 3 near here>

SOCIO-ECONOMIC IMPACTS OF Bt COTTON

Most published evidence to date indicates that Bt cotton has had a positive economic impact for small-scale farmers in developing countries. Smale *et al* (2006) review the methods and findings of 47 peer-reviewed 'Bt cotton' papers published since 1996, and conclude that the economic benefits are promising even if evidence for a sustained impact is not yet apparent. Figure 4 lists several key papers on Bt cotton in the developing world published between 2002 to 2007. Their geographical spread is patchy, with a focus on India, South Africa and China. Broadly they indicate an increase in yield, reduced insecticide use (insecticide product per hectare), reduced expenditure (as less pesticide is used) and an overall increase in the gross margin for Bt varieties compared to non-Bt varieties. But there are complications to this simple picture.

<Figure 4 near here>

Gross margin is given by:

Gross margin = revenue (yield X price) – all costs

Included in 'all costs' is pesticide, labour, fertilizer, planting material, running costs of machinery etc. These are variable costs and yield tends to increase as variable

costs increase, albeit within the limits of diminishing returns. However, while revenue is relatively straightforward to identify, the problem lies in calculating costs. Some studies include labour while others do not, and while labour may be included for some activities it may be omitted for others. Also, while hired labour can readily be costed there are complications with household labour. Some discount household labour as effectively free, but this is not strictly correct as it does not take into account the opportunity cost. Modes of data collection in Bt impact studies also differ. Several early studies relied heavily on data derived from experimental plots which researchers established and managed on farmers' land, but critics were quick to label such work as unrepresentative and potentially biased. Other studies avoided this problem by focussing on plots owned and managed by farmers. Such methodological variations make comparison between studies difficult, even if the work has been carried out in the same country.

Data analysis from such studies has typically employed multiple regression, with yield as the dependent variable and the various inputs as independent variables. However, even if data are available the studies are typically focussed on gross margin assessed over a short time period, possibly a single or a few growing seasons. They provide snapshots rather than a long-term picture, and fail to answer key questions about the sustainability of an increase in gross margin. Moreover, such studies have not tended to ask how any extra income or labour savings have been used by farming households.

To provide insights into these questions the research conducted on the impacts of Bt cotton in South Africa from 1999 to 2005 will be explored. This covers only six

years, but it constitutes one of the longest time frames of research available on the economic impacts of Bt cotton in the developing world. The research took place in the Makhathini Flats, KwaZulu Natal, one of South Africa's poorest areas. Agriculture is the primary source of income in Makhathini, and small plots of land (typically 1 to 3ha) are allocated to rural household by tribal chiefs. The major cash crop is cotton, and there are potentially 5,000 smallholder farmers of which approximately 1,400 used to grow cotton in any one year. Recently, that number has fallen to around 700 farmers, the reasons for which are discussed below. Some 60% of farmers are women, a consequence of men migrating to urban areas for work.

South Africa is the only African country to grow GM crops commercially with Bt cotton having first been planted in 1997 (Wilkins *et al*, 2000). Large commercial farmers began adopting Bt cotton in the 1997/1998 season with resource poor farmers following suit in 1998/1999 in Makhathini Flats. The Bt cotton variety in Makhathini is NuCOTN 37-B with BollgardTM. By 2002, an estimated 92% of the smallholder cotton growers in Makhathini had adopted this variety, increasing to almost 100% by 2004/05 (Figure 5). Makhathini cotton production was relatively low with yields of 600 kg/ha or less prior to the introduction of Bt varieties, the biggest constraining factor being the lack of irrigation especially as the area is vulnerable to drought. Pest attack is a further problem. Farmers combat pest attack with insecticides, usually applied with a knapsack sprayer, though this is costly and arduous. In addition to spraying, the necessary water often has to be transported from a distance of up to 10 kilometres (Ismael, *et al*, 2002b).

An important facet of the cotton production system in Makhathini is the limited options available to farmers in terms of input supply and marketing. Until 2002 all cotton producers in Makhathini had to use Vunisa Cotton (a private, commercial company) for purchasing inputs, notably seed and pesticides, and also for credit (from Land Bank; www.landbank.co.za/) to pay for these inputs. Vunisa also purchased the cotton from producers, deducting the credit owed before making payment. No other cotton supply or cotton marketing companies were in the area until 2002 when a new cotton ginnery, NSK (Noordelike Sentrale Katoen) was established. With a capacity to gin 10 times more cotton than is actually produced, NSK forced Vunisa out of the region. Given low cotton yields in Makhathini there was simply insufficient production to sustain both companies. Unlike Vunisa, NSK does not provide credit and thus only the wealthier and more efficient farmers could continue to grow cotton. The lack of credit is the main reason for the decline in the number of cotton growers in Makhathini and would have occurred irrespective of the widespread adoption of Bt cotton.

The results presented here are based on 3 separate, but related, studies of cotton production in Makhathini between November 2000 and January 2006. The first, based on a questionnaire survey of 100 smallholder farmers, was conducted in November 2000 (Ismael *et al*, 2002a; Thirtle *et al*, 2003). While limited in scope data on yield, revenue, seed and insecticide costs of Bt and non-Bt plots were obtained. The survey covered two growing seasons: 1998/1999 (first year) and 1999/2000 (second year), and thus relied on memory recall for 1998/99.

The second study was designed to complement the first (Bennett *et al*, 2003, 2006a; Morse *et al*, 2004, 2005c; Shankar *et al*, 2007, in press). Computerised records from Vunisa detailed the area of cotton sown, the variety, inputs purchased and yield for every individual farmer growing cotton in Makhathini over the three seasons, 1998/99 (first release of Bt cotton), 1999/00 and 2000/2001. While some 1283 clean records representing 89% all cotton growers in the Makhathini area were obtained for the 1998/99 season only 441 (32% of all growers) were available for the 1999/2000 season, and 499 (33% of all growers) for the 2000/2001 season. Therefore, the term 'sample' in this context refers to the number of records that were included in the analysis following verification of the Vunisa data. The second study had several advantages over the first. Sample sizes were larger, negating the obvious criticism that the first study was only based on a relatively small number of farmers. Second, memory recall was not required and good quality data were available for 3 seasons. Also, some limited data on labour costs were available, although the Vunisa records only give labour costs which had been paid for from credit. Family labour or help from friends would not be included.

The third study (undertaken between October 2005 and January 2006; Morse and Bennett, 2008) was similar to the first in being based upon a relatively small sample (100 farmers) and an element of memory recall, but did take into account the full labour inputs (hired, family, friends etc.) required for production (Morse and Bennett, 2008). The focus was upon the growing seasons of 2003/04 and 2004/05. The difficulty with the third study was the lack of a comparative element since by 2005/06 most cotton growers were only planting Bt varieties.

Therefore gross margin in these studies is not strictly comparable (Table 2). In study 1 the gross margin did not take into account any labour costs, while in study 2 only the labour costs recorded by Vunisa were included (i.e. the labour for which farmers had taken out credit). The third study provides the most complete picture because all labour (family, help etc) was costed at the equivalent daily rate for that task. Indeed this is a microcosm of some of the issues raised above with regard to the studies summarised in Figure 4.

<Table 2 near here>

Some of the results (mean and 95% confidence intervals) for the three studies are summarised in Figures 6 to 9. Figure 6 shows yield and revenue data; in all studies yields were significantly higher for Bt plots relative to non-Bt plots, which resulted in a significant increase in revenue. In Studies 1 and 2 the decline in yields for season 1999/2000 relative to the others is due to that season being particularly wet. Thus the smaller sample of Study 1 mirrors the picture obtained from the larger dataset of Study 2. The average yields for Bt cotton in 03/04 and 04/05 (Study 3) are higher than in the previous seasons. This could be due to the elimination of particularly marginal cotton farmers plus the availability of more complete records for fewer farmers compared with the Vunisa dataset.

<Figures 6 to 9 near here>

Figures 7 and 8 present some of the main costs for growing Bt and non-Bt cotton. These are seed, insecticide and labour, i.e. spraying, weeding and harvesting. Not all

labour activities are included (e.g. land preparation and planting), but these are the activities where differences were noted. In Studies 1 and 2 the cost of Bt seed is higher than non-Bt, and seed cost is a significant proportion of overall cost, but insecticide costs are lower for Bt plots. The labour picture is mixed. In study 2 the Bt plots clearly use less labour for spraying than non-Bt plots, as obviously less insecticide is required, but have increased harvesting labour costs as yields are higher. Weeding labour costs are much the same for Bt and non-Bt, as might be expected. Generally, the extra seed and harvest labour costs are reclaimed through reduced expenditure on insecticide and spraying so that the overall costs of growing Bt and non-Bt cotton are comparable.

A significant feature of Figure 7 is the implication that insecticide costs per hectare for both Bt and non-Bt cotton increased between 1998/99 and 2004/05. This hypothesis is tested in Table 3. Taking a dummy variable (values of 1 to 5) to represent season it is apparent that insecticide costs increased between 1998/99 and 2004/05, with an R^2 of 34%. Much of this, of course, will be due to inflation as is supported by the data for spraying labour which suggest, if anything, that this expenditure declined over the same period, reflecting the need for less pesticide as a result of growing Bt. But increased prices could also be linked to a shift away from bollworm products towards those which target pests attacking vegetative plant parts.

<Table 3 near here>

In relation to gross margin the benefits of higher Bt-cotton revenues with costs that are approximately the same as growing non-Bt results in Bt plots having a higher

gross margin than non-Bt. This differential of between 387 SAR/ha (1999/00) and 1,090 SAR/ha (2000/01) was statistically significant for Studies 1 and 2, but in both studies it is probably overestimated given that only some labour costs were included. In the third study no comparison between Bt and non-Bt plots was possible. However, it is pertinent that the gross margin of Bt cotton at SAR 1,200 per hectare was considerably higher than that recorded for any of the non-Bt plots in studies 1 and 2.

Thus while each study had limitations collectively the picture is convincing, i.e. increased gross margin results from improved yields rather than lower costs. Plant resistance, whether based on GM or not, is efficient insofar as there is less dependence upon farmers making the right decisions over spraying: the GM technology reduces chances of error. Even one of the most pessimistic studies of the impact of Bt cotton in Makhathini, which was based on a very small sample size of just 10 farmers growing Bt and 10 growing non-Bt, much smaller than any of the studies reported here, still pointed to marginal economic benefits of Bt cotton (Hofs *et al*, 2006). Their mean yield for Bt cotton was 760 ± 301 kg/ha and 671 ± 209 kg/ha for non-Bt.

But what do farmers use this extra income for?

Bt COTTON AND LIVELIHOODS

In the third Makhathini study the farmers were also interviewed about the uses made of any additional income from Bt cotton (Morse and Bennett, 2008). Some

descriptive statistics for the sample of 100 respondents are given in Table 4. The sample comprised 37% male and 63% female, reflecting the gender proportion in the area, while the average age of respondents was 47.6 years. Each household comprised an average of 8.6 members, of which 2.5 were male adults and 2.7 female adults. Respondents had on average 7.2 years of cotton farming experience, and some 74% of the total land owned by a household was under cotton cultivation.

<Table 4 near here>

Results are summarised in Figure 10. When asked about the constraints to growing cotton it is not surprising that many respondents cited drought. Only seven respondents cited lack of finance as a constraint, although the farmers included in the study were arguably the better off and thus did not need credit. No respondent mentioned insect pests as a serious problem, but this may be because their adoption of Bt cotton had substantially reduced the impact of bollworm, the chief pest. When asked about the benefits of growing Bt cotton, most respondents mentioned an increase in income. Other responses included: 'less credit', 'less risk' and 'less labour'. Thus it appears that Bt cotton failed to address the main constraints of cotton production (drought). When asked how additional income was used, most responses involved investment in their children's education with the next most popular category being investment in cotton. Overall, the responses suggest that extra income is used for investment. Increased investment in education is particularly interesting, and in order to validate this conclusion children's attendance for two schools, Esiphondweni High School and Hkloloko Primary School, were analysed from 2002 to 2005. Between 2002 and 2005 percentage attendance rose from 86% to 97% for

Esiphondweni and 86% to 93% for Hlokoloko. According to the heads of both schools the increased ability of Bt growers to pay school fees meant that children attended school more frequently. However, a downside is that increased yields of Bt mean that children were more likely to be absent from school at harvesting time.

<Figure 10 near here>

DISCUSSION

Increases in income from Bt cotton are certainly positive, and evidence suggests that households use the income constructively by investing in physical and human assets. Could this just be a short-term benefit? Are these benefits sustainable? Much, of course, hinges on what is meant by ‘sustainable’. A recent and wide-ranging definition of sustainable agriculture is:

“a sustainable agriculture must be economically viable, environmentally sound, and socially acceptable.....it must also be politically achievable.”

Zimdahl (2005)

In this context GM crops are not sustainable in some places such as Europe as they are not yet “*socially acceptable*” or “*politically achievable*”, but would appear to be so in several countries, including South Africa. But they must also remain economically viable and environmentally sound. What does the evidence from the studies in Makhathini say about these aspects?

If a reduction in pesticide is seen as important for sustainability (Rigby and Cáceres, 2001) then Bt cotton is a positive move in the right direction. However, given the time period of only 5 years covered here it is impossible to make a definitive statement regarding the sustainability of Bt cotton in Makhathini. There is no evidence for gene escape into wild relatives of cotton; nor is there any evidence that the Bt-based resistance is any more or less susceptible to breakdown than resistance derived through conventional breeding. To date and despite more than 500,000 square miles of Bt-engineered crops worldwide there has yet to be a demise of Bt-based resistance with the possible exception of the diamondback moth (*Plutella xylostella*; Gujar et al., 2007). Li *et al* (2007) predict that Bt-based resistance could break down in China in 11 to 15 years if no preventative measures are taken. Why the Bt resistance is so durable given the extent of the selection pressure placed on the pest remains enigmatic (Biello, 2006).

Is the livelihood impact of Bt cotton different from that of other technologies that would enhance agricultural income? The same benefits would presumably have accrued if a new non-GM bred variety of cotton had been introduced with resistance to bollworm. Frankly, whether the resistance derives from a bacterial source or conventional breeding would not be an immediate issue for Makhathini farmers. What they recognise are the gains from growing Bt cotton, and its rapid adoption is testament to its popularity. Indeed, perhaps the greatest threat to livelihood sustainability in Makhathini is the reliance on income from cotton. In effect the companies (Vunisa and more recently NSK) have a monopoly and farmers relying on cotton have little choice. This, however, was the case prior to Bt's introduction and

has not been caused or exacerbated by that technology. Bt seed does cost significantly more than non-Bt seed and critics have identified debt problems due to crop or market failure (Biowatch, 2004; Grain, 2005). One complication in this scenario is that Vunisa did not begin offering credit when Bt cotton was introduced. Thus while the Biowatch/Grain point is valid it is important to note that this vulnerability would equally apply to increasing costs of any input, including a rise in non-GM cotton costs. In the 2005/06 study the detailed costs for all inputs, including labour, were determined and the ratio of seed cost to all other costs (land preparation, insecticide and labour) was 1:4.3 in 2003/04 and 1:4.6 in 2004/05. Increasing land preparation or labour costs would equally increase vulnerability. The deeper issue considered in the Biowatch/Grain critique is the narrowness of the livelihood base: a reliance on just one crop. A broader livelihood base would enable households to cope with failure of one component. GM crops may not necessarily resolve or worsen that underlying constraint.

Will the yield advantage of Bt cotton continue and if so will farmers see a reduction in price for their cotton due to laws of supply and demand? Increased yield, resulting from almost all farmers growing Bt, means more cotton for NSK to purchase and prices may decline. This has not happened so far but it cannot be ruled out. However, it could happen with any yield or revenue enhancing technology and is not GM-specific. Fertilizer and irrigation increase yields, as do hybrid varieties. Farmers have to buy non-Bt cotton seed at the start of each season, so even if Bt cotton was banned in Makhathini this would not change. In that sense Bt cotton is not a quantum leap in terms of its socio-economic impact but is instead a new variation on an old theme.

CONCLUSION

Evidence suggests that Bt cotton increases profits for resource-poor farmers and reduces insecticide use, and that such gains can be sustained over relatively short periods. Will these benefits continue or will pests develop resistance? Will the markets maintain the price of cotton as production increases? The jury remains undecided. However, it is important to note that these issues are the same as those linked with non-GM technologies. Yields and gross margins of cotton in Makhathini could conceivably have been boosted in other ways, but the same issues over access, distribution of benefits, market trends etc. would still exist. Farmers are poor in that part of South Africa not because of Bt cotton but neither can Bt cotton be expected to remove the root causes of that poverty. Even the biological dangers are not new. Non-GM based resistant crop varieties have existed for many years, and many have shown a breakdown of resistance to pests and pathogens. That danger is certainly not unique to Bt cotton. While pesticide reduction is to be welcomed it could conceivably have been achieved, albeit at much greater cost and longer time spans, with non-GM methods to arrive at plant resistance to pests. Bt cotton may have become a popular variety and crop diversity may have declined as a result, but that is also far from being a new phenomenon which GM has introduced.

The range of characteristics which GM can create is much wider than the Bt example given here, and that makes generalisations difficult. GM crops elicit responses ranging from claims of miracle products which alleviate poverty at a single stroke at one end of the spectrum through to the opinion that they will devastate agriculture and

the environment. The reality lies between these extremes. GM crops are not miracle products re poverty alleviation, but nor is there evidence that they will cause the scale of damage associated with indiscriminate use of pesticides and fertilizer or indeed with the removal of hedgerows and woodlands to produce larger field sizes. For some GM antagonists, perhaps even the majority, any debate is irrelevant as they consider the transfer of genes between species as unnatural and unethical. For them GM crops will never be acceptable however intense pressures become to increase world food production.

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Figure 1. A summary of the advantages and disadvantages of GM crops (adapted from Mannion, 2006).

Figure 2. Global area of biotech crops (adapted from James, 2006)

Figure 3. Global adoption of Bt maize and cotton (1996 to 2006; millions of Ha). Bt and stacked Bt/Herbicide Tolerance (HT).

3.1 Maize

3.2 Cotton

Source: James (ISAAA), 2006

Figure 4. Example studies showing a statistically significant economic advantage from growing Bt cotton in developing countries.

Note: Hoffs *et al* (2006) have shown a raised yield and gross margin for Bt over non-Bt cotton in South Africa but difference was not statistically significant (small sample sizes)

Figure 5. Adoption of Bt cotton varieties in the Makhathini Flats (1998/99 season to 2004/05).

Figure 6. Mean (plus 95% confidence limits) yield and revenue from Bt and non-Bt plots for the 3 studies in Makhathini.

Figure 7. Comparison of seed and pesticide costs of growing cotton between Bt and non-Bt plot. Figures are means and 95% confidence limits

Figure 8. Comparison of some labour costs of growing cotton between Bt and non-Bt plot. Figures are means and 95% confidence limits

Figure 9. Gross margin of Bt and non-Bt plots.

Figure 10. Main constraints and perceived benefits to growing cotton as perceived by the respondents (after Morse and Bennett, 2008)